Pilot test guideline for wireless networks for open pit mining
This guideline contains recommendations collected from the experience of mining companies and suppliers for the proper implementation of pilot tests on communications networks.
**Workshop Review**

The guideline describes a series of recommendations and aspects identified that have to be considered when doing pilot tests of the equipment, evaluating the performance of its connection with the wireless network. This a second guideline in wireless communications for open pit mines and it is the result of the work carried out with the mining companies to identify common problems with wireless communications networks that need to be in pilot testing.

**Acknowledgments for their contributions to:**

Codelco Norma Vargas, Alejandro Matus  
BHP Oscar Pérez de Arce, Maximiliano Tapia  
Angloamerican Mauricio Ramírez, Luis Díaz  
Lundin Mining Sergio Silva  
Colhuasi Gonzalo Núñez

**Authors:**

- Cristóbal Águila CCTVal  
- Werner Creixell CCTVal  
- Leonardo Guerrero CCTVal  
- Juan Jara Interop  
- Héctor Valenzuela Interop  
- Sergio Vergara CCTVal  
- Orlando Orozco CCTVal

**Editing and design team Fundación Chile**  
Loreto Velázquez  
Mauricio Becerra

Intellectual Property Registry Original Document N° 307.008  
# INDEX

1 EXECUTIVE SUMMARY 8

2 INTRODUCTION 10
   2.1 SCOPE 10
   2.2 DISCLAIMER 11

3 CONCEPTUAL FRAMEWORK 13
   3.1 ANTENNA RADIATION PATTERN 13
   3.2 WIRELESS SITE SURVEY 18

4 PILOTS TEST ON WIRELESS NETWORKS OF THE MINE 23
   4.1 PREPARATION FOR THE WIRELESS SITE SURVEY 23
   4.2 PLANNING FOR THE WIRELESS SITE SURVEY 23
   4.3 EQUIPMENT PREPARATION 24
   4.4 MEASUREMENT PROCEDURE 29
   4.5 MEASUREMENT SCENARIOS 30
   4.6 MEASUREMENT PERIODICITY 32

5 TECHNICAL SUMMARY 34

6 REFERENCES 38

7 ANNEXES 40
   7.1 HOW TO MEASURE THROUGHPUT WITH IPERF 40
   7.2 DOCUMENTATION OF ACCESS POINTS 43


FIGURES /

Figure 1: Simple dipole antenna and its radiation pattern. 14
Figure 2: Dipole antenna main plane. 15
Figure 3: 3D radiation pattern and azimuth plane of dipole antenna. ANSYS HFSS. 17
Figure 4: Effect of the truck metal on the radiation pattern of the dipole. ANSYS HFSS. 17
Figure 5: 3D radiation pattern and azimuth plane in truck. ANSYS HFSS. 18
Figure 6: Dipole located on the metal level in the truck. ANSYS HFSS. 25
Figure 7: Azimuth plane of the dipole located on the metal level in the truck. ANSYS HFSS. 26
Figure 8: Vehicle with mast and antenna, adapted for measurements of wireless networks. 26
Figure 9: Sectoral antenna master plans. 27
Figure 10: Coverage of sectoral antennas in mining truck seen from above. 28
Figure 11: RF link in Chuquicamata pit. RadioMobile GoogleMaps Map. 31
Figure 12: Measurement with iPerf in client machine. 42
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP</td>
<td>Access Point</td>
</tr>
<tr>
<td>FMS</td>
<td>Fleet Management System</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HFSS</td>
<td>High Frequency Structure Simulator</td>
</tr>
<tr>
<td>WLAN</td>
<td>Wireless Local Area Network</td>
</tr>
</tbody>
</table>
1. EXECUTIVE SUMMARY /

The purpose of this guideline is to provide recommendations on the pilot testing of equipment or devices that connect to the telecommunications network in an open pit mine. This guideline was carried out by Interop - Fundación Chile, Valparaíso Technological Scientific Center (CCTVal) with the purpose of complementing Interop’s mining experience with updated knowledge in telecommunications from the academy. It describes a series of recommendations and aspects to consider when doing pilot tests of the equipment, evaluating the performance of its connection with the wireless network. Specifically, the configuration in the “last mile” network is analyzed, that is, the connection of the mining equipment or machineries with the network access points. By considering the recommendations of this guideline, it is expected to improve the procedures to evaluate the telecommunications networks and to avoid future problems, in the context of the open pit mineral extraction process.

Keywords: Communications, mining, open pit, surface mining, pilot testing, piloting, mining telecommunications networks, wireless networks, radiation diagrams, Wireless Site Survey, ANSYS HFSS, iPerf.
2. Introduction
2. INTRODUCTION /

In open-pit mining, the proper functioning of telecommunications networks represents a challenge. Adverse climatic conditions, such as the high temperatures that occur in the areas of operation in the mine, as well as the concentrations of metallic dust in suspension, the vibrations produced by the blasting and humidity, are just some of the frequent features in this ambient.

Chile is a country privileged by its mineral reserves, where copper ore is the most common extraction material. For this reason, there comes up the need to promote concepts, techniques and procedures on mining networks that aim to achieve interoperability of systems and processes involved in this area.

This document, developed by Interop and Fundación Chile, with the collaboration of the Scientific Technology Center of Valparaíso (CCTVal), corresponds to the first version of a guideline on considerations for the pilot tests of telecommunications networks and their components in open pit mining. The Communications Guideline presents a section on pilot tests with information on the requirements that the services that operate on the network have and the measurement parameters necessary to determine the health of the network. This new document tries to cover in depth the aspects of the pilot tests and intends to be the beginning of an iterative process among all the mining participants, refining the concepts described here and improving the procedures in the daily life of the mining operation. Finally, it is expected to generate a standardization in Chile, according to our national mining reality, which promotes a continuous improvement in the levels of production and development of our country.

2.1 SCOPE /

This first document, related to pilot tests of telecommunications networks in open-pit mining, focuses on the connection difficulties presented by the equipment in the material extraction process.

Exposing these problems, it is expected to generate a culture for mining production, which promotes out the need of interoperable systems, improving on the current methodologies to make the processes more efficient.
2.2 DISCLAIMER /

The contents exposed in this document have been compiled from the experience and knowledge of people related to mining, such as miners, technology suppliers and the academy.

The accuracy or completeness of the contents exposed here is not guaranteed. Adherence to the guidelines described in this document is completely voluntary.
3. Conceptual framework
3. CONCEPTUAL FRAMEWORK

Before proceeding to conduct pilot tests in the mine network, it is important to understand certain concepts related to wireless telecommunications.

This section presents relevant information about the radiation diagrams of the antennas and their characteristics in the context of mining. In addition, concepts related to the process of a Wireless Site Survey on wireless networks in general are exposed, also emphasizing the important aspects in mining.

3.1 ANTENNA RADIATION PATTERN

In wireless communications, good management of the parameters that define the antennas used in the transmission and reception of the signal is fundamental for a satisfactory communication. One of the most important parameters of the antennas corresponds to the radiation diagrams. It is not very useful to have high power levels in the antenna if its location and orientation is not the appropriate with respect to its counterpart antenna. The knowledge about these parameters allows you to take advantage of the maximum gain the antenna can reach and take precautions on angles with lower gain.

DEFINITION

A radiation diagram (also called a radiation pattern) “is a graphic representation of the radiation properties of the antenna, a function of the different spatial directions, at a fixed distance” (Ángel Cardama Aznar, 2004).

An antenna radiates energy in all directions. The geometric distribution in the construction of the antenna is what determines in which directions it radiates more energy and in which it radiates less.

It is important to understand that when radiating characteristics of the antennas are described, they apply both to the transmission and to the reception of the signal.
RELATED CONCEPTS

The radiation diagram is a 3D representation of the energy radiation of the antenna.

To understand the orientation of a radiation diagram in space, it is important to establish a coordinate system together with the physical appearance of the antenna. In Figure 1 (a), a simple dipole antenna appears with the reference system in its center. This type of antenna radiates energy in an omnidirectional way, this effect can be seen in Figure 1 (b). The red areas represent high signal gain levels, while the yellow ones have an intermediate level and the green ones have a low gain.

Figure 1: Simple dipole antenna and its radiation pattern.
However, it is common to represent the radiation pattern by two planes, called the master pattern planes. These planes are the Azimuth Plane (horizontal pattern) and the Elevation Plane (vertical pattern).

In Figure 2, the main pattern planes of the radiation diagram shown in Figure 1 (b) are shown in polar coordinate graphs. On the one hand, we have in Figure 2 (a) the Azimuth Plane, which shows the energy radiation in directions of the XY plane. Figure 2 (b) illustrates the Elevation Plane, which characterizes the energy radiation in the XZ or YZ plane.

In these polar representations, the gain of the signal is plotted (in this case, measured in dBi) for each angle of the corresponding plane. In this case, the plans illustrate that the antenna radiates energy with the same magnitude in all directions of the horizontal plane, but it does so differently in the vertical plane, being maximum in the lateral zones and minimum in the upper and lower areas of the dipole. In addition, Figure 2 plots an opening angle (blue lines of the diagrams), which indicates the area of the space in which the power remains above half the maximum value that the antenna can radiate in that plane.
CONTEXT IN MINING

The radiation diagrams allow to locate the antennas optimally, so that the gain remains high in the direction of the wireless link, allowing a persistent connection between them. In the extraction process in open pit mining, this becomes a fundamental aspect, because the equipment and machinery need to stay connected to the communications network.

It is important to understand that electromagnetic signals are affected in different ways by materials, where reflections of the signal occur, directly influencing the radiation pattern of the antennas.

An example of the above corresponds to what happens with mining trucks. In Chile, according to the Mining Equipment Registry 2013/2014 prepared by the Editorial Editec Group, there is a universe of 1,592 trucks identified in the larger mining operations. The companies that stand out in the market share of large off-highway trucks are Caterpillar with 52%, Komatsu with 44% and Liebherr with 4% (Chilean Mining, 2014). The trucks used by these companies, as well as the rest of the mining trucks, are made largely of steel.

Conductive materials such as steel cause attenuations and reflections in the propagation of electromagnetic waves, deforming the original radiation pattern of the antenna located in the truck significantly. This factor must be taken into account when pilot tests are carried out on mine networks.

As a way to demonstrate how the truck conductor materials can affect the radiation pattern of an antenna, the ANSYS HFSS (ANSYS) software is used in this guide. This tool allows the modelling of 3D structures, assigning different types of materials and simulate their interaction with high frequency electromagnetic signals. This method is frequently used in the design of a variety of electronic products.
Figure 3 shows the result of the simulation with the ANSYS HFSS software, of the total gain (expressed in dBi) of a dipole antenna operating at 2.4GHz. These graphs correspond to the radiation in free space, without elements that can cause absorption or reflections of the signal. On the other hand, Figure 4 shows the radiation pattern of the same antenna, but in an unfavorable position for communication with the network, where the pattern is deformed by the steel present in the structures of the mining truck.

The intensity of the electromagnetic radiation is expressed in colors, being those of red color of high intensity, those of yellow color of medium intensity and finally the green areas correspond to low intensity of radiation. Figure 4 shows a complete region of the 3D green graph, which can also be seen in its Azimut plane, between 165 ° and 290 ° in a clockwise direction, where the gain is under the 0 dBi.
Figure 5 shows the radiation pattern with respect to the structure of the mining truck. It is evident that the directions of the radiation pattern with less intensity correspond to the place where the steel structure of the truck is located, between the metal surface of the box below, above and behind the cabin, in addition to the cabin itself. In conclusion, for this antenna configuration between the metal plates of the truck, it is not possible to give connectivity to the truck in 360° in a stable way in the horizontal plane, because the signals of the antenna in the direction of the structure of the truck have an extremely low gain.

### 3.2 WIRELESS SITE SURVEY

In a WLAN (Wireless Local Area Network) or wireless local area network, a first step to ensure that the desired operation works properly is to perform what is known as the Wireless Site Survey or RF Site Survey.

**DEFINITION**

The Wireless Site Survey, corresponds to the process of measuring in the field parameters such as: wireless coverage, data transfer rates, network capacity, (QoS) quality of service, among others.

The results of the measurement correspond to an input for the planning and design processes of the network, adjusting the configurations of the nodes and links, with the purpose of fulfilling the desired requirements.

There are 3 types of Wireless Site Survey: active, passive and predictive.
PASSIVE TYPE

Passive Wireless Site Surveys correspond to measurements in “listening mode”, where the measurement equipment is not associated with any AP. In these measurements the information obtained is: power of reception of the signal; frequency channels in which each AP is configured; level of radio frequency noise present in the place, which can be emitted by other components of the network or by external sources. This type of information is useful to generate coverage maps of the signal in the area of interest, identifying the locations where there is little signal or there is significant interference, both adjacent channel and co-channel interference, putting at risk the connection of the equipment to the communications network.

ACTIVE TYPE

The active methodology in the Wireless Site Survey consists of associating the measurement equipment with the APs of the network. By establishing a connection with the network allows entering data traffic, with which you can obtain other types of relevant metrics such as the effective rate or Throughput of the connection, as well as the rate of Lost Packets, Jitter, Latency time of communication, among others.

PREDICTIVE TYPE

In the predictive type, the focus is to determine parameters by using software, without the need to make measurements in the field. The information of the general coverage area where the network is intended to be used is used to obtain the number and locations of the necessary APs, using radiofrequency algorithms. It is convenient to carry out this type of Wireless Site Survey in design stages, prior to the deployment of the network, with the objective of estimating budgets relative to the necessary hardware in the implementation.
CONTEXT IN MINING

Wireless telecommunications networks in open pit mining must be able to support the traffic of different services related to the mining operation. Specifically in the extractive process of minerals, there are additional difficulties to high traffic, which are caused by adverse temperature conditions and the presence of metallic dust in the air. In addition to this, the different services of the mining operation present specific and diverse requirements, where some processes are monitored in real time, requiring shorter latency times in the network.

These circumstances make necessary a procedure that allows to see the real capacities presented by the wireless telecommunications network in the field, where the signals are affected by the real environment.

The 3 types of Wireless Site Survey mentioned above are useful for obtaining information of different types in the mining network.

- The predictive method can help to estimate the number of wireless nodes needed for the deployment of a new network in the areas of material extraction.

- The passive method is useful for planning the frequency channels to be used and avoiding co-channel interference and adjacent channel interference.

- The active method allows to measure the performance of the network by entering data traffic

From the parameters of measurement for the health of the network, exposed in the first Communications Guide for open-pit mining, it is possible to relate what parameters can be achieved with each type of Wireless Site Survey, focusing on the passive and active types.
**Passive type:**
- Power received
- SNR
- Redundancy
- Adjacent channel interference
- Co-channel interference

**Active type:**
- Throughput
- Bandwidth
- Latency
- Jitter
- Lost packages

Although both methodologies are relevant and can be complemented by performing them in the same path, the most important one in the context of network requirements in mining services is the active type. The fact of introducing traffic to the communications network allows to measure the Throughput of the network, as well as the latency times in the communication with respect to the central server or the location in the mine in charge of controlling the processes. These parameters reflect whether or not the network is in acceptable conditions to support services with high traffic demand, especially those that need to operate in real time, such as teleoperation of machinery or continuous monitoring of sensors, for example.
4. Pilot tests on wireless networks of the mine
4. PILOT TESTS ON WIRELESS NETWORKS OF THE MINE /

The wireless communications networks, in open-pit mining, present different topologies that allow to interconnect the command centers or central servers with the equipment involved in the extraction of the material. In this pilot test guide, the “last mile” network is considered, that is, the connection between the equipment and machinery with the access points to the network.

This section presents general Cisco recommendations on the process of conducting a Site Survey on Wireless Networks (Cisco, 2013).

The main focus of the proposed methodology is that the measurement conditions should be as close as possible to the real conditions of the mining operation.

4.1 PREPARATION FOR THE WIRELESS SITE SURVEY

The first step to start preparing for a Wireless Site Survey is to have good communication with the personnel or customers who request the measurements, to clearly understand the requirements and the type of measurement that is needed. For this task, meetings can be carried out complemented with questionnaires, where the main requirements are detailed.

This first stage helps to see the types of needs in radiofrequency applications, such as voice, data, position, etc. Additionally, the type of devices presented by the client are identified and what type of parameters they want to measure, together with their desired values for the correct functioning of the services in the network.

4.2 PLANNING FOR THE WIRELESS SITE SURVEY

Before carrying out the tests with the equipment in the field and measuring their interactions with the telecommunications network, it is necessary to identify the aspects that may affect in some way the normal development of the measurement in the field. In this context, it is suggested to consider the following points:

- Plot the measurement route for the Wireless Site Survey.
- Verify that there is free access, both to travel and to connect to the network, through the entire measurement route.
• Anticipate the areas where there may be obstacles to transit and verify in the field. If there are obstacles, you must find a way to clear the path, making sure to measure the network along the same routes that the mining equipment follows.

• Review other details in the field that may hinder the measurement and that do not appear in the sector plans.

• Consider the type of mobility the measurement will have. This refers to whether the measurement will be made in constant motion and at what speed it will travel along the route, or whether static measurements will be made every certain distance. To measure the pit access network, it is recommended to conduct a Wireless Site Survey in constant motion.

• Select a suitable software tool to measure the parameters of interest for the client. Among the most common softwares for this purpose in the Wireless Site Survey industry, are Air magnet Survey and Ekahau Site Survey.

• Define the type of reception device that will be used for the measurements, making sure to be consistent with the approach in this guide, it is recommended to use the same type of antennas as the equipment or machinery that is intended to represent the mining operation.

4.3 EQUIPMENT PREPARATION

To carry out a good Wireless Site Survey, all the equipment involved in the measurement must be correctly prepared. In this context, the main elements correspond to the measurement antenna to be used, as well as the tools for data acquisition. Finally, it is important to understand that the additional traffic existing within the telecommunications network while the measurements are being made must be in accordance with what is intended to be evaluated.
MEASURING ANTENNA

Following the main focus of this pilot test guide, the antenna to be used in the measurement must represent the same conditions present in the equipment or machinery in a mining operation under normal conditions.

It should be noted that the first option to make measurements on the connection between a computer and the telecommunications network should be to use the same equipment or mining machinery in the Wireless Site Survey measurements.

In the case of the mining truck, subsection 3.1.3 of this document mentions the importance of the location of the antenna and how the metals of the truck affect its radiation pattern.

In Figure 6, a new position of the antenna on the truck is shown, where the dipole is located in a better position compared to Figure 5, on one side and above the height of the upper limit of the box on the truck.

In this configuration, the radiation pattern improves with respect to Figure 5. However, despite being above the level of the metal, in any case, reflections of the signal that affect the radiation pattern occur.

*Figure 6: Dipole located on the metal level in the truck. ANSYS HFSS.*
In Figure 7 it can be seen that the gain of the antenna varies considerably in the Azimut plane. The values of the gain stay above 0 dBi in all directions. However, this pattern and the differences in gains should be considered in the same way as the antenna changes orientation, since the connection could be affected by this factor.

If it is not possible to use the same equipment or machinery to carry out the Wireless Site Survey, alternatives can be implemented to measure the performance of the network.

Figure 7: Azimuth plane of the dipole located on the metal level in the truck. ANSYS HFSS.

Figure 8: Vehicle with mast and antenna, adapted for measurements of wireless networks.
A viable alternative to mimic the behavior of truck antennas is the adaptation of a vehicle with a mast and the antenna at its apex. This helps measure the telecommunications network at the same height as the antennas located in the mining truck, as shown in Figure 8.

It is important to highlight that this methodology not only tests the network, but it also seeks measures it in a mining operation context, seeking to represent a specific equipment or machinery. For the case in which it is intended to represent the mining truck, it is not enough to imitate the height of the antennas that it has with respect to the ground, but also they must be of the same type of antenna (if possible the same model) and with a Radiation pattern as similar as possible. In this context, if the truck’s antennas are located in positions where the metal significantly affects the radiation pattern of the antenna, as in the cases detailed in this guide, the effect of the metal on the truck should be incorporated into the measurement antenna that the vehicle has. One idea to achieve the above, is to position metal plates in the vicinity of the measuring antenna, representing the metal structures that are closest to the antennas in the mining truck.

There is another common configuration to connect the mining truck with the telecommunications network, consisting of two sector antennas, one on each side of the truck

![Figure 9: Sectoral antenna master plans.](image)
In Figure 9 the azimuth and elevation planes appear. A contrast can be made with the images in Figure 2, comparing the radiation with the dipole antenna.

The sectorial antenna does not cover all directions with uniform gain in the azimuth plane, as does the dipole in free space and without disturbances. In addition, the sectorial antenna presents greater directivity, concentrating the power in a certain direction of space.

The objective of locating two sector antennas in the mining truck is to try to cover the 360 ° in the horizontal plane, as shown in Figure 10.

If the configuration in the truck is of sectorial antennas and it is intended to perform a Wireless Site Survey with an adapted vehicle, sectoral antennas should also be placed on the mast, replicating the area of coverage that is achieved in the truck.

**DATA COLLECTOR**

The software selected to perform the measurements must be able to obtain all the parameters that are of interest, for the type of Wireless Site Survey to be performed, as mentioned in subsection 3.2.2.
It is advisable to use a method to obtain the position of the measuring antenna during the course of the Wireless Site Survey, such as a GPS device. This is especially useful when combining this information with measurements, allowing the generation of coverage maps and identifying areas with interference problems, both adjacent channel and co-channel interference.

In the Wireless Site Survey market, there are two tools that are often used: AirMagnet Survey and Ekahau Site Survey. Both provide coverage maps, along with reports with different output formats, ranging from electromagnetic spectrum analysis, to measurements of the performance of the telecommunications network, using implementations of iPerf, software capable of obtaining metrics such as Throughput and signal latency, introducing data traffic in the network.

AirMagnet Survey and Ekahau Site Survey require paid licenses to use all functionalities. However, iPerf is free software, so it is possible to search for its integration with some other tools to generate coverage maps, among other interesting results. In section 7.1 in Annexes, there is a brief manual on how to use iPerf.

**TELECOMMUNICATION NETWORK UNDER MEASUREMENT**

In the realization of an active Wireless Site Survey, where there is an association with the telecommunications network and data traffic, it is important to understand the context that it is intended to represent. The measurements of throughput and latency of the packets that are transferred between the equipment or machinery and the central server of the mine, are affected by the data traffic already existing in the network and that is generated by other connected equipment. In this context, if the aim is to measure the maximum possible performance of the mining equipment in the telecommunications network, then it should be avoided, as far as possible, the presence of traffic generated by other components in the network. On the other hand, if it is intended to measure the performance in the context of the mining operation, the telecommunications network must present a level of traffic close to that it would have in a normal day, with other connected equipment introducing traffic.

**4.4 MEASUREMENT PROCEDURE**

Once a correct preparation of the equipment has been made, both the right positioning and orientation of the measuring antenna, as mentioned in subsection 4.3.1, seeking to reproduce the physical characteristics of the equipment that is to be represented when
measuring, as well as the tool to collect the data of subsection 4.3.2 and the considerations on traffic in the telecommunications network of subsection 4.3.3, the Wireless Site Survey is carried out.

Using the mining truck as an example, if the measurement is made with the same truck, it must be guaranteed that the speed with which the route is traveled while the parameters of interest are measured, is similar to the context of the truck in the normal operation, the same condition applies fo an adapted vehicle, imitating the conditions of the truck.

Another relevant aspect to take into account during the measurement is whether the sampling is done automatically by the tool used in the route or if it requires the intervention of a person. It is recommended to configure it so that data is automatically collected while the measurement route is travelled.

### 4.5 MEASUREMENT SCENARIOS

In addition to traveling along the measurement route in the Wireless Site Survey, it is also necessary to perform tests for different scenarios or situations in which the team may be involved during the mining operation.

Using the mining truck as an example, some possible scenarios can be:

**COMPARISON BETWEEN ROADS THAT CONNECT DIFFERENT SECTORS OF THE MINE AND ROADS IN THE PIT.**

To get an idea of the variations in the signal intensity and the values that the parameters can take in varied environments, one Wireless Site Survey can be carried out for the roads inside the pit and another one for the rest of the roads present in the mine. The pit has a high concentration of metallic dust suspended in the air, so that the effect it has on the signal could be measured, by comparing the different measurements.

A useful tool to simulate wireless links is RadioMobile. This software allows to locate antennas in specific geographic positions, establishing their gains, transmission powers, among other variables. Figure 11 shows a simulated link in the Chuquicamata pit, with a sectorial antenna giving coverage to an area of the pit and an antenna located in a position inside the pit. Among the results obtained in the simulation, is the expected reception power, a value that could be contrasted with the actual measurements of the Wireless Site
Survey in the pit. The attenuations of the signal caused by the metallic powder can be verified in this comparison.

Figure 11: RF link in Chuquicamata pit.
RadioMobile GoogleMaps Map
OBSTACLES BETWEEN THE MEASUREMENT ANTENNA AND THE CONNECTION AP

During the daily operation of the mining, the line of sight between the equipment and the AP could be obstructed. To carry out measurements in this situation provides information on the intensity of the signal arriving by multipath and the performance of the connection under these conditions. The fact that the mining team maintains an acceptable connection despite the presence of obstacles could be desirable in the mining operation.

TEAM CHANGING ORIENTATION

It is important to take into account the variations that may exist in the connection with the telecommunications network, in the case that the mining equipment changes its orientation or rotates on its vertical axis. Using the mining truck as an example again, depending on the configuration of the antennas you have, there will be some position in which the quality of the connection is expected to decrease. If the truck has a dipole antenna as in Figure 7, this decrease would be expected when the metal structure is between the truck antenna and the connection AP. On the other hand, if the truck has a configuration of sector antennas as in Figure 10, the decrease in connection would be expected when the AP is just behind the truck, where the coverage is lower.

4.6 MEASUREMENT PERIODICITY

The frequency of pilot testing of networks in open pit mining depends on the internal policies of each mine, where they evaluate possible breaks in the operation as a result of measurements in the field, which produces a series of associated costs.

Some periodicity is suggested to carry out measurements in the field, depending on the level of criticality that the system presents in the general context of the mining operation, verifying that they maintain a correct operation in relation to the communications network.

• At least once a month, in systems that work autonomously.
• At least once every 6 months, for fleet management systems or FMS, with an approximate deployment of between 100 and 150 teams.
• At least once a year, for the rest of the systems
5. Technical Summary
CONCEPTUAL FRAMEWORK:

• Antennas radiation diagram: The correct positioning and orientation of the antennas are fundamental for satisfactory communication. The materials of the mining truck and of the machinery in general, produce attenuations and reflections of the electromagnetic waves, which modifies the radiation pattern of the antennas. This effect should be considered when conducting pilot tests in the networks, since both the transmitting and the receiving antennas must be oriented in such a way that the gains of both are adequate in the direction of the wireless link.

• Wireless Site Survey: This procedure consists of making measurements in the field of different parameters in the wireless telecommunications networks. There are 3 types of methodologies: active, passive and predictive. It depends on the parameters that are required to measure the type of methodology needed. For services that require high rates of data transfer and minimum latency times, it is recommended to perform an active Wireless Site Survey, introducing data traffic.

PILOT TESTS ON WIRELESS NETWORKS OF THE MINE:

• Preparation for the Wireless Site Survey: It is important to be clear about the needs of the people or clients requesting the measurements. This first stage helps to see the types of needs in radio frequency applications, also identifying the types of facilities and devices present in the mine. Finally, the specific requirements of each device must be detailed to take this information to the measurements.

• Planning for the Wireless Site Survey: Before taking the measurements, it must be clear the route through which the equipment will pass measuring in the field. After plotting the measurement route, there are several aspects that must be evaluated, in order that the measurements can be carried out smoothly and without setbacks. The selection of the software to be used will depend on the parameters of interest to be measured, along with the results that are expected to be obtained, such as measurements reports and coverage maps, allowing decisions to be made about changes in the configuration of the network.
• Equipment preparation: Among the factors to consider for the measurement, three components stand out: the measurement antenna, the data collector and the traffic already existing in the network. For example, if you want to evaluate the performance of the connection between the mining truck and the network, you should consider making the measurements with the same truck in the first instance. If this is not possible, find a way to adapt a vehicle that represents the truck, both in height of the antenna with respect to the ground, and in the pattern of radiation present. Here it is important to consider the effect of the truck’s metals on the pattern and replicate it in some way in the adapted vehicle. On the other hand, the selected software must be integrated with a GPS or another way to obtain the position of the measuring antenna, if it is intended to generate coverage maps. Finally, the existing traffic in the network caused by factors other than those involved in the Wireless Site Survey should be consistent with what is intended to be measured, differentiating between measuring the maximum possible capabilities offered by the network infrastructure or measuring the performance of the network connection in the context of the mining operation.

• Measurement procedure: In the implementation of the Wireless Site Survey, it is recommended to configure the software in such a way that it captures the samples automatically, without the need for human intervention, while the measurement route is traveled.

• Measurement scenarios: In addition to the measurements along the measurement path, it is recommended to measure various contexts to which equipment or machinery in the mine could be confronted. Carrying out measurements on the roads inside the pit and on the rest of the roads of the mine, would allow to measure the impact that metallic dust in the can have, at places where its concentration is greater inside the pit. Carrying out measurements where the wireless link of the equipment has no line of sight, would allow the connection to be analyzed by the multipath of the signal, where it might be desirable for the connection to be maintained despite obstacles. Finally, the measurements of the equipment in different orientations, rotating with respect to the vertical axis, would allow to apply measurements in those situations where the connection decays.

• Periodicity of measurement: In general, each mine has internal policies to carry out pilot tests of its networks. Based on the experience of the mining systems, suggestions are made for each type of system, according to its level of criticality in relation to the mining operation.
6. REFERENCES
6. REFERENCES /


ANSYS. (s.f.). Obtenido de ANSYS HFSS: https://www.ansys.com/products/electronics/ansys-hfss


7. Annexes
7. ANNEXES/

7.1 HOW TO MEASURE THROUGHPUT WITH IPERF.

IPerf is a very useful and simple tool when measuring Throughput. To run this tool, you need to have a machine working as a server at one end of the network, while at the other end you must build another machine that will function as a client. On both machines the result of the test will be displayed at the end.

INSTALLATION

First, you need to download iPerf.
If you are on a machine with Linux operating system based on Ubuntu, just execute:

```
sudo apt install iperf
```

If you are on a machine with a Windows operating system you should download iPerf from https://iperf.fr/iperf-download.php#windows.
For other operating systems refer to https://iperf.fr/iperf-download.php, where you will find binaries and installation manuals for different platforms, including Windows, Windows 10 apps, Android, Apple iOS, Apple macOS, Ubuntu, Fedora, openSUSE; Arch Linux, FreeBSD, among others.

CONSIDERATIONS BEFORE PERFORMING THE TEST

IPerf does its best to use the entire available channel width in the network. This means that, if there is another device in the same network, the quality of your service will be affected. Thus, iPerf can be used to measure the maximum Throughput or the Throughput available in the network in production, as to evaluate the feasibility of raising a new service, for example.

In the case of evaluating the maximum Throughput, it is important that the network is not being used by any device before making measurements. If measurements are required in a production environment, it may be necessary to schedule the test for a time when there is a minimum number of services running on the network and a minimum number of users in the network.
Another important point is that iPerf by default only measures Throughput from the client to the server, so if the link used to get from one device to another is asymmetric, the test could be seriously affected.

The last important point before performing the test is the existence of firewalls. If any of the devices is behind a firewall, it will be necessary to enable some port for the test in it. Due to the existence of a large number of firewalls (software and hardware) is that this section will not explain how to add the corresponding rule to allow transit through a specific port.

7.1.3 Performing the test

Let us suppose that there are two machines, one with ip address 10.10.10.1 and another 10.10.20.1, configured so that there is connectivity between both.

On a machine, which will act as server (10.10.10.1) must execute the following command on the command line:

iperf -s -p 7575

In the previous example port 7575 was used, the port number can be anywhere between 1024 and 65535. Using a low number 1024 is possible, but will require special permissions on the machine. Also, if you use a port that is being used by another service, the command will fail, and you should try another port.

In a second machine, which will act as a client (10.10.20.1), you must execute the following command in the command line:

iperf -c 10.10.10.1 -p 7575

In this case -c indicates that the machine will act as a client, of the machine 10.10.10.1 that listens on port 7575.

To execute a test in which both upstream and downstream are measured sequentially (ie first upstream, then downstream) the -r option must be added, if you want to measure both flows simultaneously, you will need to add the -d option, for example:
iperf -c 10.10.10.1 -p 7575 -d

The results that will be displayed on the screen will come as shown in Figure 12.

Figure 12: Measurement with iPerf in client machine.

In the case of Figure 12, 1.54 GBytes were transferred in a 10-second interval and it was determined that the Bandwidth of the channel is 1.33 Gbits / sec. It is important to note that the result is Bandwidth, but in reality what is shown is the capacity used of the channel, that is, the Throughput. Under ideal conditions, the indicated value will effectively represent the Bandwidth

USEFUL PARAMETERS OF IPERF
AS A SERVER

-D: lift the iPerf server as a service
-R: remove iPerf service raised with -D
-u: perform the test in UDP
-P x: allows a number x simultaneous connections
-m: show MTU
-w x: set the TCP window size
-f [bkmBKB]: Formats the output in bits / s, kbits / s, Mbits / s, bytes / s, KBytes / s or MBytes / s
AS A CUSTOMER

-T ttl
-i x: Set the duration in x seconds for an interval
-t x: Set the duration of the transmission in x seconds

7.2 DOCUMENTATION OF ACCESS POINTS

To carry out pilot tests of the networks in the mine, using the methodology of Site Survey, it is advisable to keep a clear, accurate and updated documentation on the access points deployed in the network. This must be done in digital format to give traceability to changes and facilitate access to information. Next, the following list of important characteristics is presented to a document.

• **Name of the location:** to facilitate maintenance, you can identify the physical location where the access point is installed with a name specific to the mine.

• **Geographical coordinates:** Expressions accurately in latitude and longitude.

• **SSID:** Identifier of the wireless network to which users of the access point can access.

• **Frequency of operation:** You can express the central frequency in which the service operates or the frequency standard, such as WiFi.

• **Channel of operation:** It specifies the frequency range of the channel or the identifier of the channel, typical of the standard in which it is operating.

• **Type of antenna:** Dipole of half wavelength, parabolic, sectorial, among other examples.

• **Aiming:** Physical orientation of the antenna with respect to three-dimensional space. A reference system is established from the physical aspect of the antenna and what angles it describes on the horizontal axis and on the vertical axis.

• **Azimuth plane:** Radiation diagram that expresses the gain in the horizontal plane according to the reference system of the antenna itself.

• **Elevation plane:** Radiation diagram that expresses the gain in the vertical plane according to the reference system of the antenna itself.
• **Transmission power:** Specify the transmission power of the antenna. Use the same unit of measurement for all the antennas that are documented.

• **Installation date:** Date and time when the antenna was installed.

• **Last modification:** Date and time when the last modification of the access point occurred and a brief description of the event.

• **Standards and / or standards:** Standards and / or standards with which the installation of the antenna, configuration, communication protocol, etc. complies.

• **History:** The idea of this point is to have a list in chronological order (date and time specified) of the events that occur with the access point, be it maintenance, physical modifications, changes in its configuration, among others.