Deployment Of Large-area Radio-enabled Tailings Monitoring Systems In Open-pit Mines

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Several instrument geotechnical monitors are routinely used to monitor the status of mines and their tailings. The most direct and commonly instrument used is the piezometer because it gives direct measurement of pore water pressure but there is a plethora of other instruments : inclinometers, thermistors, extensometers, settlement plates, etc.

Historically, measurements have been, and sometimes still are, conducted manually. In a typical monitoring plan, a large number of instruments is scattered in clusters across a large area. In large-area northern mines, the harsh weather, rough terrain and long distances make manual data collection unreliable and infrequent in the winter. Long term costs are also incurred by having staff regularly survey all instruments along kilometers-long dikes. Running instruments cables across harsh terrain, dikes and permafrost is cost-prohibitive and sometimes downright impossible. In a modern industry 4.0 framework, operations are closely managed and require consistent real-time updates of measurements. In addition to improving the cost-effectiveness of regular data collection, it opens the door to remote real-time alarms that can be used as an added safety measure by engineers and operators.

With the advent of industry 4.0 practices in the mining industry, monitoring systems often have a real-time component that requires an innovative approach combining manual readings, automated data loggers, and cabled or radio communications. Radio communications built around Campbell Scientific (CS) products and Loadsensing (LS) products were compared in this work. In the former, there high flexibility is available for the choice of compatible instruments and other accessory functions such as pump control. In the latter, a novel type of radio technology enables long range communications and very low power requirements. Both technological approaches are compared with regards to flexibility, power requirements, distances covered and advanced functionality. The availability of real-time data and its inherent limitations will also be discussed. The advantages of real-time long range monitoring will be discussed in terms of gains for the engineers overseeing production, geotechnical and environmental monitoring.

INTRODUCTION

Monitoring of tailings systems and water control systems has been, and sometimes still is, conducted manually. However, modern operations are often closely managed and require more consistent and real-time updates of the measurements than can be obtained from manual surveys. In large-area open-pit mines, the cold winters, rough terrain and long distances make manual data collection unreliable and infrequent for most of the year. One approach to tackle is this issue is to run instrument cables back to a central logger, but doing so across harsh terrain, dikes and permafrost is cost-prohibitive and sometimes impossible. Furthermore, long term costs are incurred by having staff available to regularly survey all instruments along kilometers-long dikes.These issues can be addressed with the use of a fully integrated industry 4.0 data management approach. We have developed, installed and maintained complex networks of geotechnical instruments at several northern mines.

This paper will cover and compare two example mine sites. Both located in Northern Canada, Mine 1 is an open-pit gold mine and Mine 2 is an open-pit iron mine. In Mine 1, a thorough monitoring plan was set up with many instruments scattered over a large area but often concentrated in tight clusters. This system has a real-time component that requires an innovative approach combining manual readings, data loggers, and cabled or radio communications. Radio communications in this system were built around Campbell Scientific (CS) products (Le Borgne et al. 2017). In Mine 2, a network of instruments that was manually surveyed was upgraded to a modern system, based on the Loadsensing (LS) technology (Abanco et al. 2017). Both allow the instruments to be internet-of-things (IOT)-enabled. A method to classify monitoring priorities into categories and apply the right level of connectivity to each will be discussed. In this case study, both technological approaches will be compared with regard to flexibility, power requirements, distances covered and advanced functionality.

OVERVIEW OF TYPICAL MINE SITES

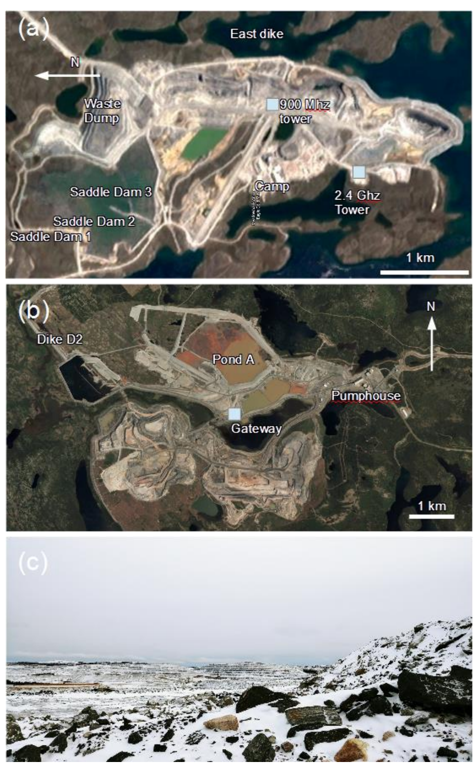

Figure 1 (a) Overhead view of Mine 1 (b) Overhead view of Mine 2. Relevant dams and ponds are identified on both figures. Locations of the radio base stations and gateways are identified with light blue squares. (c) Typical terrain found in arctic mines.

The picture shown in figure 1 provides an overhead view of Mine 1. To the right (south), the main pit can be seen with the dikes holding back lake waters. In the middle, a large tailings pond is easily identified. The map also shows where the camp is located, as well as the two main radio towers. Figure 1 (c) shows typical terrain in arctic mines : jagged terrain, snow and -40 °C weather.

Unlike Mine 1, extraction is conducted atop a hill thus the requirements to keep water out are less stringent. The mine's dewatering system has been put in place to contain water within the tailings ponds. The mine had been shut down in 2015 and prior to its reopening in 2017, all instruments that follow pore water pressure on and around the dikes were surveyed manually.

INSTRUMENTATION

MINE 1

The three main types of instruments were installed: thermistor strings, piezometers, and time domain reflectometers (TDR) to follow soil movements. Instruments can be sorted by the rate at which measurements should be obtained from them. *Background* instruments are usually read manually whenever possible. *Regular* instruments are often read by hand on a daily or weekly basis or have a standalone dedicated data logger. Finally, *critical* instruments are connected to a radio-enabled data logging system. These instruments are typically in the vicinity of dikes where failure could have major consequences on operations.

Thermistor strings, while a critical component of many arctic projects, can be difficult to install in temperatures below -20°C. Cold-rated sensor cables can be manipulated slowly but any sharp movement or impact could break the sheath (Keane et al 2013). Piezometers are installed in grouted wells, with several depths at each borehole, giving the opportunity of having a 2D mapping of water pressures away from the dikes..

MINE 2

The instruments required for the water management system of this mine were chosen and installed prior to the decision of implementing a radio-based system. However, as a cost-saving measure and to improve reliability and safety, the mine operator requested that the instruments be automated and all data be made available online automatically. Piezometers were entirely automated over an area of several square kilometers. In this project, all instruments can be classified as *critical* instruments.

DATA LOGGING AND NETWORKS

Figure 2 (a) shows an overview of the work site at Mine 1, with the main data logger locations identified as well as the locations of the two base towers (900 MHz and 2.4 GHz). For this installation, data loggers are all built from CS technology. A typical data logger system is built from a central data acquisition system, one or two radio modules, a power system and data acquisition peripherals.

The network can be broken down according to the measurement requirements for each instrument category as described above. *Background* instruments are usually read and analyzed manually. They do not require any type of real-time component and their survey is infrequent. *Regular* instruments often have a small dedicated data logger whose data is regularly collected by a field technician. When the technician returns to base, the data is added automatically to a database for online visualization and analysis. While most regular instruments measurements are collected every week, some are in difficult to reach area that are only accessible in the winter and are left over the summer until water freezes again. This method is often a first step before full IOT integration as the only extra step missing is the live connection between the measurement point and the automated visualization tools.

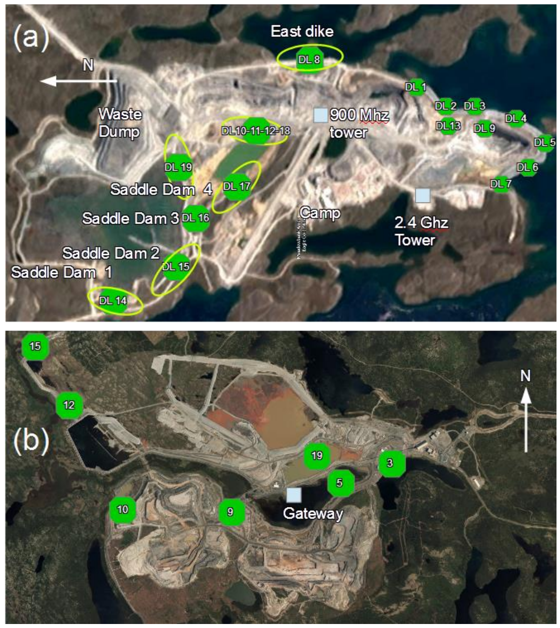

Figure 2 : (a) Main data logger locations at Mine 1 (c) Overview of selected data logger locations at Mine 2.

Critical instruments, who require real-time monitoring, are cabled back to local data loggers, typically over a short distance of less than 50 m. They comprise a single data logger with one or several multiplexers that allow it to read a large number of instruments. The yellow ellipses in Figure 4 (a) show the approximate area from which instruments are directly cabled to each data logger. The data loggers are connected back to the base station through a radio link to transmit readings that are automatically integrated into the database for visualization. This approach of having local dataloggers transmit their data automatically back to a base station grants much better reliability for the price than other options. A first option, IOT option typically only has the instrument and its communication hardware at any given location. It has the advantage of lowering costs but because no data can be logged locally, if the radio link or the base station go down, no new measurements are taken. A second option is to have a full package at each measurement location : measuring, logging, and internet connection. This options provides the most reliability as each instrument is fully independant but this comes at a significant cost due to duplication of hardware.

Figure 3 shows typical installations at both sites. A large number of instruments and instrument types can be connected to a single data logger at Mine 1, justifying the expense and trouble of building a larger shack: it comfortably houses all the required accessories and peripherals and shelters the workers during installation and maintenance. Commisionning is greatly facilitated when workers are sheltered from the wind and intense cold of arctic winters. For Mine 2, the small number of instruments at each location makes installing a small box and antenna.

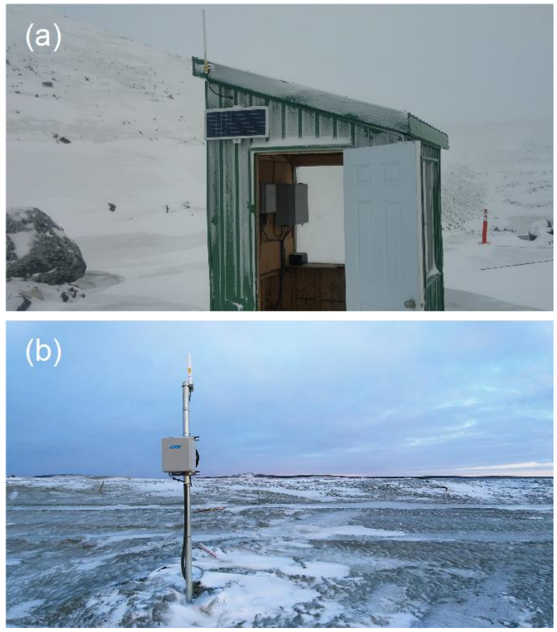

Figure 3 (a) Typical installation at Mine 1(b) Typical installation at Mine 2

The network topologies can be seen on the schematic of Figure 4 : instruments (yellow circles) are connected to multiplexers (pink triangles). The multiplexers can be cabled directly to the data loggers or connected through a short range radio link, typically less than 500 m. The data loggers are then connected directly to the base stations according to their chosen frequency through radio links and the base stations are connected to the mine's servers through regular optical fiber connections. The basic standalone configuration for *regular* instruments is also shown in the bottom left.

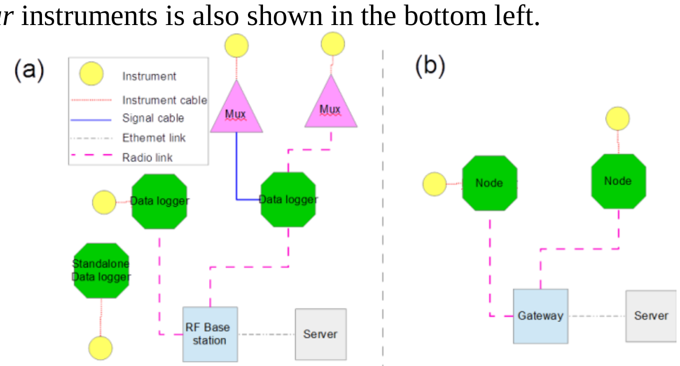

Figure 4 (a) Schematics of the of the network topology of the system deployed at Mine 1 (b) Schematics of the network topology at Mine 2

The RF base station is connected to a server that makes all data available to the relevant parties, as will be discussed in section 6. Each data logger acts as an aggregator for several radio-connected multiplexers while the two base stations act as the main integrator for all the data loggers. This deployment can be seen as an extended star network. Star networks provide a good compromise between complexity and reliability. They are somewhat more complex and more reliable than daisy chain or bus network topologies but are easier to implement and deploy than the more complicated mesh networks.

Figure 2 (b) shows an overview of the worksite at Mine 2 with the main data logger locations identified. Up to 4 piezometers are connected to each single node. The nodes are then connected through a radio link directly to the gateway. In this system, all instruments are automated and is thus not a hybrid system that combines manual readings, standalone data loggers and radio-connected data loggers. LS networks work under a pure star topology built on a gateway-node structure. The gateway acts as an aggregator for all nodes. The nodes themselves are a small datalogger that can transmit their data back to the gateway.

DISCUSSION

There are three areas to focus on when selecting and designing a radio-enabled industry 4.0 monitoring system: Flexibility, radio power and range, and power requirements.

FLEXIBILITY

Vibrating wire is an instrumentation technology common in geotechnical monitoring due to its ruggedness, durability and low power requirements (Dunnicliff 1993) but is not common across other fields. The options for compatible data loggers are therefore limited to a few specialized manufacturers. CS-based systems are programmable and they provide the opportunity to poll different instrument types with unique requirements in a single data acquisition system. They are expansible with the use of multiplexers. Consequently, a large number of instruments in a small area provides the best situation for automating acquisition with CS-based technology. For instance, at Mine 1, some locations along one of the main dams have up to tens of thermistors and up to 16 piezometers, fully taking advantage of the options offered by multiplexers.

Conversely, LS-based data loggers are less flexible. They however individually retail at a price point much lower than most CS-based systems and have a built-in 15 km range radio. They are thus best suited for smaller number of instruments in a given location. LS-based systems do not have programming capabilities beyond configuring each instrument's acquisition mode and frequency. Not only can CS-based systems be programmed, they can be reprogrammed remotely through the radio links. The greater flexibility of CS-based systems allow for on-the-fly adjustment of measurement settings and for remote diagnosis if any data is missing or faulty.

RADIO COMMUNICATIONS

A more powerful radio will usually transmit data over longer distances than a less powerful radio but at the cost of more electrical power consumption. Moreover, lower frequency radios have lower path loss than higher frequency radios (Johnson 1984), provided the Fresnel zone is kept clear of obstacles (Ahmadi 2016). It is generally accepted that 40 % of the first Fresnel zone, given by equation (1) should be kept free of obstacles to maximize transmission range.

$$F_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}} \qquad (1)$$

Where F_n is the nth Fresnel zone radius, d_1 is the distance from one end, d_2 is the distance from the antenna and λ is the wavelength (see diagram underneath).

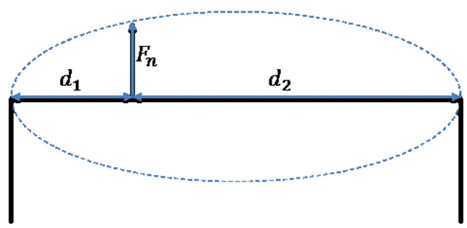

Figure 5 Fresnel zones

It is often more convenient to compute the maximum value of F_1's radius and use that as a reference, as given by equation (2)

$$F_1 = \frac{1}{2}\sqrt{\frac{cD}{f}} \quad (2)$$

where c is the speed of light, D is the distance between the two antennas and f the radio frequency. For instance, for antennas located 2 km apart for 900 MHz frequency radio waves, the radius of F_1 is approximately equal to 12.9 m. It follows that in this specific application, antennas should be 5.1 m (i.e. 40 % of 12.9 m) off the ground for an acceptable transmission quality. As seen in the pictures of Figure 3, antennas were rarely installed more than 3 m off the ground to prevent this. The following table summarizes this information for selected nodes at Mine 2. Node 5 provides very strong and consistent signal. Node 15, over 4 km away, has acceptable signal strength (-120 dBm being the cutoff) and very few, if any, messages dropped. However, node 10, located approximately 2 km away from the gateway has very poor signal and a very high fraction of messages dropped. The silo where the antenna is located (Figure 6) was chosen in part due to its central location, but it has the drawback of being at a lower elevation than other parts of the mine. For node 10, both the node antenna and the gateway antenna are lower than the summit of the pile located between them, blocking line of sight and the Fresnel Zone. To address this issue, the acquisition frequency of node 10 is multiplied by 6, ensuring that enough data reaches the gateway in all conditions.

Figure 6 Gateway Antenna installation

Table 2 Comparison of signal quality for selected nodes at Mine 1

Node	Signal strength	% message dropped
10	-120 dBm	30%
15	-118 dBm	<1 %
5	-78 dBm	<1 %

POWER REQUIREMENTS

Power requirements are also a major component to take into account when selecting a technology in the design process. The harsh weather and long winters of put stress on solar and battery-powered systems. For instance, the regions where Mine 2 is located has an average of 2 hours of bright sunlight during day during the winter. For mines near and above the arctic circle, the low sunshine and intense cold, battery packs should be designed to last at least several months, and to be recharged over summer by a solar panel. It should be noted that the cold weather (< -20 °C) cuts in half the available charge of batteries (Hutchinson 2004) which further increases battery requirements when compared to installations in warmer climates. However, the low temperature greatly decreases the self-discharge rage of lead-acid batteries, allowing for easier long-term installation than in applications in warm climates. With these parameters, a bulky 26 Ah lead-acid battery is required to last through the winter months with a 30 W solar panel for a CS-based panel.

In contrast, an LS node can be powered for over 10 years on its internal lithium batteries without a solar panel, lowering long term maintenance expenses. In locations where logger maintenance is difficult or cost-prohibitive, long battery life is an effective method of reducing lifetime costs.

DATA VISUALIZATION

The final step of any industry 4.0 monitoring system is the visualization method. Indeed, bringing all sensors online provides unprecedented opportunities for automated data visualization and real-time remote monitoring. Relying on manually plotting all data would defeat the purpose of deploying automated systems. For both projects, online visualisations were built to provide tools required for taking the right decisions at critical moments. For instances, plots that show temperature as a function of depth provide a quick and easy way to monitor the behaviour dikes and tailings dams. Visual indicators on plans show the values of specific instruments on a map with a color status, giving workers an overview sensors in alarm states over the entire mining project.

CONCLUSION

Manual surveying of instruments have inherent problems such as a low turnaround, having to send people on-site regularly for this specific task, and the difficulty of data collection during winter months. Some of these issues can be alleviated with regular standalone data loggers, but running instruments cables in this harsh environment is cost prohibitive. We have shown how using radio-enabled data loggers are a good avenue to solve these issues in two remote mines in Canada. Two technologies and approaches were compared : a hybrid topology based on CS radios and a star topology based on LS systems. The CS based systems offer the greatest flexibility as far as what instruments can be read and is easier to scale up. On the other hand, the LS based system offer good value for the price when there is a smaller number of instruments distributed over a very large area. Power requirements were also discussed, and though both systems draw very little power, LS-based radios edge out CS-based systems for autonomous systems with battery life over a decade.

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