International Joint Feasibility Experiment with a Copper-mining Company in Chile

Kazuhiko Nozawa†*, Kazuto Noguchi, Masanari Shoji, Hideki Uehara, and Ryutaro Ohmoto*

Abstract

NTT Laboratories has carried out a joint feasibility experiment in Chile with CODELCO, the world's largest copper producer. Based on CODELCO's specific needs for environmental protection, workers' health and safety, and effective information sharing, four NTT technologies/products were selected and verified in terms of applicability in actual mining environments. This success should lead to better business efficiency for CODELCO and wider markets for NTT than originally envisaged.

1. Background

Corporación Nacional del Cobre de Chile (CODELCO) [1], which is 100% state-owned, is the world's largest copper producer. It is planning to improve the efficiency of the mining industry by introducing the latest technology. The collaboration between CODELCO and NTT across business fields and national borders is based on the "AccessNova program" [2], [3], which has involved joint research activities undertaken by NTT Laboratories and the University of Chile over approximately the last ten years. Professor Eduardo S. Vera of the university, who is very familiar with NTT technology, acted as a mediator based on his belief that the latest NTT technology was particularly suitable for CODELCO's needs. Mining involves many processes such as rock crushing, smelting, chemical refining, quality control, material distribution, and environmental protection. CODELCO and NTT jointly investigated and identified a number of needs at mining sites.

After several exchanges of engineers, we focused on specific needs related to environmental protection, workers' health and safety, and effective information sharing and identified applicable NTT technologies and products. Finally, CODELCO selected four themes and CODELCO and NTT agreed to conduct a joint feasibility experiment designed to last between six months and a year. The experimental themes were: (i) a remote mining operating system using optical networks (NTT Photonics Laboratories), (ii) optical fiber strain sensing (NTT Access Network Service Systems Laboratories), (iii) dust sensing (NTT Energy and Environment Systems Laboratories), and (iv) wireless applications (NTT Access Network Service Systems Laboratories). These themes were based on NTT products originally designed for photonic networks, optical fiber sensors, sensor networks, and wireless access, respectively.

NTT R&D products are initially developed for ordinary IT (information technology) markets such as office environments. Therefore, the main purpose of the experiment was to prove that they could work effectively under severe conditions such as the dusty environment of a mine. To date, we have not experienced any major technical problems. This successful conclusion to the experiments will open the way toward better business efficiency for CODELCO. Meanwhile, NTT will be able to broaden its originally envisaged target markets. For example, a pollen sensor that was developed for a cedar pollen forecasting system [4]-[7] can also be used as a mining dust sensor.

† NTT Energy and Environment Systems Laboratories
Atsugi-shi, 243-0198 Japan
E-mail: k-nozawa@aecl.ntt.co.jp

2. Experimental themes

The four themes are outlined below. The official test period ended in December 2005 and four of the tests were terminated then.

2.1 Remote mining operating system using optical networks

This test was carried out in the Andina underground mine located in the Andes Mountains close to the Argentine border. In the underground mine, adits (horizontal tunnels) extend for tens of kilometers into the heart of a mountain, and ore is carried out along them.

For this test we used an AWG-STAR network [8] that incorporated wavelength division multiplexing (WDM) transmission and wavelength routing technologies based on an arrayed-waveguide grating (AWG) router. This network is connected by optical fibers in a star-shaped configuration with an AWG router at the center and WDM nodes situated around the periphery, allowing full-mesh wavelength paths to be configured between the nodes. Systems of this type have already been installed in networks for local governments, metropolitan areas, and campuses.

CODELCO is building an experimental system for the remote operation of heavy machinery such as rock crushing hammers in underground mines with the aim of improving the work environment. Video, audio, and data communication is supported by a mixture of coaxial cable, wireless links, and optical fibers. However, video data has sometimes been disrupted as a result of signal delays and noise induced by radio waves. Also, since the mines are located in the Andes Mountains, the area is buried under several meters of snow in winter, causing obstructions to traffic and communications and leading to reduced work efficiency.

The AWG-STAR network system provides both high capacity and immunity to inductive noise, which are characteristics of optical fiber communication systems. Furthermore, since it can also handle different types of signal simultaneously and has little signal delay, and since the adits in the underground mine have been dug in a star configuration, this system is highly suitable both technologically and physically for use in underground mines.

As an experimental system, we installed WDM node equipment at three locations: inside the Andina underground mine (altitude 3200 m), at the mine entrance (altitude 2600 m), and at an office in the city of Los Andes (altitude 800 m); in addition, an AWG was placed at the mine entrance (**Fig. 1**). The optical fibers run the whole distance of 100 km from Los Andes to the mine entrance without any repeaters. These three sites are linked by WDM optical signals (STM-16/OC-48, 2.488 Gbit/s) and connected to CODELCO's video, audio, and data communication equipment. We confirmed that the system can transmit clear video and audio signals of the mine interior to Los Andes and that the rock-crushing hammers can be operated remotely with little latency. This system is still functioning and so far has not exhibited any problems. We also verified that this equipment could operate stably during the winter months. Since the results have been favorable, we hope to extend the nodes inside the mine and apply systems of this type to other mines.

2.2 Optical fiber strain sensing

An optical fiber strain sensing test was carried out at El Teniente, CODELCO's largest underground mine, which is situated south east of Santiago.

In an underground mine, the adits are excavated while ore is being quarried, so the strain in the adits changes constantly. To provide a safe working envi-

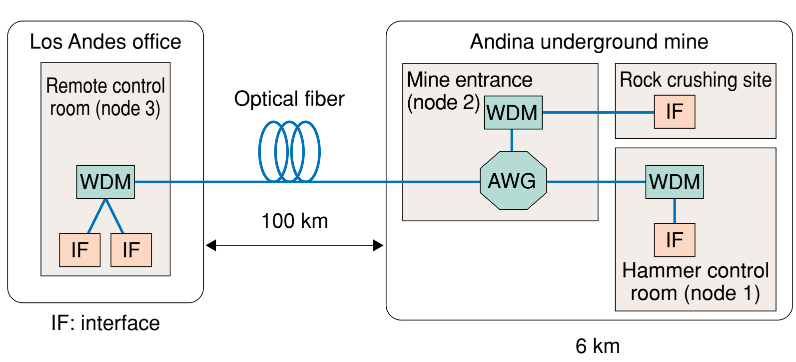


Fig. 1. Structure of AWG-STAR network installed in Andina underground mine.

ronment, it would be useful to recognize symptoms of deformation or bedrock collapse so that steps can be taken in time to prevent an impending disaster. Therefore, we constructed a system for measuring this strain by applying an optical fiber sensing technique called Brillouin optical time domain reflectometry (BOTDR) [9].

BOTDR exploits a useful characteristic of optical fiber: the frequency distribution of backscattered light (Brillouin scattered light) produced by an injected light pulse is proportional to the strain along the fiber axis (**Fig. 2**). By extending optical fibers across rivers, mountains, and artificial structures, it is possible to detect and measure the displacements caused at different locations by events such as earthquakes, flooding, landslides, and construction activities. In Japan, NTT Group has already marketed this technique for monitoring river embankments, landslide-prone areas, tunnels, and other such structures.

This test was carried out at a section of mine with sensors placed on the ceiling and walls over spans of about 500 m. We achieved an accuracy of 0.3 mm in measuring the deformation and displacement caused by excavation work at higher-level adits. At the same time, we verified that the system worked properly despite the harsh local conditions. Here, sensor cables were fixed to the rough surfaces of the adits through which the vehicles travel (**Fig. 3**), and optical fiber strain measuring equipment was installed in a room that gets very dusty. The measurement data was monitored via the network both at a site office and at an NTT office in Japan (NTT Infranet).

The system operated stably and well when used for intensive data collection during this test, especially during large-scale excavation work in September 2005.

BOTDR optical sensing technology is suitable for sensing in places where the displacement locations cannot be predicted. It can detect signs of deformation or collapse in structures such as tunnels. In this experiment, we were able to confirm the existence of these faults with certainty. Therefore, we expect to find a wide range of other applications in the mining industry based on replacing conventional electrical wires and sensors.

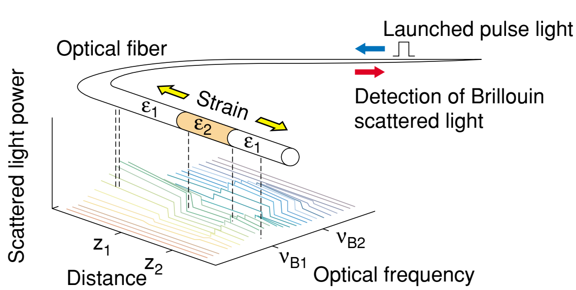
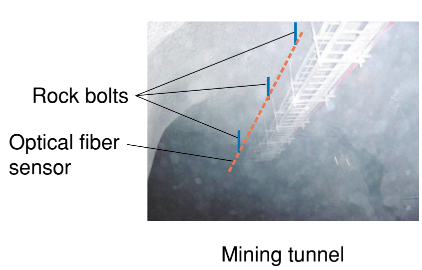


Fig. 2. BOTDR strain measuring system.

2.3 Dust sensing

This test was performed at Chuquicamata open pit mine in the desert region in northern Chile. Open pit mines differ from underground mines in that the quarrying holes (pits) are dug directly from the ground surface. With a maximum diameter of about 4 km and a depth of about 800 m, Chuquicamata is the largest open pit mine in the world. Blasting work and the movement of heavy equipment such as ore transporter trucks inside this pit generate huge amounts of dust. Under certain weather conditions, this dust can reach towns some 20 km away, and there are fears that it may be affecting the environment.

In general, the atmosphere contains various kinds of particulate matter (PM) such as dust, salt particles from coastal areas, and fumes emitted from factories, automobiles, and the like. The effects of PM vary depending on the size, quantity, and properties of the particles. However, since PM has a wide range of effects not only on human health and regional ecosystems but also on the global climate, countries throughout the world are establishing environmental



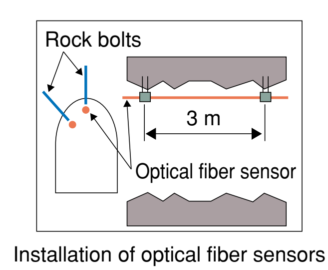


Fig. 3. System installation overview. The optical fiber sensor was fixed under tension by rock bolts every 3 m.

standards for it. A typical benchmark is the PM-10 concentration (the total mass concentration of PM with an aerodynamic diameter of roughly 10 µm or less suspended in 1 m^3 of air). For example, Japan's environmental standard requires that the concentration of PM with a diameter of 10 µm or less must have a daily average value of 0.10 mg/m^3 or less and a one-hour average of 0.20 mg/m^3 or less. When PM is inhaled by humans, particles with a size of approximately 10 µm are nearly all trapped by the windpipe, while smaller particles are thought to penetrate deep into the lungs where they are thought to have a more serious effect on human health. Consequently, there have also been recent moves towards monitoring the PM-2.5 or PM-1 concentrations (i.e., the concentrations of PM particles with an aerodynamic diameters of ≤2.5 or ≤1 µm).

The large amount of dust generated by an open pit mine is clearly a major source of PM. Moreover, when heavy metal mineral resources are being mined, the dust's toxicity must also be considered, so it is important to deal with dust for various reasons.

It is not easy to completely prevent dust from being generated. However, to minimize the effects of dust dispersal on the surrounding environment, CODELCO is considering regulating work depending on the weather conditions. We therefore decided to undertake continuous dust measurements with a networked system of dust sensors to obtain a quantitative evaluation of the amount of dust around the mine. NTT Energy and Environment Systems Laboratories had already developed a cedar pollen forecasting system consisting of atmospheric simulations and a network of pollen sensors [3]-[6], so we were able to apply our technology, know-how, and experience to the problem of dust sensing around mines.

The tests were undertaken with five dust sensors situated in the region surrounding Chuquicamata mine (**Fig. 4**). Monitoring was performed for more than eight months. The dust concentration was measured at 30-minute intervals, and the resulting data was sent via the Internet to Japan for analysis. This allowed us to evaluate not only how the dust concentration varied, but also how the dust sensors worked in terms of performance, durability, and operability. At the same time, we also monitored various weather-related parameters such as temperature, humidity, and wind speed/direction.

The main purpose of this joint study was to obtain continuous measurements with the dust sensors. However, since the sensors functioned well and produced large quantities of data, we also began looking into the development of an atmospheric simulation model. Smaller dust particles are carried further in the atmosphere. The fact that yellow sand from continental Asia can be transported to Japan demonstrates that dust can be dispersed over a very wide range by air currents under certain atmospheric conditions. Based on the results of this study, we aim to work towards the development of a risk assessment system that combines a dust sensing system with a simulated assessment of exposure levels.

Fig. 4. Dust sensing facility. The roofed black cylinder is the measuring chamber of the dust sensor. The box below it houses a controller and a data collection device.

2.4 Wireless applications

A wireless application test was performed at the Chuquicamata mine. There were two aims. One was to construct a network for collecting video images of several locations in the open pit to improve the efficiency and safety of mining work with WIPAS (wireless IP access system) technology [9] and confirm the performance of applications such as video transmission. The other was to check the effects of dust on the transmission characteristics and long-term environmental robustness of WIPAS in a desert environment. Wireless systems are suitable for an open pit whose shape changes as a result of excavation because they can be easily installed and/or moved.

Since WIPAS technology has been available in commercial services such as B FLET'S since 2003, the test was conducted on a practical use basis. Consequently, the WIPAS equipment used in the test was purchased by CODELCO so that they could continue using it after the test.

WIPAS is a fixed wireless access (FWA) system that can provide broadband IP (Internet protocol) services at low cost. This system has certain advantages. It offers a fast data transmission speed approximately equal to that of optical services (peak wireless transmission speed: 80 Mbit/s), compactness, and low cost. Two topologies were used for the WIPAS link: a point-to-multipoint (P-MP) network composed of a single access point (AP) and multiple wireless terminals (WT), and a point-to-point (P-P) link composed of two WTs communicating with each other.

The configuration of the test system is shown in **Fig. 5**. One P-MP network (composed of one AP and two WTs) and two P-P links are deployed in the open pit, and the control center and four remote monitoring locations are connected by the WIPAS. Cameras are deployed at three of these locations. At the fourth location, the WIPAS equipment is connected to wireless LAN (local area network) equipment, which is connected to the corresponding wireless LAN equipment on a light truck with a camera to provide mobility. The resulting video images are monitored in an office connected to the control center by an optical fiber.

In the test, the received signal power and error performance were continuously measured to investigate any long-term variations in this data. The influence of dust created by wind and blasting was examined through continuous measurement. Moreover, continuous video monitoring using the WIPAS network was achieved.

The received signal power in the WIPAS networks remained stable during the test period with no degradation in the error performance, even during periods of high dust concentrations. In addition, the remote video monitoring operated smoothly from all of the locations, including the video from the camera mounted on the light truck.

Based on these results, CODELCO was impressed with WIPAS's high-speed transmission performance, reliability, stability, simple installation, and superior environmental robustness.

The test has been continued to determine both the long-term stability of the received signal power and error performance in the WIPAS networks and the video monitoring performance.

3. Future prospects

In this article we outlined the four themes of our joint feasibility experiment. To date, we have not experienced any major technical problems, despite being initially concerned about severe environmental conditions such as the high temperature of the open pit mine, the humidity of the underground mines, and the dusty atmosphere.

The experiment was completed in December 2005. We are now analyzing the data with CODELCO before writing up the results in a report. We expect NTT's technology to enable CODELCO to achieve better business efficiency. Furthermore, NTT can now look forward to a wider range of markets for its technology than originally envisaged. We hope to deploy the same techniques at other mines.

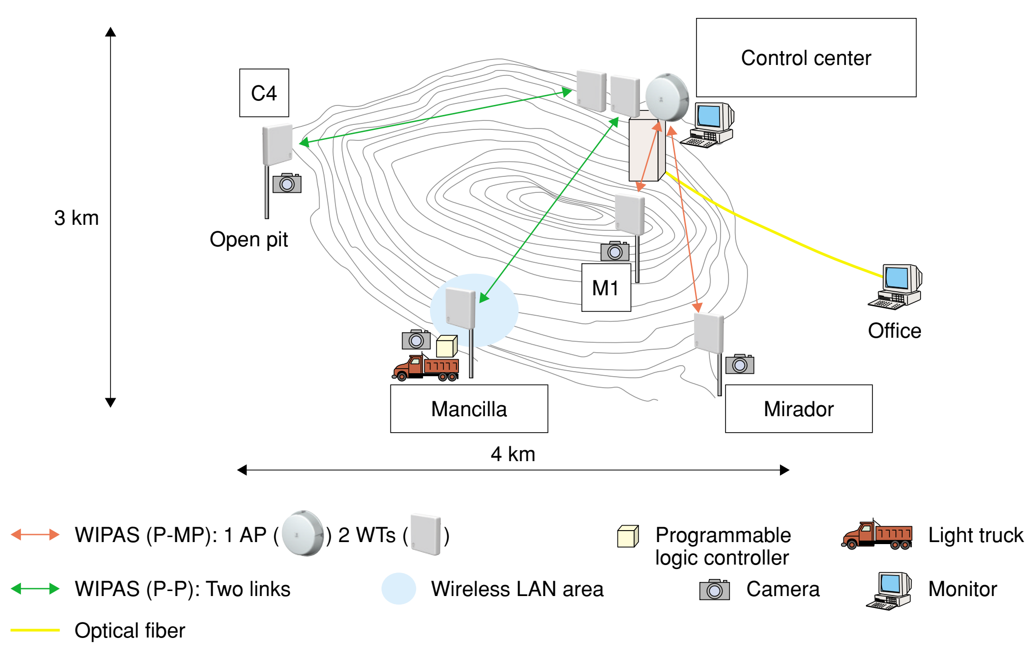


Fig. 5. Configuration of wireless application test system.

References

[1] http://www.codelco.com/english/
[2] N. Yamanouchi and H. Yamamoto, "Summary and future prospects of research exchanges between NTT and Chile University (Access-Nova)," NTT R&D, Vol. 50, No. 3, 183, 2001 (in Japanese).
[3] N. Yamaguchi, E. Vera, H. Yamamoto, and H. Uose, "Progress in Network Experiments in Research Collaboration between NTT Laboratories and the University of Chile: AccessNova," NTT Review, Vol. 14, No. 2, 2002.
[4] M. Shoji and T. Kato, "Development of automatic pollen monitor and its performance," The Institute of Electrical Engineers of Japan, Micromachine and Sensor System Workshop, MSS-03-34, 31 (2003).
[5] J-J. Delaunay, "Toward the Dissemination of Environmental Information Designed to Improve the Quality of Life," NTT Technical Review, Vol. 2, No. 1, pp. 6-11, 2004.
[6] T. Tanaka, H. Ban, S. Ogawa, Y. Y. Maruo, J-J. Delaunay, and T. Ieyasu, "Environment Assessment Technology," NTT Technical Review, Vol. 2, No. 4, pp. 41-45, 2004.
[7] Y. Shimojo, "Accurate pollen dispersal forecasting service," NTT Technical Journal, Vol. 17, No. 2, pp. 58-61, 2005 (in Japanese).
[8] M. Matsuoka and K. Oguchi, "Full-mesh WDM Network System," NTT Review, Vol. 14, No. 3, pp. 9-15, 2002.
[9] K. Fujihashi, H. Uehara, M. Okutsu, and K. Komatsu, "Development of a Road Disaster Monitoring System Using Optical Fiber Sensing Technology," NTT Technical Review, Vol. 1, No. 9, pp. 48-51, 2003.
[10] K. Nidaira, M. Baba, and T. Saito, "Development of Wireless IP Access System (STEP 2) in the 26-GHz Band," NTT Technical Review, Vol. 1, No. 5, pp. 68-73, 2003.

Kazuhiko Nozawa

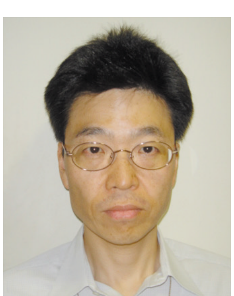
Senior Research Engineer, Energy Systems Project, NTT Energy and Environment Systems Laboratories.

He received the B.S. degree in chemical engineering, the M.S. degree in physical information engineering, and the Ph.D. degree in electrochemical engineering from Tokyo Institute of Technology, Tokyo in 1982, 1984, and 1996, respectively. Since joining Nippon Telegraph and Telephone Public Corporation (now NTT) in 1984, he has mainly been engaged in research on semiconductor physics. After working at NTT global business headquarters from 1997 to 1998, he started to work on the development of a solid-state fuel cell. He is a member of the Japan Society of Applied Physics (JSAP).

Kazuto Noguchi

Senior Research Engineer, Photonics Development Project 1, NTT Photonics Laboratories.

He received the B.S., M.S., and Ph.D. degrees in electrical engineering from Waseda University, Tokyo in 1984, 1986, and 2001, respectively. After joining NTT Electronics and Mechanics Technology Laboratories in 1986, he worked on high-speed optical components for large-capacity optical transmission systems and full-mesh WDM networks. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan, JSAP, and IEEE.



Hideki Uehara

Senior Research Engineer, Supervisor, Civil Engineering Project, NTT Access Network Service Systems Laboratories.

He received the B.E. degree in civil engineering from the University of Tokyo, Tokyo in 1983 and joined Nippon Telegraph and Telephone Public Corporation (now NTT) the same year. He has worked mainly in the telecommunication facility planning section. Since 2000, he has been working in the multimedia communication and customer service sections. He has been in his present post since 2003. He is a member of the Japan Society of Civil Engineers and the Japan Association for Earthquake Engineering.

Masanari Shoji

Research Engineer, Environmental Information Systems Project, First Promotion Project, NTT Energy and Environment Systems Laboratories.

He received the B.S., M.S., and Ph.D. degrees in physics from Nagoya University, Aichi in 1986, 1988, and 2002, respectively. He joined NTT Electrical Communication Laboratories, Tokyo in 1988. He is a member of JSAP.

Ryutaro Ohmoto

Senior Research Engineer, FWA Development Project, NTT Access Network Service Systems Laboratories.

He received the B.S. and M.A. degrees in environmental science from Hokkaido University, Hokkaido in 1987 and 1989, respectively. Since joining NTT Wireless Systems Laboratories, Yokosuka in 1989, he has been engaged in R&D of wireless communication technologies such as radar interference compensation, fiber radio, wireless LAN, and FWA. He has also been engaged in standardization activities at ITU-R SG9 conferences (Fixed Wireless Service) since 2000. He is a member of IEEE and IEICE.