Analysis of Mobile Communication Coverage and Capacity for Automation in Open-Pit Mines

Viviane da Silva Borges Barbosa(✉), Gilberto Rodrigues da Silva,
Pedro Henrique Alves Campos, Pedro Benedito Casagrande,
and Luciano Fernandes Magalhães

Mining Department, Universidade Federal de Minas Gerais, Antônio Carlos Av.
6627, Belo Horizonte 31270-901, Brazil
grsilva@demin.ufmg.br

Abstract. The search for greater safety and operational performance has pushed the mineral industry towards the automation of large scale operations, an important feature in intelligent mines. Wireless connection plays an essential role in the automation of open-pit mines, although representing a technical challenge. The growing number of features with high demands from networks and the transmission of real time videos increased data traffic from kilobits/second to megabits/second, requiring wireless networks of greater capacities. Additionally, as working benches distance from the communication infrastructures in open-pit mines, increased coverage is required throughout the life of a mine. This work investigates the coverage and capacity of a wireless communication network in an open-pit mine for a 7-year period, addressing the influences of topography, technology and fleet size. The results indicate the integration of mining and network planning is a natural requirement for mining automation, necessary to guide the positioning and scaling of communication structures in all phases of a mining project.

Keywords: Open-pit mines · Wireless communication · Intelligent mines

1 Introduction

Communication is always present in mining environments and can take place as voice transmissions and data transmission (digital applications). In the former, messages can travel between people using radio devices, *e.g.,* walkie-talkies, as for the latter, messages travel between equipment or software.

Intelligent mines integrate technologies which support remote and automated loading and hauling operations, aiming at increasing both the fleet and the operators' productivity as well as meeting safety standards [1]. Data transmissions are necessary for applications in fleet management (dispatch), telemetry and automation, and take place without the use of cables, *i.e.*, they are modulated in radiofrequency (RF) signals which travel between transmitters and receptors. As decisions are taken by Control Center algorithms, which are capable of compiling large amounts of data from all mining operations, intelligent mines need their own robust communication

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infrastructure [2, 3]. Brucutu (Vale, Brazil) [4], Chuquicamata (Codelco, Chile) [5], KazAtomProm (Kazakhstan) [6] and Jimblebar (BHP Billiton, Australia) [7] are examples of intelligent open-pit mines which aggregate technologies to operations depending on data transmission between equipment in the mining site and the Control Center.

The Vale S.A. Brucutu iron ore mine is located in the municipality of São Gonçalo do Rio Abaixo, Brazil. It is classed as a large size mine having produced 28.7 million metric tons of concentrate in 2013, with a 0.9 stripping ratio. In order to achieve this production rate, the mine had a fleet which could be divided into large size equipment (16 trucks with a transport capacity of 235 tons, 6 loaders and 1 electric excavator) and small size equipment (16 trucks with a transport capacity of 35.5 tons and 3 excavators) [8]. As of 2018, the Brucutu mine kept its iron ore concentrate production rate by making some changes in its fleet, with the addition of seven 235 tons autonomous trucks, besides auxiliary equipment, *e.g.*, autonomous drill and semi-autonomous bulldozers [4].

The implementation of equipment with automated skills require continuous monitoring and stricter systems for data transmission, which demands greater investments in the mine's wireless infrastructure. Planning the communication network is an essential phase for the mine planning of intelligent mines, although this task is non-trivial. The mine site is a hostile environment, exposed to sunlight, rain, dust, mist and formed by an irregular topography (benches and faces), making it difficult to ensure the expected network performance. The position of the fixed infrastructures (*e.g.*, the macro-cell) and the mobile infrastructures (*e.g.*, the access-points), are key elements to ensure a reliable communication signal and, more importantly, a proper operation of fleet management, telemetry and automation. Additionally, the wireless network infrastructure should match the continuous distancing of the working benches regarding the macro-cell and the growing number of machines.

This work indicated that the integration of network planning and mine planning processes can provide the knowledge necessary to design an adequate communication infrastructure, ensuring a high performance and personalized service for mining applications which rely on wireless networks. Although the mine site is a scenery of intense modifications, there is predictability for the evolution of each alteration in a yearly, monthly or even daily basis, which can be used to prepare for the forthcoming wireless network working conditions and requirements.

2 Methodology

2.1 Macro-cell and Access-Points

This work presents data from Brucutu Mine and premises of the Brazilian iron ore industry [4, 8] to show how mine planning and network planning are a natural unfolding of automation in the mining industry, necessary to guide the location and scaling up of communication structures (*e.g.*, macro-cell and access-points). Brucutu mine was chosen for case of study because of data availability and the ongoing implementation of autonomous fleet. This expansion required the implementation of a communication infrastructure to support the different technologies present in the mine site, allowing any expansion needed. This infrastructure consists basically of a macro-cell and its access-points, as shown in Fig. 1. The Control Centers, usually connected to the master antenna by cables, are fixed administrative centers which concentrate a large amount of information and support computers running high computational cost software. Although part of this network is cabled, the interaction between the equipment in the pit and the Control Center takes place necessarily through the wireless network, via radiofrequency waves which travel directly to the macro-cell or to the intermediate mobile access-points, as shown in Fig. 2 [9].

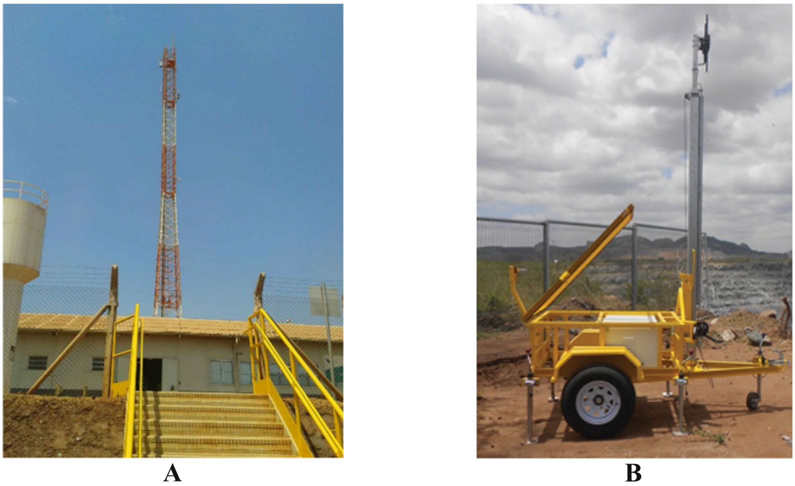


Fig. 1. Examples of typical macro-cell (A) and access-points (B).

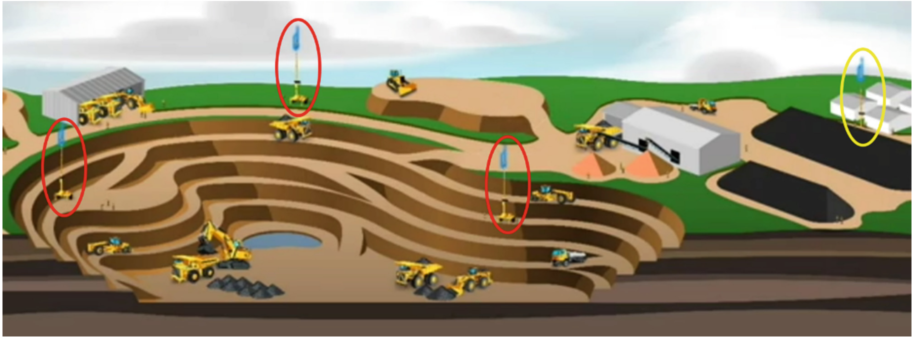


Fig. 2. Communication infrastructure: mobile access-points (in red) and macro-cell (in yellow).

2.2 Simulated Scenarios

This work was based on a surface digital model and in an estimated number of clients (equipment) of Brucutu mine in a 7-year period. It was considered that the equipment required have to send and receive data according to its telemetry, automation and fleet management applications. This inputs (*e.g.*, the mine topography, number of clients and data traffic estimation) was used to build the scenarios investigated in the Atoll® software, for radiofrequency predictions.

The software outputs indicate when the clients are able (or not) to download data from the macro-cell according to radiofrequency predictions. For example, when a semi-autonomous dozer is able to receive the data packet which describes the actions it should perform. The ability to download data is a function of the distance between customers and the antennas, so this capacity is reduced as customers move away from access-points or macro-cell.

The final goal is the estimation of Received Signal Strength Power (RSSP) that can indicate areas in the mine which have strong or weak signal. Figure 3 presents the flowchart adopted for this study showing the inputs and outputs expected for the simulation.

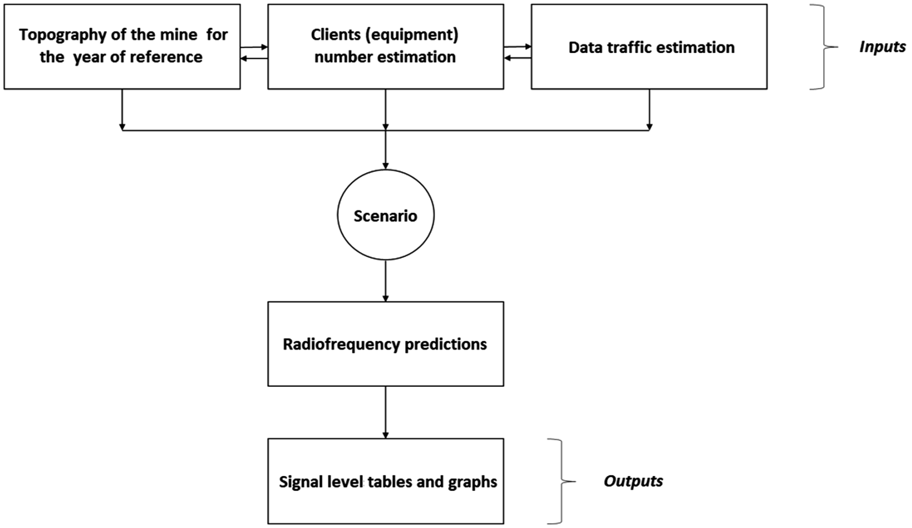


Fig. 3. Methodology flowchart.

In order to analyze the possible changes which may take place in a 7-year period due to new technology, changes in the mine morphology and fleet size, two scenarios were considered: (A) Conventional Mine scenario and (B) Intelligent Mine scenario. Their characteristics are summarized in Table 1.

The network planning software (Atoll®) employs models for wave propagation which relate the frequency, the terrain morphology and the loss during propagation to estimate the RSSP in each of the surface model pixels which represent the topography of the mine. The power level received refers to the throughput available to the

Table 1. The main characteristics of scenarios A and B.

Scenario	Year/Mine's area	Clients
A – Conventional Mine	Year 1 (2007)/2.12 km^2	3 dozers; 2 drills; 26 trucks; 6 loaders
B – Intelligent Mine	Year 7 (2014)/4.02 km^2	5 dozers; 4 drills; 32 trucks; 10 loaders

application according to its position under the signal coverage, *i.e.*, it refers to the maximum data the application will be able to receive from the macro-cell considering its position in the mine.

Scenario A. Mining operations only make use of telemetry and fleet management to conduct manual truck allocation, presenting an average throughput of 32 kb/s per equipment. If the most demanding scenario is considered, in which all the machines host applications download data simultaneously, the communication infrastructure must be able to properly meet a demand of 1,184 kb/s.

Scenario B. After 7 years, due to the topographic changes and the addition of autonomous equipment which presented greater network demands, it was investigated if the changes in the initial infrastructure provided an adequate communication service. In year 7, the area to be covered by the communication network was larger, as well as the number of machines and the global data demand. The number of equipment for loading and hauling was expected to increase because of the larger stripping ratio considered for the year 7, although the run-of-mine target was kept constant for this work. Additionally, the mining faces become increasingly more distant from the original dumping points, increasing the average transport distance and reducing the productivity (tons/h) of the trucks. All the machines used in the Intelligent Mine were considered to be in the automation state-of-the-art, leading to a global data demand 44 times greater due to the introduction of new application in the equipment hosts which, in this scenario, must run remotely guided operations (*e.g.*, dozers) and operations with

Table 2. Global data demand for the Intelligent Mine.

Equipment	Applications	Throughput kb/s	Number	Global demand kb/s
Dozer	Video, audio, commands, dispatch, telemetry, high precision GPS	3,500	5	17,500
Drill	Video, commands, telemetry, high precision GPS	3,600	4	14,400
Truck	Telemetry, dispatch, commands, high precision GPS	500	32	16,000
Loader	Video, telemetry, high precision GPS	500	10	5,000
	TOTAL			52,900

higher level of automation (*e.g.*, drills and trucks). Table 2 summarizes these considerations.

3 Results and Discussions

The first simulation considered the implementation of a Long Term Evolution 4G (LTE 4G) wireless network infrastructure able to properly meet the demands of all the clients in scenario A in year 1. This requires considering strategic choices, *i.e.*, the ideal or viable location for the macro-cell. As building its tower is a costly process, the antenna location should be carefully planned to avoid moving for the longer period possible. The location choice for the macro-cell in the simulation of scenario A assumed its real position at Brucutu mine from 2007 up to 2016.

Figure 4 shows the average Received Signal Strength Power (RSSP) levels for the morphology of Brucutu mine in year 1. It was observed, based on Monte Carlo simulations using the software Atoll®, that the macro-cell was able to meet the demands of all the clients in the Conventional Mine.

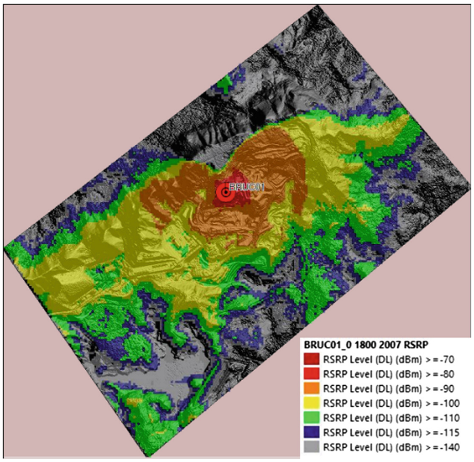


Fig. 4. RSSP in Brucutu mine for year 1 (2007).

Aiming at raising the capacity of the communication system in Scenario B, 4 access-points were included in the surroundings of the mining faces and the macro-cell location was altered. These changes increased the communication reliability since the master antenna coverage could then superimpose the coverage of the small cells, working as an alternative for connection in case the access-points failed or even as the main link in the areas not covered by them, as shown in Fig. 5.

The analyses with Atoll® indicated the proposed infrastructure was able to cover all the mine, providing adequate connectivity for at least 98.3% of the clients in the Intelligent Mine. The simulations also indicated that using the infrastructure of year 1

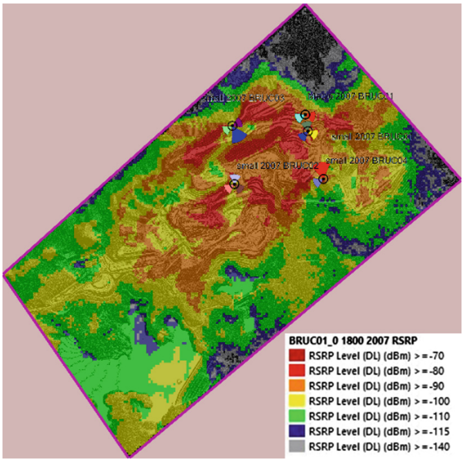
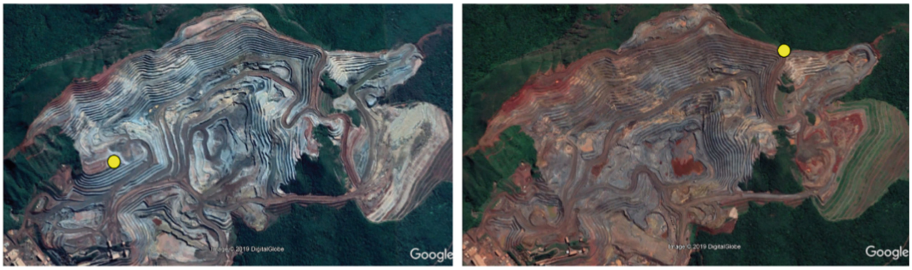


Fig. 5. RSSP in Brucutu mine for year 7 (2014).

in the scenario of year 7 would provide adequate connectivity to only 37.8% of the 51 equipment.

When this work was finished, it suggested that the most appropriate location for the master antenna, aiming at providing connectivity for autonomous applications in Brucutu mine, was at the eastern hill, at the coordinates UTM 670.450 E, 7.804.066 S (23K, Datum SAD 69). The Google Earth satellite images in Fig. 6 show the change in the antenna location by the time the autonomous truck fleet was implemented in 2018, which was consistent with the proposed alteration. The research integrating mine planning and network planning also resulted in patent applications in Brazil [10] and in Europe [11].



2016 2018

Fig. 6. Macro-cell location (yellow circle) in 2016 and 2018.

4 Conclusions

The characteristics of an open-pit mine which affect the performance of a wireless network infrastructure are not familiar to network engineers while the peculiarities of the required infrastructure are commonly not well understood by mining engineers. This gap led to the supply of non-optimum solutions in the market, resulting in networks designed to match immediate demands and expectations for scale-up which are greater than what the systems can offer. The solutions offered for wireless dead zones or low capacity are based on oversizing the number of access-points or trial and error methods which aim at positioning the cell at a location with acceptable coverage and capacity for the clients in the operational area.

The study indicated the addition of equipment with a higher level of automation, throughout the life of the mine, required reorganizing the network infrastructure. Four access-points were then included next to the working benches and the macro-cell was relocated, resulting in high connectivity for 98.3% of the clients. It is important to mention, however, that this performance is still not adequate for a full automation scenario, in which high connectivity should be offered to 99.999% of the clients to allow relying on autonomous equipment safely. It is also necessary to point that, even if the solution provides high connectivity to 100% of the clients, this would not be permanent as the topography and the lithology of the mine constantly changes, requiring continuous network planning to avoid lack of coverage and capacity for mining operations.

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