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LKAB COMMUNICATIONS

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Introduction

LKAB is as everybody knows an underground mining company. Great efforts are made to cut costs and automation is one of the cornerstones in this work. To keep in the front-line of competitors with open pits, the company has been forced to work on the cutting edge of technology as the mine is going deeper down with rising costs as a result.
LKAB has a long experience in automated solutions. The present haulage level on 1045 m level is the third level with automatic driverless trains and remote loading in the tapping galleries from a central control-room. In this area LKAB has more than a 20 year experience.

LHD's

The main purpose of the COM2000 project is to introduce automatic operation into parts of the mining process primarily and drilling rig operation. For this purpose the LHD's (Toro 2500 from Tamrock) will be equipped with functions for autonomous operation

Normally the only operator action is to handle the filling of the bucket either in the caved material or for drift cleaning. If necessary the operator will be able to take full control of the LHD and teleoperate it. To obtain this goal this new generation of LHD's will be equipped with a number video-cameras, a microphone,a system for automatic navigation etc.

Drilling riggs

Today LKAB operates today two types of drilling rigs, the BK-rigs from Atlas Copco and DataSolos from Tamrock.
These drilling rigs are fully automised and in normal operation it drills one drilling ring in automatic mode for about 8 hours without manual interference. Then the rig will be moved (3 meters) by miners down in the production areas, the rig is put into automatic mode and drills another drilling ring. The operator in the control room will only make minor corrections, respond to alarms et cetera.
The drilling rigs are using Siemens PLC S5 and Profibus for the communication between the operator console and the drilling rig. The solution is built around a transparent link for the Profibus traffic. The automation network is only replacing the cable.

Figure A - LKAB Combines RF links with an ATM network to create the automation Network.

SALT II

In the end of the 80'th LKAB in co-operation with Tamrock conducted full scale tests with LHD's equipped with a guidance system, four video cameras and a communications system. During the test period an amount of near one million tons of iron ore was carried by the LHD to the shafts. The result was promising but didn't fulfil the goals set up for production and availability. LKAB decided to wait for better solutions to appear on the market.

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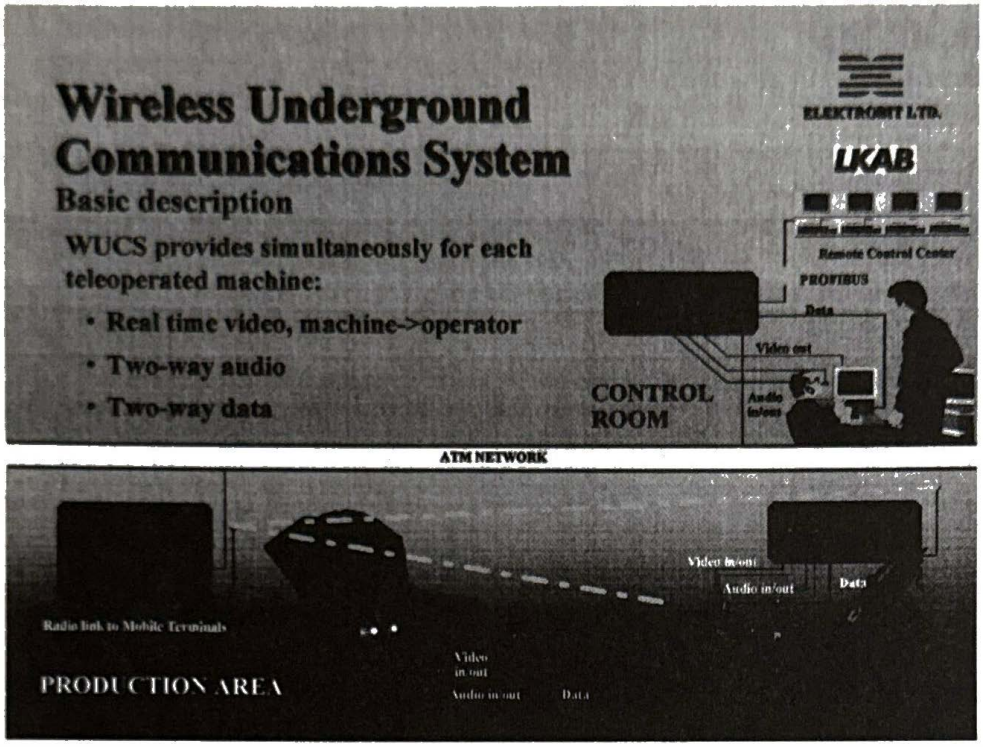

The production method used during the test was sub level stooping not the present method, sublevel caving. Using the sub level stooping method of mining a LHD is loading in the same production area for a period of 6 month after every blast. With the sublevel caving method the length of life for a production block is 18 month. A main conclusion was that it wouldn't be cost-effective to implement a technology heavily based on infrastructure.
The communications- and navigation methods used during the test did not fulfil this requirement.

Economy

The test also gave input to economical simulations. The simulations that LKAB made are so to say very conservative from the cost (high) point of view. There is certainly a reducement in the number of workforce when one operator can control up to three or four LHD's. And of course there's a improvement in the working conditions. The main conclusion is nevertheless that there are profits to be made with LHD automation, especially profits from better machine utilisation. The automated LHD doesn't stop for lunches and keeps on working the whole night. An important parameter is also the possibility to reduce the running costs.
The conclusion from SALT II in the area that is this papers concern, communications solutions was that a digital video solution is preferable rather than a analogue due to specific conditions in the mining environment such as high propagation attenuation and strong multipath propagation.

Requirements.

The COM2000 design parameters where coming from:

- SALT II
- The Mining Method in Kiruna
- The Kiruna Mine Architecture
- The mine operation itself

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The basic requirements that was passed on from the SALT II project are:

- Small latencies 100 - 150 ms is needed .
- No (or little) infrastructure to keep running costs low
- High Availability (99,8%)

Earlier experiences pointed out the 900 MHz frequency band as one of the best propagating frequencies for RF mine communications. This was also confirmed via channel measurements that where carried out.

Other design parameters that the COM2000 project have considered is the mine layout it self and the optimum of vehicles used to obtain the planned production results.

The length of iron ore body is approx. 4 km. The ore body will be divided into 10 productions blocks (today 8).

LKAB is intending to have 3 levels "in working mode" in each production at a given time. One level for drilling and two levels for loading. This gives a total of 30 production blocks in use at the same time. The submergence with today's production is aprox. 24,75 m/year which means that a new level is taken into production each year. The distance from control-room on the 775 level to the production blocks is approx. 1,5 - 5 km.

A maximum of 3 vehicles will be in use in a production block, 2 LHD's and 1 Drilling rig or vice versa. LKAB will have a total of aprox. 11 LHD's (Tamrock 2500) in production and is planning to use 8 drilling rigs, 6 BK-rigs from Atlas Copco and 2 Solo riggs from Tamrock.

One of the big trends during the recent years is that Information Technology is more and more used in the mining environment. Electrical power systems, water pumping systems etc. are all implemented with different IT implementations.

The COM2000 project was originally formed around the requirements derived from automation and technology driven trends. The basic idea behind the project was to create a multipurpose infrastructure in order to carry different types of digital information, data, audio and video.

The project was also divided in two different parts,

1) a RF part and 2) a cable based Network infrastructure. One of the early decisions for the second part of the project was to implement an ATM Network. Another decision was to find a solution for the LHD RF communications. The reason for this is that the project considered that if a RF solution would fit the LHD requirements it would fit for the drilling riggs.

To fully understand the final decisions it's necessary to discuss the different basic technical requirements,

- latencies
- picture quality
- the communications architecture
- RF Method

that was formulated in the early stages of the project and the experiences the project acquired during the projects different stages.

Latencies.

Instead of transmitting the analogue video signal directly on the air digital image processing is used for mobile video communications to reduce bandwidth. The analogue video signal bandwidth is using approximately 5 MHz of bandwidth on a link. By digitising, filtering and compressing the image the information bandwidth can be reduced as much as down to 10% of the original signal bandwidth. Although it is questionable if that amount of compression provides a satisfactory image quality. The backside of digital image processing is that it introduces latencies into the system.

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Teleoperation sets special requirements for the latency over the communications link. From various discussions a latency between 100 and 150 ms was defined as tolerable. The latency was defined as the time from which a command was performed until it was showed on the operators monitor. The main reason for the latency is the time to digitise the video picture. The figures was also set with consideration to additional latencies caused by for example the hydraulic system of the vehicle.
A problem was that there wasn't that much experience in how a latency of 200 or 300 ms would affect the operation of a teleoperated vehicle. Driving loaders with a control stick and a video monitor may, however, require some training despite the latency is short enough. Later it turned out that the calculated latency of the Atlas BK drilling rig with an cabled analogue video solution and separate Profibus communication link from the operator to the rig was near 230 ms. A latency still tolerable for the operator. In a test with an ordinary wireless Ethernet LAN (Wavelan) and a Bitfield Video card indicated a latency around 500 ms.
A latency figure not acceptable.
The conclusion to handle latencies is to consider the whole operation cycle in order to minimise latencies. The design of control panels etc. should be a part of the design process. This means that different suppliers has to cooperate in order to create the optimal solution. An example of such an co-operation could be to design the operator interface in an automated environment.

Picture quality.
The quality of the picture is defined from a set of parameters:
- frame speed
- available bandwidth
- picture coding algorithm
- size of monitor

There are a several image compression algorithms used in image transmission . In an early stage the following
algorithms was considered:
- H.261 / H.263
- MPEG-1/MPEG-2
- Wavelet

Some of the algorithms (H.261 / H.263 and MPEG-1) where developed for applications such as video conferensing and are based on block DCT encoding. An image frame is divided into small blocks which are then encoded. After encoding the results are compared to the previous frame. For the most of the time, only changes in blocks between successive frames are sent and the required bandwidth is reduced drastically.
There are also other, even more effective, compression methods which are not based on block coding. However, in case of bit errors the block encoded images are only partially disturbed while the other algorithms may loose entire frames. Wavelet coding is one example of this coding method.
On the other hand, broadcasting image quality would be obtained by extremely complicated algorithms such as MPEG-2 but the hardware required to run this kind of compression algorithm is too expensive and complicated. MPEG-2 also requires lots of bandwidth (8 Mbit/s).
Experiment during 1996 indicated that the use of the H.261 algorithm with a resolution of 352 * 288 pixels was good enough for the teleoperation of mining machines.

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RF Method

Another early decision in the COM2000 project was to use spread spectrum technology for RF links. The spread spectrum technology offers a powerful way to communicate over a harsh radio channel present in mining environment. The technology is a widely used broadband digital communications technology (radio LAN's, satellite communications) and was originally developed for military purposes in 1960's.
The spread spectrum radio offers several advantages over a conventional narrow-band radio system including:

- Excellent performance in multipath radio channels such as in mines
- Robustness and immunity to interfering signals
- Security due to pseudo-noise codes
- Lower signal power density generating less interference to other radio systems

The communications Architecture

Automation and teleoperation sets new requirements for a mining communications infrastructure.
A conventional leaky feeder based communications system is not capable of providing the data transfer capacity required for teleoperation.
The basic requirements on the communications system is the ability to simultaneous carry,

- video
- audio
- Data (condition monitoring, production information, statistical information, teleoperation data) between the production areas in the mine. The communication system should also at some point interface the company's LAN.

As earlier stated the early objectives of the communications project was to create a multipurpose communications network based on ATM. ATM is however a complicated communications technology. An other disadvantage with ATM was the lack of standards in certain areas like traffic control. Never the less the decision was to go with ATM.
Other requirements defined from various needs in the mine was:

- Access to maintenance systems and company LAN from the mine.
- The need to connect other types of systems and devices to the network. Ex PLC's, shaft measuring etc.

The next consideration was to design the architecture of the network. There is three possible ways of designing the ATM infrastructure.

1. A dedicated automation Network
2. A dedicated network with tunnelling functions for ex. Ethernet.
3. A general purpose network.

Based on the installed links in the Kiruna mine the following conclusions can be made in the comparison between analogue and digital video:

- Clear disturbance free image over the entire communications range
- No problems with reflections (no ghosting)
- Noise free image (no snowfall)
- No synchronisation problems caused by strong multipath propagation

The final decision was based on the assumption that it is easier to keep high availability in a dedicated automation network than the general purpose network.
From the original idea of creating a multipurpose network for audio, data and video the project at the end implemented 2 separate networks for the Kiruna mine

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(Yet another one was already implemented on the haulage level).
1 An automation's network based on ATM
2 A switched Ethernet network with an ATM backbone.
PAL / NTSC CIF colour video, 25/30 Fr/s
• two-way audio which is using ordinary LKAB voice communications equipment. Service personnel working near the rig can via wireless headsets interfaced with the WUCS communicate with control room staff.

Status

For the moment 5 Atlas drilling riggs are remotely operated from the 775 control room in the Kiruna mine. Operating drilling riggs requires other solutions than the operation of LHD's. An obvious difference is that while a LHD is constantly moving a drilling rig moves every 10'th hour when a drilling ring is completed. The drilling riggs unmobility caused disturbances that hadn't been predicted. In some parts for example the picture could be a worse than it was just three meters longer in the tunnel. Just by moving the drill the picture got better. This phenomena is probably caused of parts of the tunnel with more multipath propagation and the fact that the rig is standing still. With a LHD this part of the tunnel just causes some bit errors when the LHD drives ahead.
Another area that the project has spent time in is to tune the illumination of the drilling rig. Early tests pointed out the illumination as an important parameter for good picture quality. However the mining environment with vibrations, water and falling rocks is a hard for ordinary lamps. Another important object is the dynamics of the camera which can improve the picture quality.
Other important issues are the operation and maintenance of the network itself. Knowledge's that in some cases are new for mining operation.

Conclusions

Finally some remarks on the future options given by automation.
The operation of remote mining equipment using RF and digital video has been proven as feasible. Although some important issues has to bee further defined:
• Standards for interfaces that the communications equipment should interface.
• Co-operation between mining automation suppliers and communication technology suppliers in order to optimise solutions and operation.
• The introduction of new technology requires new skills to operate and maintain the technical solutions.
• New communications technology gives new opportunities for mining suppliers. Via the Internet and automation Networks suppliers can provide real-time maintenance functions to rolling stock.

WUCS (Wireless Underground Communication System)

LKAB has chosen the Finnish company Elektrobit Oy to develop and deliver the RF communications solution. The name of the system is Wireless Underground Communications System (WUCS).
The WUCS transfers real time image, audio and data between the control centre and underground machines in the production areas. The WUCS consists of Mobile Terminals (MT) installed on the vehicles, Base Stations (BS) installed in fixed locations in the production areas and Control Stations (CS) located in the control room.

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The BS and the CS communicates via an ATM network. Basically using Private Virtual Circuits (PVC's) and Multicasting. The connection between the MT and the BS is provided by a wireless spread spectrum link at 900 MHz. One Base Station can communicate with three Mobile Terminals simultaneously without interference.
The most significant technologies utilised in the WUCS are:

- Spread spectrum radio
- Digital image processing and image compression (H.261)
- Advanced high speed data switching (ATM)

The WUCS provides multiple transparent data interfaces such as RS-232, RS-485 and Profibus between the operators and the underground machinery. In addition to data, WUCS provides interfaces for video and audio transfer. Each communications link between an MT and the control centre is capable of providing simultaneously:

- 2 x RS-232
- RS-485 or Profibus (physically RS-485) (RS-422 is planned for LHD automation purposes)

The interface is possible to configure via software in the user interface.

- PAL / NTSC CIF colour video, 25/30 Fr/s
- two-way audio which is using ordinary LKAB voice communications equipment. Service personnel working near the rig can via wireless headsets interfaced with the WUCS communicate with control room staff.

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