Industrial Passive Optical Network (PON) Applications in Smart Mining

Yuanqiu Luo
Futurewei technologies
New Jersey, USA
yuanqiu.luo@futurewei.com

Ming Jiang
China Telecom Research Institute
Shanghai, China

Hui Sun
China Telecom Research Institute
Shanghai, China

Tao Zeng
China Telecom Research Institute
Shanghai, China

Frank Effenberger
Futurewei Technologies
Texas, USA

***Abstract*—This paper proposes a network architecture of industrial passive optical network (PON) for smart mining. Typical network services in the coal mining industry are evaluated. Tests show salient results to meet the service requirements.**

Keywords—Industrial PON, smart mining, mining machine control and configuration, mining surveillance

I. Introduction

The evolution of industrial networks is motivated by enhanced automation, improved monitoring, and smart interconnectivity. This evolution is enabled by technologies such as access networks, smart manufacturing, artificial intelligence (AI), machine-to-machine communication (M2M), robotics, and the internet of things (IoT) [1]. International standards organizations, such as European Telecommunication Standards Institute (ETSI) and International Telecommunication Union (ITU), are actively developing standards on industrial networks with highspeed access capabilities [2].

Use cases of employing highspeed access technologies in various industrial sections such as manufacturing, mining, tele-educating, and smart hospital have been discussed in [3]. Technical requirements in industrial applications and the generic network architecture have been specified in [4]. Most recent effort in this direction is to employ highspeed passive optical network (PON) systems [5-8] for industry networks. Specification [9] reviews various deployment scenarios of utilizing PON for industrial networks. It also specifies industrial PON system characteristics, key functions, interfaces, management systems, and recommendations of environment adaptation in industrial PON.

This paper applies the framework from the above international standards in the area of smart mining. In particular, we propose an architecture of employing industrial PON in the smart mining sector. Industrial PON replaces the existing copper-wire networks with fiber connections. Capacity of the intra-plant communication hub for offices, factories, and other industrial facilities is largely enhanced to the level of 10 Gb/s and possibly beyond. Functions of the key network elements are discussed. A deployment case in the coal mining industry is investigated in detail. Various services are tested in this application. Our test results demonstrate salient performance of employing industrial PON to improve coal mining.

The rest of this paper is organized as follows: Section II proposes the network architecture of industrial PON for smart mining; Section III discusses functions of the key elements; Section IV illustrates the deployment case in a coal mining company and presents the service test performance; conclusions are drawn in Section VII.

II. Smart Mining Architecture

Mining is an important industry sector. It involves a set of procedures including prospecting for ore bodies from the earth, analysis of mine, geological material extraction, management, processing, and mine land restoration. Various valuable products can be obtained from mining, such as coal, diamond, metallic ores, and oil. Mining remains one of the most dangerous professions in the world. Despite the efforts in many countries, the toll of death among the world's mineworkers remains high. Although only accounting for one percent of the global workforce, it is responsible for about eight percent of fatal accidents at work [10]. Increasing automation and management is the best way to save lives and increase productivity. This is extremely critical in the mining industry.

Recent advances in machine learning, system automation, AI, as well as IoT are introducing intelligence to the mining industry. This effort is called smart mining. Smart mining combines valuable data from drills, trucks, shovels, conveyors, trains, and ships to facilitate product automation and business management. It targets to increase productivity, assure operational excellence, manage major hazard risks, and most important of all, to enhance worker safety in the mining industry. As the backbone of the smart mining infrastructure, industrial networks with highspeed interconnectivity are the basis for providing different types of smart mining services.

Ethernet switches and Category 5 cables are widely used in the traditional industrial networks. Limited by the characteristics of Category 5 cables, the signal transmission range is up to 100 m. Beyond that range, severe signal loss and degraded data rate are experienced.

The new trend is to design the industrial networks using fiber access technologies [11]. Fiber optic cable is the preferred medium as it withstands harsh environments, RF interferences, and electrical faults. These features are fully attractive for supporting smart mining applications, as mining involves a huge amount of data transmission in the environment of underground.

The most successful optical access system is gigabit-capable passive optical network (GPON) [5]. Its typical rates are 2.5 Gb/s downstream and 1.25 Gb/s upstream. The GPON global market size in 2021 exceeded 10 billion US dollars, and the GPON shipments were more than 250 million units [12]. From 2018 there are more and more deployment of the 10 gigabit PON (XG(S)-PON) systems [6,7], which are the next generation after GPON. The downstream rate is 10 Gb/s and upstream rate is either 2.5 Gb/s or 10 Gb/s. In 2020, more than 2 million XG(S)-PON ports were deployed. The XG(S)-PON deployment is expected to reach more than 5 million ports per year [13, 14]. GPON and XG(S)-PON support a reach of up to 20 km between the central office and the end users.

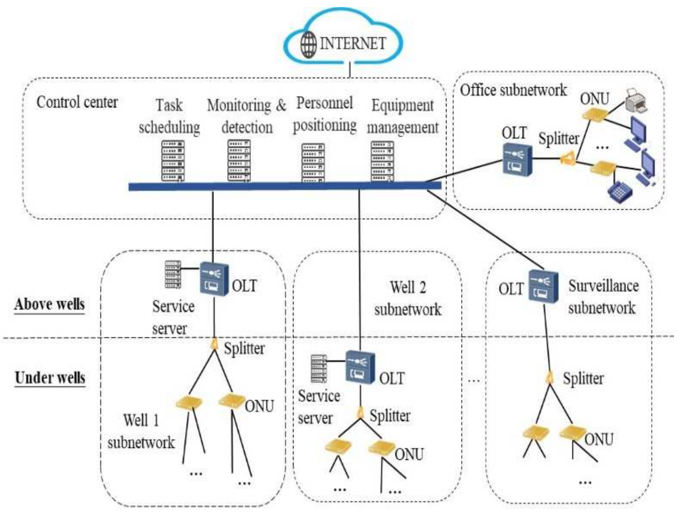

Figure 1. Industrial PON for smart mining.

The network architecture of using PON for smart mining is shown in Figure 1. The architecture comprises two levels: above well level and under well level. The above well level contains offices, the control center, servers, and machines installed for tasks conducted on the ground. Most sensors, devices, and surveillance cameras are installed in the under well level. All subnetworks are connected to the control center using PONs. A PON system consists of an optical line terminal (OLT), the associated optical network units (ONUs), a passive power splitter, and the fibers to connect the OLT and ONUs in a point-to-multipoint (PtMP) topology. Its downstream (from the OLT to ONUs) medium sharing is time division multiplexing (TDM). The upstream (from ONUs to the OLT) medium sharing is time division multiple access (TDMA) [5-8].

The smart mining industrial network in Figure 1 consists of four subnetworks: Well1 subnetwork, Well2 subnetwork, surveillance subnetwork, and office subnetwork. In the Well1 subnetwork, the OLT is installed above the well, the ONUs are installed under the well, and a power splitter is used to connect ONUs to the OLT. Machines under the well include drills, shovels, and conveyors. Well2 subnetwork covers a well deep under the ground. It contains many sensors and devices of mining. Its server and OLT are installed under the well, making the service server close to the sensors and devices. In the surveillance subnetwork, the OLT is deployed above the well to monitor video signals and support personnel positioning. The ONUs are installed under the well to connect surveillance cameras. The office subnetwork is designed to conduct tasks of office administration, and this subnetwork is installed above the well. In all of the four subnetworks exemplified in Figure 1, the maximum distance between an OLT and its ONU is 20 km. When using XGS-PON for each subnetwork, both downstream and upstream transmission rates are 10 Gbps.

The control center stores data collected from sensors, devices, and machines. It also hosts management systems to analyze the data and control different aspects of the mining business [15]. Examples of these systems are the mining task scheduling system, the mineworker personnel positioning system, the device and machine equipment management system, and the monitoring and detection system. Note that the personnel positioning system is unique for smart mining. It provides information on mineworkers' precise positioning and navigation details in real time. It helps mineworks to obtain surrounding information during work to improve safety. It also provides individual positioning information for rescue when disasters occur.

III. An Industrial PON Solution for Smart Coal Mining

Based on the proposed architecture in Section II, this Section discusses an industrial PON solution for smart coal mining. This solution is designed to support a coal mining company which operates multiple coal wells on two campuses. The two campuses are located more than 1 km apart. All wells are equipped with sensors and monitor stations to supervise the mining progress as well as to keep track of the working environment safety. Figure 2 illustrates the smart coal mining solution.

Each campus consists of an office subnetwork and multiple well subnetworks. The office subnetwork manages coal mining onsite. An XGS-PON is deployed to provide interconnectivity of office equipment in each office subnetwork.

Well 1 on the west campus is close to the surface. An XGS-PON is deployed to support Well 1. Its OLT is installed on the ground. Some ONUs are also installed on the ground to support machines, such as tractors, belt conveyors, and coal crushers. Other machines (e.g., coal drills, shearers, and excavators), coal mining sensors, and surveillance cameras operate in the underground environment. Several ONUs are installed to provide network connections to these elements. Some ONUs are also equipped with WiFi interfaces to connect wireless devices underground. Specifically, there are wireless sensors for hazardous chemical detection. Smart helmets provide mineworkers with a number of features to ensure worker safety, assist with compliance, and support hands free wireless communications to the management office and/or the control center.

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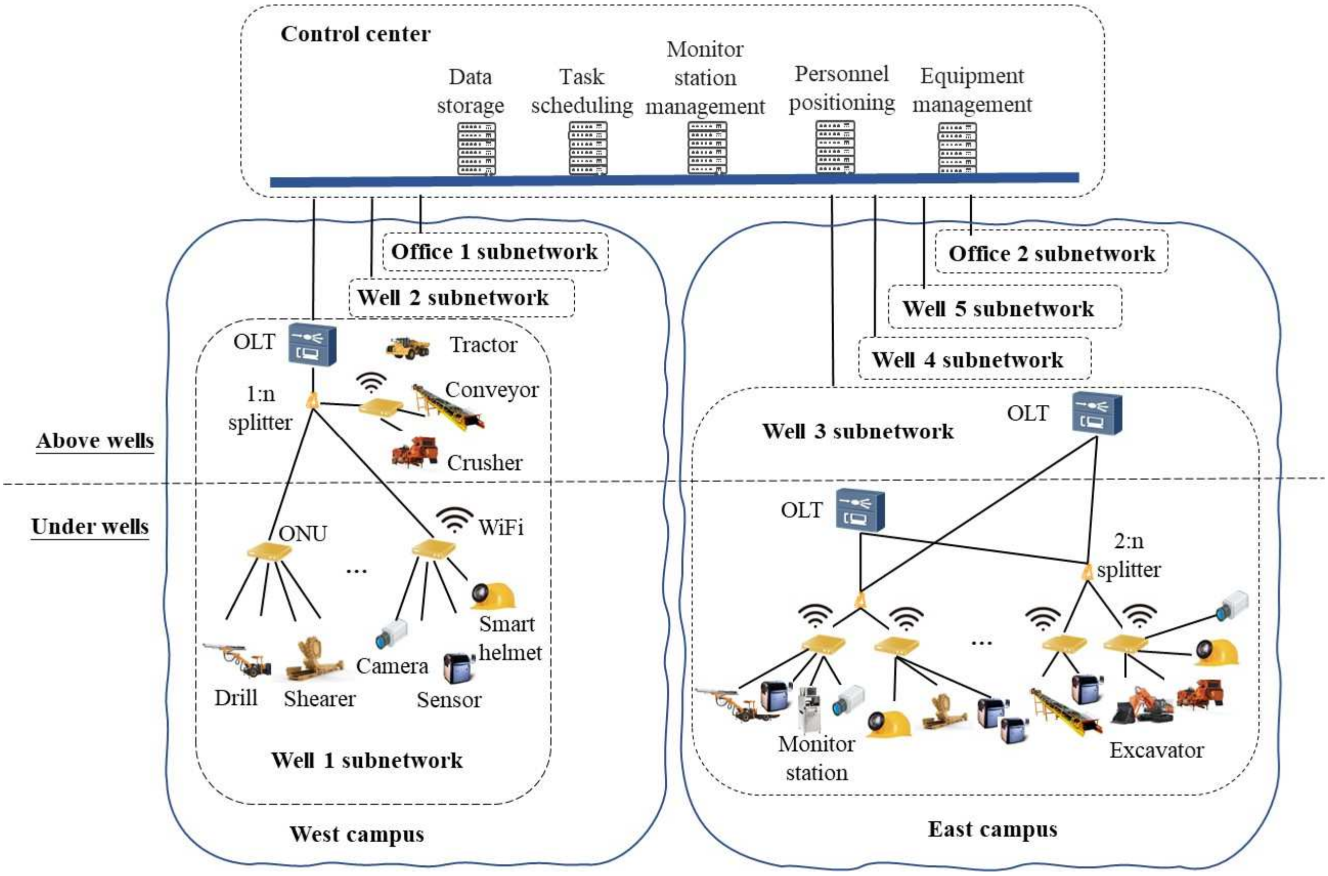

Figure 2. Smart coal mining solution with industrial PONs.

Wells on the east campus are more than 100 feet deeper than the ones on the west campus. Their underground areas are much wider. Most of the mining machines, devices, and sensors are installed under wells. Two XGS-PON systems are deployed to provide connectivity in each well. In Well 3, one OLT is installed on the ground, another is deployed underground. 2:n splitters are employed to pair these two OLTs to provide protection for each other. This is an implementation of the Type B protection specified in the ITU-T PON standards [8]. In normal operation, both OLTs work with their associated ONUs to transmit data. When failures occur in one OLT and its links, the other OLT can continue transmitting data from/to the impacted ONUs.

IV. TEST RESULTS

Several types of services are tested in the network of Figure 2 to evaluate the performance of the proposed smart coal mining solution. In this Section we report two sets of tests to represent the typical services.

The first set of tests is on mining machine control and configuration. It represents the most popular service provided in smart coal mining. The control and configuration command is given by the equipment management server in the control center. It is transmitted all the way down to an XGS-PON. The destination ONU forwards it to the machine, and the machine conducts the designated operation by following the command. The command message size varies between 46 and 1500 bytes. Its requirements on data loss, delay, and jitter are 10^{-7}, 100 ms, and 50 ms, respectively [9].

Tests are conducted at different work shifts. Each test lasts for more than 15 minutes. Figure 3 reports typical results of the instantaneous delay and jitter measured between the control center and a mining machine in a time window of 5 minutes. The maximum delay is 11 ms, the maximum jitter is 5.04 ms, and the packet loss is zero during the test. The measured performance meets the service requirements.

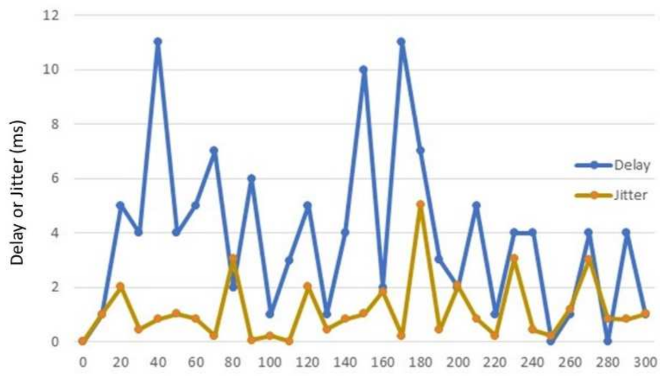

Figure 3. Delay and jitter of mining machine control traffic.

The second set of tests is on multimedia-based mining surveillance. This service consists of data, audio, and high-definition video traffics. Unlink the mining machine control service, the mining surveillance service is more interactive. Its video traffic is in the upstream from the field to the control center, while the audio and data traffics are full-duplex. The combined traffic is bursty in a rate of 40~80Mbps. The requirements on data loss, delay, and jitter are 10^{-5}, 100 ms, and 15 ms, respectively [9].

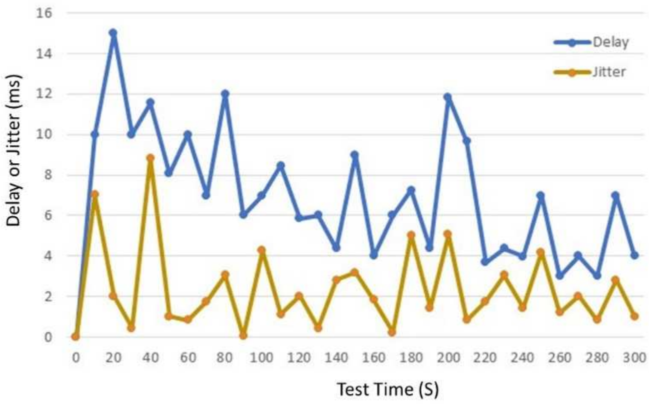

Figure 4. Delay and jitter of multimedia surveillance traffic.

Figure 4 shows typical results of the surveillance traffic tests. During this test period of 5 minutes, the maximum delay is 15 ms, the maximum jitter is 8.83 ms, and the packet loss is zero. They all meet the traffic requirements of the surveillance service.

V. CONCLUSIONS

In this paper, we have proposed an architecture of using industrial PON for smart mining. Key elements of this proposal have been reviewed. This proposal has been implemented in a coal mining company. The deployment covers two campuses with multiple coal mines. Industrial sensors, mining machines, surveillance devices are installed to form subnetworks for fulfilling various tasks. XGS-PON systems are employed as the backbone to support subnetworks. Multiple sets of tests are conducted to evaluate the service performance. Test results have shown the industrial PON-based solution is able to meet different service requirements of smart mining.

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