Wireless communications guideline for open-pit mining
This guideline contains recommendations collected from the experience of mining companies and suppliers for the proper functioning of telecommunications networks.
Workshop review:

Interoperability is a fundamental aspect in multiple professional areas, by allowing systems to communicate and operate based on a common objective. This concept has taken special relevance in the mining sector in recent years, due to the large number of systems it has and a series of difficulties in daily operation. This guideline is the result of several challenges identified by the mining industry in a workshop held by the Council of Technological Standards for Mining “Interop”, in April 2018 and in which it was determined that the greatest impact is achieved by improving the design of the communication networks.

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CONTENTS /

FOREWORD
1 EXECUTIVE SUMMARY 8
2 INTRODUCTION 11
  2.1 SCOPE 13
  2.2 DISCLAIMER 14
3 TELECOMMUNICATIONS NETWORK DESIGN 16
  3.1 NETWORK CRITICALITY ANALYSIS 17
  3.2 AVAILABILITY AND RELIABILITY 19
  3.3 QUALITY OF SERVICE (QOS) 21
  3.4 MULTISERVICE 22
  3.5 INTEROPERABILITY 23
  3.6 SCALABILITY 24
  3.7 COVERAGE 26
  3.8 SUPPORT 28
  3.9 NETWORK ADMINISTRATION 29
  3.10 DOCUMENTATION 30
4 PILOT TEST ON WIRELESS NETWORKS 34
  4.1 COMPILATION OF SERVICES’ NETWORK DEMANDS 35
  4.2 NETWORK HEALTH MEASUREMENT PARAMETERS 36
5 CONSIDERATIONS IN THE PROCUREMENT OF TELECOMMUNICATIONS SERVICES IN MINING 42
6 TECHNICAL SUMMARY 45
7 REFERENCES 48
8 ANNEXES 50
FIGURES /

Figure 1: Simple example of a criticality matrix, CA methodology 18
Figure 2: Outline of relationship between availability, reliability and maintainability 20
Figure 3: Reception strength levels in wireless node (RadioMobile software) 27
Figure 4: Signal-to-noise ratio 38
Figure 5: Channels in the 2.4 GHz bandwidth 41

TABLES /

Table 1: Examples of availability values and annual downtime 51
Table 2: Sample template of network requirements by service 52
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP</td>
<td>Access Point</td>
</tr>
<tr>
<td>HO</td>
<td>Handover</td>
</tr>
<tr>
<td>ITU</td>
<td>International Telecommunications Union</td>
</tr>
<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
</tr>
<tr>
<td>MTBF</td>
<td>Mean Time Between Failures</td>
</tr>
<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
</tr>
<tr>
<td>OTM</td>
<td>Original Technology Manufacturer</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of Service</td>
</tr>
<tr>
<td>SLA</td>
<td>Service Level Agreement</td>
</tr>
<tr>
<td>SNR</td>
<td>Signal to Noise Ratio</td>
</tr>
</tbody>
</table>
FOREWORD /

The mining industry generally faces lower mineral grades, complex geologies in its deposits, greater transport distances, among others. In addition, the environmental, occupational health and safety regulations are becoming stricter and demanding of internal processes that facilitate compliance. This forces mining operators to be more competitive, reduce costs and increase the efficiency and sustainability of their operations.

The incorporation of strategic technologies has historically been a way to reduce costs, improve safety conditions and increase the efficiency of the industry’s production. In general, these products are currently offered by the major equipment and technology manufacturers OEMs and OTMs, which are developed independently, without ensuring compatibility between brands, this restricts the capabilities of a mining company to achieve the integration of its systems and processes. This lack of interoperability constitutes an important entry barrier for new competitors, facilitating the concentration of the market.

For the technology industry to enable the integration of strategic technologies developed by new actors, other than traditional mining equipment suppliers, numerous companies could provide various subsystems, without renouncing to guarantee safe operations, activating an opportunity for technology-oriented entrepreneurship in global markets it is necessary to define interoperability standards among systems, equipment and fleets in mining.

In response to the difficulties presented by the mining industry and with the objective of promoting the integration of technology as an enabler for an interoperable and intelligent mining, the Chilean Government through Corfo promotes the creation of a Technology Interoperability Program for Mining. As part of the development of this program, the Technological Standards Council for Interop Mining (CET-INTEROP) is formed, with resources from the Ministry of Economy, which is entrusted with the execution.
The Technological Standards Council for Interop Mining (CET-INTEROP) is an International Organization of Standards for Mining Interoperability that, from Chile, constitutes an enabling and motor platform for the digitalization of the industry, aimed at the development, adoption and promotion of open international standards for the interoperability of systems and equipment, resulting in efficient and safe mining operations.

On the other hand, today the industry has understood that technologies are fundamental to be more competitive and that to move towards an industry 4.0 through digital transformation, guidelines and technological standards are needed to facilitate this process.

In this scenario, having ad hoc telecommunications systems ensures the integration and operational continuity of these technological applications, allowing us to evolve towards an intelligent mining where multiple developments will be used in Monitoring, Automation, Teleoperation, Big Data, IoT, Robotics, Data Science, Simulations, Cloud, Sensory and Artificial Intelligence, among others. All areas, concepts and innovations of the Industrial Revolution 4.0 that require interoperability.

This first guide is the result of the work carried out by various professionals from Interop, Fundación Chile, mining companies and R & D centers, an effort that was financed by the Ministry of Economy of the Government of Chile, through Corfo. This document defines the basis for the implementation of a communications system for open pit mining with a view to achieving a technological and international standard that fully meets the expectations of the mining industry.

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1. EXECUTIVE SUMMARY /

The purpose of this guideline is to recommend best practices for the installation of telecommunications devices in open-pit mines. This guideline was coordinated by Interop (Consejo de Estándares Tecnológicos para la Minería), with the support of Fundación Chile and the Centro Científico Tecnológico de Valparaíso (CCTVal), based on information collected in a workshop held with the main mining firms in the country and international stakeholders to complement the latest academic knowledge on telecommunications with the Interop mining experience. A series of recommendations are made, along with points to be followed when designing a telecommunications network and engaging in pilot tests of the same. In addition, it makes recommendations for the procurement of telecommunications services. The recommendations contained in this guideline are aimed at improving the design of telecommunications networks and to avoid problems later on when it comes to servicing, repairing, updating or modifying telecommunications network devices or infrastructure.

Keywords: Communications, mining, open pit mining, surface mining, high availability, telecommunications network for mining, wireless networks, interoperability, multiservice, critical services.
2. Introduction
2. INTRODUCTION

The global mining market has changed with an increase in the processing of metals like gold, silver and molybdenum, though copper extraction continues to dominate significantly.

Chile is a privileged country thanks to its deposits of this mineral, which total 22% of global reserves and accounts for a 27% share of market production, making it one of the world’s leaders in production and number one in Latin America (Consejo Minero, 2018) (“Chilean Mining Council, 2018”). However, while significant, the share represented by our country has fallen by close to 8% over the last 10 years and is likely to continue on that course unless important national strategies are established.

In this context, Interop and Fundación Chile have played a fundamental role in unifying the efforts of all relevant actors in this sector, creating spaces for cooperation among the country’s main mining companies and international stakeholders, positioning the interoperability of the mining industry as a central axis.

A series of difficulties currently affect the different operational processes within a mine, thanks to their continual growth and dynamic environments, where telecommunications and its proper operation are essential for the productive processes.

This document, prepared by Interop and Fundación Chile, with cooperation from the Valparaiso Scientific and Technological Center (CCTVal), is the first version of a communications guideline aimed at establishing a conceptual framework for managing telecommunications in open-pit mining and focusing on the interoperability of these systems.

This first step is intended to be the start of an iterative process among all participants in the mining sector, improving the concepts described herein and the procedures followed in everyday mining operations. Ultimately the goal is to reach a level of standardization in Chile that is in line with our national mining reality and drives the continual improvement of production levels and our country’s development.
2.1 SCOPE

Based on information compiled on the main obstacles for telecommunications in open-pit mining, this first document focuses on those issues that present the largest number of problems. These issues are: telecommunications network design; pilot tests of such systems in mines; and certain considerations to keep in mind in the procurement of systems and services and according to the current reality in the mining industry.

After examining these points, the idea is to create a mining production culture that aims for interoperable systems that create more efficient processes.

2.2 DISCLAIMER

The contents presented in this document have been compiled from the experience and knowledge of people related to the mining sector, such as miners, technology supply companies and academics.

The precision and completeness of the contents presented herein cannot be guaranteed. This document is a guideline, its content will increase as new information is being integrated by the mining ecosystem. Following the guidelines described is completely voluntary.
CONSEJO DE ESTÁNDARES TECNOLÓGICOS PARA LA MINERÍA

INTEROP / 15

WIRELESS COMMUNICATIONS GUIDELINE FOR OPEN-PIT MINING
3. Telecommunications network design
3. TELECOMMUNICATIONS NETWORK DESIGN /

Central concepts are established and suggestions made for designing a telecommunications network with the goal being to aim for interoperability in the mining industry. This section and its concepts must be considered not just in the stage prior to installing a network, but also with all changes of every kind that are made to the elements that comprise it.

The logical order of this section seeks to facilitate the reader’s understanding and it is structured in the following way: first, the concept is defined; second, its context in mining operations is presented; third, the suggestions for implementing the concept are made; and fourth, the value proposition in each case.

3.1 NETWORK CRITICALITY ANALYSIS /

DEFINITION

The criticality analysis is a methodology that allows systems, facilities and equipment to be prioritized as a function of their overall impact.

CONTEXT IN MINING

There are diverse critical mining processes and services that use telecommunication networks, meaning that ranking them by priority from the design stage on is fundamental in order to distribute the resources among the most critical ones. Being aware of this ranking facilitates decision-making in design, as well as in subsequent stages like maintenance or the replacement of hardware.

IMPLEMENTATION SUGGESTIONS

There are several methods to evaluate the criticality of a system’s components. One of them is the criticality analysis (CA) methodology, which evaluates the frequency with which the system fails and the consequences it has for the mine operation.
When estimating the frequency of failure, ranges are established to evaluate the MTBF\(^1\) of each system, with each range corresponding to a category. In estimating the consequence of failures, impact categories are established that are of interest to the operation and each of them defines consequences, ranking them from lesser to major seriousness in the event of a system failure. The objective is to relate both the frequency as well as the consequence of a failure with a quantitative value to calculate the criticality. This result is evaluated in the Criticality Matrix with all possible values and their respective levels, assigning a low, medium or high criticality to the system. For more information, please see the references. (Análisis de Criticidad)

![Criticality Matrix](image)

**Figure 1:** Simple example of a criticality matrix, CA methodology.

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1. Mean Time Between Failures.
The left column of the Figure shows the failure frequency calculation. The lower row contains the numbers of the failure’s consequence. Both factors intersect in the matrix, resulting in low (B), medium (M) and high (A) levels of criticality.

**VALUE PROPOSITION**

- Provides information that allows preventive measures to be taken in the event of a failure in the most critical systems.
- It allows to optimize the resources distribution according to the criticality of each system (from economic resources like maintenance and replacement of equipment to prioritizing network resources like bandwidth).

### 3.2 AVAILABILITY AND RELIABILITY / DEFINITION

The availability of a component or system is the likelihood that it will be operating at a given moment in time. For its part, reliability is the probability that the component or system will be operating free of flaws for a given time.

Both terms are frequently confused and used interchangeably. Availability and reliability can be referred to in equivalent terms when a system failure leads to the end of its life cycle. However, if the system or component can be repaired, then the concept of maintainability arises, which together with reliability contributes to the component or system’s availability.
Figure 2: Outline of relationship between availability, reliability and maintainability.
CONTEXT IN MINING

When hiring a telecommunications service, this availability value is specified in the SLA offered by the service provider. The criticality analysis (see section 3.1) must be taken into account in this availability agreement, adjusting the tolerable downtime per system according to its criticality for the mining operation.

IMPLEMENTATION SUGGESTIONS

Levels of availability must be established for each of the systems involved in the telecommunications network, in addition to defining maximum tolerable continual downtime for each network element operating in the mine. These values should be considered in the SLA when hiring telecommunications services. It must be kept in mind that each of the elements in the telecommunications network affects availability, from electric power sources to transmission and reception antennas, meaning that equipment redundancy should be considered to avoid single points of failure in the network. The use of mobile carts to deliver coverage in different mine areas is common, meaning that their power autonomy must be considered in the overall network availability balance.

VALUE PROPOSITION

• High telecommunications network availability allows to avoid undesired interruptions in mine operations, thus preventing productivity losses.

3.3 QUALITY OF SERVICE (QOS)

DEFINITION

The ITU defines this concept as the “collective effect of service performances, which determine the degree of satisfaction of a user of the service” (Rec ITU-T E.800).
CONTEXT IN MINING

A mine operation’s telecommunications network allows the operation of services that are considered critical. An important factor influencing user satisfaction in this particular scenario is for the network to be capable of prioritizing certain services depending on the mine’s operational needs. For example, the ToothMetrics system could be more critical than the Dispatch system, making the former a priority with more network resources allocated to it.

IMPLEMENTATION SUGGESTIONS

It is recommended that a remote network administration service be available that allows the bandwidth use assigned to each service to be verified and modified in each of the nodes in a simple and swift way according to the calculated needs per service.

VALUE PROPOSITION

• Prioritizing services allows the operation’s productive needs to be satisfied, ensuring that the most critical services are always available.

3.4 MULTISERVICE /

DEFINITION

A multiservice network consists of the integration of voice, data and video in a single infrastructure.

CONTEXT IN MINING

The dynamic environments in mine operations create multiple needs. This has prompted the emergence of diverse solutions using sensors to measure worksite parameters, including video images to see exactly what is happening. In this context, interoperability in mining seeks the proliferation of solutions that integrate multiple services.
IMPLEMENTATION SUGGESTIONS

It is recommended that network nodes be equipped for wireless and physical connections, in addition to having different physical interfaces and bandwidths. The installation of this hardware must be accompanied by increased flexibility in IP communications for voice, data and video traffic.

VALUE PROPOSITION

• Reduces telecommunications network infrastructure, support and maintenance costs.
• Facilitates the implementation of interoperable systems and processes.

3.5 INTEROPERABILITY /

DEFINITION

Interoperability could be defined as “the capacity of information and communications technology (ICT) and operational technology (OT) systems, in addition to the business processes that sustain them, to exchange data and transfer control. At the same time, this endows systems and organizations with the capacity to work together without problems (inter-operate)” (CORFO).

CONTEXT IN MINING

Currently mining has a small number of OEMs/OTMs that dominate the market of suppliers when it comes to telecommunications systems, creating certain vices in the industry. For example, OEMs/OTMs have certain business models that allows them the compilation and ownership of data generated during operation in the mine and the mining companies do not have free access to this information.

At least two types of interoperability can be identified in mining: interoperability between processes and interoperability between brands. Interoperability between processes refers to allowing the exchange of information among the different activities in a mining operation. For example, for the sensors on the loading shovel to deliver data to the truck transporting the ore. On the other hand, interoperability between brands refers to making it possible to use multiple brands when replacing systems and equipment; that is, the mine’s operation does not depend on using a specific brand. This last point is complicated to implement due to the current reality in the telecommunications
industry. In the context of mining, the intention is for both customers as well as mine system suppliers to gradually pursue this objective.

IMPLEMENTATION SUGGESTIONS
From the telecommunications network’s perspective, to think about interoperability is to design things in such a way that universal communication standards can be used between systems and mining equipment.

VALUE PROPOSITION
• Improved process performance in mining operations.
• Innovative mining solutions are promoted.
• Market competition is generated, which ultimately regulates the price of telecommunications equipment and systems.

3.6 SCALABILITY / DEFINITION
A telecommunications network’s scalability is defined as its ability to adapt to continuous growth without losing functionality and quality. This concept has different dimensions depending on the type of growth, which include:

• **Load dimension:** When data traffic on the network increases, strategies for distributing loads among different network nodes to prevent increased response times should be considered.

• **Geographical dimension:** A characteristic that seeks to maintain network quality and functionality, regardless of how far away the users or resources are. Example: long distances through the network from the equipment and machinery to the central server’s location.

• **Administrative dimension:** The growth variable in this aspect has to do with the number of organizations or users sharing network resources, ensuring that quality is maintained despite this growth. Example: increased the number of shovels and trucks.
In addition to these different perspectives, a telecommunications network can present two types of scalability:

- **Vertical scalability:** This is the case when the system as a whole improves when resources are added to a particular node.
- **Horizontal scalability:** This is the case when an improvement is achieved by adding more nodes.

**CONTEXT IN MINING**

Scalability is a particularly desirable feature in the mining reality, where operating environments are dynamic and steadily growing.

Design of telecommunications networks must consider the growth capacity of the network to be designed. The QoS establishes the desirable and minimum operating bandwidths for each of the services that operate with the network.

Administrative and geographical scalability are especially important to mine operation. This is why knowing the minimum bandwidth requirements of each of the network’s clients and the maximum response times tolerated for each service, among other aspects, is important information that must be known from the design stage and which is fundamental to determining how much the network designed can grow before needing to modify the infrastructure or add resources to continue operating.

On this last point, aspects of interoperability like allowing the use of multiple technology brands are fundamental to achieve network scalability and to facilitate its growth when needed.

**IMPLEMENTATION SUGGESTIONS**

The implementation of a scalable telecommunications network requires thinking about design in a modular way. This means, to the extent that it is possible, ensuring that each network resource can be expanded without having to undertake major network infrastructure changes.
To achieve this goal, there is a need to go over the concepts of scalability and dimension described in this section when deciding on implementing a given piece of equipment in the network, or asking oneself whether the implementation behaves in a satisfactory manner in the following 3 situations:

1. Increased number of network user connections.
2. Communication needs to be established between the equipment or system to be implemented and remote equipment, if applicable.
3. Increased network traffic.

In addition to covering the above situations, consider whether it is possible to increase equipment or system resources and whether it can be replicated in the network in the future if necessary.

VALUE PROPOSITION

- Knowing a network’s scalability allows one to know the maximum number of devices that can use it.
- It cuts implementation costs and times by adding resources to the telecommunications network.

3.7 COVERAGE

DEFINITION

In telecommunications, this concept refers to the geographical space where a service is available.

This simple definition reveals how coverage is directly related to availability, both for the network as well as the service, as it is not enough just for the power irradiated to cover a geographic area, but the signal service received must also be available to speak of coverage.

CONTEXT IN MINING

Wireless networks are very widely used to provide coverage to the different operation services, especially in open-pit mining.
The users of the telecommunications network in this environment correspond to mobile equipment that moves between the sector where the material is extracted and the areas where it is stockpiled for processing. This equipment requires a constant connection to the mine network so their parameters can be monitored and information sent to central servers, among other aspects. An important point to consider in telecommunications network design are the mine’s constant topographical changes, which can ultimately affect network coverage.

IMPLEMENTATION SUGGESTIONS

Communication between mobile equipment and the telecommunications network’s nodes must go through a proper HO process when a connected user moves from one wireless cell to another. The idea is to minimize the time to reconnect with the new antenna and for the connection transfer not to harm the integrity of the data transmitted, which in turn could affect the mine’s operation. It is recommended that a complete coverage map be created showing the location of each of the network nodes and the strength of the reception levels, ensuring that the latter are acceptable in all areas of interest, especially on the boundaries between wireless cells. Figure 3 shows the particular case of a coverage map on a single network node.

Figure 3: Reception strength levels in wireless node (RadioMobile software)

Lastly, it is recommended that the location of network users and their mobility be planned in such a way as to produce a balance in the connections between wireless nodes.

VALUE PROPOSITION

- Proper coverage planning allows constant connectivity for all of the operation’s equipment.

3.8 SUPPORT /

DEFINITION

Consists in assistance by qualified network and telecommunications staff to engage in maintenance and repair work. Support can be provided remotely as well as onsite, depending on the type of failure and the intervention required. It also entails an in-person contribution to the activities required in section “3.9 Network administration” of this document.

CONTEXT IN MINING

A significant proportion of the information related to the mine operation is on devices that are in constant movement, are relocated or far from the wired network. These devices therefore depend on the wireless network to transport their data and that is why its proper operation is important to the process. Another important factor that hinders support tasks is the mine’s distance from urban centers, delaying such activities in situations where specialized staff external to the mine operation are needed.

IMPLEMENTATION SUGGESTIONS

The mine must hire full-time trained support staff in cases of critical processes in which the supplier’s response time to resolve problems remotely or to send a specialist to the operation site do not fulfill expectations. The time one is willing to have a process inoperative must be estimated according to how critical it is, as well as whether mitigation measures exist. This support can be provided by mine personnel trained by the network supplier or the supplier’s employees.

This information must be set out in the SLA. The SLA is a contract with the provider that defines failure response times, support levels, fines, compensations, among
other aspects, meaning that it is important that it be aligned with the requirements identified above, such as tolerable failure times, criticality and affected processes.

VALUE PROPOSITION

• Proper dimensioning of support allows failure downtime to be reduced.
• Avert failures with preventive maintenance
• Relevant information on failures compiled so it can be avoided

3.9 NETWORK MANAGEMENT /

DEFINITION
Telecommunications network management involves a great variety of functions, including activities, methods, procedures and the use of tools that ensure that the network continues to operate reliably. Strictly speaking, this concept does not consider terminal devices like work stations or hardware installed in machinery, but instead focuses on the efficiency and capacity of communications channels.

CONTEXT IN MINING
The dynamism and constant growth of mine operations mean that telecommunications networks must adapt to these changes, making changes in terms of resources, network topology and the bandwidth assigned to given services, among others. For this reason, administering a network installed in a mine operation poses a major challenge.

IMPLEMENTATION SUGGESTIONS
First, the KPI to be measured in the context of the telecommunications network must be determined. Some examples of these that might be useful in wireless networks for mining are:

• Average number of active network users, separated by wireless cell and service.
• Average data download and upload speeds, separated by wireless cell and service.
• Maximum and minimum data download and upload speeds, separated by wireless cell and service.
• Average data upload volumes, separated by wireless cell and service.

It is important that the KPI that are defined are clearly related to the mine operation’s production indicators.

The use of software allowing continuous and real-time control and monitoring of the measurement of these KPI is recommended.

**VALUE PROPOSITION**

• Allows possible telecommunications network failures to be identified and followed up on.
• Measuring KPI allows the proper operation of the network to be validated according to the mine operation’s objectives.

**3.10 DOCUMENTATION**

The objective of this section is to provide the reader with a series of best documentation practices when installing or modifying telecommunications systems in a company.

**DEFINITION**

By documentation we refer to the act of keeping record of a series of information that will be important when it comes to reviewing, designing, modifying or upgrading the architecture of existing telecommunications systems.

**CONTEXT IN MINING**

In mining, as in other sectors, there is an increasing need for telecommunications systems with high levels of availability and reliability. The devices installed in these networks must be serviced on a regular basis, considering the diverse and adverse conditions that they must operate in. In addition, the continual modifications in the terrain, the use of machinery and other factors like metallic dust in suspension, characteristics of open-pit mining that mostly affect wireless devices, should be considered. Servicing and maintenance is greatly simplified if a series of documentation best practices are followed. Some of these will be described in this section.
IMPLEMENTATION SUGGESTIONS

Documentation for mine operations can be separated into 2 approaches: documentation of devices and documentation of events.

Documentation of devices:

All telecommunications devices must comply with certain standards, protocols and regulations and adhering to these will facilitate their maintenance of these and prevent interference. In addition, it will be easier to determine the specifications that equipment needs to comply with when a replacement is needed. For each device it is recommended that a record be kept of at least the following points:

i. Installation date
ii. Conditions under which it was installed (for example, angle and altitude of the terrain, signal-to-noise ratio, the level of strength of signal reception)
iii. Place of installation
iv. Changes made to the environment to install the device
v. Operation frequencies and channels (if applicable)
vi. Radiation patterns (if applicable)
vii. Installation specifications (for example, operation voltage, electrical installation needed, types of supports needed, among others)
viii. Changes made to the device
ix. Specifications, standards, regulations and laws that it complies with.
ix. General observations that could facilitate subsequent modifications and maintenance.

Documentation of events:

Keeping an up-to-date record, hopefully digital, lets one know the status of all devices and the changes made to them, both in the past as well as those planned for the future. It will also allow measures to be taken or decisions made in a better way, thus improving the planning of spending and making it more transparent. Lastly a large number of processes can be automated if a digital record is kept. A series of characteristic events that it is recommended be documented are listed below.
i. Installation of a new device  
ii. Removal of a device  
iii. Device upgrade (hardware or software)  
iv. Change in the device’s external conditions (for example, change in location, and installation of machinery nearby that could cause interference, among others).  
v. Changes in configurations (for example, changes in operation channels or frequencies).  
vi. Future events (for example, planned maintenances or installations, among others)

Starting with documentation is a good start, but unclear or illegible documentation is as useless as no documentation. To ensure that this work is not in vain, we make the following recommendations:

• First, write in a clear, precise and understandable way. Documentation must preferably be written electronically and in the best of cases using a platform that allows documentation to be kept in a way that is organized, indexed, up-to-date and easy to access.

• This brings us to the second point: documentation must be easy to access and highly available. It is of the utmost importance that the information be available when it is needed. In the best of cases it would be available virtually.

• It is important to keep in mind that keeping good and up-to-date documentation favors the company as well as its suppliers and both parties should have access to it when necessary. Both sides win if the company knows what to order or if suppliers know what to offer.

• Part of the documentation consists in keeping an up-to-date record of what exists in a company. The majority of companies already do this by way of inventory, meaning that documentation can be considered in part as a sort of complement to inventory or else a more detailed inventory.
VALUE PROPOSITION

- Documenting which standards to follow, facilitating procurement and upgrade of equipment and wireless technologies. It also prevents interferences among them and saturation of channels.

- Documenting the events that occur, be they installations, maintenance or upgrades, among others, allows precise control of what is happening with each piece of equipment installed. Furthermore, it allows improved planning of procurement and spending, making them more transparent and improving the mine’s administration in general.
4. Pilot testing on wireless networks
4. PILOT TESTING ON WIRELESS NETWORKS /

This section expresses basic knowledge on field testing of telecommunications networks in open-pit mining. A guideline entirely dedicated to this type of procedures and containing more specific information will be published in the future.

Extreme climate conditions like high temperatures and concentrations of dust in suspension, vibrations from blasting, humidity and metallic dust are some of the features that can be found in this environment, conditions that constitute a particularly hostile environment for telecommunications equipment and the signals they transmit through the air.

Because of this, it is fundamental that dedicated and rigorous field testing be performed on all equipment that will operate on the network. What follows is a description of the initial stages for performing pilot tests, such the compilation of all technical requirements for equipment to operate properly and the parameter definitions to measure the telecommunications network’s health.

4.1 COMPILATION OF SERVICES’ NETWORK DEMANDS /

OBJECTIVE

To establish all parameters that services require to operate on the telecommunications network properly. This information must be provided by the system and technology suppliers that offer these services to the mining operation.

Among these requirements, those pertaining to signal transmission and propagation performance, those related to network equipment configurations and those inherent in the use of the electromagnetic spectrum must be considered.
CONTEXT IN MINING

Mine operations have a large variety of services that operate using telecommunications networks and each has different resource requirements.

One of the most important requirements is performance, also known as throughput. This parameter presents the result of a series of obstacles that the information that was transmitted had to overcome, such as deficient signal strength, noise signal, delays in processing, interference from adjacent channels, among other factors, which could potentially contribute to a service failing to operate properly.

IMPLEMENTATION SUGGESTIONS

It is important to keep the information on requirements by service organized and accurate. For this, it is suggested that a table be created relating each of these services with their corresponding parameters. Table 2 of the Annexes section contains a sample template that could be of use in keeping record of this information.

4.2 NETWORK HEALTH MEASUREMENT PARAMETERS /

The telecommunications network has parameters that determine how “healthy” it is. Proper network operation depends on these parameters remaining within the design levels.

THROUGHPUT

Definition

Throughput is the net rate at which information is transmitted through a communication channel, measured in bits per second. In other words, it is the quantification of the amount of data being sent through a channel (LirneAsia).

Taking a highway for vehicles as an analogy, the throughput would be the number of vehicles that are effectively circulating on that highway.

Context in mining

In addition to considering the maximum capacity of the telecommunication channels implemented, it is important to know the real capacity that is being used. A channel’s saturation can be harmful, making communications slower. If the throughput required is greater than the network’s capacity, it will have to be expanded.
Mining has a large number of services that are being performed simultaneously, meaning that current throughput and how much more can be asked of the channel must be considered before a new service is added.

**BANDWIDTH**

*Definition*
In the context of digital transmissions, this concept refers to the maximum data transfer range in a physical communication link, measured in bits per second. Viewed differently, it is the maximum limit that a service’s throughput can reach.

*Context in mining*
The telecommunications network infrastructure deployed in the mine must guarantee adequate bandwidth for each service, as appropriate.

**SIGNAL STRENGTH**

*Definition*
The reception strength is the amount of energy that the receiving device accepts. It is important to stress that one cannot expect the power transmitted to be the same as the power received, as it will change with the gain and effective area of the receiver, in addition to the distance between the transmitter and the receiver. In addition, the signal strength received is affected by the trajectory that the signal must travel to reach the receiver, as well as by the obstacles, among others, that weaken the signal and therefore its strength.

*Context in mining*
All of the telecommunications devices used in mining have antennas that act as both receivers as well as transmitters. It is important for these antennas to be adapted in such a way as to maximize the strength of reception, thus improving communications. Despite the fact that the signal strength received is less than that which is transmitted, the closer and they are and the higher the values, the better the communication will be.
SIGNAL-TO-NOISE RATIO

Definition

The signal-to-noise ratio (SNR) indicates how many times stronger the signal of interest is compared to the noise level, a difference that is measured in decibels. By noise we refer to any interference that might disrupt the signal. In general, all electronic equipment generates random signals that contribute to the magnitude of the noise floor.

As can be seen in Figure 4, it is important to be able to discriminate the desired signal that we are receiving from the noise.

Context in mining

Mining uses a vast diversity of machinery with immense capacities, but which also generate a large amount of electromagnetic noise. In addition, metallic dust in suspension and other factors can also generate noise. Managing the signal-to-noise ratio well is of the utmost importance to avoid the loss or corruption of data.
Furthermore, the issue of making sure that the ambient noise does not interfere with the signal gains is even more important if these data are for the remote operation of machinery, for example.

**REDUNDANCY**

**Definition**
Redundancy refers to the existence of more than one device, piece of equipment or software fulfilling the same purpose. Having redundant systems in telecommunications ensures and improves service reliability. For example, including many access points in the same wireless network allows more users to be connected and should one of the access points fail, it also allows others to substitute its function.

**Context in mining**
In mining there is a need for redundancy at the access or connection points (AP), given that the machinery itself can prevent a device from connecting to the AP. Having more than one AP for a same sector makes it very hard to interrupt the line of sight between the receiver and all APs. For example, a large truck forms a solid metal wall that blocks the wireless signals from an AP. To resolve the connectivity problems in the truck’s movement, the installation of more than one onboard antenna must be considered.

**LATENCY**

**Definition**
Latency refers to the difference in time between when data is sent and when it is received (LirneAsia). When this time is relatively long one can speak of a lag in the network, which is influenced by delays in both propagation within the network, as well as in transmission between nodes belonging to it.

Basically, high latency can be caused by a congested network or other types of problems that can increase service response times. When latency is very high, the expiration of waiting times (timeout) can cause the connection to be lost.

**Context in mining**
Mining requires real time communication for monitoring, diagnostic, optimization, automation, fleet control and energy consumption applications, among others. High network latency, or delays in communication, prevents these services from effectively
being provided in real time. There are even warning systems that are supposed to be activated the moment that an emergency occurs, making a real-time response important. Thus, high network latency can end up creating problems and security flaws.

**JITTER**

**Definition**

Jitter represents the variability of the latency in packet transmission. Jitter is produced when the IP packets of the same service show different delay times in arriving at their destinations (LirneAsia). This time difference can cause packets to be lost, network congestion, route changes, among others.

**Context in mining**

Open-pit mine networks cover a large geographical space with their different operation areas. For this reason, it is important to know whether a service’s data packets take alternative routes to reach their destinations and how often this happens, which could affect the service’s throughput if not controlled. Jitter can cause echo effects on voice services and lack of data coordination in other services like remote operation and control of processes.

** PACKET LOSS**

**Definition**

When the packets transmitted over the network do not reach their destination. This loss can be caused by various factors, such as signal deterioration and network congestion, among others (LirneAsia).

**Context in mining**

Mining includes a huge variety of services, from those of a multimedia nature with protocols that tolerate packet losses without significantly affecting their operation, to monitoring services where the data is relevant and the information that is lost along the way is retransmitted.
ADJACENT-CHANNEL INTERFERENCE.

Definition
The interference from the signals transmitted over communication channels that overlap or are very close to each other in the electromagnetic spectrum. Each channel is determined by its central frequency and by its width. Figure 5 shows the channels in the 2.4 GHz bandwidth. In this bandwidth, there will be interference between the signals if an AP is configured to operate on Channel 1 and another nearby AP is on Channel 2. This does not happen if they are configured to use Channels 1 and 6, respectively, as they do not overlap.

Context in mining
This is not generally controlled, given that unknown equipment could be using the same frequency on the network. For this reason, a record must be kept of the networks and the equipment with wireless connections, specifying their characteristics. It is important to maintain AP redundancy to prevent dropped connections and for these APs not to operate on nearby channels. Otherwise, self-inflicted interference could be produced, causing connection problems, packet loss and deficient connectivity.

Figure 5: Channels in the 2.4 GHz bandwidth

5. Considerations in the procurement of telecommunications services in mining
5. CONSIDERATIONS IN THE PROCUREMENT OF TELECOMMUNICATIONS SERVICES IN MINING /

There are a number of obstacles in the current reality of Chilean mining that do not contribute to generating an atmosphere of interoperability among a mine operation’s different processes and systems.

This section presents a number of issues to keep in mind in the procurement of telecommunications services and systems, both for the mining clients as well as their service and systems suppliers.

With the goal of fostering interoperability in mining, the considerations are mainly aimed at these two actors with the intention of improving their everyday practices and to promote an industry in which interoperability is seen as a competitive advantage and not an obstacle.

1. The majority of OEMs prefer to work with their own networks on when it comes to installing new systems or offering new services to the mine operation.

This reality goes in the opposite direction set out in this document, given that it disaggregates and makes network administration and the interoperability between new systems and existing ones more difficult. On the one hand, it is the client’s responsibility to keep the mine’s network operating properly and to provide enough resources to allow new systems and services, especially for the most critical processes. On the other, what is offered must focus on telecommunications systems that are compatible with other types of solutions so that systems can “talk” to each other.

2. Clients have limited access to the data obtained in systems that are installed inside their own mine operations.

There are cases in which the data obtained from the sensors on machinery or equipment operating in the mine is part of an additional service that the client has to pay for to gain access to, even when the equipment is its property. However, even when paid for, the data can be delivered to the client partially or with some sort of processing, without access to the full information. This reality limits the potential development and improvements to productive processes that clients might be able to make with the complete original data.
3. There is certain mistrust among service and systems providers regarding mines’ proper network operation, meaning that they prefer to measure and monitor the network themselves before installing their equipment.

The fact that a service provider could obtain additional information on the network installed in the mine can cause certain problems. One of them could have to do with conflicts of interest on the part of the supplier by having knowledge of the equipment installed in the mine, which could condition market strategies that favor it. The exchange of information between customer and supplier must be in terms of needs, not for monitoring and measurement of the existing mine network.

4. Standards for anti-collision systems like DSRC (Dedicated Short Range Communication) are not regulated in Chile.

The Telecommunications Undersecretariat (Subtel) is fundamental to this point as the agent that determines the standards and regulations governing the use of the radio spectrum in Chile. However, all actors involved in the Chilean mining sector are responsible for proposing measures that could be part of the solution to this problem.

5. In the procurement of services, the basic information for starting implementation of the design for the mine must be shared.

Bidirectional communication between the customer and the supplier to access basic information is an important part of designing a solution for mining customers. For example, if the customer needs a new antenna installed in the mine it must provide a map specifying the location of the new equipment, the location of electricity supplies, location of access points to the telecommunications network and the location of other nearby antennas, among other information that may be relevant to the supplier in creating an appropriate design. In addition to the customer making this information available to the supplier, a technical visit by the latter must be considered so it can get to know the conditions of the terrain where the equipment is to be installed.
6. Technical Summary

Telecommunications network design
6. TECHNICAL SUMMARY
TELECOMMUNICATIONS
NETWORK DESIGN /

- **Interoperability:** Design using communications standards that allow different equipment and systems to communicate. Implementing this should cut equipment costs and increase productivity by improving information on the process.

- **Multiservice:** Verify that network notes are equipped for wireless and physical connections, in addition to different physical interfaces and bandwidths. Multiservice is facilitated with the use of a single protocol for voice, data and video traffic.

- **Documentation:** Keep a complete record of every stage of network design, in addition to the equipment installed and the events that take place in the mine’s communications network. Timely access to this information favors both the mine as well as its suppliers.

- **Criticality analysis:** Identify the different services and processes that will operate on the network and prioritize them according how critical they are to the mining operation. Values like MTBF and failure frequency can be used to quantify criticality, following the CA methodology.

- **Availability and reliability:** Establish the availability of services in the SLA according to the criticality analysis performed. In addition, keep record of failures and their duration to calculate real availability, contrasting it with what was agreed to with the supplier.

- **Scalability:** Make sure that your network can grow in the way you project through a given time horizon. When deciding to install new equipment in the network, ask yourself whether it responds satisfactorily under 3 situations: if the number of network user connections increases, if one needs to communicate with equipment that is far away and whether it increases network traffic.

- **Coverage:** Distribute network nodes in such a way as to ensure that there is a connection in every one of the mine operation’s sectors and create a complete coverage map to document the locations and scope of each node. Watch out for signal strengths between cells and interferences.
**Network management:** Determine indicators (KPI) to measure the performance of the telecommunications network and use software tools that control and monitor the values of these indicators.

**Quality of Service:** Compile information on the bandwidths that each service uses and contrast it with the priority that was assigned in the service quality terms agreed to with the supplier. The network administration tool can be used for this purpose.

**Support:** Design support according to how critical a process is and how it impacts on the mine’s operation. For certain critical cases consider keeping specialized staff onsite at the mine to minimize the response time to repair potential failures.

**PILOT TESTING ON WIRELESS NETWORKS:**

- **Compilation of services’ network demands:** Compile all of the necessary parameters for each service to operate properly. Suppliers must provide this information.

- **Network health measurement parameters:** Define the parameters needed to measure how “healthy” your network is. They can be used for subsequent measurement of its health.

**CONSIDERATIONS IN THE PROCUREMENT OF TELECOMMUNICATIONS SERVICES IN MINING:**

- OEMs/OTMs prefer to work with their own networks
- Customers have limited access to the data
- Suppliers mistrust the network installed in mines
- Lack of regulation on communication standards for mining.
7. References
7. REFERENCES


8. Annexes
### 8. ANNEXES /

Table 1 provides some examples of the availability percentages offered by telecommunications systems and services and their respective equivalence in hours of inactivity per year.

<table>
<thead>
<tr>
<th>Percentage of availability</th>
<th>Annual downtime 24-Hour day</th>
<th>Annual downtime 8-Hour day</th>
</tr>
</thead>
<tbody>
<tr>
<td>90%</td>
<td>876 hours (36.5 days)</td>
<td>291.2 hours (12.13 days)</td>
</tr>
<tr>
<td>95%</td>
<td>438 hours (18.25 days)</td>
<td>145.6 hours (6.07 days)</td>
</tr>
<tr>
<td>99%</td>
<td>87.6 hours (3.65 days)</td>
<td>29.12 hours (1.21 days)</td>
</tr>
<tr>
<td>99.9%</td>
<td>8.76 hours</td>
<td>2.91 hours</td>
</tr>
<tr>
<td>99.99%</td>
<td>52.56 minutes</td>
<td>17.47 minutes</td>
</tr>
<tr>
<td>99.999% (<em>five nines</em>)</td>
<td>5.256 minutes</td>
<td>1.747 minutes</td>
</tr>
<tr>
<td>99.9999%</td>
<td>31.536 seconds</td>
<td>10.483 seconds</td>
</tr>
</tbody>
</table>

Table 1: Examples of availability values and annual downtime.
Table 2 shows examples of services in the mine operation context. Each piece of equipment that uses this service is specified, along with the requirements each of them has to operate properly.

<table>
<thead>
<tr>
<th>Service</th>
<th>Type of equipment</th>
<th>Throughput</th>
<th>Bandwidth</th>
<th>Latency</th>
<th>Jitter</th>
<th>Maximum packet loss %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fleet Management System</td>
<td>Truck</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Precision GPS Service</td>
<td>Shovel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vital Signs Monitoring</td>
<td>Truck, Shovel, Loader, Drill, Ancillary Equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drill Navigation System</td>
<td>Drill</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mine Emergency Management System</td>
<td>Truck</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decision Support System</td>
<td>Truck</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Table 2: Sample template of network requirements by service