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THE OPTIMUM COMMUNICATIONS ARCHITECTURE FOR DEEP LEVEL GOLD MINING

by

Mark Henry Bruce Miller

Submitted in partial fulfilment of the requirements for the degree

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SYNOPSIS

"THE OPTIMUM COMMUNICATIONS ARCHITECTURE FOR DEEP LEVEL GOLD MINING"

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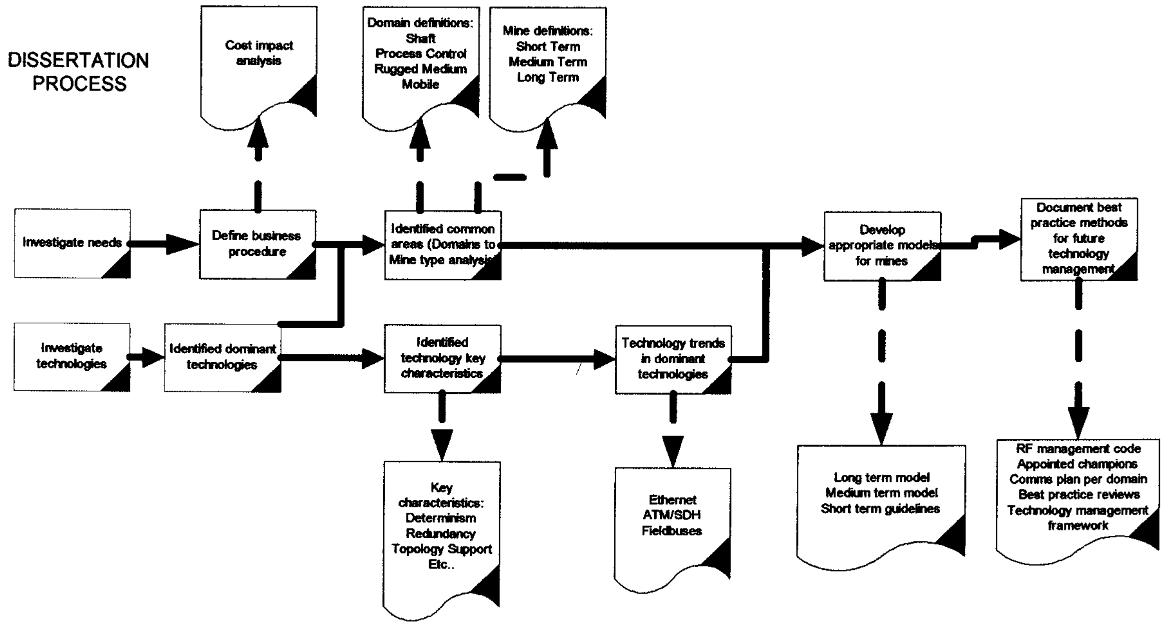
If systems for multi media communication are implemented haphazardly in a business then one can end up with a 'patchwork' of communication systems, difficult and expensive to maintain and expand. The objective of the dissertation was to develop the vision or generic models for future communication systems in deep level gold mines, and to identify and define the more important engineering and technology practices necessary for the implementation of this vision.

APPROACH

The approach taken is best summarised by the flowchart below where the needs of the business were analysed and applicable technologies available investigated. These combined led to the concept of 'domains' which was developed and defined in order to rationalise the number of communication systems required.

Technology trends were investigated further and finally appropriate models were developed for classified types of mines. Additionally the more important practices and measures were also defined.



RESULTS

The cost of communication systems was found to be significant and appropriate engineering is required to reduce the total cost of ownership. The profit opportunity enabled through communication systems is also enormous, and therefore 'downtime' is of major significance.

This emphasised the need for generic design guideline models, and the development of critical measures or practices to be adhered to within the business.

Three classes of mines ('Long', 'Medium' and 'Short Term') were identified in preparation for the technology models, primarily differentiated on the basis of automation requirements, expected life, and how much of the envisaged communications infrastructure was already in place. Four communications domains were identified as necessary for the 'Medium Term' mines, but with the possibility of reducing this for the 'Long Term' mines.

Models were developed for use as a guideline or vision for the long and medium term mines, and a set of criteria developed for the use as a guideline for technology choice of short term mines.

A number of measures were identified as necessary for the optimum management of communication system type issues and are listed as follows:

- Firstly the systems must be documented as they are, and planned with future need in mind.

- In the radio domain a 'Code of Practice Guideline' was developed primarily to control frequency spectrum use and critical aspect to radio systems
- The concept of 'Best Practice Reviews' was developed and implemented in order to maximise the benefits available with the professional resources deployed in the business units, and to recognise the dynamic and sometimes volatile nature of the technologies dealt with in the communications field. This is intended to be used, together with the proposed tailored project management process, as a solution for comprehensive 'Communication Systems Life Cycle Management'.

CONCLUSIONS

It is believed that if the mines use these models as a guideline for the choice and engineering of their future communications systems, together with the methods developed during the dissertation, then the optimum benefit available from communications technology will be obtained

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CONTENTS

1 INTRODUCTION

This section is intended as an overview of the dissertation and reference should be made to the main dissertation for further detail if required. This dissertation investigates an approach to the choice, implementation and management of communications technologies and systems, that is geared to strive for maximised system life and benefit for the deep level gold mining industry. It quantifies, to some degree, the potential cost benefit of a communications system. As a necessary step it identifies the needs of the deep level gold mining industry, and the qualities and aspects of the technologies that are important to the issue.

The **main technical issues** covered by this dissertation are; firstly the radio coverage issues, and secondly the pertinent properties on the emerging bus technologies for process control.

The **main technology management issues** covered are; firstly the trends investigated in the emerging and converging field of communications, and secondly methods to manage these in the deep level gold mining industry.

Finally the **engineering management issues** to the dissertation are; firstly the potential cost benefit quantification, secondly the project management process to implement such projects, and thirdly the management methods to maintain the continual review of current systems and the spread of best practice.

The dissertation is written such that **Chapter** 3 covers the needs analysis of the deep level mining industry, firstly explaining the typical business process of the industry, secondly grouping the common needs in preparation for the fitting of available technologies. **Chapter 4** explores issues from an engineering management perspective, firstly identifying and quantifying the tremendous financial benefit communications systems potentially have for the industry, secondly proposing a sound project management process tailored for the communications type project in the underground mining industry, and thirdly looking at methods to continually manage the dynamic technology issues of communications systems, finally packaging this together as a 'Communication Systems Life Cycle Management plan'. **Chapter 5** analyses issues around available technology, identifying qualities we need to look for when choosing communications technology, and also exploring the main technologies available today and the trends they seem to show. **Chapter 6** handles the technical issues behind radio transmission underground. In this case an RF (Radio Frequency) simulation model was developed to investigate reception probability. Radio is the most technically challenging of the media and hence deserved its own special chapter. Finally **Chapter 7** pulls the picture together proposing a model for each category of mine, and emphasises controls to be followed for future management of this technology.

2 BACKGROUND

The gold mining industry has been through a boom phase during the early 80's and now faces a tough competitive phase that seems to be here for at least the medium term. In this competitive environment it is essential for mining companies to find competitive advantage. A major opportunity for productivity improvement is in the optimal establishment of communications backbones to support both process automation and business decision support systems. Various "legacy" systems exist in the mining environment due to haphazard implementation of technology to monitor and, in isolated cases, automate. The challenge remains now to establish communications backbones with a view to the future where demands on communications systems are expected to grow substantially.

This dissertation examines the mining process's communications needs in terms of data, voice and video. It investigates the currently available technologies on the market, their strengths, weaknesses and intended niche, and matches these to the needs of the deep level mining industry.

2.1 An Overview of Literature and Work Done

This approach to technology management of communications systems from a user perspective is relatively unique, particularly from a deep level gold mining perspective. Consequently literature for this dissertation was difficult to find.

In overview, the literature seems to have been available in pockets of narrow interest, for instance take the references [1], [2], [3] and [4]. A large function of this dissertation was to assemble the big picture and develop an optimum communications infrastructure, managed as a utility for the deep level mining industry. A dissertation was found that was similar in the respect of generating a generic communications model, but more on the IT specialist side of electrical engineering than on the communications side [5]. It was done by the student, E. Reinecke, for a MSc. in Electronic and Computer Engineering. The dissertation investigates a single network solution for a multi-vendor, multi-network environment which strives for architecture and protocol transparency. This was a transitionary solution to allow networks to migrate to the OSI layered model and to achieve integration. The main objective was the design model for such networks. This is a thesis very similar to this dissertation, only in the IT environment where this dissertation is in the process control and mining world.

The nature of the subject has led to many of the references being taken from the Internet. Technology trends are also of major importance in the decision of which systems to invest in.

In areas of the communications field the commercial competition from the suppliers is fierce (e.g. Fieldbus Foundation and Profibus - [6] and [7]), and one needs to objectively evaluate what the technology will do in the long term. The dissertation did do its own technical investigations to supplement or extend the investigations found in literature ([8], [9]). In this instance, the radio field where specific underground environments had to be modelled.

A large part of the thesis was in technology management necessitating the need for technology management theory ([10],[11]).

3 NEEDS ANALYSIS

3.1 Macro Process Description

The mining process can be viewed as a number of sub-processes feeding each other. From the mining itself where the rock is broken, to the transport of this rock to surface, and finally the treatment of the rock itself in the metallurgical plant where gold is extracted. The sub processes are defined and the communications needs analysed in the following section.

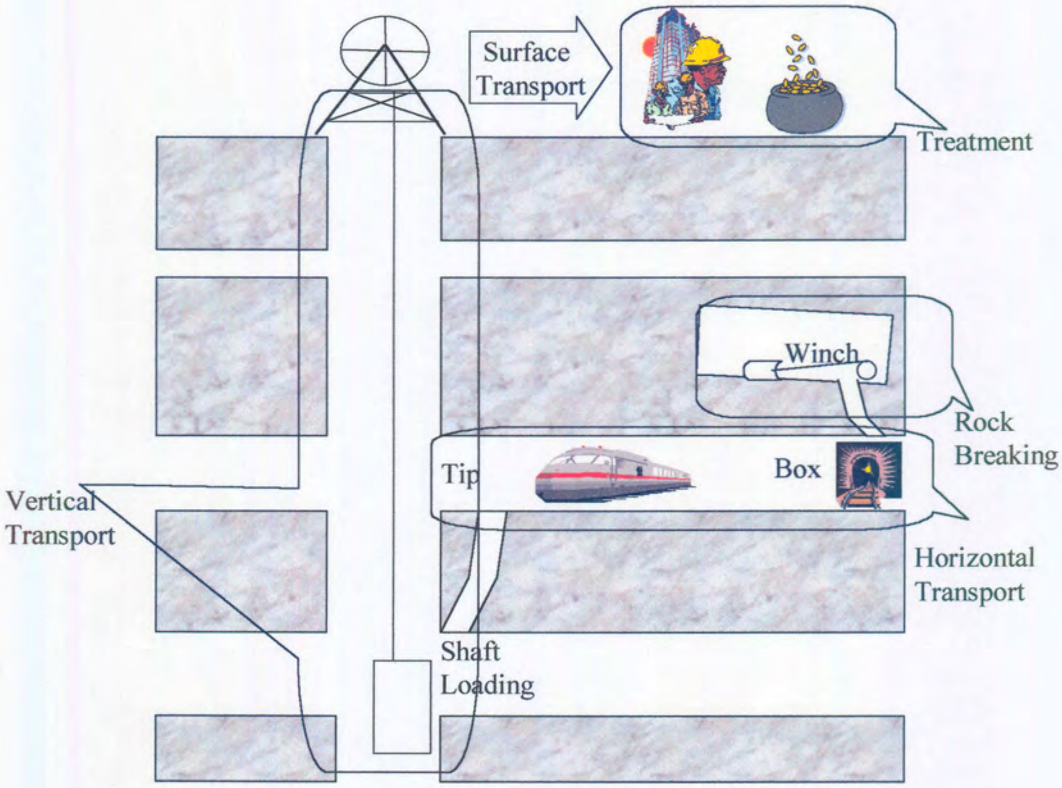

Figure 1: The Mining Process

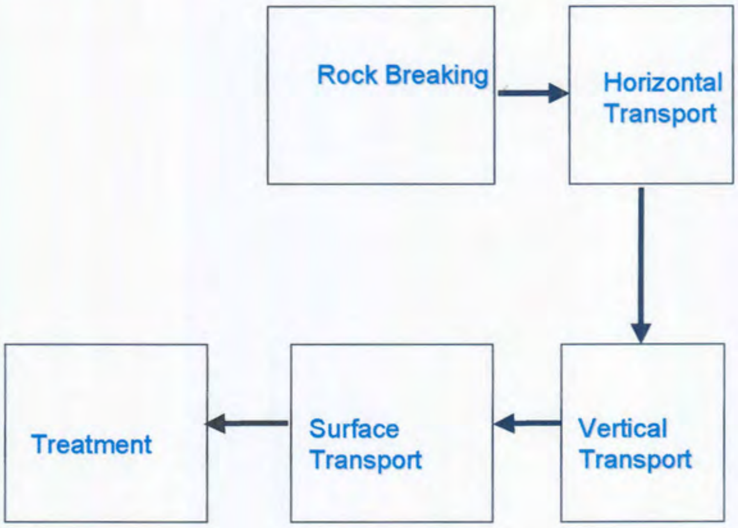

Figure 2: Macro Process Flow

The mining environment is best envisaged using the three dimensional diagram shown in Figure 3. Typically there are two main *shafts* the second shaft providing a second outlet for emergencies, and a return path for used ventilation air that is pumped through the mine by extraction fans sucking it out of the second. Large winders transport men, material and rock between underground levels.

The *haulage* (tunnels) to the working areas carry battery powered locomotive transport as well as providing a travelling way for pedestrians. Haulages also are normally laid out in parallel, one for ventilation supply and a second for return ventilation.

Once the reef (Ore body) is reached, "cross cuts" are used to access the area below the inclined narrow tabular reef body. A travelling way upward towards the reef is developed for access of men, material and equipment. A box hole is developed down from a suitable point close to the mined reef body in the "stoping area" (the area where the reef body is successively blasted and extracted).

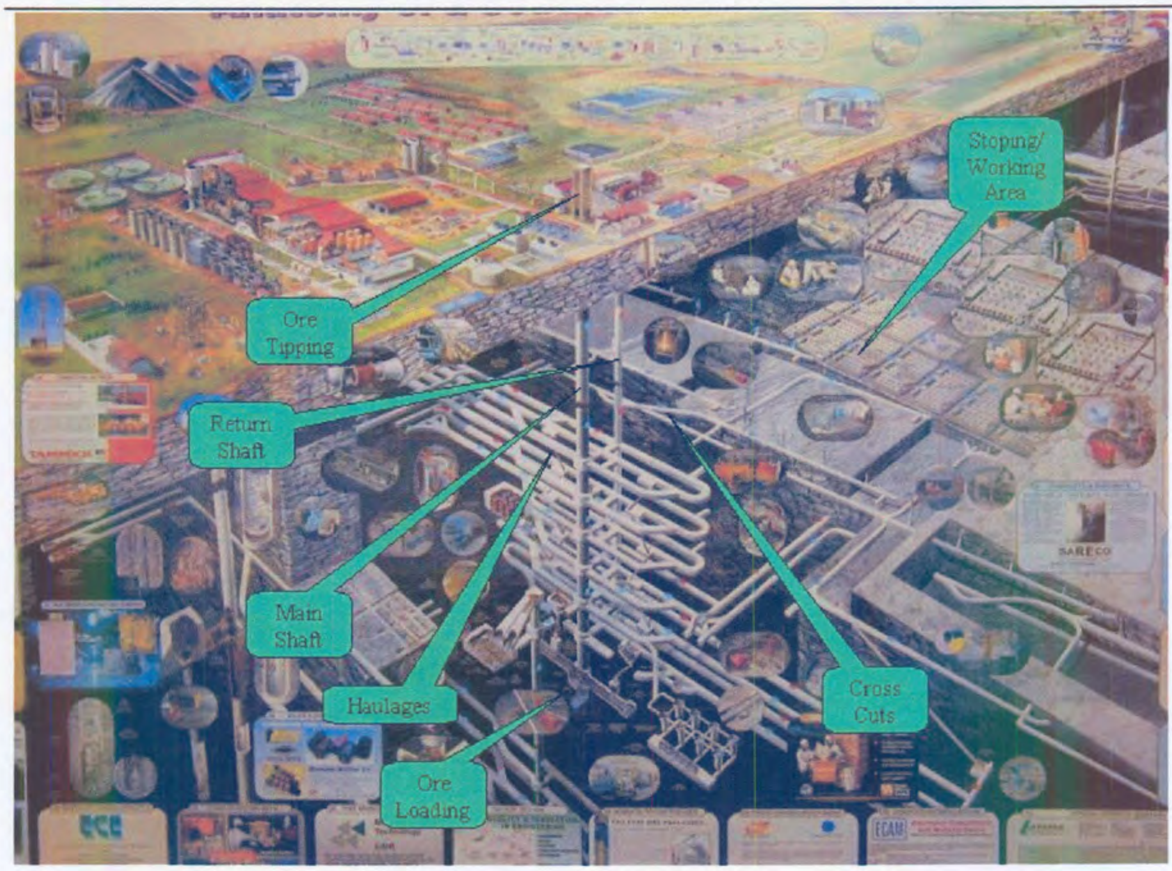

Figure 3: Three Dimensional Overview of a Deep Level Mine

3.2 Micro Process Description

This section defines the sub processes and analyses the communications needs. Refer to Figure 1, Figure 2 and Figure 3.

3.2.1 Rock Breaking

The ore bodies encountered are narrow and tabular resulting in small *stope* (working face) height. This seriously restricts access for machinery into the stope area making automation very difficult.

Currently pneumatically powered, manually operated, drills are used to drill holes for explosives. A working team in a stope consists of about 15 to 17 people split into a team leader, mining assistant, winch driver, drilling team and support team (who work behind the drillers installing support for the roof and other miscellaneous work). Anglogold has a target of installing 10 drill rigs (rigs for the mounting of drills upon and hence reducing some manual effort for labourers, additionally leading to more precise drilling) by the end of 1999. These rigs will allow the start of automation initiatives but in the short term they will only be implemented as a manually supervised system leading to increased labour efficiency, increased safety for personnel and mainly improved rock stress management and blast control. If automation initiatives become feasible then video might become a need. This would probably be fixed camera with transmission via hardwire, but a possibility exists that mobile video would be required.

Rock is blasted then pulled to the boxes (storage cavities underground) using electrical winches.

Due to the manual methods and extremely rough environment the main need is for mobile voice communications. Monitoring of equipment status, i.e. Run/Stop conditions of winches and ventilation fans, would lead to improved management of the process with benefits derived from scheduled maintenance based on duty monitoring, and also power savings due to stopping unnecessary fans.

The box is the storage cavity near the stoping area where broken rock is pulled into to wait collection by the horizontal transport. Figure 4 is explanatory regards basic layout.

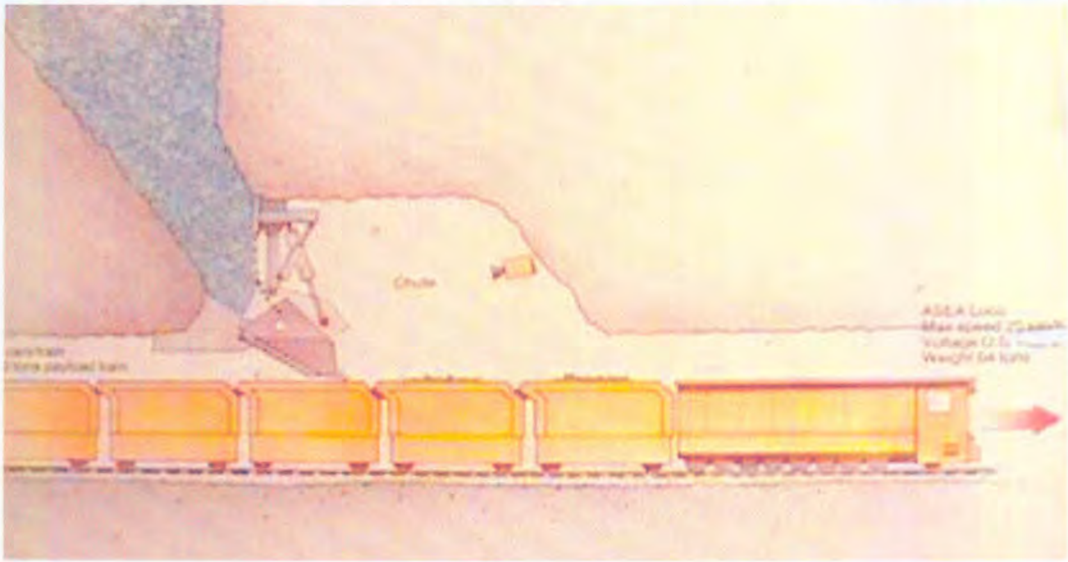

Figure 4: Typical Layout of Box

Further, in the following section it is seen that the level of boxes is required to improve the dispatching of tramming stock. The box is an extremely harsh environment to measure due to rock impact, dust and humidity/water. There are typically 100 to 200 boxes to be measured in the average mine and cost effective, robust means are important. The following means have been tried without success: laser, microwave, load cell and ultrasonic. Current thinking is for the box level to be inferred by means of measuring the activity of the winches feeding the box. This coupled with the measurement of what is taken out of the box by the tramming process described next, will give indication of remaining ore in the box. However further experimentation is required to correlate winch power consumed to rock successfully pulled into the box. This implies that winch power consumption should also be measured. These readings then need to be communicated to the central control system for interpretation. If this is implemented then there is no need for the winch status to be measured separately since power reading can infer the running status of winches as well.

In summary the needs for communications in the stope area then become mobile voice, Fan Run status, and winch power. Radio Frequency (RF) systems should have upgrade facility for video but in the short term only need cater for voice and low bandwidth data.

3.2.2 Horizontal Transport

Here underground battery operated locomotives are used to load ore from chutes under the boxes. They travel typically via single track back to tips near the shaft where their payload is discharged into the ore pass system of the mine. The ore pass is just a series of steeply inclined tunnels allowing rock to fall to the loading system where the winders operating in the main shafts draw it off.

The tipping operation is done with various methods but Figure 5 shows one and is helpful in understanding the operation.

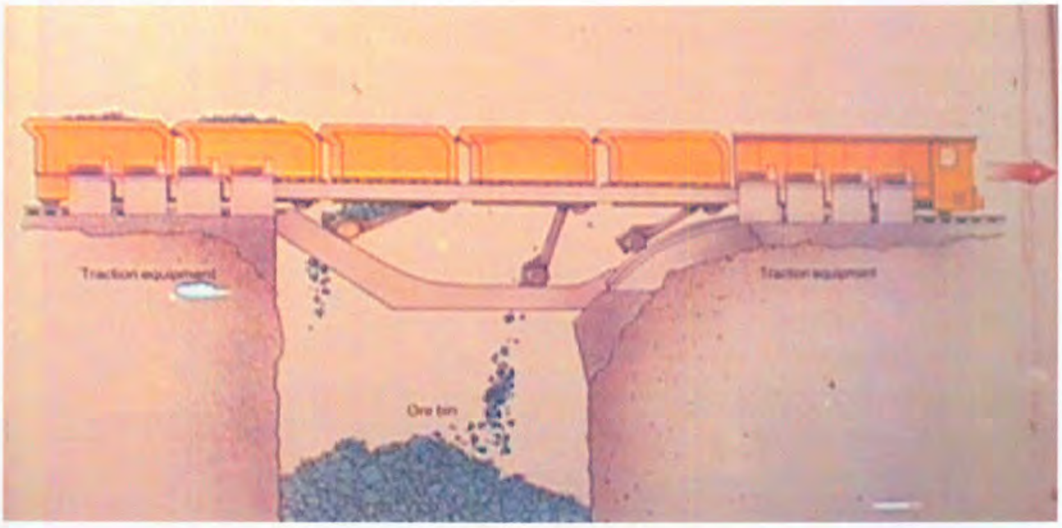

Figure 5: Tipping operation

A typical track layout plan is shown in Figure 6. This is dependent on the mine concerned but typically we have multiple locomotives competing for the use of a few tracks.

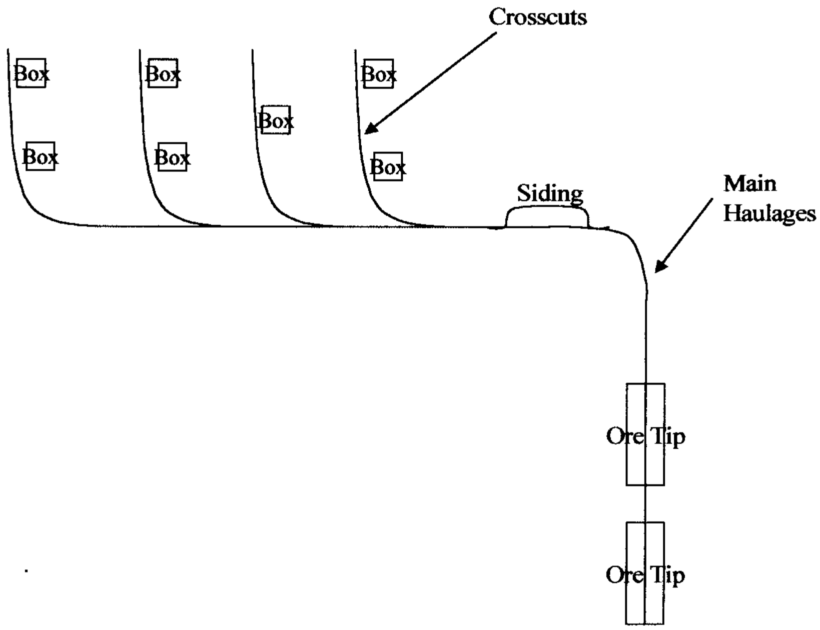

Figure 6: Typical Track Layout

Much improvement is possible in optimising the dispatch of locomotive stock to boxes that require unloading.

The current operation is very manual, but a number of automation initiatives have begun. Typically these initiatives involve a phased approach. Five levels of automation have been identified and the idea is to choose an optimum entry level and implement systems that allow growth into the more highly automated levels as working methods, and infrastructure allows. These levels are defined as follows:

- Level 1: Basic voice communications for drivers to allow them to communicate amongst themselves.
- Level 2: A centralised controller who directs assignment of trains to boxes.
- Level 3: Monitoring equipment is installed to assist the controller to know where trains are. If possible the status of main ore passes and boxes are given to the controller. This typically is presented on SCADA.
- Level 4: Expert control is implemented to begin optimising locomotive dispatch. More sophisticated algorithms are run on PC to infer ox level status. Rules bases are used to optimise locomotive assignment.

- Level 5: The tramming is made autonomous (driver-less) and the system is integrated into an Enterprise-wide Resource Planning system (ERP).

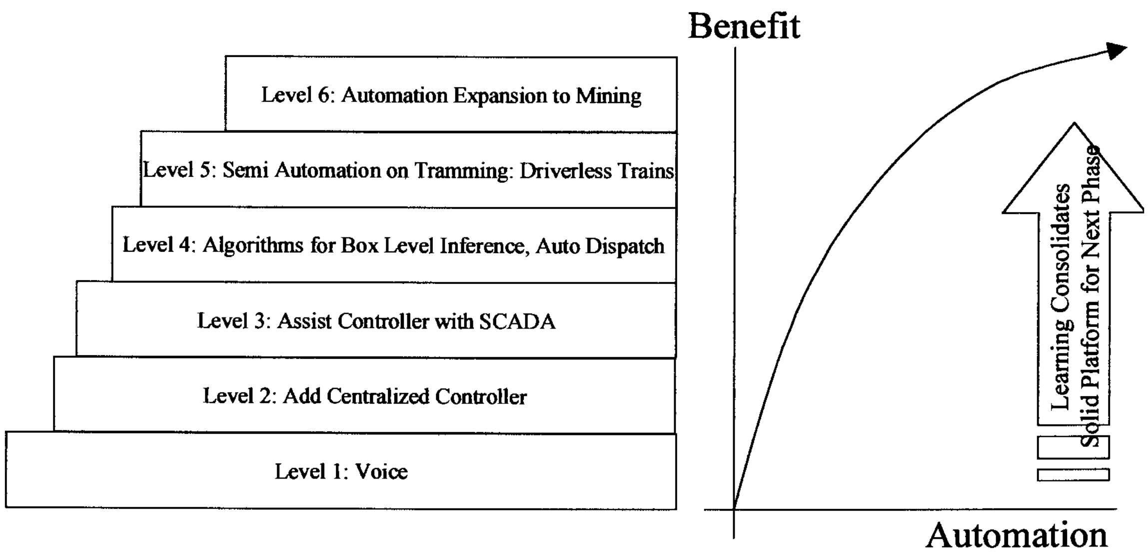

Figure 7: Phased approach for Underground Automation

Communications needs include mobile voice and low bandwidth control data, mobile video (point to point), and possibly capability of system upgrade to mobile video remote to central station control (for when level 5 automation becomes feasible). Typically level 5 requires tele-remote control from a central control centre on surface.

Another important technology within horizontal tramming is *tag reading technology*. To illustrate the need for this consider two typical uses:

- Zone control communications to locomotive control system

An option to enforce speed limits with underground locomotives is to define 'Go slow zones'. At the entry and exit points to the zone we have a 'Beacon' or RF Tag. With an on board tag reader the locomotive then picks up that it has entered a zone and according limits its own speed. Similarly the controller can deduce the exit of the zone.

The tag reader needs only to read a single tag at a time. Tags can also be used at reef and waste boxes and tips to ensure that only permitted offloading at the correct tip is done. This is achieved by interrogating the on board tag reader and deducing whether it has come from a reef or waste zone, and accordingly only permitting it to tip its load in the right tip using interlocks.

- Position reporting of locomotives

If the central traffic control system requires the position of the locomotives for monitoring purposes then this can be achieved as follows. Firstly the locomotive control unit can report which zone it is in, this being deduced by monitoring which tags it has passed. Alternatively, if a more accurate position of the locomotive is required, then an onboard navigation device can be used such as a gyroscope and once again, on polling, the position can be reported.

3.2.3 Vertical Transport

This is basically transport of rock from the ore pass system via the main rock winders up the shaft to the tips where it is stored waiting for surface transport to take it to the plants.

Winders themselves are highly automated. Loading and tipping systems are also substantially automated consisting mainly of conveyor belt control systems. The communications needs of this process are typically signalling, control data, cage (man conveyance) voice and low bandwidth data.

The transport of men, material and equipment can be viewed as a process in parallel where another winder requiring full control to all levels typically does this. Winders currently vary in degree of automation

3.3 Communication Domains Defined

Good technology management dictates that systems should be rationalised to facilitate simpler maintenance, easier integration, improved economy of scale benefits and reduced spares holding. Past practice has lead to numerous systems being implemented to service isolated automation, control, monitoring and inter-personnel communication needs. This now has to be taken into account in the form of catering for legacy systems while envisioning and moving towards an integrated, rationalised infrastructure. Currently no one system is considered to be able to service all needs, so as part of this dissertation 'Domains' have been defined and technology matched to each domain to provide a holistic solution. Each domain is discussed in detail as follows:

3.3.1 Shaft Barrel

This encompasses digital communications through the shaft. Current technology being implemented in long life mines is mainly fibre optics communications. Systems chosen have offered plug in electrical support for the major communications standards, such as RS485, Ethernet, and RS422. Voice PABX links and video networks are typically run through this backbone. Two systems showed potential to meet our needs, this was the Siemens Open Transport Network ('OTN') system and the 'Sonet Lynx' Systems. Due to slight cost advantage and a fuller range of interface cards, Anglogold has chosen the Siemens OTN technology.

Bandwidths available in this range are 36Mb, 155Mb, and 630Mb. The system is based on a network protocol similar to SDH. In fact the latest range of the system is based on SDH. An open network standard was desired for the fibre backbone but this is not totally achieved. The SDH is common to both Sonet Lynx and Siemens OTN however further compatibility is required in higher layers of the OSI model to achieve connections between nodes from competing vendors.

When it comes to the choice between multi-mode and single-mode cable, single-mode transmission equipment is more expensive but achieves greater transmission distance. The distance between nodes in the shaft backbone is however within multimode capabilities and in most case this then becomes the chosen technology.

3.3.2 Process Control Domain

This encompasses communications between PLCs and also between field instruments (including the emerging field bus standards).

The de-facto standard strongly emerging as an inter-PLC standard is TCP/IP Ethernet. Most PLC manufacturers now offer this as a network interface option.

The Fieldbus options are and will continue to be strongly influenced by the market war between Profibus[7] and Fieldbus Foundation [6]. The Fieldbus Foundation has established a standard at 31.5Kbaud termed, H1, which is also available as a bus-powered option. They are presently developing a 100Mb Ethernet option, termed H2. The latest reports show that Ethernet, as a field bus standard, might be the long-term winner as a de-facto market standard.

Technical comparisons between Profibus PA and Foundation Fieldbus (FFB) show that FFB will allow true distributed control intelligence and more flexible traffic management.

However Profibus PA currently has far more market share and many more devices are available from numerous suppliers.

The current cost per transmitter with Profibus PA is approximately R1000 more than conventional transmitters. This additional cost needs to be considered with respect to the cabling cost savings possible by installing single bus cabling as opposed to multi-core cables used to run individual loops to each instrument in conventional plants. This saving is more apparent in widely distributed plants where cabling, installation and engineering effort cost savings have been know to be in the order of 40%.

Further with FFB there is significant information that can be remotely accessed and used to optimise maintenance, resulting in cost savings due to predictive maintenance techniques as opposed to scheduled maintenance.

3.3.3 Remote Production and Environmental Monitoring

In underground mining there exist substantial networks of cable that are inferior for communications but if systems can use this infrastructure then numerous opportunities present themselves for a higher degree of production equipment monitoring. The two types of cable concerned are 3-phase power cable, and 'fire survival' cable (used for analogue, frequency multiplexing, bus powered, communications for fire detection systems underground). These cable types are particularly susceptible to noise and signal loss. The emerging standard from Echelon [12], 'Lontalk' has brought about a technology well suited for such cable infrastructure and generated a broad availability of products in the market place for users to choose from. Four systems have been installed in Anglogold mines to date, used as a technology for digital bus fire detection systems. Anglogold have a strong interest in developing this communications technology for power line born communications to collect winch status and power consumption information in stope.

3.3.4 Mobile Communications Domain

The Mobile Communications domain includes voice communications between personnel, data between mobile locomotives and base stations (in the future this is likely include video) and general data connections to mobile stations or remote fixed stations.

A fundamental choice needs to be made in underground radio systems, this being the choice between 'distributed point antenna systems' as opposed to 'leaky feeder systems' where Radio Frequency (RF) is intentionally leaked out of partially screened coaxial cable to allow a more controlled signal coverage. Problems have been encountered with the point antenna systems due to signal cancellation caused by signal reflection. This was seen during an overseas technology tour (see Section 5.1). On the other hand leaky feeder has more limited bandwidth capacity since at the higher carrier transmission frequencies (High UHF) it becomes impractical to design suitable leaky feeder cable. Some research and success has been found for leaky feeder attenuation characteristics ([1], [2] and [3]). Further a RF transmission level model was done for both stope and haulage conditions as discussed in section 6.2. Currently leaky feeder systems offer the most cost effective coverage of our underground tunnel networks for voice service. However leaky feeder has insufficient capacity to carry real time video for tele-remote operation of tramming stock. Further R&D is planned on this and will involve partnerships with suppliers in attempting to prove current claimed capacity and develop future video ability. This R&D is referred to in the final sections of this dissertation.

Tetra is an emerging digital protocol standard and would offer a widely accepted platform for vendors to develop on achieving interoperability. Unfortunately this standard offers no frequency in the VHF range, the frequency most common mining systems work at. It is also prohibitively expensive at this stage.

3.4 Specific Need Areas

This section groups the needs into areas for satisfaction by the final system solution.

3.4.1 Video

The main areas of video need are as follows:

- Monitoring video at winder shaft stations.

  Shaft stations are the places where people wait to board the conveyance pulled by the winder. Personnel on surface would like to monitor what is happening at the winder stations on every level. It is required to supervise that no unsafe activities are happening close to the shaft underground and also for security reasons, in case of labour unrest.

- Box chutes monitoring

  Boxes, as previously explained, are where the rock is stored once pulled out of the stope. The locomotives arrive at the chute to load the trains with rock. The drivers do this by manually operating the feed chutes at the box. With the imminence of driverless trains it is expected that personnel in a control room will operate the train by tele-remote control and remote control this loading function. Hence a future need of video is control quality video at every box chute. There are approximately 20 active box chutes per active level, and 5 active levels per mine. This implies that there are approximately 100 video cameras required in daisy chain configurations of 3 per crosscut

- Mobile video for locomotives

As automation initiatives progress it is expected that we will reach a point where operators based in control rooms must remotely control some trains. For this we require mobile RF video, of quality sufficient for control purposes.

3.4.2 Voice

The main areas of voice need are as follows:

- Voice coverage in stope

It is necessary to have two-way communications with key personnel at the stope face (refer to Figure 17 - page 55, and Figure 18 , for a diagram of the layout).

- Voice coverage in the haulage

This is mainly required for communication between and to locomotive drivers.

- In the shaft

This is primarily for maintenance personnel during inspections of the shaft. Additionally voice communications are required to persons on the conveyances during emergencies. This has not been included in the needs summary (Table 1) since it is a specialised system at this stage, delivered with the winder system.

3.4.3 Data

Data needs are extensive and are primarily addressed in the process control domain and the rugged medium domain. These needs can be classified as follows:

- Utility management

This monitoring information is mainly from utility systems monitored in the process control domain

- In stope data

Communications need to be development to capture status information of winches, ventilation fans, box levels

- Locomotive monitoring and automation

Presently data communications between locomotives and central control is necessary to track locomotives. In the future the data will be for remote control of locomotives

- Material tracking

An enormous amount of material is delivered to the work face daily. This is by means of loading this on surface on material cars (rail bound), and then scheduled delivery to the respective level during the material pulling shift and then delivery for the station to the workings after that. A means of recording what is loaded on the cars and then tracking cars individually to the workplace entry is required. Although this is a specific need it is not included in the needs summary table (Table 1) since RF tag reading is a specialised subject considered beyond the boundary of this dissertation (i.e. not backbone). The tag reader itself will need to comply with the backbone standard (most likely an Ethernet standard) and will plug in as the communications engineer sees fit.

- Asset tracking

Some items are of enough value or importance to merit having a permanent RF tag attached to them and then a tracking system is required, similar to the material tracking system, which will track where these assets have been delivered. This is also not included in the needs table for the same reason that material tracking was not.

Table 1: Communications Needs Summary

COMMS NEEDS		Video	Video	Video	Voice	Voice	Ctl Data	Mon & Ctl Data	Mon & Ctl Data	PDA LAN
		Shaft	Boxholes	Locos	Locos	Stope	Locos	Utility	Stope	ALL
Mines:	Long Term	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Medium Term	✓		✓		✓	✓	✓		
	Short Term							✓		

4 ENGINEERING MANAGEMENT ISSUES

4.1 Return on Investment Evaluation

The cost and benefit of a system such as a communications system is difficult to evaluate and must be looked at from a number of different aspects. Primarily the return on investment is the total benefit generated from the system after the 'Total Cost of Ownership' is taken into account. The best way to evaluate this is to use the method of Internal Rate of Return ([13]- IRR). In the following sections the total cost of ownership is detailed, followed by an evaluation of benefits. Then the IRR of typical scenarios are discussed. Reference is made to the benefits and cost analysis in appendix A. 7.

4.1.1 Total Cost of Ownership

The total cost of ownership is made up of three parts, the capital cost, the maintenance part and the replacement cost. These need to be slotted into the IRR analysis to evaluate their impact. They are now discussed in turn.

a. Capital Cost

This cost is the total project cost including equipment, engineering and installation components. In the case of Anglogold mining operation this is evaluated as a typical cost per mining level and then expanded to the typical number of working levels there are in a mine and further expanded to a total cost for all mines in the Anglogold South African Operations. This then becomes the total project capital investment necessary to equip all major levels in all mines in Anglogold South African Operations (a significant system – probably the largest deep level underground mining coverage area in the world)

The system budget that was done was made at a more extravagant figure than conservative. During analysis it was seen that there was large benefit values and that extremely attractive IRR figures were achievable even with pessimistic forecasts. It is difficult to estimate prices on these systems but a good feel for pricing has been gained through a number of exercises recently done in Anglogold. Prices are at times speculative since some of the systems are based on technologies in the development part of the technology maturity curve.

b. Maintenance Cost

The maintenance or running cost is made up primarily of skilled labour and spares cost. In this analysis this is calculated per level and per mine as in the capital cost calculation, and this expanded to the total Anglogold needs. Figures for skilled labour are generously estimated in the analysis leading to a conservative estimation on IRR. Spares requirements for the system are based on a percentage of the capital cost per year.

c. Replacement Cost

Eventually the system will outgrow its market support. It will reach a stage when spares become expensive or not available. Additionally technology would grow and mature to a stage where increased functionality or capacity starts to make an upgraded system look attractive. The analysis takes this into account by making a provision for new system after 5 years and increasing the benefit achievable from new functionality on a percentage basis (discussed later).

4.1.2 Benefits Analysis

The mining operations front is where the business is most susceptible to loss of revenue due to the inability to achieve the blasting of panels. The mining team in the stope is dependent on four supporting factors which all must be in place before they can do a blast and the sub-optimal management of these are the root causes for blasts which could not be achieved. A lost blast means that there is less gold available at the end of the month and from a business perspective then lost revenue.

- **Labour**

A typical team consists of a drilling sub team (who drill the panel/face) and a stope cleaning sub-team (who clean the area and put in support packs). At times the cleaning team are available to assist in other panels where problems might occur. This dynamic assignment of labour can lead to the reduction of 'lost blasts'. A good qualitative estimate is that 20% of total lost blasts could be avoided if a communications system was implemented, together with innovative management practice, for this type of dynamic and flexible labour gang use..

- **Services (Utilities)**

The mining team is dependent on the good quality supply of drilling water, compressed air and electrical power. Many times if there are problems in this supply the quick communication to the responsible person could avoid a lost blast. A good qualitative estimate is that 5% of total lost blasts could be avoided if a communications system was implemented allow quicker problem solving.

- **Material**

The mining team is also dependent on receiving consumable items such as wooden packs for support, on time. By the implementation of a communications system it is estimated that 10% of total lost blasts could be avoided.

- **Equipment**

Similarly for delivery/supply of equipment such as winches etc..., a good qualitative assessment of avoidable lost blasts is 5%.

This totals to 40% of lost blasts that could be avoided with decent communications systems and the necessary management practice to control. This can be translated according to two strategies:

a. Labour Cutting Strategy

The calculations show that increasing revenue is more attractive than cutting labour.

b. Production Increase Strategy

Calculations in Appendix A. 7 show that benefits are approximately R670 million to Anglogold a year. This translates to an Internal Return on Investment (IRR - [13]) of about 160%, and a payback period of less than 8 months, a very attractive prospect for any business.

4.1.3 Factors Affecting Cost of Ownership

Firstly the longer a system lasts the less expensive its cost of ownership is. This needs to be considered in relation to the length of service that the system can be retained for. A number of factors determine the length of service. These are discussed in turn:

a. Suppliers support

Often support for a system ceases when market demand for the new such systems ceases. Reputable suppliers do commit to provide spares for a system after replacing the system with a new version/model. Additionally the supplier may provide an upgrade option or an "Old Technology Buy Back" option. These supplier approaches are vital to consider when evaluating potential suppliers for new systems.

There reaches a point where spares cost becomes excessive when considered in relation to a reducing system life of the current system. The impact on the IRR of the system needs to be taken into account when deciding on replacement systems. With the substantial benefits available with these systems, replacement cost does not impact much on IRR, hence it is better to ensure system availability and reliability considering the high cost of downtime.

b. Functionality delivery

As technology grows so does the functionality of new systems on the market as compared to the existing systems. There comes a point when it makes financial sense to upgrade the system.

c. Capacity for expansion

A communications system is a good example of the wisdom of considering future need up-front. A lot of times people, when seeing the good that comes from communications, increase their requirements after system implementation. A full needs analysis is required before system specification.

4.1.4 Factors Affecting Benefit Delivery

It is sometimes extreme speculation to estimate monetary benefit of a communications system since its final benefit delivery is often due not only to the presence of the communications system, but rather in using it as a tool supporting a greater effort at improving a process efficiency or capacity. The communications system becomes the catalyst to supporting initiatives leading to improved system management. It can become the empowering tool for the work team allowing them to make better decisions or shortcut normal delays caused by the lack of communications. This implies that it is not solely dependent on the communications system for realisation of benefit but also on initiative and innovation of management practice empowered by the communications system. To provide for this element the concept of risk (in achieving this benefit) needs to be used. This leads to the concept of Potential Value Add (PVA) for a system. One can never really guarantee that improved communications will realise the PVA, so a measure of confidence needs to be given.

Factors affecting the follow through from the management team can be greatly enhanced by following a few principles. Referring to the recommended project management process (Figure 8 on page 22), it is critical to get the following aspects correct for proper "buy in" from the client (production management team). These include the following

- Involvement of the production team in the project - discussed later
- Actively addressing the fear of automation as a threat to jobs

Automation and job enhancing technology such as communications systems should rather be looked at as opportunity generators than job threats. With improved efficiency work teams can mine previously unplayable ground. This approach must be actively marketed before and during projects.

- Creating total dependence on the system

  New technology systems often fail when implemented since people cling to the old ways. When implementing a new technology system such as a communications system one should immediately enforce dependence on the system. In this way the people fix problems rather than bypassing problems.

4.2 Project Management of Communications System Projects

A project management process, tailored for communications system type projects, is proposed in Figure 8. This is now explained in the following paragraphs step by step. Project management practice should be made up of other components such as cost management and planning, but the aim of this dissertation is to explore the unique aspects of the approach for communications systems. As such this is discussed in the following few sections with emphasise on the aspects most important from a communications system viewpoint

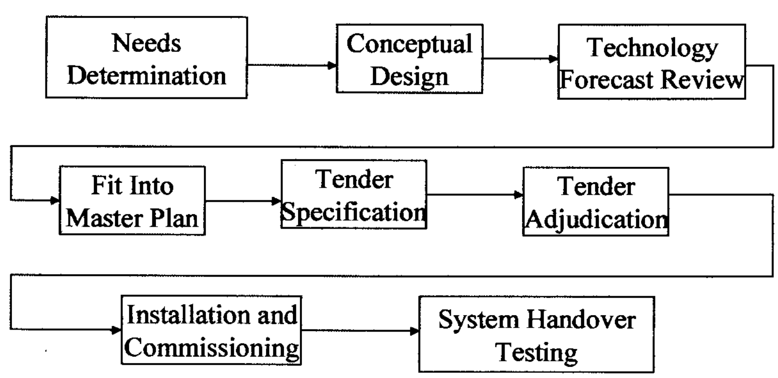

Figure 8: Recommended Project Management Process

4.2.1 Needs Determination

The needs determinations must be done for all disciplines and processes. The best way for this is to hold a workshop with role-players. Facilitating such a workshop is a demanding task since you must not only listen to needs but also sketch a vision of a future system. You must understand the business process, where the gaps are, and realise the potential of the technology. Then marry these to capture everyone's current and potential needs.

The objective is to group needs so that these could be serviced by a rationalised number of communication systems.

4.2.2 Conceptual Design

This is really a 'big picture' documentation of the envisaged solution. It considers system protocols, standards, hardware platforms, network nodes and entities, information transfer, and interface strategies. The documentation of this details systems, interfaces and services.

4.2.3 Technology Forecast Review

Technology forecasting is a continuous process and normally done by a few experts in the field. What is preferred is to identify which technologies need matching and then to formalise viewpoints with the compilation of 'contemplative stances'. It then becomes a formality to involve the key technical experts at this point to debate the conceptual design and align this with their forecast (contemplative stances) of where the industry standards and technologies are headed. This can have substantial impact on lengthening prospective system life and capturing current technology features available.

4.2.4 Master Plan Fit

A key concept to Anglogold in the controls for communications engineering is to have master plans per business unit. Once the conceptual design is complete it needs to be formally incorporated into the master plan, approved and implemented. This control measure is vital to avoid the haphazard proliferation of small communications systems into the organisation.

4.2.5 Tender Specification and Adjudication

The tender specification is normally a more detailed version of the conceptual design. In the mining industry a major portion of the communications system detail design is left to the external supplier. It is desirable to stimulate pricing and quality competition between suppliers, but depending on technology maturity there might be insufficient suppliers of the technology for adequate competition. In that case it is preferred to approach the supplier directly and negotiate the specifications of the system. In some case to even agree on a reasonable and fair profit for the supplier. The advantage of this is that a better-fit system solution is obtained, flexible to any changing needs from the mine.

4.2.6 Installation and Commissioning

Installation in the underground environment is often difficult for the supplier so it is best for mine personnel to install cabling under the specification of the supplier, then for the supplier to install electronic equipment and configure and commission equipment. Performance tests are necessary to be done to quantify system operation. Typical tests are reception coverage tests for radio systems, data rate throughput and data package error rates for data systems. Also interface between systems needs to be thoroughly tested.

4.2.7 System Handover

Finally handover to the client occurs. The client in this case is the operational staff of the business unit. It is important to get formal client acceptance even with a “punch list” of outstanding items. The objective is for the client to take ownership of the system.

4.3 Technology Management Strategy for Anglogold Communication

4.3.1 Existing Problems

In the past we have found that when operations personnel have required a system involving communications then they have bought these without any thought to the macro communications picture. This ends up in causing numerous problems when it comes to managing the communications system later. Downtime and expansion constraints become issues that cause major production or production opportunity loss. As will be seen later the returns on investment on communications systems are tremendous but consequently the loss during downtime is also high so these issues must be carefully considered during the engineering phase.

Further some of the main value adding opportunities are expected to come from the general information enablement derived from the availability of all these measured statuses. To capture this the integration of all the systems is critical and this will only be possible with planned communications engineering.

4.3.2 Communications Pla

In the same way that the mine's high voltage reticulation is planned, so too should our communications systems. Through our 'Best Practice Reviews' (discussed in that section), we are now implementing communications plans for each business unit. There will be a plan for each domain. There will also be a communications champion appointed by senior management who will take responsibility for these plans, and no system will be permitted to be purchased before approval is received from this communications champion. This champion will actively solicit the input from all disciplines and process managers at the business unit, identifying future communications needs and obtaining "buy in" from key stakeholders to these communications plans.

4.3.3 CIC Best Practice reviews

Further to the communications plans a system has now been implemented in Anglogold where on a bi-monthly basis business units present their CIC practices and receive constructive criticism and rating from a panel of their peers from other business units. With the dynamic nature of communications technology this method of regular practice review is suitable to continually ensure that best practice and optimum technology is used in the communications systems of the business unit. As part of this review the communications champion presents his communications plans to the group and in this way the champions are stimulated to track technologies and needs closely.

The first best practice reviews have been held and an example of the results in shown in Figure 9.

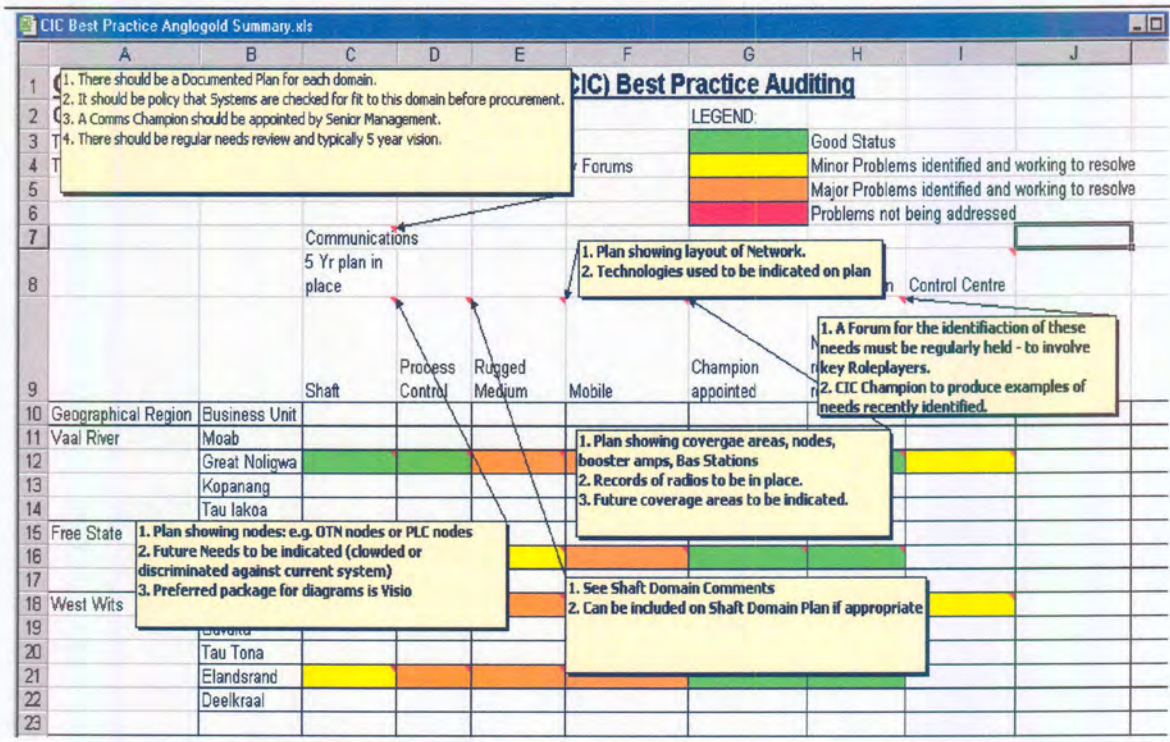

Figure 9: Example of Best Practice Audit

The best practice audit is done according to criteria that are dynamically updated, and leads to a continual improvement in standards, a method appropriate to the dynamic technology scenario on communications.

4.4 Communication System Life Cycle Management

Integrating the concepts discussed above we arrive at the model in Figure 10. The key to communications systems management is to continually review needs and technology. In the process the networked professionals review current systems in the Best Practice reviews. Business units, facilitated by the CIC champion, review future needs in formal forums. A project can be initiated from either source. The networked professionals additionally keep a watching brief on identified key technologies. The resulting 'contemplative stances' are used in the technology reviews during the project process.

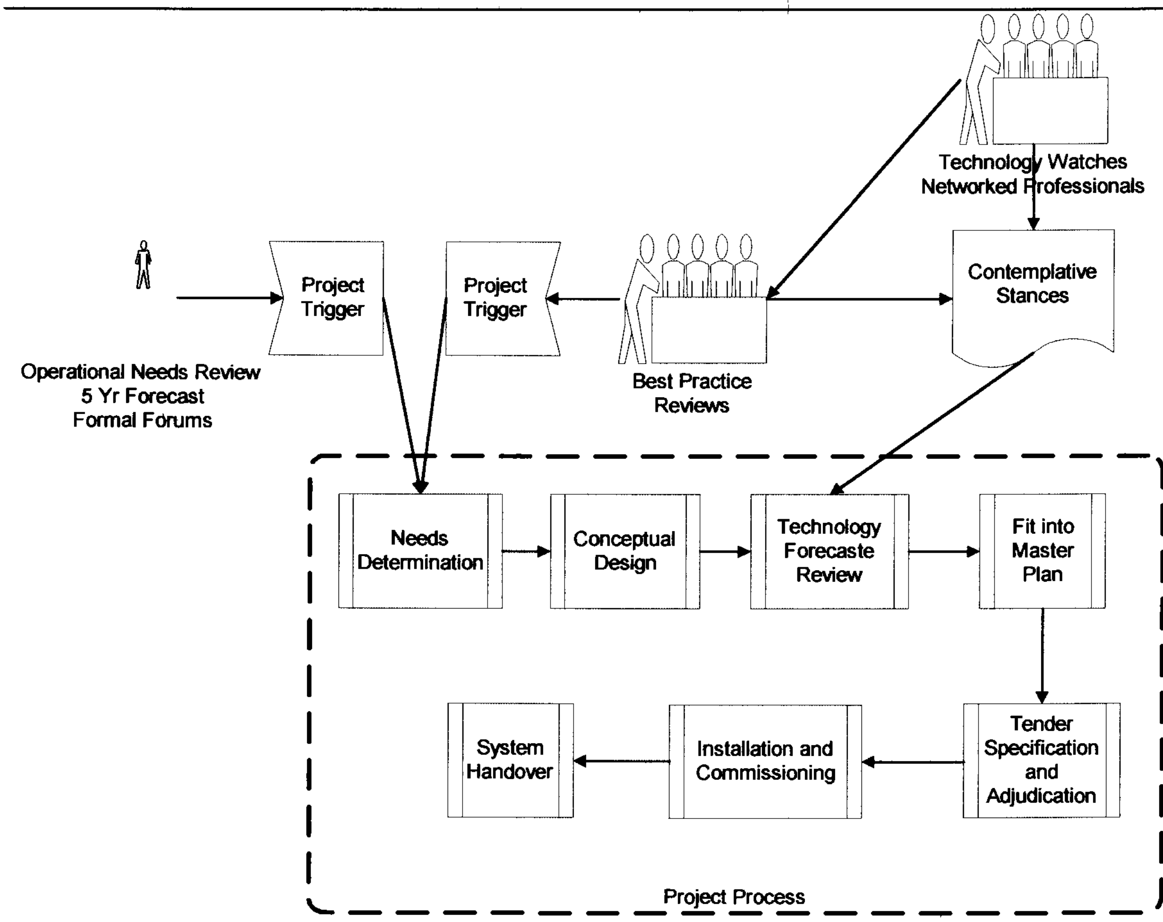

Figure 10: Communications System Lifecycle Management

5 TECHNOLOGY ANALYSIS

5.1 Review of Automation Approach Trends Internationally

An overseas trip was undertaken specifically to evaluate approaches and trends in automation and communications systems. The places visited, together with brief detail on the motivation for each visit, is given below:

- The UK Underground Railway Systems

  More specifically we visited the recent rail system expansion at Heathrow Airport to evaluate technologies used to communicate with high-speed trains and for use with maintenance and rescue staff in tunnels.

- LKAB Kiruna mine in Sweden

  This was to evaluate their high degree of Automation and Digital high bandwidth communications infrastructure. LKAB are world leaders in autonomous Trackless drilling and Rail bound autonomous tramming.

- Modular mining in Tucson Arizona

  Modular Mining is an automation company specialising on automatic traffic despatch systems for large surface vehicles. They are expanding to offer similar systems for underground tramming applications and are suppliers for two major tramming management systems installed in Anglogold mines. The visit was primarily to discuss the next generation of communication backbones for their future systems.

- Echelon Development Centres in Los Angeles

  This was to evaluate future trends on Echelon communications technology, a communications protocol we are using to enable data communications across bad quality cable such as the Fire detection cables and power lines.

- Noranda Technology Centre, and the STAS company in Montreal, Canada

  Noranda are a technology development centre for a group of base metal mines. The prime purpose of this visit was to review Noranda's successful technology development methodology that develops required technology from concept to commercialisation. STAS is the commercialisation partner company for Noranda.

- Inco Mining and the El-Equip company in Sudbury, Canada

  This was to discuss future leaky feeder radio system developments with El-Equip, suppliers of our two biggest leaky feeder systems at our Great Noligwa and Kopanang mines respectively. The visit included a visit to Stoby mine where Inco Mining have installed autonomous trackless LHD vehicles navigated by 'Light ropes'.

The main trends found in approaches to automation are discussed in the following points.

- Technology Transfer

  On of the main problems encountered in successfully transferring developed technology to the production/operations environment is the production team taking ownership after the handover of the project. A key approach taken by mines must be for them to appoint a champion in the production environment to push the technology into successful operation as soon as possible. This champion must be involved at project conceptual design phase.

  Another problem is benefit estimation and the realisation of this benefit for technology projects such as communications and automation. We find ourselves qualitatively guessing benefits rather than quantitatively calculating these. The overseas mines have a greater labour cost and hence it is easier to justify automation and labour productivity initiatives.

  An approach proposed is the phased implementation of the successive levels of technology sophistication. This is outlaid in Appendix A. 8.

- Communications Backbones

  Overseas R&D is generally done on the latest communications technology (such as Kiruna mine who implemented full blown ATM), or on proprietary protocols when the development is abdicated to commercialisation partners. At the stage of R&D technology trends are not normally considered and this is an issue we believe important in our deep level mining industry.

- R&D and Commercialisation

  The approach worldwide is to do R&D in-house where concept and design are proved, and then develop technology commercialisation partners to get the product to market. This is a good approach as it is not in a Mining House's interest to make money out of selling the technology but rather using it innovatively to improve production efficiency or increase output.

Resulting from this visit we put out a standpoint for automation (appendix A. 8), which was primarily centred on the horizontal transport where we had a production bottleneck at the time.

5.2 Key Characteristics of Market Technologies

This section discusses what are considered to be desirable qualities or aspects to be considered when choosing or engineering communications systems.

5.2.1 Determinism

This is the ability of the communications system to provide a communications service in a predetermined time. This is important with systems that cannot withstand a delay outside certain limits. For instance voice connection quality is reduced when delay is introduced. The accepted sampling period for voice is 125μs. If the discrete levels of voice are represented with 8 bits (256 discrete levels) then this translated to data bandwidth becomes 64Kbps. However if 64Kbps is allocated alone to the voice channel then full determination is required. Techniques such as Streaming have been developed to allow networks with intermittent peak loading to deliver the required data stream in low periods and play this back as a stream. Similar techniques have been applied to video transmission to overcome lack of determinism in networks. Video bandwidth is similarly quantified in section 5.6.

Control critical data can require guaranteed transmission within a certain time. Considering the OSI 7 layer model, each layer must be built to provide this determinism. For instance the medium access method of CSMA/CD used by typical Ethernet hardware is detrimental to determinism. Care must be taken not to allow too many devices on an Ethernet Network since competition for airtime can seriously effect time delay sensitive equipment. The delays that are tolerable in an Ethernet network are quantified to a degree in section 5.3.1.

5.2.2 Redundancy

Redundancy is the provision of alternative communications paths or equipment that can be used immediately on failure of the in-service path. Depending on the criticality of the control of the process, a risk assessment needs to be made through which it should be decided whether the expense of designing in redundancy is financially attractive.

5.2.3 Bandwidth

This is the effective rate the data is transferred at. It is different to the communications rate since an overhead is needed according to the protocol used.

5.2.4 Supported Mediums

In the mine environment the communications infrastructure is normally comprised of different types of media, i.e. UTP, fibre optic, power lines and radio. The ability of a communications system to transmit over multiple media is important since this allows us to have one system integrated over multiple media. This leads to simpler maintenance and system management.

5.2.5 Multi-Media Communications

Medium refers to the type of information transported, i.e. is it voice, management information data, control data or video. It is sometimes difficult to incorporate all these into one communications system since each has different transmission quality and interface needs, and making one system to solve all of these is sometimes extremely expensive. On the other hand if multiple needs are combined then one can afford to spend more money on a quality system as opposed to buying many smaller systems. Effectively this is achieving an economy of scale by combining needs.

5.2.6 Topology Allowed

Essentially this describes the network connection arrangement. It is necessary to ensure that your serviced points/nodes can be suitably reached with the topologies supported by the system.

Typical topologies are bus, tree, hub/tree, ring and star. The topology chosen is often influenced by the physical layout of the stations. For a mine the most suitable topology is a combination of bus and hub/tree.

5.2.7 Interoperability

Interoperability is a measure of a technology's ability to interface with other technologies. From another aspect it is the property of the engineered system that allows multi-vendor equipment implementation. With a multi-vendor environment, market competition from suppliers leads to lower prices, better support and better quality. Resultant manufacturing volumes lead to economy of scale, and system life is extended due to continuous market support.

To achieve interoperability one needs to define protocol and hardware interface standards. The larger the acceptance of the standards, the better the chance of achieving interoperability. Standards should preferably be developed by a non-product biased workgroup with wide representation. At times suppliers can achieve such a degree of market acceptance that their standard, as long as it is open, can become the *De-facto* standard.

One tends to be overwhelmed with the claims to openness from suppliers. There are essentially only three levels of interoperability that benefit the user. These offer increasing value to the user and are listed as follows:

- Proprietary systems

  These systems are prevalent in emerging technologies where companies tend to implement systems without disclosure regards protocols and hardware platform standards. This has no potential for the evolution towards a vendor independent system. This interoperability benefits are taken as the zero base.

- Physical layer compatibility

  With systems that can share the same physical medium the benefit becomes cost savings due to rationalised physical infrastructure.

- Peer interoperability

  At this level of interoperability the systems can communicate with each other to exchange process information. Typically point to point connections can be made to exchange data between equipment of different vendor origin. Standards at this stage should have been published and formally accepted internationally. This is the level of interoperability that the seven layer OSI model hopes to achieve. The value that this adds for the user begins to show itself by supporting the information enabled environment sought after by new generation business management.

- Full interoperability

  Here interoperability even extends into the application layer of the OSI model. Typical examples of this full interoperability are when the system nodes can be managed fully with respect to internal diagnostics, remote configuration and dynamic configuration when nodes are plugged into the system. All this functionality must be achievable independent of which vendor supplies which equipment. The benefits realised here are simpler engineering and system management complexity, leading to even more information enabled business decisions.

5.3 Emerging Standards

5.3.1 Ethernet and TCP/IP

Ethernet is derived from the computer communications industry. It helps to examine the standards background in this industry. There are 3 main international bodies that have driven the standards:

- International Standards Organisation (ISO)
- Institute of Electrical and Electronic Engineers (IEEE)
- International Telecommunications Union (ITU-T)
  Formally called the CCITT.

Essentially the ISO and IEEE produce Computer Communications Standards and the ITU-T produce standards related to Public Switched Networks. There is substantial cooperation between the organisations.

In addition to this the United States Department of Defence funded research into computer communications through the Defence Advanced Research Projects Agency (DARPA). This led to the interfacing of many computers from a large number of universities into an inter-network known as ARPNET, finally to evolve into the well known Internet. Subsequently the Internet protocol suite was establish, known as Transmission Control Protocol/Internet Protocol (TCP/IP)

The world has adopted Ethernet TCP/IP as a major standard. Ethernet card prices have dropped tremendously illustrating the benefits of buying technology with wide market share. Video and voice are already carried on this standard and any limitations in terms of determinism problems due to media access methods are being overcome by over designs in network speed capacity. Studies done show that a 10Mbps network running at 2Mbps loading can be depended on to have a 50ms maximum delay [14]. Extending this to a 100Mbps (10 times the speed) and to 30% loading it is reasonable to assume that communications delay will be better than 20ms (The benchmark PLC algorithm delay for mining process control). The figure already mentioned as reasonable for deterministic response within an Ethernet network is 30% loading, and extending this study supports the figure.

Most PLC manufacturers have Ethernet TCP/IP as a standard interface. This seems to be a standard that is here to stay and is the most unifying communications technology today especially at LAN and multimedia levels.

More detail on the technical issues around Ethernet can be found in the Appendix A. 2
Future developments in this field are expected to be Gigabit Ethernet for Network switching, and IP version 6 which will cater for multimedia COS requirements

5.3.2 Hi-Speed Broadband Networks

There are a number of technologies to cater for mixed media signals, i.e. data, video and voice. However when looking at the market the main competing technologies are:
FDDI II, ATM, Siemens OTN, and SDH
The main technical points of these are discussed in Appendix A. 1 and the technology trend forecast curves are shown in Figure 11 on page 42.
The main domain this technology is applicable to is the Shaft Backbone domain. When looking at the needs of this domain a full ATM solution is an overkill since most connection points are point-to-point traffic without complicated switching requirements as delivered by ATM. Technology seems to be converging on ATM as a universal broadband solution but this is taking longer than expected and when the prices of ATM drop to the levels of OTN then this will be a very attractive solution.
Siemens OTN solutions offered a full range of interface cards for the mines' needs (mainly RS485 and RS 232 etc..) while the competing SDH and FDDI solutions were slightly more expensive and did not offer the full range of Interface cards. Siemens OTN now offers their same system with optional SDH cards. This does move somewhat to interconnectivity and vendor independence but further standardisation is required in other portions of the OTN before full "Plug and Play" interconnectivity is achieved.

5.3.3 Fieldbus

Fieldbus essentially replaces the old analogue 4-20mA standard (refer to Figure 31: Profibus PA comparison to 4-20mA conventional standard on page 91 for a look at how the field equipment requirements are reduced). It is a network between field input and output devices (I/O) which allows the transfer of information such as an analogue value of a measured parameter (e.g. a level, temperature etc..).
The special requirements for a network technology specifically for field I/O devices are summarised as follows:

- Suitable power supply arrangements. Typically the more developed bus technologies offer power off the same wires that carry the data stream. In this way the cabling to each device is reduced (one cable instead of separate signal and power supply cables).

There are a number of ways to carry this power on the same wires as the communications signal. The IEC1158 physical layer standard effectively transmits the signal by controlling loop current. Power for the device is taken off this loop current in the high periods. Many times the power supply requirements determine the transmission distance limitations. When instrument power is too high to supply by the integral communications cable then a separate power supply is taken to the instrument (e.g. magnetic flow meters, valves etc..)

- Deterministic Response: The transmission of a value must be guaranteed to ensure control loop integrity. Most field bus technologies/standards implement a synchronous type of communications protocol where each device is allocated time space in the data cycle. In this way a device is guaranteed adequate communications space all the time. The emergent Ethernet standard is an exception to this. Ethernet is a Collision Detect type of Media Access. Hence devices compete for the use of the bus. The logic in this case however is that with the high bandwidth Ethernet options available today one can afford to significantly under schedule communications on an Ethernet network and hence effectively allow communications space to devices when required. In effect determinism is practically achieved by the oversupply of bandwidth.

There are a number of different field buses available on today's market. Numerous comparisons on technical criteria have been done and some of these are available on the Internet (references [15], [16], and [17]). Some of the more prominent ones are:

- Ethernet

Discussed in detail in the rest of this dissertation.

- Fieldbus Foundation

Discussed in detail in the rest of this dissertation.

- Profibus

Discussed in detail in the rest of this dissertation.

- Modbus (and Modbus Plus)

Process Automation, typically derived from Modicon PLC environment

- ControlNet and DeviceNet

ControlNet is a bus technology that handles both the real time deterministic demands of control traffic, as well as the system management non-deterministic traffic demands such as PLC monitoring and programming. The technology is based on a 'Producer

Consumer' model allowing peer to peer communications and multicast type transactions. The technology is particularly suited to analogue I/O transmission. It is derived primarily from the Alan Bradley PLC environment. Future developments are that ControlNet would be encapsulated in TCP/IP Ethernet, and progress in conformance testing.

DeviceNet is a technology intended for use for the connection of discrete field I/O, mainly used by the manufacturing industry. CAN bus is based on the 'Producer Consumer' model. The message length is 0 to 8 bytes ideal for low-end devices.

- Interbus

This technology is primarily for process, factory and process automation.

- AS-Interface (Asi) bus

A bus developed in 1990 as an alternative for hard wiring of binary field devices. ASi has been accepted as part of the EN50295 international standard, attaining recognition as a vendor independent standard. ASi is particularly suited to digital I/O and is a bus-powered technology. The system is Master/Slave configuration with only 4 bit cycles per device, achieving only 5ms cycle time, well within most PLC determinism requirements. The topology is typically conventional tree structure and includes line, star and ring configurations. Limits are 31 devices per segment with a maximum of 124 I/O. Current development expectations are an increase in capacity, both nodes and I/O is imminent, as well as enhancements for handling analogue I/O, and improved diagnostics.

- Hart Protocol

A signal protocol implemented on top of the analogue 4-20mA signal and decoded at the receiving end. Primarily used for process automation. Hart has the most market share world wide of pressure transmitters [16]. It does not capture cabling savings advantages since it still requires cabling per analogue I/O. However it can be relatively implemented on existing analogue I/O transmitters by replacement or upgrade of the transmitter units, avoiding the need to re-cable the installation.

- CANbus

Originally developed by Bosch in the mid 1980s this bus is mainly used on vehicle on-board bus applications. It is a bus powered technology and really only defines the data link and physical layers. Further standardisation is achieved with the higher-level protocol (HLP) and this is used to implement the communications systems management functionality. HLP has also been used on top of DeviceNet as well as other similar standards.

- LonTalk

A bus technology particularly suited for inferior medium cables. Derived initially from the building industry and used for power line borne communications. This technology implements full seven layer ISO functionality, and provides connection orientated communications service depending on the connection class chosen. The strength this technology has is the ability for it to be implemented on different mediums and the amazing freedom one has with putting down network topologies, to the extent of achieving loop back redundancy fairly easily. The Lonmark Association [12] is the conformance and interoperability certifying authority worldwide. Echelon is the product development company primarily driving the core component developments and these are often marketed under the name of Lonworks products.

There are significant benefits to be realised by implementation of a fieldbus and these are considered in turn (Some of these were taken from the reference [18]).

- Installation and maintenance benefits: A Profibus design and installation done by the Anglo American Technical Design Offices estimated realised benefits from fieldbus to be approximately 40% of control and instrumentation project cost, a significant amount of money. Further the article "Dawning of the Digital Age for Process Control", written by Ian Verhappen [16], cites possible cost impacts of up to 41% savings in terms of installation and engineering cost for fieldbus systems as opposed to conventional analogue systems. The bus allows wiring of field and control devices onto a single pair of wires. This means less:
  - Wiring (cables and cores), panels (e.g. marshalling cabinets), junction boxes
  - I/O and control equip (including card slots, power supplies)
  - Design effort and planning requirements
  - Ease of maintenance and reconfiguration
- You can remotely access parameters and set-up the installation.
  - With the additional information available via the bus, predictive maintenance as opposed to scheduled maintenance can be implemented. This leads to optimum maintenance (less and better quality). An example is maintenance on a valve according to the number of operations it has completed.

- Quality Benefits:
  - Better accuracy of the signal

    A conventional 4-20mA standard relies on two aspects which impact on signal accuracy:
    - In conventional systems the signal is converted from its process value to a representation on the 4 to 20mA scale via an analogue conversion stage. This has certain zero (offset) and span inaccuracy. At the receiving end the 4-20mA signal is converted to a digital representation incurring similar zero and span inaccuracy. With a fieldbus system the analogue conversion stages are reduced and hence span and zero errors.
    - The signal is typically sent a significant distance in 4-20mA form with some inaccuracy introduced by cable capacitance. Although with small signal variation this effect is minimal. With a digital signal the value is represented discretely along the transmission path between device and control room and eliminates this potential source of inaccuracy.
- Distributed Control
    - Some fieldbus technologies provide for a substantial processor on board the field device. This coupled with the communications functionality available from the bus system allows peer devices to take on control functions/algorithms in the field. An example of this is the Fieldbus Foundation technology. Distributing the control functions this way now opens up a great number of options in where one can put the control algorithms. For example one can have a level transmitter with its own PID controller on board (i.e. on its own CPU) communicating directly to a peer field device, the valve. If communications on an upstream or downstream segment of the bus fails then this control loop can go on controlling even after getting disconnected from the plant master control system. This produces significantly reduced risk of failure.
  - Redundancy

    By completion of buses into loops (by means of specially designed termination units if required), implies the potential for bus redundancy. If the bus is severed it can transmit back to plant master control via the remaining loop section.
- Increased Management Information

- The amount of information available from field devices increases dramatically. The challenge becomes in how this is analysed and not in how to get it. It can be used for fault and maintenance system diagnostics and predictive maintenance.

Technology seems to be converging on two of these fieldbuses, namely Profibus PA and Foundation Fieldbus (FFB). We now consider the technical points of these two:

5.3.3.1 Fieldbus Foundation (FFB)

Foundation Fieldbus is able to implement far truer distributed control functions (i.e. PID control on the instrument itself). The network has flexible network traffic control so scheduling and bus cycle time is adjustable. Similar to Profibus the H1 standard is implemented with layers 1,2 and 7 of the OSI stack. The H1 standard is based on the IEC61158 standard. This is a reliable implementation of current loop type control with Manchester Encoding. A new version is currently being developed, called H2, and this is based on high speed Ethernet as a physical layer standard, and TCP/IP as the Transport and Network layer standards. The development began on this product in 1998 and the first commercially available H2 products are expected in early 2000 [16]. The architecture of the Foundation Fieldbus is for H1 from the field I/O concentrator to instruments, and H2 from the concentrator back to the control centre (also called the 'home run'). It is also conceivable that H2 might become options for field instruments further unifying this communications domain. With the convergence of communications worldwide onto these standards as unifying standards, this approach will certainly have cost and compatibility benefits for the user. .

The Standards driving committee is remarkably vendor dominance free, which could result in a more widely accepted standard in the long term. Unfortunately there is significant disagreement found amongst the Fieldbus Foundation committee members, which is hampering wide product availability. The latest consequence of this disagreement is the recent decision of the IEC standardisation committee to implement the Data link layer standard of Foundation Fieldbus with eight different Protocol options [16], effectively giving the eight major market fieldbus suppliers options for their protocols. This slows down the achievement of full interoperability benefits (refer to section 5.2.7), but at least achieves some degree of medium compatibility benefit.

More technical detail is available on the standard in Appendix A. 4

5.3.3.2 Profibus PA

Profibus is a standard primarily originating in Germany and driven traditionally by Siemens. The standard has three versions, namely FMS (Field Messaging Service), DP (Distributed Processing), and PA (Process Automation). The PA standard is based on the Physical Layer standard IEC 61158, the same one as used for the Fieldbus foundation H1 standard and described in that section. The standard does not effectively support distributed control intelligence down to field instrument level, i.e. it does not provide for the control algorithm to be implemented on a transmitter or other field device. It does however capture the savings available by the reduction in field equipment and engineering when comparing to the conventional 4-20mA technology.

The main advantage of Profibus is its currently wide market domination however there is risk that Fieldbus Foundation will supersede it in the medium to long term.

More technical detail is available on the standard in Appendix A. 3.

5.4 Technology Forecasting

5.4.1 Factors Influencing System Life

It is important to maximise system life by buying systems that will have market support for the maximum period. However other factors also influence the lifespan of a system. The following points look at the factors that affect system life, especially those concerned with market support:

a. Functionality Offered

The functionality is essentially the capabilities, services and features the technology offers. This can include speed of communications (Data rates and factors improving quality of transmission for digital sampling of analogue values – e.g. voice and video), Error performance (improved error performance leads to reliable communications links and less need for protocol overhead which slows down throughput rate). One needs to evaluate which Functionality Factor is most relevant and influential to the likelihood for long-term market support. For example, a key functionality factor in fieldbuses is the ability of the fieldbus to distribute control algorithms within field instruments, and this is a factor used later in the fieldbus trend analysis (Figure 15). The more aligned the products features are with that of the market need, the more likely that product is to sustain itself commercially in the market, and hence be around as an option for the user.

b. Interoperability

Connectivity is a major issue when it comes to growing a system to meet future or phased need (sometimes termed the "scalability" of the system). It is important when considering the integration of systems (current and future), especially in this "information age" where enterprise wide data is such an important advantage. Interconnectivity is fortunately an issue actively pursued by market leading product suppliers and is slowly bringing benefits to users as convergence is seen on the major technology standards. The compliance of a vendor's equipment to dominant standards is a major value factor for consideration.

c. Other Factors influencing system life

With systems bought in the mining industry, future support is a major issue and reputation is a factor to be considered. The more financially established a company is the more likely it is to be around for future support. Alignment with internationally established vendors is an important advantage in today's world as it is the international market which drives the formation of market standards and hence the commercial sustainability of a product. When looking for technologies in a niche application we tend to deal with emergent and not mature technologies. In such a case it is important to partner a technology company in establishing systems to our requirements, and rely on the technology company to get the product to the market effectively. The core business of Anglogold is gold mining not technology development. With communications technology it is more advantageous for the company to spread the technology across a wider external user base, than to retain ownership on the technology.

The first prize is to buy technology that is substantially developed approaching maturity but with still future growth to ensure it does not become redundant too soon after purchase. Typically technology goes through an S curve ([10]) where if the growth of the technology is monitored against a "Parameter of Performance' then typically one will see emergent growth followed by fast exponential growth and then tapering off growth when the technology reaches its limits. One can draw an analogy to this with factors similar to a parameter of performance. In other words there are other factors that are linked to this theory of the Technology S curves.

Two technologies have been evaluated using this S curve type approach, firstly the competing technologies for the Broadband (multimedia - Figure 11 to Figure 13) technology and secondly for the Fieldbus Technologies (Figure 14 to Figure 16). Factors plotted are Cost, Functionality, and Interoperability as described above.

5.4.2 Technology Trend Curves for Broadband Networks

In the curves for the competing technologies for Broadband service (multimedia – i.e. for Data, Voice and Video), the two main technologies in the current market for the industrial type environment are considered to be the ATM technology (emerging as an option from the IT environment) and the SDH technology (also emerged from the IT side but more firmly established as an 'off the shelf' solution for the industrial environment. Brand name examples of this are Siemens OTN and SonetLynx).

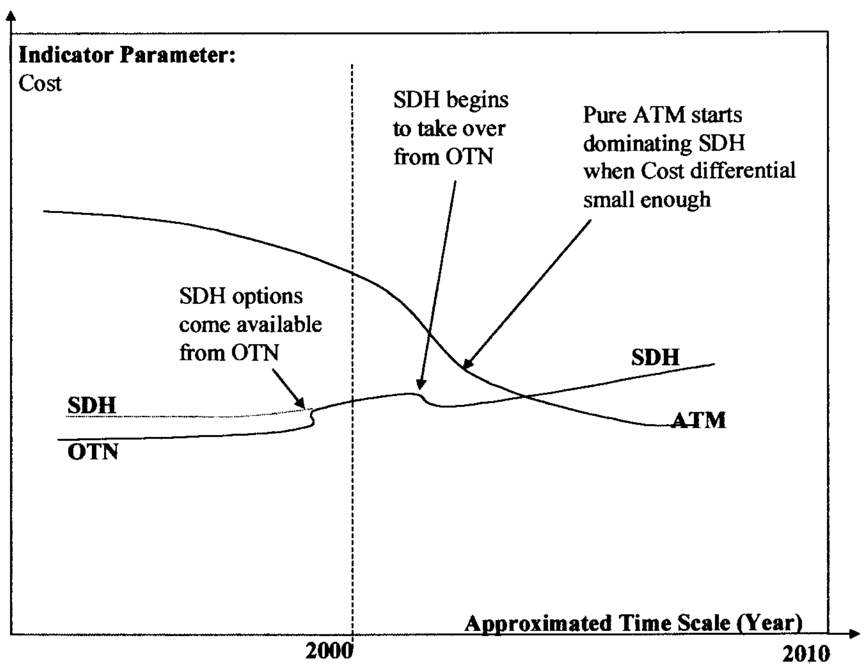

Figure 11: Technology Curves for Broadband Networks - Cost

Figure 11 considers the trends in costs. The graph is intended to be a speculation on the *trends* expected in this field, and should be seen in this light. ATM options are currently relatively expensive (approximately R300 000 per router, this price derived from the pricing for an eleven port Cisco 7500 series router, including approximately four cards with approximated legacy interface engineering requirements) as opposed to options from the SDH suppliers (around R120 000 per switch, these prices taken from Siemens OTN equipped node options). ATM however is eventually expected to capture significant market share and hence cost should drop, or more specific solutions might be offered for the Shaft environment. When this happens and the ATM to SDH cost premium gets attractive enough, then ATM would become the preferred solution, even as a 'Point to Point' technology, due to its potential routing and switching functionality advantages for the shaft network. Also for the reason that ATM might likely become the standard for a significant number of integrated systems downstream and upstream.

OTN was considered preferable for the Shaft domain since it offered interface cards for a number of legacy systems in the process control domain, while SonetLynx had some difficulty in catering for all legacy system interfaces required from a mine (RS 485 in particular).

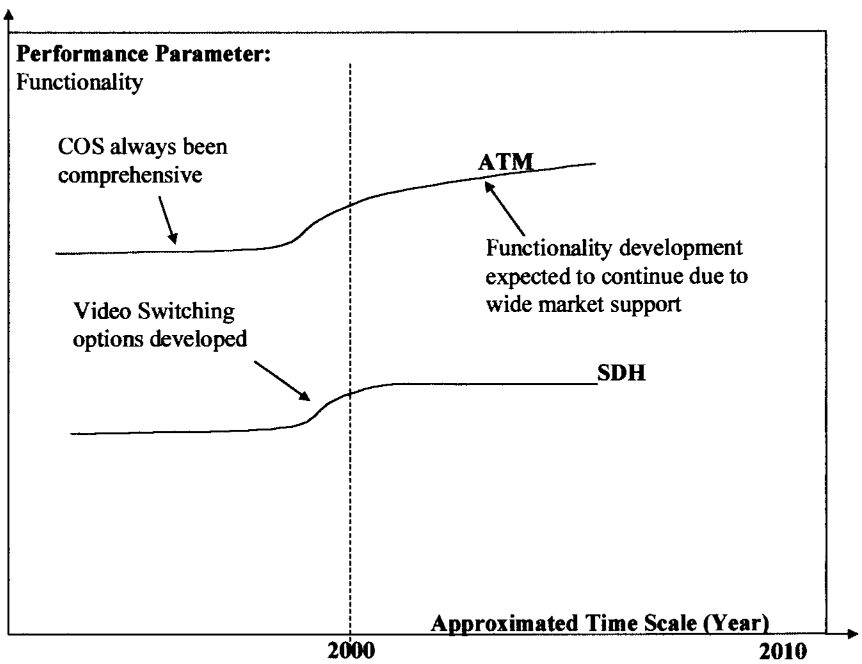

Figure 12: Technology Curves for Broadband Networks - Functionality

The prime Functionality Factor (Figure 12) to consider is the dynamic switching 'Class of Service' (COS) ability of ATM. SDH is Point to Point Technology and does not have the built in switching features of ATM. Recently *configurable multicast video switching* has become available on SDH systems. This has benefits for the shaft domain where analogue video cameras need to be concentrated to a few monitors on surface. ATM in the long term is expected to steadily increase its functionality seeing as it is likely to become the broadband technology of choice.

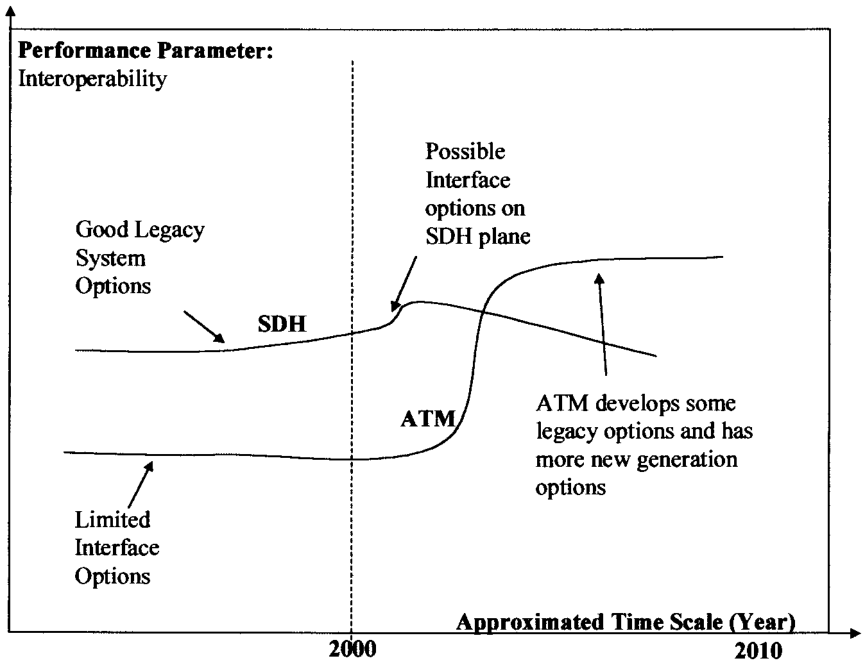

Figure 13: Technology Curves for Broadband Networks - Interoperability

Further interoperability is considered (Figure 13). There are 2 aspects to this, one being the interface ability to external systems, and the second being the ability for the system nodes to "plug and play" with other vendor equipment, i.e. on the same ATM or SDH backbone. In the first respect OTN was built more for the process control side and as such had a number of desirable Input cards for legacy standards such as RS485. ATM is expected to eventually have cost effective cards for some of these standards. Hence ATM interoperability is expected to increase when this happens. Further considering the expected long-term market support for ATM, the interface options for new generation standards will be sustained while SDH Technologies might stagnate in this regard. As regards Backbone interoperability ATM, as a standard, is expected to be adopted by many more Suppliers than SDH. Currently SDH is a Datalink layer orientated standard common to a number of product ranges, but further compatibility is required on the higher ISO layers for full interoperability. ATM achieves this full interoperability.

In conclusion ATM is predicted as a longer-term option but for current needs and medium term needs OTN/SDH is the preferred standard.

5.4.3 Technology Trend Curves for Fieldbus Networks

Looking at the fieldbus technologies, there is aggressive international competition between Fieldbus Foundation ([6]) and Profibus ([7]), to be the dominant fieldbus standard. Technology curves as shown in Figure 14, Figure 15, and Figure 16 illustrate a qualitative estimate of future trends in this field.

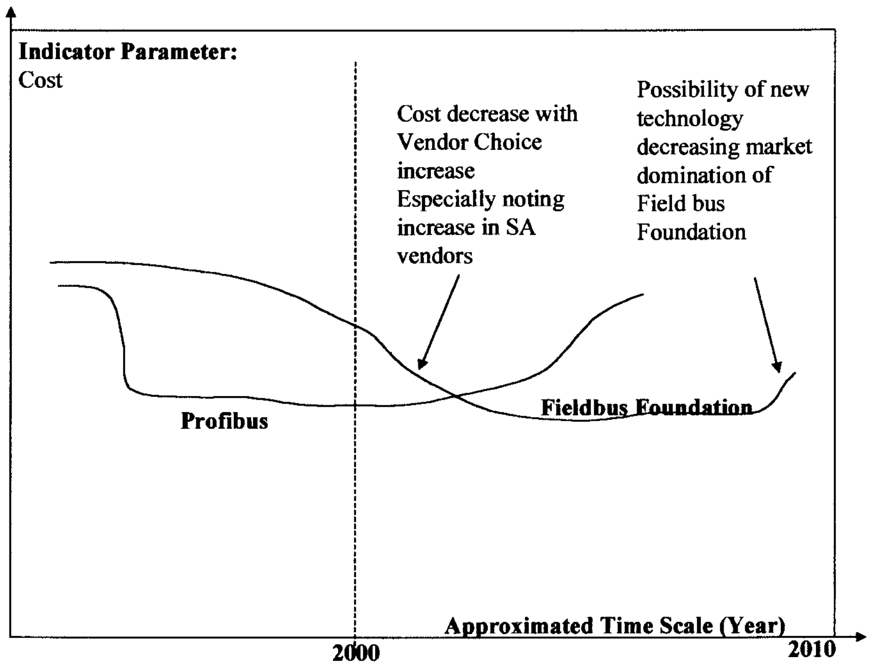

Figure 14: Fieldbus Technology Curves - Cost

Once again cost is of particular interest. Up until recently Foundation Fieldbus equipment has been significantly more expensive than Profibus, and this was mainly due to its limited availability in South Africa. The Foundation Fieldbus suppliers seem to have had a strategy to concentrate marketing effort within the United States and only recently we have seen equipment offered from manufacturers like Smar (represented by BRCS), Alpret, and Honeywell. Endress and Hauser market Profibus PA differential pressure transmitters at approximately R7000, approximately R1000 above conventional transmitters cost. Smar currently market Foundation Fieldbus differential pressure transmitters at approximately R7200, once again R1000 above their conventional transmitter cost. Foundation Fieldbus transmitters were approximately R3000 above conventional cost within the last 12 months, significantly reducing in cost to today's price. Savings with this technology are achieved in many areas primarily though in Cabling and Engineering Cost as described in 5.3.3.

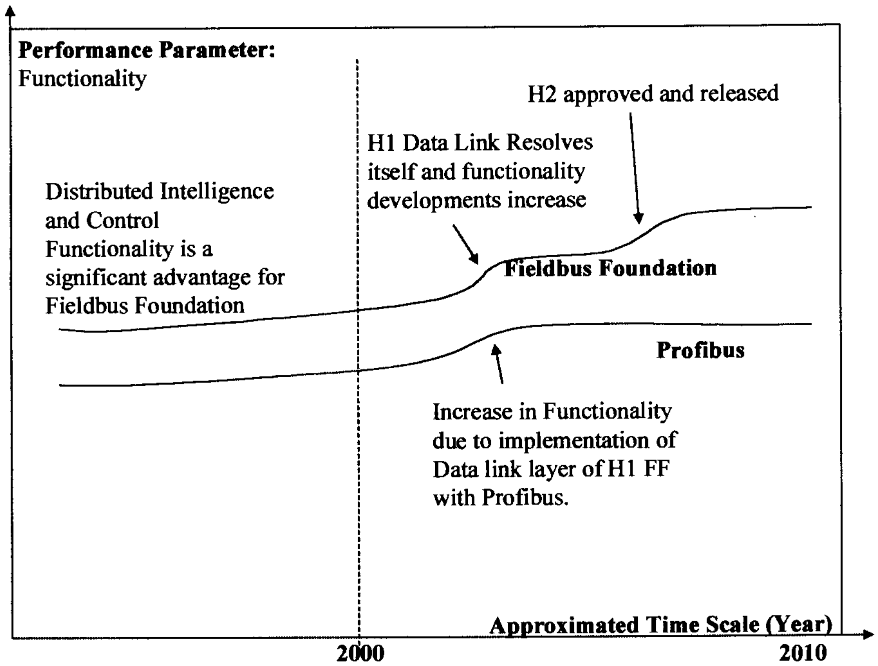

Figure 15: Fieldbus Technology Curves - Functionality

When considering functionality, the advantage Fieldbus Foundation has over Profibus is that the standard allows for control intelligence to be implemented on the field devices. This allows considerable redundancy advantage, i.e. the ability for control loops to function when the rest of the control architecture fails. Figure 15 gives a view on the trends expected on functionality within Profibus PA and Foundation Fieldbus. When the H1 data link standard is finally agreed on then this should allow suppliers to develop further functionality with confidence that their development money is aligned with international standards. Towards the end of 1999 Profibus was chosen as one of the seven datalink layer implementations for H1 fieldbus. This should give more impetus for the development of further functionality. When the much-awaited finalisation of H2 arrives this should give product developers considerable confidence in a stable international standard, removing any hindrance for functionality development.

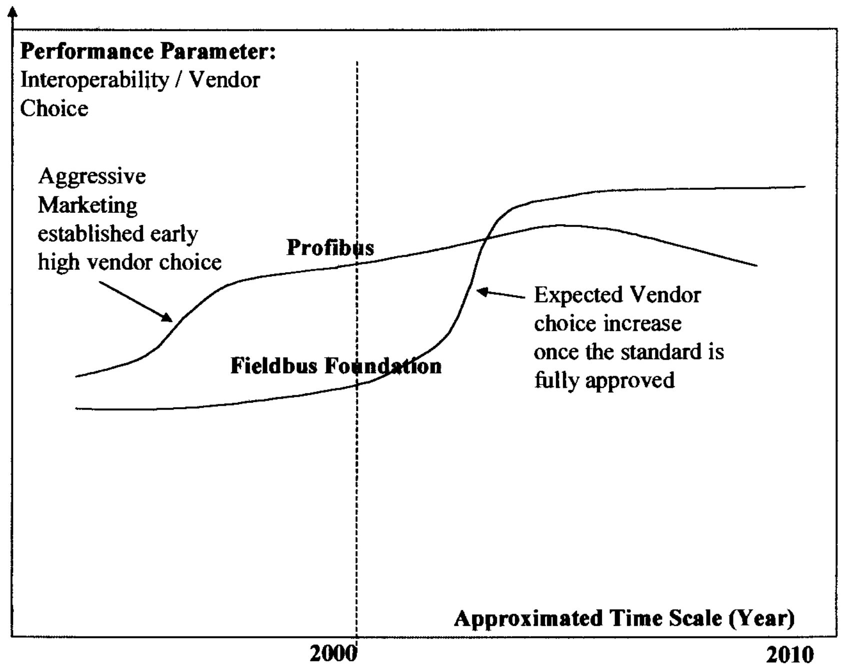

Figure 16: Fieldbus Technology Curves - Interoperability

Interoperability of Profibus has been successfully achieved. There are now well over two thousand vendors supplying Profibus Equipment. Fieldbus Foundation is now beginning to enter the same level of interoperability.

If Foundation Fieldbus equipment cost falls to the level of Profibus PA then it is very financially attractive to deploy Foundation Fieldbus technology with its increased distributed control functionality on new plants. However there is still debate happening on the Fieldbus Foundation H2 option which, once finalised as a standard, should mean great strides towards interoperability. Currently the main problem with H1 Foundation Fieldbus is the lack of availability of H1 interface cards for PLC's. It is assumed that manufacturers are awaiting clarity on the H2 standard before investing development resources in H1 technology. The Delta V PLC from Alpret supports H1 fieldbus most effectively in the current South African market. Modicon PLC's have reported that they are busy developing an H1 interface card, but this is not currently available in South Africa at this stage. The current decision of the IEC standard body to allow 7 different datalink layer forms for H1, effectively still constrain vendor independent interoperability, but with the envisaged natural selection of one of these implementation forms, and with the evolution of H2 interoperability is expected to increase dramatically.

5.4.4 Conference on Converging and Emerging Technologies for Industrial Communications

a. Background and content

As part of the efforts on this dissertation a conference was arranged to identify technologies in communications that are either converging to a standard, or potential standards and technologies that are emerging. Although the Delphi method ([10]) suggests that formal technology trend forecasting should be done individually rather than in a group, this conference was the most effective way to solicit group opinion amongst professionals outside Anglogold. The main worry from the Delphi theory is to eliminate extreme opinions and hence the specific objectives of the Chairman was to manage this by soliciting opinion from reserved attendees and to challenge opinions from outspoken participants.

The conference was arranged under the banner of the South African Council for Automation and Computation and was well attended (30 delegates from a cross section of industry – both suppliers and users). Presentations were given under the following headings.

- Fieldbus technologies
- Core backbone standards
- Radio technology
- General

The conference agenda and a summary of debate is given in Appendix A. 6.

b. Summarised findings from the conference

Suppliers and users in South Africa tend to hold back and wait for international trends. This is not surprising considering the market share South Africa commands in the international arena. Speculation was that there is significant convergence in both the fieldbus and core backbone areas.

There is still uncertainty when the successful development of a stable and mature Fieldbus Foundation Standard would occur, but it seems apparent that the functionality offered and non-supplier biased approach of the Fieldbus Foundation Standard would ensure a dominant standard. A significant number of instrument manufacturers already offer Foundation Fieldbus H1 equipment.

The overall unifying technology is almost certainly Ethernet TCP/IP. Already almost all PLC manufacturers offer this. The Fieldbus Foundation H2 system is along these lines.

Voice and video solutions exist on TCP/IP. Any determinism problems are being overcome by the emergence of extremely fast baud rates.

5.5 Interface of Process Control to IT environment

The main issue on interface between networks is that systems should be built on open standards. There is normally a wide selection of "converters" or gateways from reputable suppliers to provide interface between the dominant network standards.

The one issue to be considered here is the interface between deterministic networks and non-deterministic networks. The main instance of this in this dissertation is the interface between Ethernet LAN and fieldbus or between Broadband and Ethernet.

One needs to remember the needs of the Process Control function for the transmission of its data. The typical control software we use on the mine has acceptable software cycle requirement times of around 20ms. A 100BaseX Ethernet with 30% maximum subscription will perform at speeds far faster than 20ms response. Some software on advanced controlled equipment requires sub 2ms response. In this case connection orientated buses with deterministic response are required. These buses are normally handled as necessary specialist buses. An example of this is for some of our advanced control winders where fast response torque control algorithms are implemented to minimise rope stress.

We also find that most response and connection critical communications takes place within the fieldbus domain, and monitoring summary type information is the only type of information passed up to the Ethernet (Management Information System – MIS) LAN. There are times when some interlocking is done across the Ethernet LAN, such as inter-dam level control, but this information can withstand delays in the order of a few seconds which properly engineered Ethernet can easily provide.

5.6 Video Quality Aspects

Broadcast quality is typically taken as the PAL standard of 768 x 576 pixels. Black and White TV with 256 grey scales needs 8 bits to represent the intensity. Refresh rate is 25 frames per second. The resulting bandwidth becomes:

765 x 576 x 8 x 25 = approximately 88.128 Mbps

Colour will increase this by a factor of three to 264.384 Mbps

The development trends of compression and streaming techniques such as MPEG4 and wavelet compression are encouraging. Typical compression achieved with these techniques are in the region of 30:1. This implies that we could realistically achieve broadcast quality video transmission consuming bandwidths in the order of 8 Mbps or less.

Cameras from Norway suppliers (Norco cameras) are available with inbuilt wavelet compression and other techniques similar to MPEG4, and offering LAN type outputs (plug in ports directly on the camera). Compression achievements of 100:1 are claimed. The cost per camera is approximately R9000.

The company Intervid (Durban based) claim to have seen technology offerings from Germany on overseas exhibitions in March 2000. This technology dynamically approaches compression from both quality and speed viewpoints. Video signals have two interlaced fields. One of these fields is compressed for resolution/quality aspects and the other from a 'frames per second' viewpoint. The exact detail of how this is done is still proprietary but the point of this is that compression is dynamically configurable from camera to monitor. The packaging of the product is in the form of a separate unit that can accept 4 camera inputs and 'publish' this on a single TCP/IP network, incorporating substantial MPEG type compression. Costs per unit are approximately R17 000 but this can be considered in the context that it services four cameras. With dynamically adjustable quality and speed we will be able to compromise on each aspect to meet the needs. Two classes of need are envisaged as follows:

a. Monitoring quality video

   This should be high resolution, low frames per second. Perhaps broadcast resolution but around 3 frames per second. (hence reducing bandwidth by a factor of 8)

b. Control quality video

   This should be low resolution, higher frames per second. Typically reducing broadcast resolution down by an estimated factor of 5 is sufficient, but retaining 25 frames per second, hence reducing bandwidth consumption by a factor of two or four. This could even be black and white, reducing bandwidth demand by a factor of 3 again, but further work is required to confirm this.

In summary, with emergent compression ratios of 100, and reduction of quality or speed by a further factor of 8 for monitoring and 15 for control, we can expect to obtain adequate video transmission with the following bandwidth consumption

264Mbps / 100 / 8 = 330Kbps

On a fixed fibre LAN of say 100Mbps capacity, loading this to 30%, we can have the following cameras on each LAN:

100 * 30% / 0.330 = 90 cameras

With this in mind both stationary and mobile video needs should be migrated, as costs and technology availability allows, to TCP/IP video.

Capacity potential on the RF LAN is covered in section 6.4.

6 RADIO COVERAGE ASPECTS

6.1 Bandwidth and Baud Rates

When we look at the current radio situation we see that VHF leaky feeder is currently the technology of choice for voice solutions in the tunnel type haulages. Leaky feeder is a radio technology using a braided type of coaxial cable as described in the Glossary of Terms. It operates at 150 – 175MHz. This is by far the most popular way the mining industry is equipping itself for mobile voice services and consequently prices of this technology are very attractive compared to other technology solutions (installed cost of systems are typically around R30 per m).

When we consider future needs we see that leaky feeder will be inadequate for mobile video and mobile data (in the Mbps order). We do need to quantify this by examining theory on the issue and reviewing market availability of technology for this need.

The theory to do this is found in the book "Fred Halsall; "Data Communication Networks and open System Standards"; " ([19]) – sections 2.2.2, and 2.3.4.

According to Nyquist theory a bit rate of C bps can be transferred on a noiseless channel of W Hz where:

$$C = 2 \times W \log_2 M$$

M = the number of levels per signalling element

W = the Bandwidth of the Channel in Hz

However in practice this is reduced by noise and Signal to Noise Ratio Ability of receivers, however this is taken into account with the following formulae

$$R = B \times W$$

Where W is the frequency bandwidth of the channel and B is the bandwidth efficiency factor.

There are a number of ways of improving the bandwidth efficiency, namely:

- Modulation Technique

  The main types of modulation are Amplitude Shift Keying (ASK - where the amplitude of the carrier wave is adjusted according to the bit stream), Frequency Shift Keying (FSK - frequency adjusted) and Phase Shift Keying (PSK – the Phase is adjusted). Typically FSK

- Multi levels in modulation

Instead of just two levels for 0 or 1, you can increase the levels to 4, 8 or 16 (such as the Quadrature Phase Shift Keying – QPSK).

You can also combine modulation techniques and obtain more bandwidth say by using PSK and ASK to produce a QAM (Quadrature Amplitude Modulation).

All these techniques substantially increase Bandwidth Efficiency.

Bandwidth Efficiency can vary widely from 0.25 to 3.0 bpsHz^{-1} but typically RF modems have Bandwidth Efficiencies between 0.25 to 1.0. A typical 9.6Kbps modem requires 20KHz bandwidth and 10Mbps requires 18MHz.

In the VHF range current technology is 25KHz (or more recently 12.5KHz) channel spaced radio for underground. This implies that bit rates we can expect from this are around 9.6Kbps.

In the RF LAN Spread Spectrum modem range we can expect an order of magnitude jump in capability since we are seeing equipment at the 2.4GHz range that accomplishes 11Mbps (Qkon RF modems)

When we evaluate what the needs for the mining industry (refer to section 5.6) are likely to be, we see that they are of this order. The video mobile technologies are most likely to be digital video (TCP/IP) due to current technology convergence. We are already seeing video systems emerging requiring 200 to 300Kbps per video channel. It seems likely that we will be able to obtain video at less than 100Kbps. However we can speculate that at worst video can be achieved with 1Mbps type bandwidth, and this puts us in the 2.4 GHz RF Spread Spectrum range.

6.2 RF Coverage Model

6.2.1 RF Coverage Modelling Summary

In order to evaluate whether the RF Technologies chosen would be effective or not, a Simulation model was done. The modelling was done by Software called "SuperNEC", developed by the company Poynting Innovations. Dr. Derek Nitch from the Poynting, who initially developed the Software [28], did the modelling, verification of the results and wrote the final report. I was involved in the specification of the input data to the model, and jointly involved with Dr. Nitch in the measurement during the verification test, and the interpretation of the final results. The Software uses a Hybrid Method of Moments and GTD (Geometric Theory of Diffraction) approach which implements an Asymptotic Solution to Maxwell's Equations (i.e. it makes assumptions when the frequency becomes relatively high). The method of moments approach allows the software to model at lower frequencies than the GTD approach which is limited to about 2 wavelength model dimensions. It considers both the near and far field effects/calculations.

The model showed that leaky feeder at VHF-170MHz should give acceptable coverage (a fact we already new by experience), but further that we could expect good coverage in the stope area from point antennae (Refer Figure 24). We also did preliminary investigations into the coverage we could expect from 2.4GHz spread spectrum modems, and Figure 26 shows an optimistic view of achievable coverage.

6.2.2 Model Input Data

- Stope area

Figure 17 best explains a typical stope. The mine as explained in Figure 3 on page 7, is mined by approaching the narrow tabular ore slab (sloped at about 20 to 30 degrees to the horizontal) from below. Then a travelling way is made steeply up to the ore body and a gully is developed up the slope of the ore body, called the centre gully. From the centre 'Gully Advance Strike Gullies' (ASG) are developed to the side to be mined. The ASGs are kept just ahead of the panel being mined and panels are mined in a pattern similar to that shown in Figure 17. When the one side of the stope reaches its mining limit (about 90 m normally) then the other side is mined in a similar fashion. The centre gully is normally between 250 to 450m, and as such the maximum stope to be covered for radio is about 180 x 450 x 1.5m.

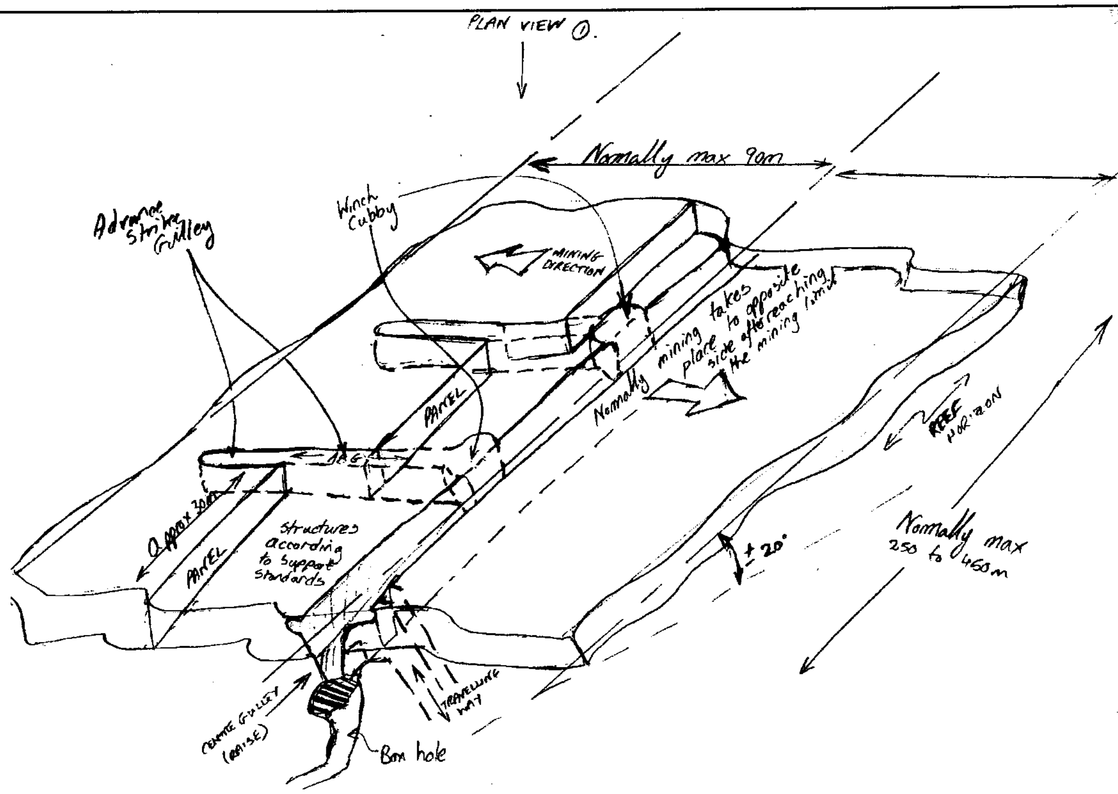

Figure 17: Sketch of a Stope Layout

The area behind the panel is supported by wood packs or a concept known as backfill (where solid cement like blocks are made to support the roofs). Dimensions of these support arrangements are given in Figure 18 and Figure 19. A diagram of support packs is given in Figure 20.

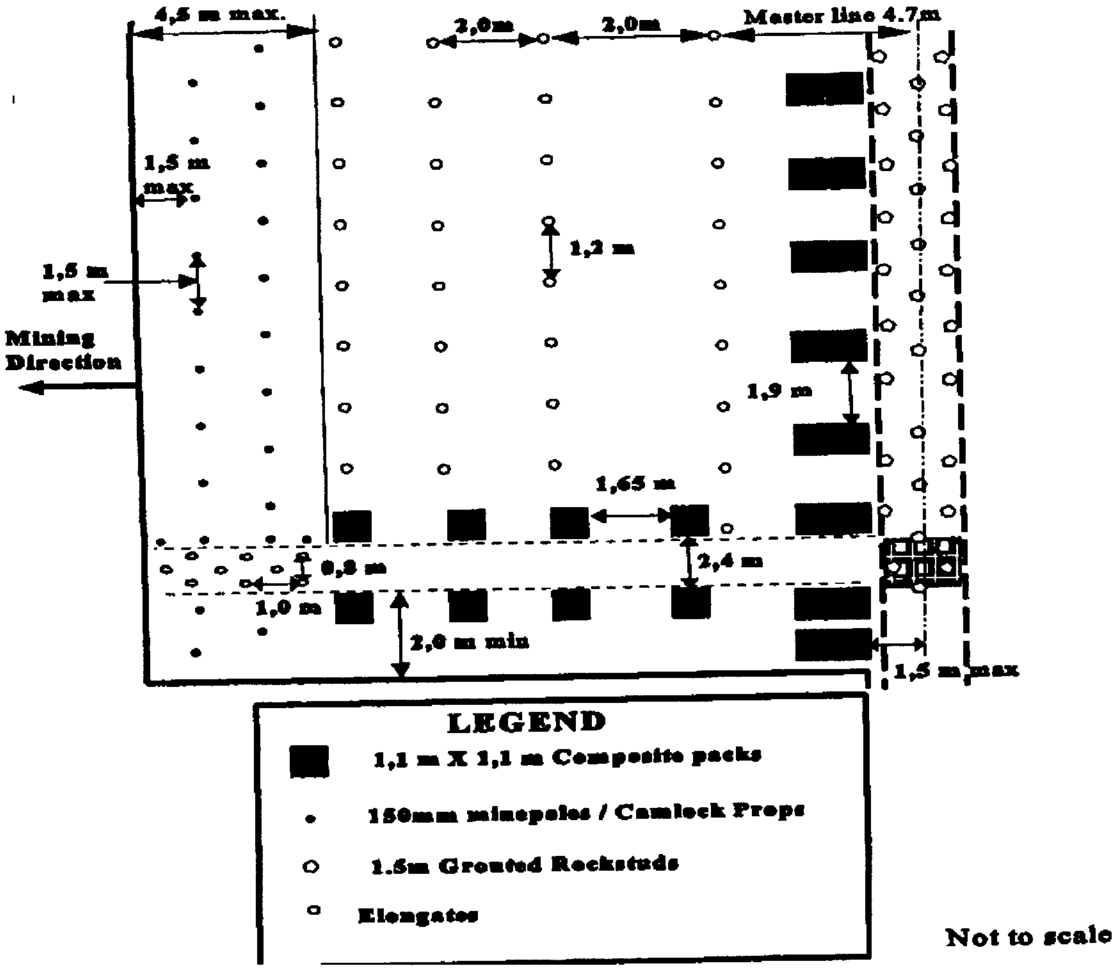

Figure 18: Conventional Support Arrangements

- Haulage

The haulage dimensions can vary between 3x3m to 4.5x4.5m. In the case of the modelling done, the dimensions used are shown in Figure 21. The haulage in the model had "meshing and lacing" on the side and roof walls. This is a type of steel mesh pinned to the wall. The apertures of the mesh are in the order of 10cm and this is far smaller than the wavelength of the radio waves at 170MHz (frequency of the model). Effectively then the mesh acts as a perfect reflecting lining and can be modelled as such. The floor remains as a lossy medium.

6.2.3 Modelling Method

The modelling was done by Software called "SuperNEC", developed by the company Poynting Innovations. Dr. Derek Nitch, who initially developed the Software [28] did the modelling, verification of the results and wrote the final report. I was involved in the specification of the input data to the model, the measurement of the verification test, and the interpretation of the results. The software uses a hybrid method of moments and GTD (Geometric Theory of Diffraction) approach which implements an asymptotic solution to maxwell's equations (i.e. it makes assumptions when the frequency becomes relatively high). The method of moments approach allows the software to model at lower frequencies than the GTD approach that is limited to about 2 wavelength model dimensions. It considers both the near and far field effects/calculations.

The leaky feeder was modelled as a series of segment sources (dipoles each a 1/10th of a wavelength in length), closely spaced inline (spaced ½ a wavelength apart) with each source reducing in strength by a factor suitable to simulate the loss per meter of the cable. A simulation of a haulage was done to verify against actual measurements on the Anglogold mine Elandsrand. The results of these measurements were compared against the SuperNEC model results and the resistance and permittivity of the walls were iteratively determined.

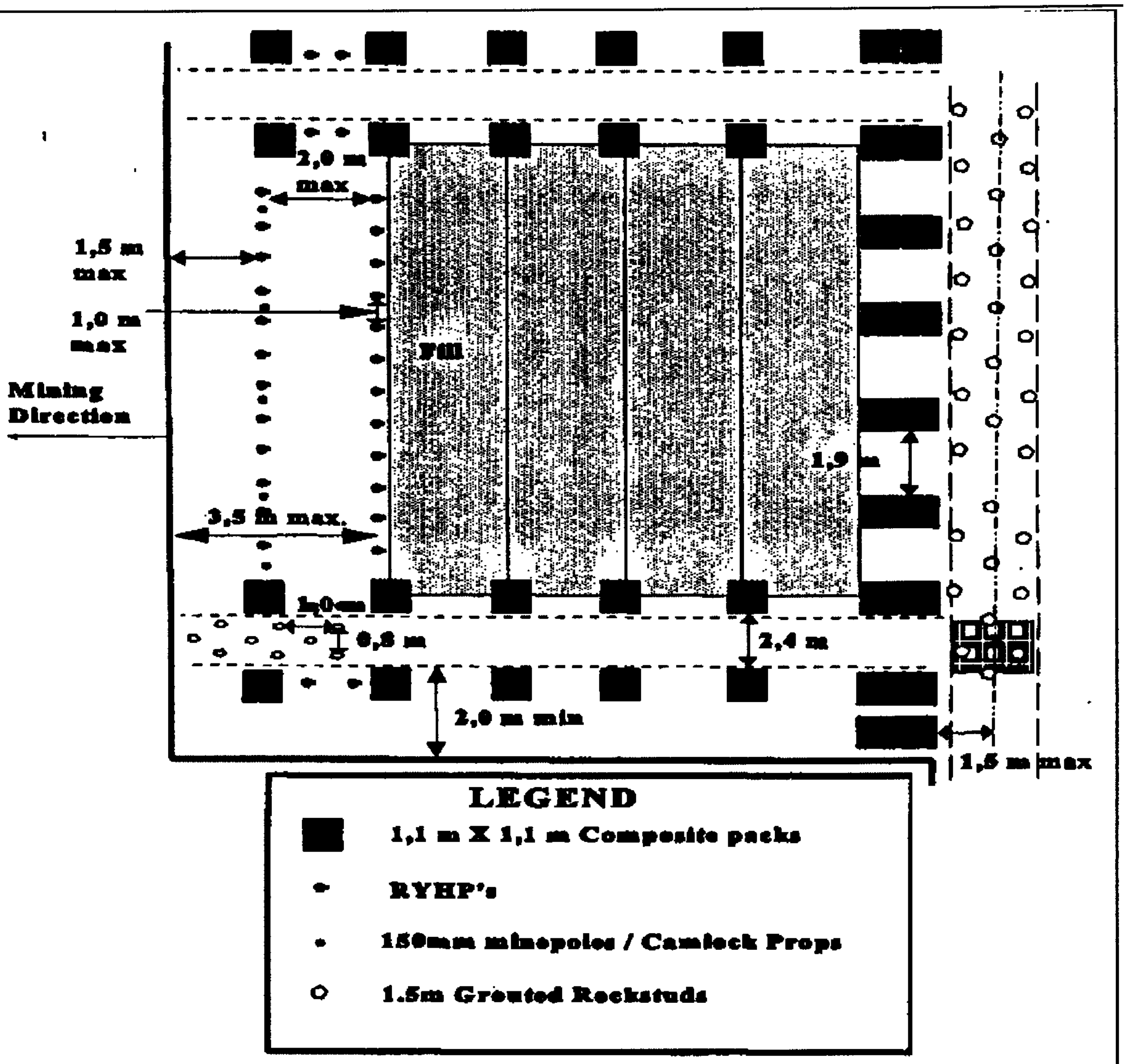

Figure 19: Backfill Arrangement

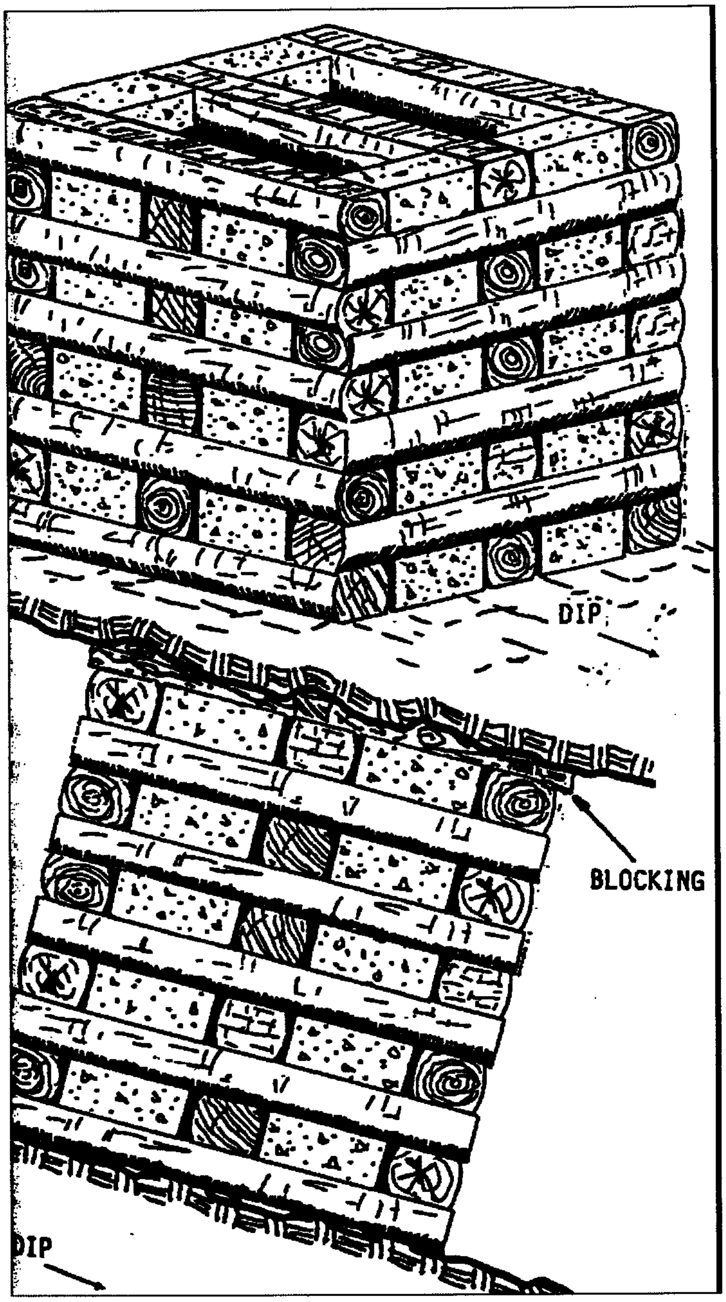

Figure 20: Conventional Support Pack

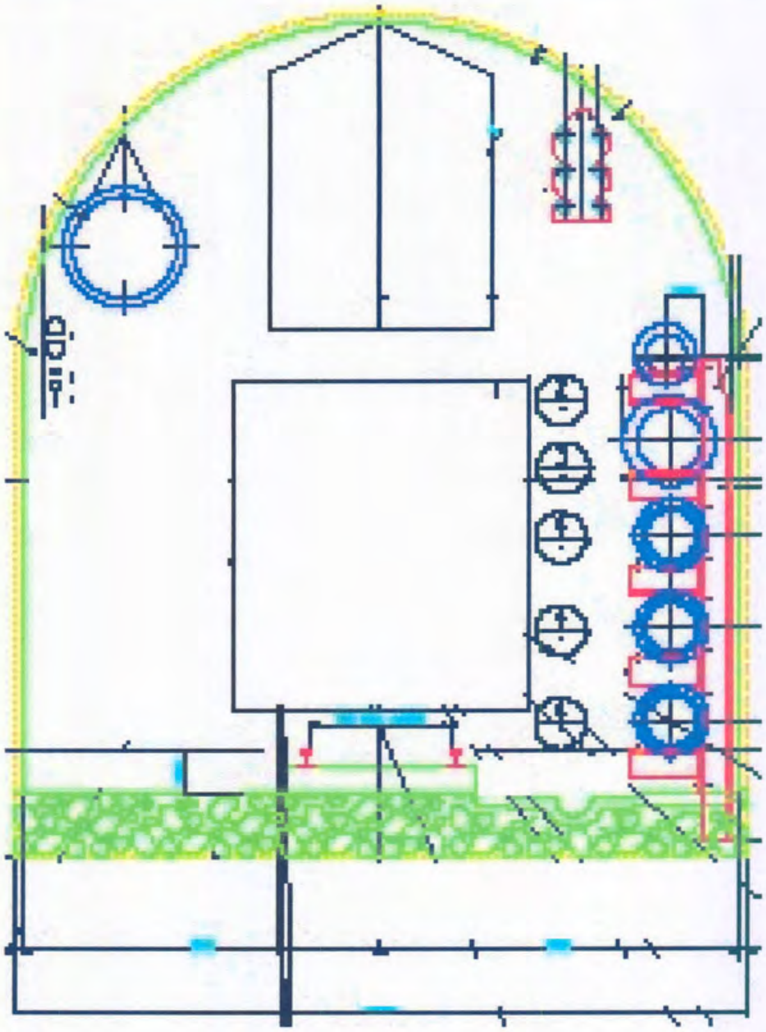

Figure 21: Haulage Layout for Modelling

6.2.4 Results of the Modelling

There is a detail report done by Poynting Innovations on the results of the model. The results of the verification were good. The model was further verified against another version of software. This propagation code is called CINDOOR. These results also showed good correlation.

Three scenarios were modelled:

- Haulage

The software gives the signal strength in the form of a colour map. The haulage was modelled and results are shown in Figure 22.

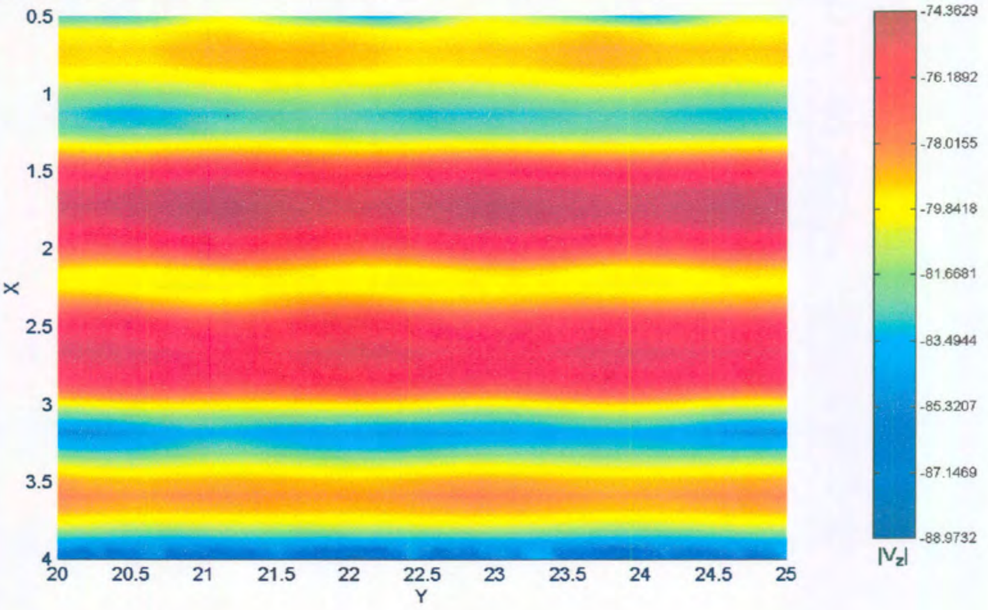

Figure 22: Signal Strength in a Haulage at height of 2.0m

- Stope without Packs

A stope with no packs similar to the arrangement shown in Figure 24 was modelled and the signal strength is shown in Figure 23.

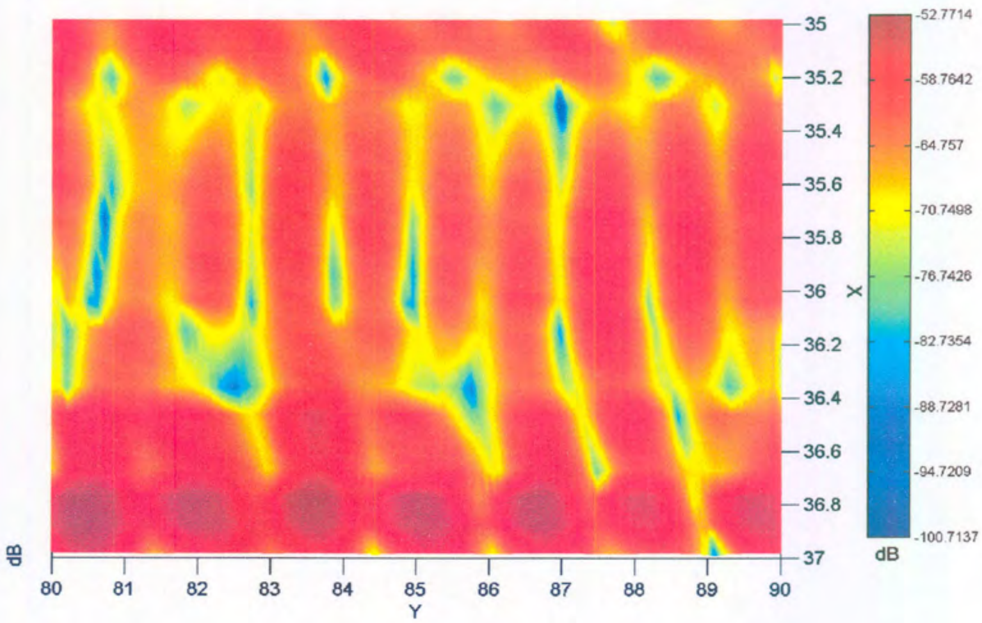

Figure 23: Signal Strength in a Stope with no Support Packs

- Stope with Support Packs

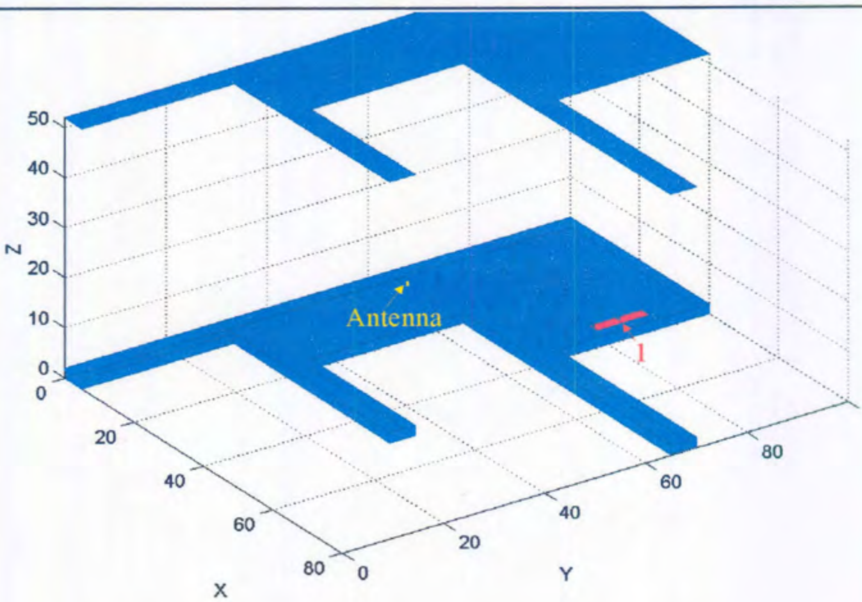

Figure 24: A top view of the stope with supports

This again is modelled as per Figure 24 and results are shown in Figure 25

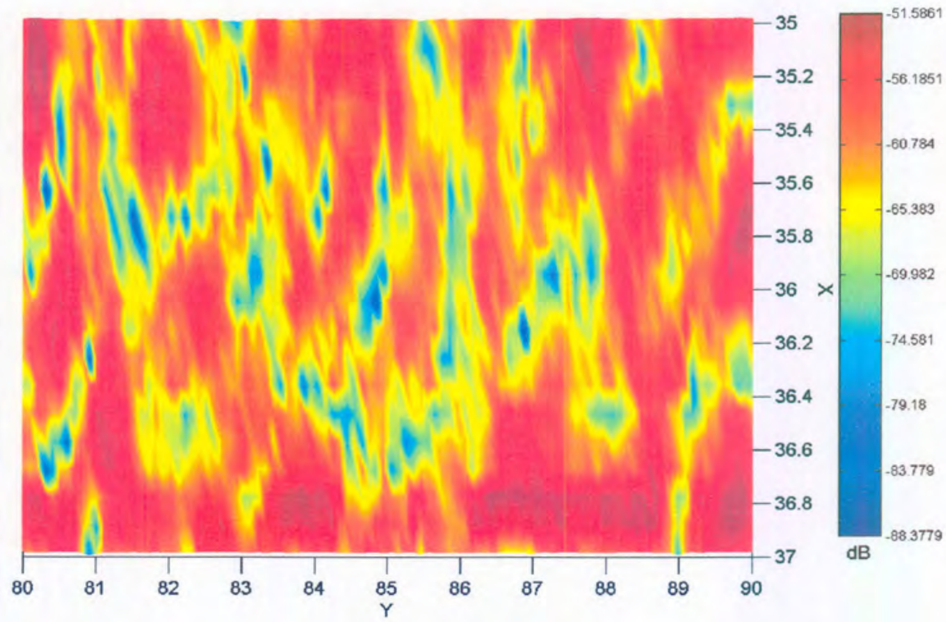

Figure 25: Signal Strength in Stope with Support Packs

- Haulage at 2.4GHz

A preliminary model was done of haulage conditions with a frequency of 2.4GHz. The conductivity and permittivity of the haulage rock surface was kept the same as used at 170MHz, however it is likely when taken up to this frequency. The work done by

Bryan Austin [20] found that for a frequency change from 0.3 to 6GHz the change in conductivity was in ratio 18/1. This implies that conductivity will increase as frequency increases further contributing to mutual interference from reflected waves. This will most likely increase severity of nulls and peaks, hence making this assumption of constant conductivity and permittivity an optimistic outlook. However on the other hand this simulation is done with a quarter wave unity gain antenna and with improved antenna design it is felt that we could achieve acceptable coverage.

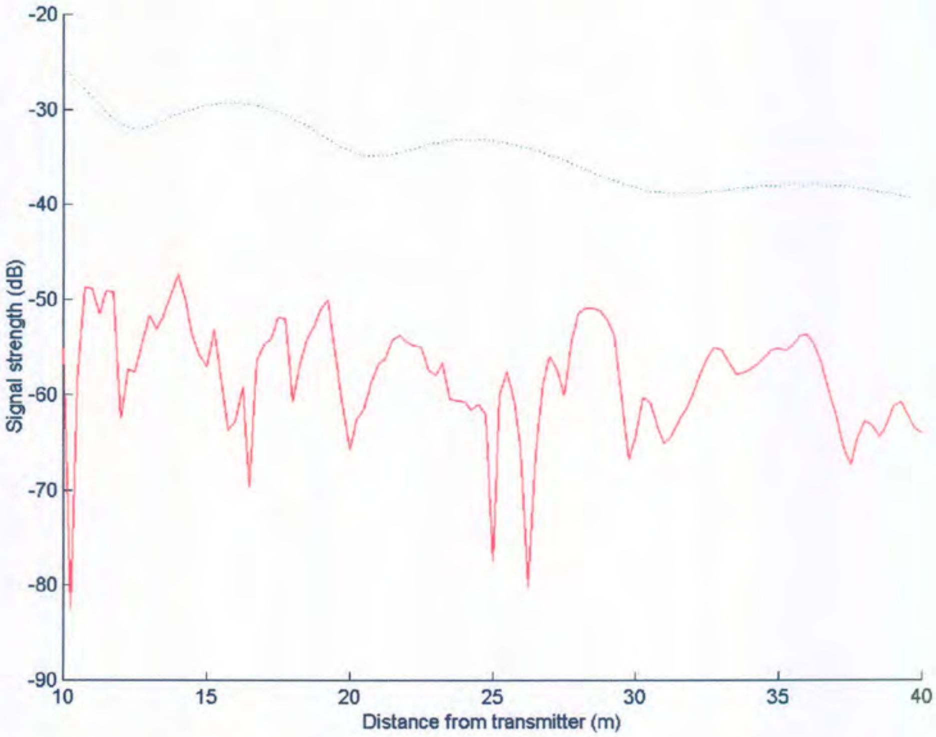

Figure 26: 2.4GHz Haulage Coverage (Optimistic)

6.2.5 Discussion of Results

The results show that signal strength at 170MHz is acceptable for radio transmission using conventional radios with Signal to Noise Ratios of –96dB. The results of the in-stope coverage with packs showed that the packs helped by smoothing out the patterns improving the signal strength dip potential.

Further work is recommended in the form of a pilot project to determine optimum design and positioning of the antennae. These results show that acceptable coverage is achievable.

For the 2.4GHz haulage option, we see that significant dips are expected but it is believed that with antenna design and a pilot system this could achieve acceptable coverage.

6.3 RF Topology

The layout of underground haulages is very linear from a topology viewpoint. Reflections from walls, roof and floor also lead to problems at certain frequencies. The leaky feeder concept of distributed antennae wire suites this layout of haulage very well. The leaky feeder in effect has optimum RF emission along the run of cable to control its RF coverage very well for the type of haulages we have, hence avoiding any reflection problems.

Another topology that would suite the haulage layout is mini-cells. If one could pass from cell to cell as you go along the haulage then RF emission could be reduced to levels where reflection is not a problem.

This leads us to the concept of an integrated RF LAN and leaky feeder. If the cell transmitters are integrated to the booster amplifiers then we have a simpler system to manage. Preliminary results from the RF modelling undertaken in the Poynting project, show that coverage of cells at 2.4GHz is ideally done with about 40m cells or less – considerably less than the current spacing of the leaky feeder booster amplifiers. This would have to be addressed in the design of the antennae.

6.4 RF LAN Considerations

Current RF LAN Technologies implement spread spectrum RF techniques and this is comprehensively covered by IEEE802.11 (Refer Appendix A.2.3 for more technical detail to the standard). The use of spread spectrum techniques underground introduces specific complications to the antennae and topology engineering. The “near far” problem, detailed in the appendix, implies that direct sequence technology might be unsuitable for confined space use like our underground environment. However this requires further test work to establish. Current data rates for these technologies are 1Mbps with frequency hopping and 2Mbps with direct sequence (non-standard performance of 11Mbps with direct sequence have been claimed but this needs further development).

If you consider a single access point every 300m in the haulage, then one can expect no more than 3 mobiles working in each cell. If video coverage is achieved in 300Kbps per channel then we see we have Ethernet capacity at less than 33% and can achieve deterministic response.

7 ASSEMBLING AND MANAGING THE ARCHITECTURE

When looking at what is best for the mines, it becomes a choice between catering for existing standards (some considered *legacy* systems), and re-engineering (or in the fortunate position of new shafts to engineer from scratch) to align the communications infrastructure with the expected standard of the future (Ethernet TCP/IP). Considering the effort of re-training, additional expense of buying equipment before it is mature in the market place, against the benefits of extended system life from buying "state of the art" systems, three different approaches were developed (detailed in the next sections). Only long term shafts (15 years plus) were considered as warranting "cutting edge" solutions. Medium Term Mines would tend to taper off in communications infrastructure roll-out within the next 2 to 5 years, and already had a communications systems population of 80% of envisaged maximum. Long term mines on the other hand would have automation infrastructure growth such that communications systems were currently only 50% or less rolled out.

7.1 Model for Long Term Shafts

The vision for long term mines is to reduce the communications systems to three domains with a unifying technology namely TCP/IP.

As such first choice Plug In for video, voice and data will be Ethernet 100baseX (Fibre or if required UTP).

The Control and Monitoring architecture remains principally the same as current implementations. The SCADA (supervisory software) remains on surface communicating with distributed PLC's. A process control database is generated for integration to the Business Systems IT environment. This will be on an SQL compatible database standard. The video systems, of which a significant amount are expected to be for security purposes, will be integrated into the IP environment.

Voice phones will be UTP TCP/IP compatible plugging into the nearest hub.

Field instruments are expected to be on the latest fieldbus standard, and this is expected to be Fieldbus Foundation Ethernet option H2 (further complimenting the global Ethernet environment).

Voice radio is still expected to be in the VHF leaky feeder arena, but high-speed data transmission will be on RF LAN Spread spectrum modems that will implement a roaming TCP/IP environment for PDA and IP video. The clarity, resolution and frame speed of video should be achieved with the MPEG 4 or MPEG 6 standard should allow us to connect acceptable quality video with 300Kbps bandwidth. Current spread spectrum capacities allows us then to implement RF TCP/IP Video.

The conceptual plan can be seen in Figure 27.

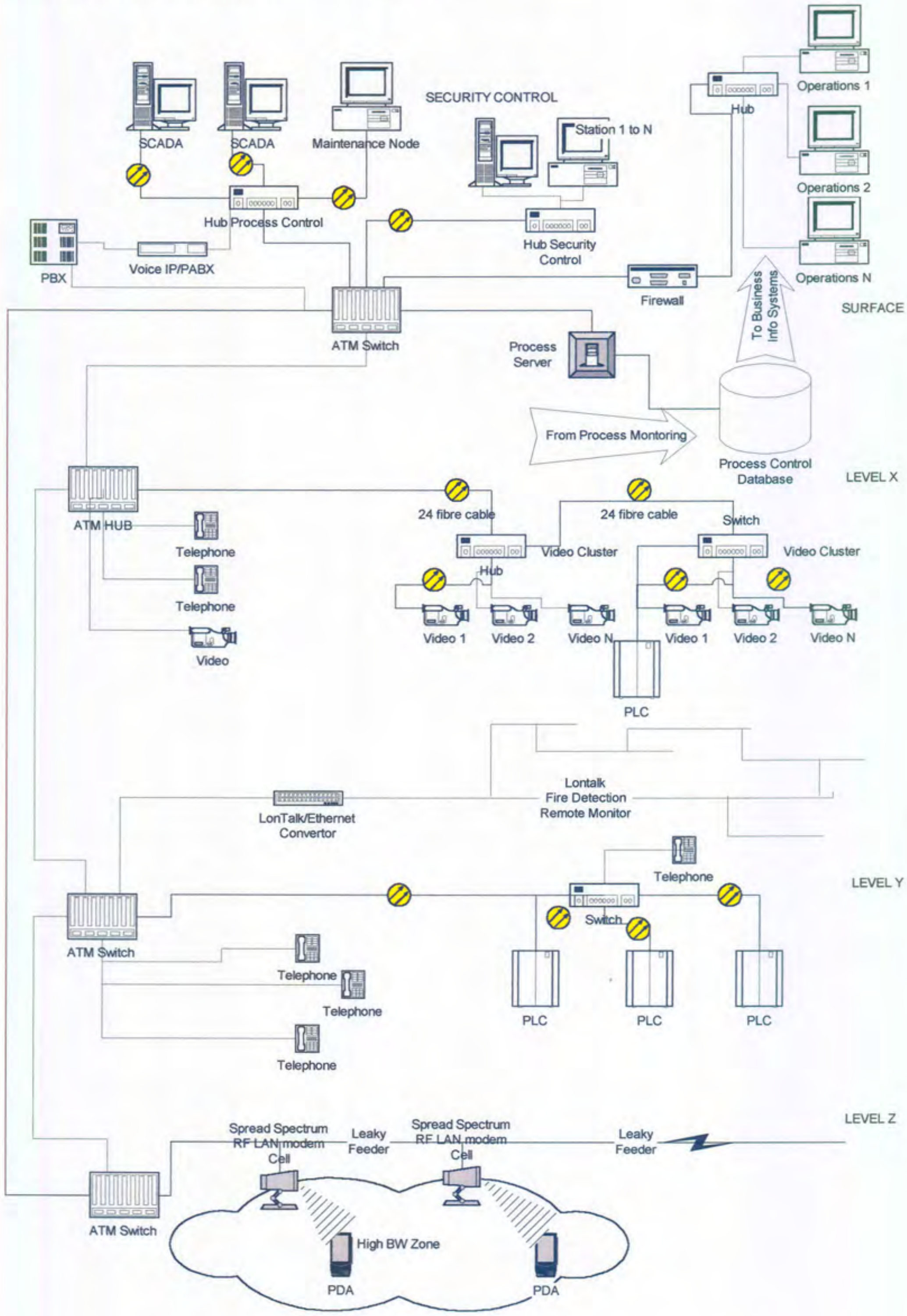

Figure 27: Long Term Mines Communications Model

7.2 Model for Medium Term Shafts

The vision for Medium Term mines is to reduce the communications systems to four main domains catering for legacy systems where appropriate.

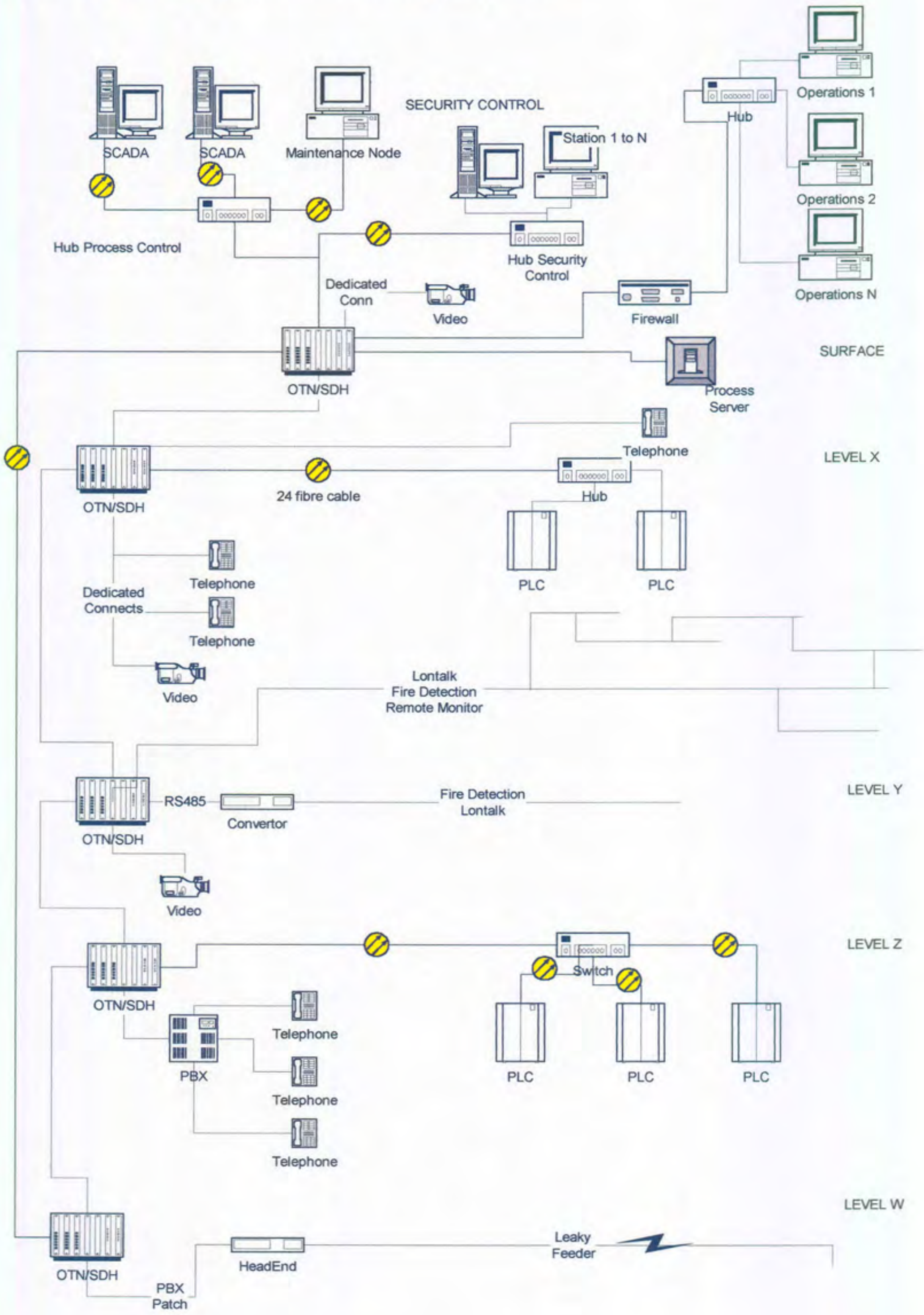

Figure 28: Medium Term Mines Communications Model

The domains can be seen in Figure 28 and are: Shaft domain (OTN/SDH), process control domain (PLC and Fieldbus), rugged medium domain (Echelon - Lontalk) and the radio domain (voice alone).

The most appropriate backbone standard became one that could provide Legacy system interface integral to the unit (i.e. as a plug in card option). The SDH aligned technology "Siemens OTN" was chosen. There are separate video and voice domains but these effectively plug straight into the SDH boxes

7.3 Model for Short Term Shafts

Short-term shafts do not merit any additional costs for replacement infrastructure but with the purchase of new systems the following criteria should be used for System Choice.

a. Current skills base

One needs to buy systems that the current technical support teams are trained in. We need to remember that downtime will be dependent on their knowledge during system failures and that substantial re-training will probably not be attractive considering the short life these mines have.

b. Interconnectivity to existing systems

Existing systems will not be replaced so we need to connect to them. We still need to strive for full system connectivity to harness the benefits available from information enablement.

c. Market support over expected life

One needs to look at the likelihood of Supplier support for such things as spares, and technical support. These are essentials and if they do not exist it can lead to substantially premature system replacement. Supplier market history is the only way to evaluate this.

d. Openness for future systems

Next in priority is buying systems suitable to connect to current market de-facto standards realising that potential future systems will probably be based in these standards.

A. 1. Radio Frequency Spectrum Management

The underground situation is fortunate in that presently the competition for "air space" is small. Signals generated underground do not emerge to the surface due to natural signal decay through the rock, hence the underground radio frequency spectrum is not subject to national legislation governing the generation of radio frequency. However when we consider the critical safety systems that will be communicated in the RF Communications domain, we need to be careful and manage this spectrum. The best document for guidance on surface frequency reservation is the report on the SABRE project [27]. This gives insight to current reservation as well as future frequency plans (currently being proposed in light of international trends)

Safety critical systems need further care regarding RF transmission and this lead to the establishment of a Code of Practice guideline on RF systems for the business units (Appendix A. 5), that was done as part of this thesis.

A. 2. Technology Watch Framework

According to theory presented in [11], a suitable framework for managing technology in a complex environment is the "technology balance sheet". In similar way a technology framework has been developed for the Communication Technologies in the deep level gold mining environment (Table 2). The principle of the framework is to relate communications aspects that influence each other, and use this as a tool to monitor changes in each aspect translating their effect to other aspects of the framework.

The three aspects used in the developed framework are the required 'technology watches', the domains identified to assist in system rationalisation, and the needs of the mines. These are detailed further in the next few paragraphs. The principle is that when needs change these reflect directly on the domains. Similarly technology changes in the market place can strongly influence the domains, empowering or inhibiting them in servicing the needs.

- Technology watches

  This is a listing of technologies that are available, or potentially available, on the market place, and have been identified as suitable for the defined domains. It is necessary to track these technology's trends.

- Domains

In some mines there are more than the proposed four domains in existence and these have been included in the listing.

There are essentially two options for the shaft domain, namely the integrated option defined primarily for medium and long term mines where it motivates investment in a fibre broadband network, and secondly the 'fragmented shaft domain' where systems run down the shaft separately.

The 'haulage fibre' domain is for long term mines with a vision for fibre networks distributed down the haulage. Essentially the vision is for an Ethernet hub/tree topology servicing multimedia needs.

The 'PLC to PLC', and 'Fieldbus' sub-domains form the 'process control domain'. With the convergence of these technologies in the technology arena onto the unifying standard, Ethernet, this could form one domain with no sub-domains. At this stage they need to be monitored separately.

The four RF sub-domains are listed separately since different needs and technologies affect them.

- Needs

The needs are taken from section 3.4 and previously summarised in Table 1.

A tick in Table 2 represents a relationship that requires consideration between either the need and the domain, or the technology and the domain.

Table 2: Technology Management Framework Table

							COMMS NEEDS		Video	Video	Video	Voice	Voice	Ctl Data	Mon & Ctl Data	Mon & Ctl Data	PDA LAN
									Shaft	Boxholes	Locos	Locos	Stope	Locos	Utility	Stope	ALL
							Mines:	Long Term	✓	✓	✓	✓	✓	✓	✓	✓	✓
								Medium Term	✓		✓		✓	✓	✓		
TECHNOLGY WATCHES								Short Term							✓		
Ethernet	ATM	Fieldbus Found.	Profibus	Lontalk	Leaky Feeder	RF Modem	**Domains**										
✓	✓						Integrated Shaft		✓	✓	✓	✓	✓	✓	✓	✓	✓
✓		✓	✓	✓			Fragmented Shaft		✓	✓	✓	✓	✓	✓	✓		
✓	✓						Haulage Fibre			✓					✓	✓	✓
✓		✓					PLC to PLC								✓	✓	
		✓	✓				Fieldbus								✓	✓	
				✓	✓		Rugged Medium								✓		
					✓		RF Haulage Voice and Low BW					✓		✓			
					✓		RF Stope Voice and Low BW						✓			✓	
					✓	✓	RF Haulage High BW				✓			✓			
					✓	✓	RF Stope High BW									✓	✓

8 CONCLUSIONS

8.1 Benefits and Needs Analysis

The cost benefit impact that a communications system has on a deep level mining operation is unclear since it is a key tool in improved management, a catalyst to improving efficiency, and not the complete solution to achieving the benefit. However a qualitative and conservative estimate was made and showed an Internal Rate of Return (IRR [13]) of around 160%, very attractive for any business.

The main driver for the sophistication of the communications system is the automation vision of these mines, and the main factor in how much automation they plan is the remaining 'life of mine'. Considering technology shelf life, automation vision and system benefit realisation, we can group our mines into essentially three categories, namely; 'long term mines' (15 years plus life remaining), 'medium term mines' (8 to 15 years), and 'short term mines' (Less than 8 years). With this in mind the needs were explored and summarised in a table (Table 1 on page 17). This table was taken forward to the Technology Management Framework (on page 71). In preparation for the matching of technology and the rationalisation of systems four ***Communication Domains*** are defined.

8.2 Technology Analysis

When a communications system is chosen or engineered then there are key qualities, aspects or properties that need to be strived for. Firstly we need to look for **open, interoperable** systems that can be implemented on **as many mediums as possible**, and that can carry **multi-media traffic**. This allows us flexibility to maintain or expand, and secures the benefit of increased supplier competition with "spin offs" of competitive pricing and quality. It also combines traffic needs to enhance economy of scale. The **topology** that the technology can be implemented with is also a contributing factor in the flexibility the Network has for expansion.

Secondly the required technical quality aspects to the network need to be built into final system engineering. **Determinism** is a quality that must be considered against the time delay robustness of the traffic on the network. **Redundancy** needs to be considered against the reliance that the control architecture has on the network. Finally **bandwidth** must be matched to traffic loading and used, when appropriate, to achieve determinism.

The major technologies for the different domains are discussed in turn, expounding the more relevant technical points. Following this, the emerging standards for the major **fieldbuses**, and the core **backbone/broadband architecture** were qualitatively analysed in the form of **S curve technology forecasts**. This can be seen in Figure 11 and Figure 14 and was used in the formation of the final models.

Radio remains the most challenging technology for implementation. The two main process needs that determine which radio technology to implement are mobile video and mobile PDA type data. Both require in the order of 1 to 10 Mbps bandwidth and current RF spread spectrum technology gives us this. Leaky feeder provides a method ideal for the immediate rollout of VHF infrastructure in the haulage. Extending this VHF infrastructure to the stope areas is the next natural step. In fact the tremendous financial benefits in getting voice communications to the stope make this an urgent project. The radio coverage modelling done in this dissertation shows us that we should get acceptable coverage in the stope area with the currently used VHF frequency radios. Further modelling was begun to investigate coverage we could get with the RF spread spectrum frequencies. This showed that we can expect potential dead spots (nulls) in the haulage, however with antennae and reception algorithm design, and the intelligent use of the cell concept, we should be able to engineer an acceptable solution. This then becomes a challenge to be engineered by the end of the year 2001 in preparation for the first high speed data radio requirements.

8.3 Implementation

Communications technology is a dynamic field with technology becoming redundant at a frightening rate. The trick is to stay optimally ahead in the emerging technology market conditions and take note of converging standards that indicate the long-term winners amongst the supplier products. Methods are proposed in this dissertation to manage this. Firstly by means of best practice reviews, where the cumulative expert resource of a company like Anglogold is used to speculate on technology forecasting and to spread these approaches and knowledge. Secondly by appointing communication champions and implementing 'approved plans' for all communications domains, so that we have control over the purchase and engineering of such systems. Finally with the implementation of the technology framework developed in Table 2, to give us the relationships between the domains we identified, the technologies we need to watch and the needs we must take cognisance of.

Further there is a tailored project management process identified in Figure 8 that is geared to fit in with the macro technology management issues around communications systems.

The dissertation provides effectively 2 models for medium and long term mines (Figure 27 and Figure 28) that are the generic communication blue prints for shafts in these categories.

8.4 Summary

The mining environment and the communications technology field are both unique in their own way, requiring a defined strategy to achieve successful implementation and management. This dissertation, developed six methods to effectively manage communications systems in deep level mining, namely:

- Best practice reviews,

  Where peer professionals in Anglogold meet and present their plans and methods, and from which best practice is identified, developed and spread.

- The communications project management process,

  Where needs, technology forecasting and system implementation control are emphasised. Integrating this with the best practice review methodology results in a recommended life cycle management plan for communication systems (Figure 10).

- The RF code of practice guideline,

  Where the critical issue of RF spectrum management is taken care of and safety issues around RF in general are addressed.

- The appointed CIC champions and domain plans,

  A person must be appointed to enforce and manage the planning process, and identify future needs.

- The mine communications models,

  Where three separate generic models/approaches are presented appropriate to the value they are likely to add to the business.

- and the technology framework,

  Where a framework was developed to watch technology developments against communications needs, contextualised in the domains identified to rationalise the number of communications systems there are.

These practices and models must be integrated into the macro-management policies of existing mines to achieve the full benefit available.

As a follow on from this dissertation, both the stope antennae and RF spread spectrum haulage units need to be developed and successfully demonstrated in a pilot system.

This is only required by the end of the year 2001, and the chances of success of this development is estimated as good considering the preliminary results available from this dissertation.

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GLOSSARY OF TERMS

ATM: Asynchronous Transfer Mode – normally refers to equipment or standards that use this type of communications standard. It is a standard used for communication backbones that carry multimedia at the highest of bandwidths applicable.

Blasts: The actual explosion that breaks the rock at thee mining face

Box: The storage cavity developed in the rock for the storage of mined rock. The Horizontal Transport locomotives normally pick up rock from the boxes and deliver this to the tips near the shaft.

BU: Business Unit

C&I: Control and Instrumentation

Chute: The Control device used to control rock flow from an aperture like the discharge hole of a box. Normally a mechanically operated blade that can stop the flow of the rock.

CIC: Control, Instrumentation and Communications – Normally refers to the discipline of professionals, or equipment of this type.

COS: Class of Service

Cross-Cut: The off shoot of the main haulage which approaches the ore body (reef plane). It is essentially a tunnel peeling off the main haulage.

FDDI: Fibre Distributed Data Interface. Similar to ATM, this refers to equipment or standards of this type.

Haulage: The main tunnelling leading away form the shaft towards the working areas underground.

I/O: Input/Output. Typically refers to inputs and outputs of a system.

Leaky feeder: A Radio Technology that uses a type of co-axial cable with an intentionally leaky outer shield. This allows the RF signal to radiate out evenly over the entire length of the run of cable.

Legacy: Normally refers to a system that is catered for because it does not make financial sense to re-engineer it, but it is not the ideal system for the long term technology vision.

LHD: Load Haul Dumper – A heavy trackless vehicle used underground for the transport of rock.

Loco: Locomotive – The traction engine (normally battery driven) used underground to pull trains of **material cars** or **rock hoppers**.

Mining Team: The team of workers in a stope, normally consisting of a team leader, mining assistant, drilling team (about 4 drillers) and support team (about 4 support persons).

Mobile Communications Domain: One of the communications domains defined to rationalise communications systems and apply communications technology optimally. Essentially this is the radio transmission domain.

MRS: Mine Radio Systems – a company dealt with in the compilation of this dissertation.

Ore: Gold bearing rock

OTN: Open Transport Network. A phrase primarily used by Siemens for their multi interface dual redundant fibre optic system.

Panels: The working face. Typically the face in a stope area that gets successively blasted to produce the ore for transportation to the plant.

PDA: Personal Data Assistant – a 'Palm Top' PC which has facility for appropriate data entry and retrieval. The vision is that this should be continually on line to the network by RF technology.

PLC: Programmable Logic Controller – the microprocessor device wired to inputs and outputs in the plant for the purpose of controlling or monitoring such plant

Process Control Domain: One of the communications domains defined to rationalise communications systems and apply communications technology optimally.

Reef: The body of ground containing the gold bearing material. Normally a slab of ground about 70cm thick and sloping at 30 degrees to the horizontal.

RF: Radio Frequency

Rugged Medium Domain: One of the communications domains defined to rationalise communications systems and apply communications technology optimally

SCADA: Supervisory, Control and Data Acquisition – The PC software system used to monitor, display, trend, alarm and do high level control upon plant via a network of PLC inputs or remote inputs.

SDH: Synchronous Data Hierarchy. Similar to ATM, this refers to technology or standards of this type.

Shaft: The main access holes to go down underground. There can be sets of two shafts (one for ventilation feed and one for ventilation extraction) reaching their maximum depths underground, then feeding sub-shafts reaching further. The winding conveyances run in guides down these shafts.

Shaft Domain: One of the communications domains defined to rationalise communications systems and apply communications technology optimally

Stations: The off-loading and on-loading area at each level at the shaft.

Stope: The working area where the reef is mined.

Support: The packs or props used to support the roof in a stope and stop it from collapsing.

TCP/IP: The converging internet/network standard in the transport and network layers of the 7 layer OSI model.

Waste: Rock with no gold in it. Normally generated from developing tunnels to access the ore body.

APPENDICES

A. 1. FDDI, SDH AND ATM TECHNICAL INFORMATION

The section attempts to extract the more important technical points around these broadband standards. Most information is taken from the following references as listed in the References section: "Fred Halsall; "Data Communication Networks and open System Standards"; " - [19], and "John F. Mazzaferro; "FDDI vs. ATM - High Speed Networks"; Computer Technology Research Group; Charlestown, South Carolina, USA; First Edition, 1994, " - [21]

FDDI II and SDH are synchronous networks providing dedicated/independent channels to the multi-media sources requesting service. ATM is a cell based asynchronous technology providing dynamic service flexibly to the sources no matter what media the source is. They can almost be considered in two different leagues but these are the dominant technologies seen currently in the market for Broadband services.

A.1.1 FDDI

FDDI initially was a data orientated network synchronous technology. FDDI II has been developed to cope with the constant data delivery required of isosynchronous data (data generated at a constant bit rate and requiring delivery at a constant bit rate). This is typically the type of service required of voice and video traffic. When FDDI II is operating in hybrid mode then the 100Mbps bandwidth is divided in channels controlled by the cycle master. Repetitive data string cycle are generated every 125μs (equivalent to the basic sampling interval for the digitisation of analogue speech. All stations synchronise by means of a 20 bit synchronisation pattern at the start of each cycle.

A.1.1.1 SDH (Synchronous Digital Hierarchy)

SDH was initially developed by Bellcore in the USA under the title SONET (Synchronous Optical Network).

The basic transmission rate is 155.52 Mbps called STM-1 (Synchronous Transport Module level 1 – abbreviated to 155Mbps). Higher rates are implemented in multiples of SMT-1, such as SMT-4 (622Mbps) and SMT-16 (2.4Gbps). In SONET the basic rate is 51.84Mbps (a third of STM-1)

Again the SDH consists of a repetitive set of frames every 125μs (digitised voice aligned). SDH equipment has software with it known as a Network Management (NM) Agent allowing diagnostic information flow. Remote station configuration allows channels to be assigned and configured by the NM software.

Dual Fibre rings are typically used to set up redundant paths in case of system segment failure.

Siemens OTN (Open Transport Network) is a proprietary product with synchronous dual counter rotating rings very similar to SDH. The latest versions of OTN are available with SDH compliant cards, however higher stack level standardisation is required before true vendor independent interoperability can be achieved with OTN.

A.1.1.2 ATM

The main advantage of ATM is that it can dynamically deliver bandwidth as asked for by service requesting stations. It can support both connection orientated and connectionless traffic on the network. Its traffic management features are well suited to more complex Networks requiring switching together with support for connection orientated traffic. It has more flexible but more complex traffic control with the ability to manage the traffic on the network to the limits of the bandwidth. The small cell size also supports multimedia traffic better. The standard (as the name implies) is Asynchronous meaning it that individual bits in a cell are synchronised but timing between cells can vary, this being a consequence of the more dynamic nature ATM brings to traffic control.

The Data Link and Physical layer are implemented in cells of 53 bytes long. The first 5 bytes are the cell header containing fields for cell routing, traffic flow, cell identification, and error correction. The remaining 48 bytes are for the information payload.

There are essentially 3 ATM layers in the Protocol Architecture:

- ATM Adaptation Layer (AAL)

  Provides the convergence (adaptation) function between the Class of Service (COS) provided to the user and the cell based system underneath. Depending in the COS this layer converts the incoming data into streams of 48 bytes for the lower layer.

  The ATM technology provides essentially 4 types of COS:

  - AAL1: Class A: Constant Bit Rate (CBR) Service

    This is connection orientated, typically required for constant bit rate data length such as voice traffic.

- AAL2: Class B: Variable Bit Rate (VBR) Service

Also connection orientated, but typically for variable bit rate traffic such as compressed video.

- AAL3/4: Class C/D

This is for connectionless traffic, typically data. Previously this was 2 layers with layer 3 intended for connection orientated data traffic, but now this was merged to provide a connectionless service only for data.

- AAL5: Simple and Efficient Adaptation Layer (SEAL)

Very similar to AAL3/4 but with less control field Information (related to convergence, segmentation and reassembly) in the header. This provides a more efficient but connectionless service.

- ATM Layer

This constructs the header information and multiplexes the cells for transmission in the physical layer. It also receives transmission de-multiplexes and relays the cells to the correct AAL protocol.

- Physical Layer

The upper part of the physical layer is the transmission convergence sub-layer and generates the header check sequence an delineation information of the cell boundaries. The lower part of the physical layer is the medium-dependent sub-layer and is concerned with line coding and bit/clock synchronisation.

A. 2. OVERVIEW OF IEEE 802 STANDARDS

The IEEE 802 family of standards is best viewed using Figure 29 taken from [22]

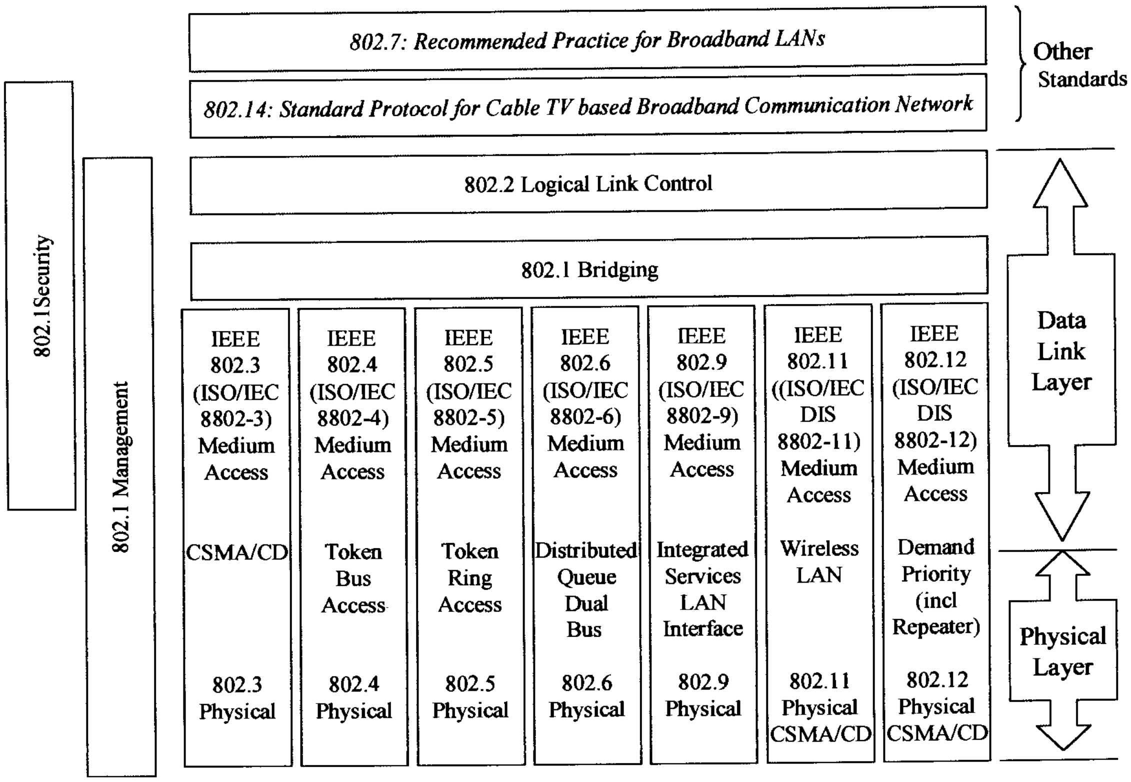

Figure 29: IEEE 802 Family of Standards

Examining the standards in detail is of mainly academic value. Rather we need to appreciate the technical detail that impacts on the use of the standard from a technology management perspective. With that in mind I will only discuss the parts impacting on this project.

A.2.1 IEEE802.3 CMSA/CD Ethernet

This is the dominant Media Access and Physical layer standard found on the Anglogold IT LAN Desktop PC's. The 1993 version of the standard ([23], [24], [25]) was used to determine scope and comprehensiveness of the standard from a technology management perspective. The following points merit discussion:

A.2.1.1 Basic Concepts

CSMA/CD stands for Carrier Sense Multiple Access with Collision Detection. Multiple stations on a common transmission medium use a "busy" detect method to grab hold of the medium when they need to transmit. The stations wait for a quiet period then transmit their data. There is both a "channel free detect" function and a "Collision Detect" function. When the channel free detect within the Data Link layer indicates a free channel, then transmission begins. The frame is formed and all stations read this and determine if the message is addressed to them. If so they pass the message up their ISO level hierarchy. There is a chance that another station can have taken hold of the medium at approximately the same time, in which case a collision in the transmission medium will occur. Collision Detect will notify the Data Link Layer and a Jam sequence of bits will be put on the Transmission medium to ensure no incorrect interpretation of such a faulty message.

A.2.1.2 Architectural Perspectives

The standard cover the Media Access Control (MAC) Sub-layer of the Data Link Layer, and the Physical Layer. For LAN networks there are effectively 4 types of Physical Layer alternatives working on 10Mbps:

- Thin wire coaxial cable with maximum segment length of 200m: 10 Base 2
- Thick wire coaxial cable with maximum segment length of 500m:10 Base 5
- Hub star topology with twisted pair drop cables:10 Base T
- Hub star topology with Optical Fibre drop cables: 10 Base F

Topologies can be implemented in a number of ways but for our purposes star with hub 10Base T, and this is where most Industry product is centred around.

Due to the collision detect method of the standard the station must wait a certain slot time before it can reliably know whether a collision has occurred. This imposes a limitation in the topology since the Slot time that must be waited is just above twice the maximum transmission path delay and this is increased as you go through hubs due to the switching delays with the repeater process. Typically one can go 3 hubs deep in a tree structure.

A.2.2 Fast Ethernet

With the 802.3 specification, the maximum cable length for 10BaseT is 2.5Km. Fast Ethernet reduces this to 100m and with the corresponding maximum signal Propagation delay reduction the data rate is allowed to increase to 100Mbps, called **100BaseT**.

There are two ways to achieve data transfer at this Baud rate, firstly using category 3 cable with 4 pairs reducing the bit rate on each pair to 33.33Mbps – This is called 100Base 4T. Secondly using category 5 twisted pair or optical fibre, and encoding every group of 16 four bit data bits into a 5 bit representations effectively compresses the data into a smaller bit rate. Then using two Pair/fibres transmit this for forward and return Transmission. This is called the **100BaseX** standard.

A.2.3 IEEE802.11 Wireless LAN

Wireless LANs currently on the market use mostly spread spectrum radio or infrared transmission technique. Infrared is more for line of sight applications hence Spread Spectrum RF LAN is more of interest to us.

Two techniques are used for spread spectrum:

- Direct Sequence

  In this technique a pseudorandom code (bit stream) is 'Ored' with the data for transmission. The code bit stream (called the chipping rate) is faster than the data stream. The receiver identifies the code by means of autocorrelation and then synchronises itself for the reception of the coded data, decoding it as it receives it. The amount that the chipping rate is faster than the data bit rate relates to the ability that the RF receiver can identify the data stream and in effect allows the unit to function in a far poorer Signal to Noise Ratio (SNR) environment. The chipping rate to data stream Rate is referred to the Spreading Factor and results in a reception ability gain referred to as the processing gain. From another aspect one can think of the situation as the receiver getting more samples of each data bit the higher the Chipping rate is.

  Each unit operates on a channel allocated via on-line configuration.

- Frequency Hopping

  With frequency hopping the data is sent across the RF medium hopping between the different channels in the spectrum. There is a defined hopping sequence that is tracked by both sender and receiver. An advantage of this method is that problem frequencies can be avoided when encountered.

The IEEE802.11 defines the MAC and PHY layers for spread spectrum direct sequence and frequency hopping, and also for infrared. It creates a framework for Ad-hoc (i.e. a small group of mobile computers) and infrastructure networks (i.e. hardwire LAN replacements). It provides for the co-existence of overlapping wireless LANs and covers authentication and privacy mechanisms.

Another standard to be used for spread spectrum technology specification is the European Standard ETSI 300.328. This standard covers minimum technical characteristics for spread spectrum radio transmission in the 2.4 to 2.4835 GHz range.

- Performance and Coverage Aspects

  Spread spectrum frequency hopping has a lower bandwidth capability than direct sequence technology. This is due to the transition or switching delays in changing between the hop frequencies.

  The Direct Sequence cannot however cope as well as frequency hopping technique in noisy environments. This is due top the **"near far" problem**. With multiple transmitter in the range of a single access point, each transmitter acts effectively as noise for the other's signal. With a very near (hence strong signal) transmitter and a very far one in the range of a single access point, the noise level for the near transmitter swamps the further transmitter's communications.

A. 3. PROFIBUS TECHNICAL DETAIL

Most of the technical diagrams in this section were obtained from the Profibus CD issued publicly.[7]

A.3.1 The Standard

The standard is defined by the European Standard EN 50 170. This covers Profibus as a protocol. The protocol architecture is oriented to the OSI (Open System Interconnection) reference model in accordance with the international standard ISO 7498. It is implemented in 3 forms as described in the diagram below:

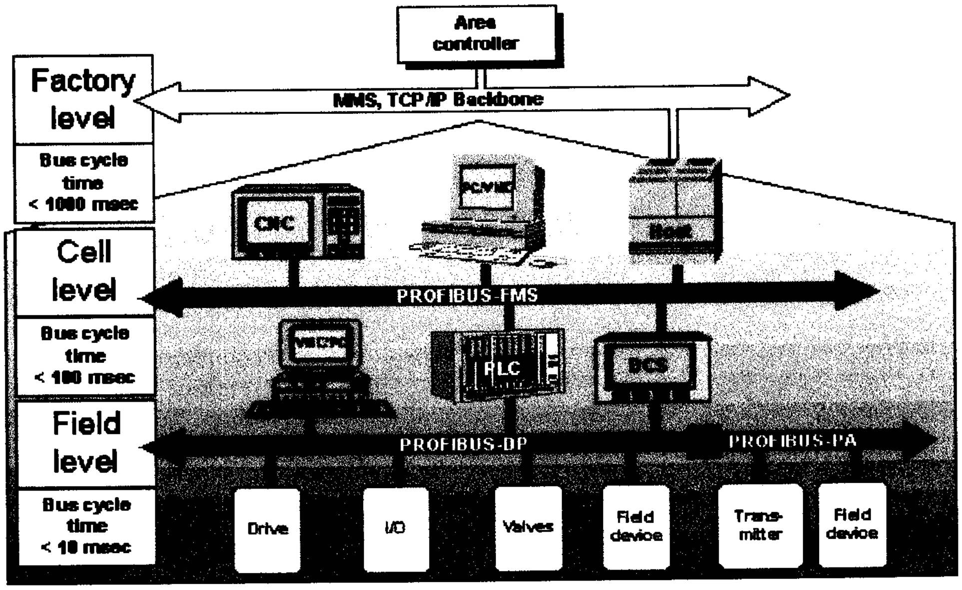

Figure 30: Profibus Protocol Positioning

a. Profibus Field Message Service (FMS)

This is geared for higher end network service providing applications where a high degree of functionality is more important than fast system reaction times. For example uploading or downloading of high volume data, and network configuration management. In PROFIBUS-FMS, layers 1, 2 and 7 are defined. The application layer consists of FMS (Fieldbus Message Specification) and LLI (Lower Layer Interface). FMS contains the application protocol and provides the user with a wide selection of powerful communication services. LLI implements the various communication relationships and provides FMS with device-independent access to layer 2. The bus cycle times are in the order of 100ms. This implements Peer-to-Peer Communications ability as opposed to the Master Slave architecture in Profibus DP described below. Typical transmission speeds between 9.6 Kbit/sec and 12 Mbit/sec can be selected.

b. Profibus (DP)

This is geared for factory automation purposes primarily to provide a 'plug and play' environment at field level (i.e. where one can just plug in a device and it configures right away with minimum configuration to integrate into the bus network). PROFIBUS-DP uses layers 1 and 2, and the user interface. Layers 3 to 7 are not defined. This streamlined architecture ensures fast and efficient data transmission. Most bus type protocols use similar layers not requiring higher level network and connection features of the middle layer. The bus cycle time is in the region of 10ms, suitable adequate control response of typical field controlled devices. Typical transmission speeds between 9.6 kbit/sec and 12 Mbit/sec can be selected.

c. Profibus for Process Automation (PA)

This is the replacement for the traditional 4-20mA control bus. It conforms to the Foundation Fieldbus Physical Standard IEC 1158-2 (as more fully described in the Fieldbus Foundation Section) to allow it to provide loop power off the communications bus.

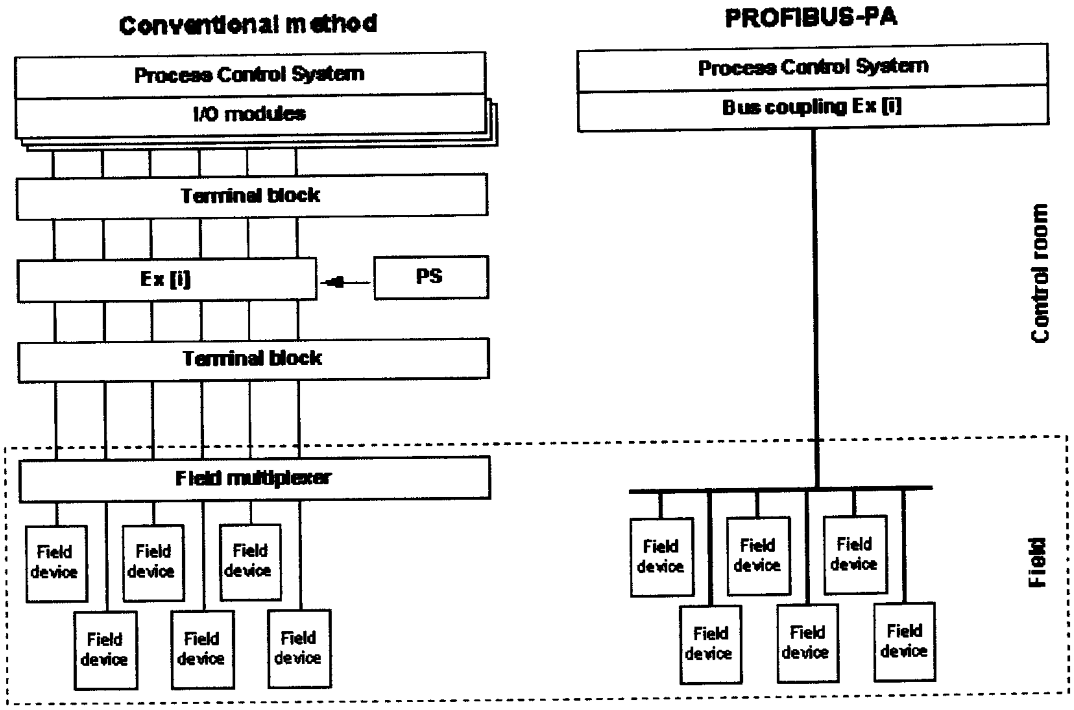

Figure 31: Profibus PA comparison to 4-20mA conventional standard

This self-powered single bus cable approach leads to substantial cable savings, reduced design complexity, and improved future loop reconfiguration flexibility. The Profibus standards do cover device profiles standardising the information available on common nodes such as pressure or level transmitters. This is similar to the Foundation Fieldbus standard. PROFIBUS-PA uses the extended PROFIBUS-DP protocol for data transmission. PROFIBUS-PA devices can be easily integrated in PROFIBUS-DP networks using a segment coupler. Both PA and DP use virtually the same transmission technology and bus access protocol. The bus cycle time is in the region of 10ms, as required for by controlled field devices.

A.3.2 Interoperability Certification

The Profibus user Organization has established a qualified certification system which includes conformance and interoperability testing. Certification is based on a defined standard, EN 45 000. There are also profiles implemented on the standard to achieve plug and play operability. In these parameters of some common devices have been defined in table format so that when a replacement device is fitted the system immediately has access to its set-up parameters. The Interface center is at Fuerth, Germany. Tel +49 911 750 2080, Email: manfred.popp@fthw.siemens.de. Alternatively contact Siemens locally.

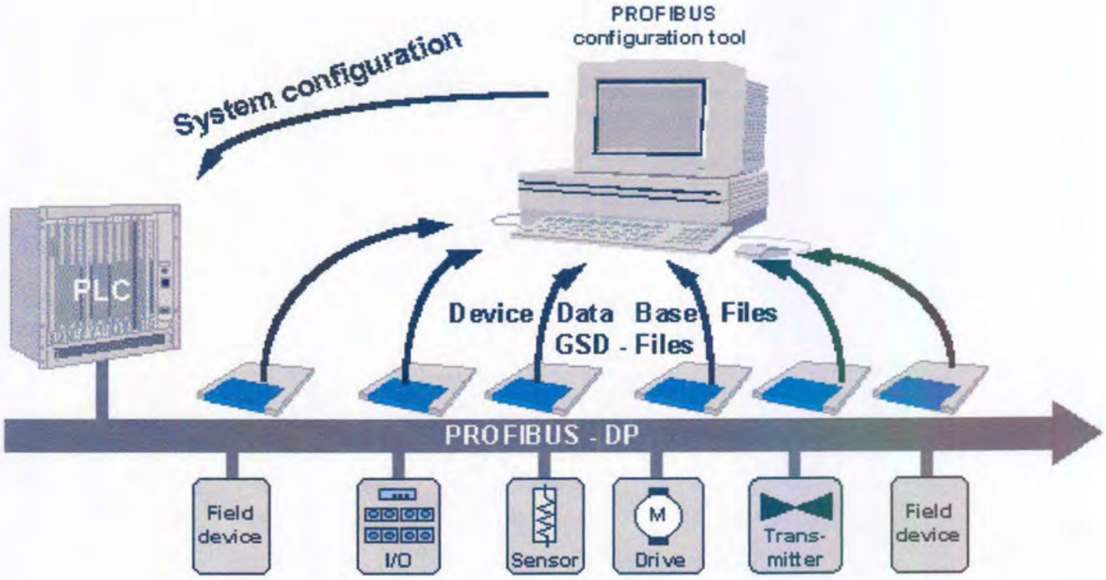

Figure 32: Device Configuration Files

A.3.3 LAN Architecture

The protocol is token ring to allow strict air time control for achievement of communications determinism. Two classes of master exist on the network. Firstly DP Master Class 1 which controls I/O data interchange to its slaves. It is permitted to have multiple DP Master class 1 devices each with their own Slave nodes. Secondly Class 2 Masters which are used for Network Management and Configuration. One can however build a device to act both as class 1 and 2 Masters. Also one can have multi-master systems with the constraint that each slave node can only be written to by one master (class 1) while it can be read by all masters. Multi-master mode does however slow down the bus cycle time. Data transmission takes place between the masters and the DP slaves in three phases every bus cycle:

- Parameterisation
- Configuration and
- Data transfer

A.3.4 Physical Layer (OSI model)

FMS and DP are based on RS485 and PA is based on IEC 1158-2. Fibre optics is an option available with FMS and DP. The topology in both cases is linear bus with active bus termination on both ends,

stub lines only permitted for baud rates of less than 1.5 Mbit/sec. The following diagram is indicative of the layering conformity for Profibus DP, FMS and PA:

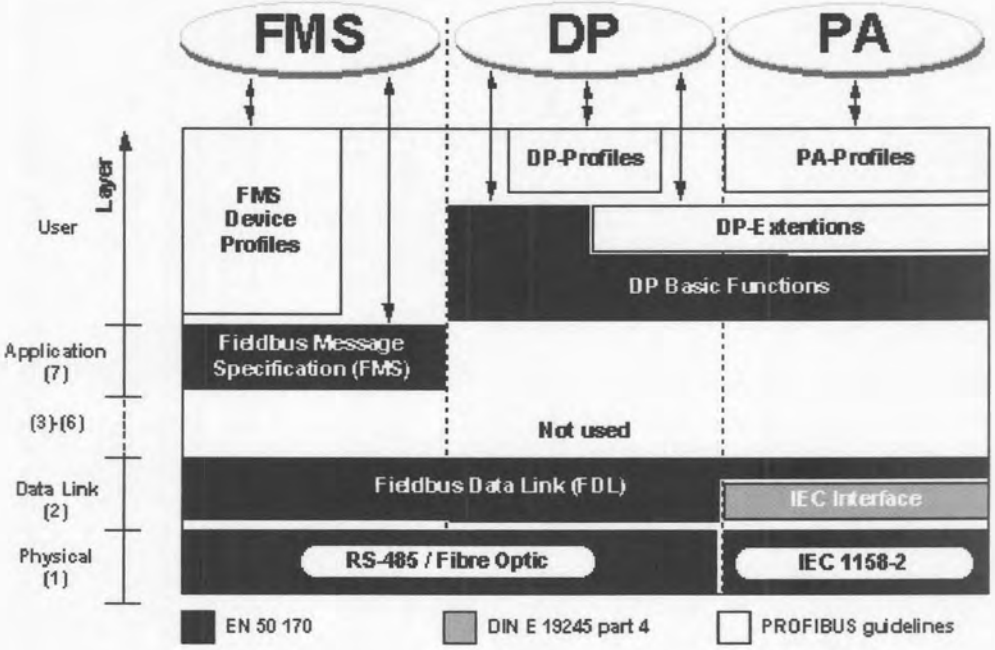

Figure 33: Profibus and the OSI model

A.3.5 Transmission Specifications Summary

	FMS	DP	PA
Data transmission	Speeds between 9.6 kbit/sec and 12 Mbit/sec can be selected		31.25 Kbit/sec; Digital, bit-synchronous, Manchester coding
Data security	Preamble, error-proof start and end delimiter		
Cable	Shielded, twisted pair cable. Shielding may be omitted depending on the environmental conditions (EMC)		Two wire twisted pair cable (shielded/unshielded)
Max Cable run	Typically 1200m at 9.6Kbit/s and 100m at 12Mbit/s		Depends heavily on Powers supply arrangements, typically from 110 to 1900m.
Number of stations	32 stations in each segment without repeaters, up to 127 stations with repeaters.		Up to 32 stations per line segment, maximum total of 126. Can be expanded with up to 4 repeaters
Remote powering	N/A		Optional, via data lines
Topology	Linear bus with active bus termination on both ends, stub lines only permitted for baud rates of less than 1.5 Mbit/sec		Line and tree topologies, or a combination
Explosion Protection type			Intrinsically safe and non-intrinsically safe operation possible

A.3.6 Bus Access Protocol

The protocol is deterministic by means of controlled token passing. The following diagram illustrates the token control from master to master, each one interrogating its slave devices.

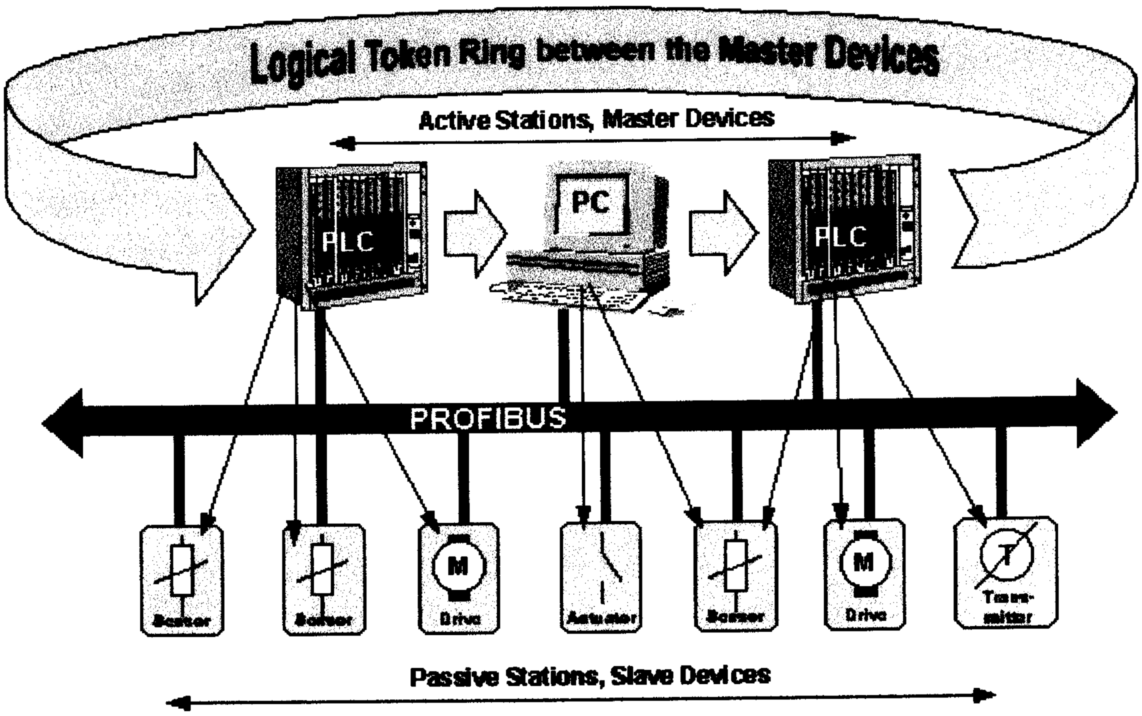

Figure 34: Token Ring Passing in a Multi-Master Environment

A. 4. FIELDBUS FOUNDATION TECHNICAL DETAIL

Foundation Fieldbus is an emerging standard intended primarily for the process control industry. There are two options emerging namely, H1 which is a 31.5Kbps bus implemented on a bus powered, current loop basis, and H2 which is the higher speed option most likely to be implemented on high speed Ethernet. The feature most likely to differentiate Fieldbus Foundation from the market competition is its ability to accept control software functions directly on the field instruments, leading to a greater degree of distributed control.

The diagrams used here are mainly taken from the public website of Fischer Rosemount (reference [18]).

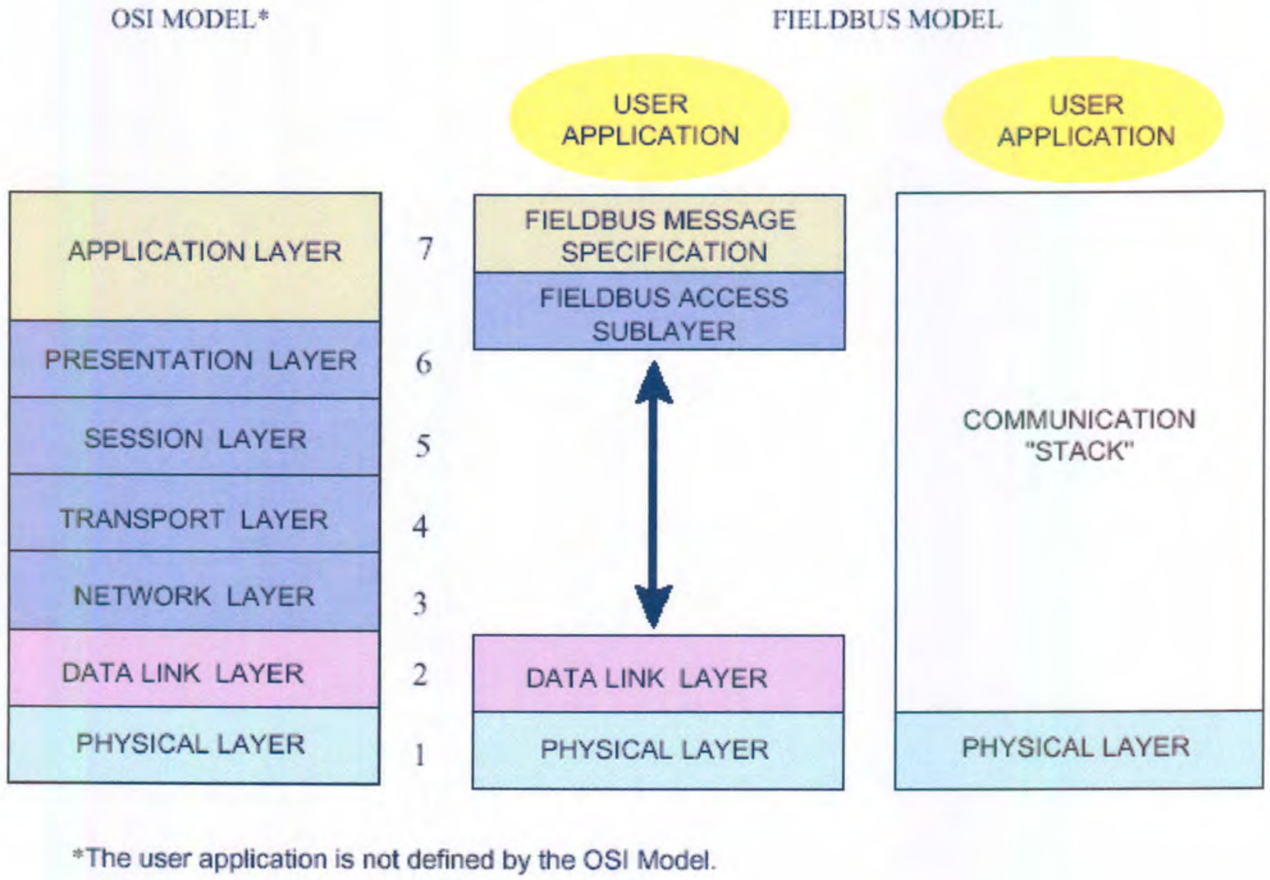

Figure 35: OSI Correlation of Fieldbus Foundation

A.4.1 Correlation with the Seven Layer OSI model

The standard is implemented on three of the OSI layers as shown in Figure 35. This is normal for a fieldbus as it does not require the higher layer routing type services due to the simplified switching requirements of the traffic. The IEC 1158 standard defines the physical layer for the H1 technology, the same standard that Profibus PA has been implemented on. Standards for compatibility of the data link layer are still being finalised, and the latest developments of the standardisation progress is that the Fieldbus Foundation has decided to allow implementation of this on eight different protocol options as discussed later in this section.

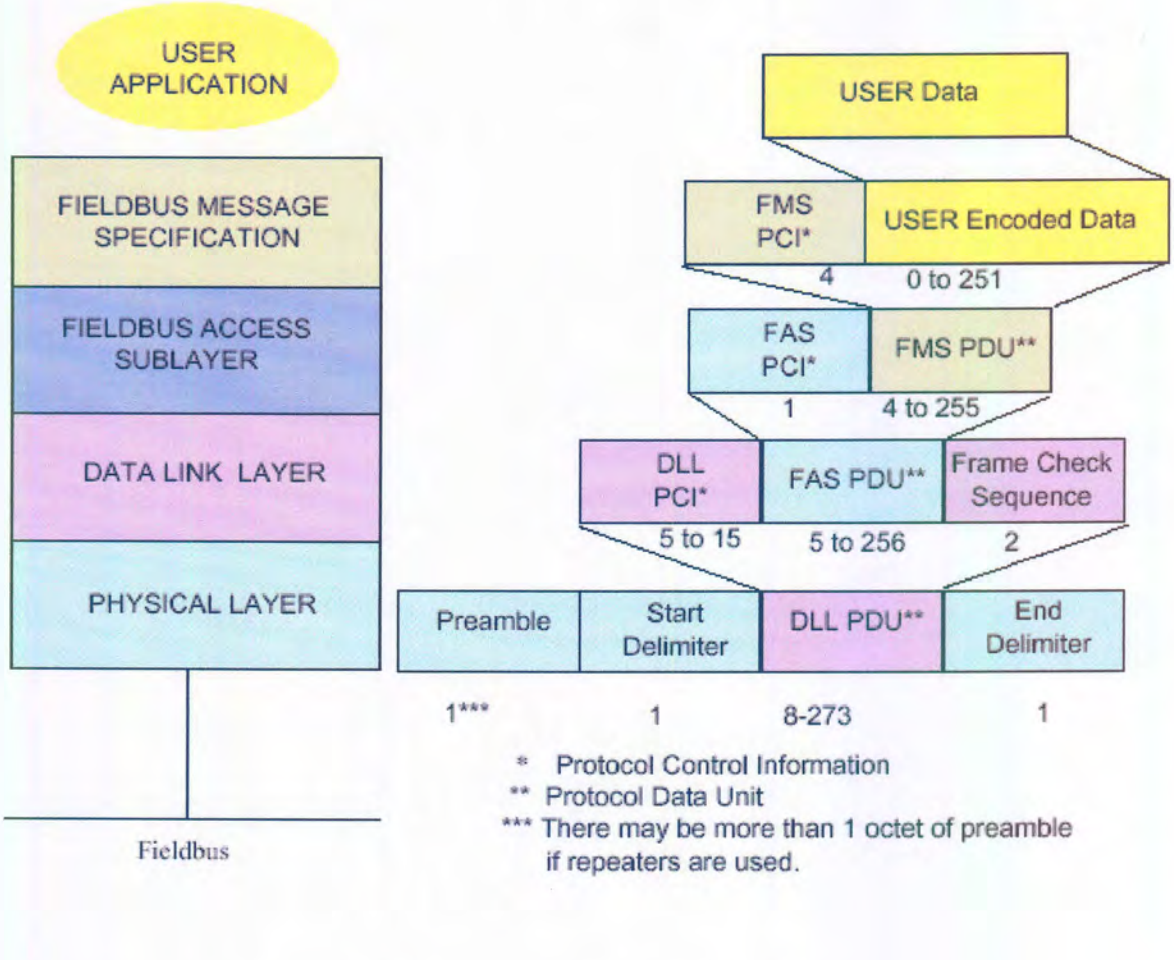

Figure 36: Fieldbus Standard Octet Use

A.4.2 Frame Usage and Encoding

The layers have their control information appended to the frame as shown in Figure 36. The data payload is 251 bytes as opposed to the 274 byte total frame.

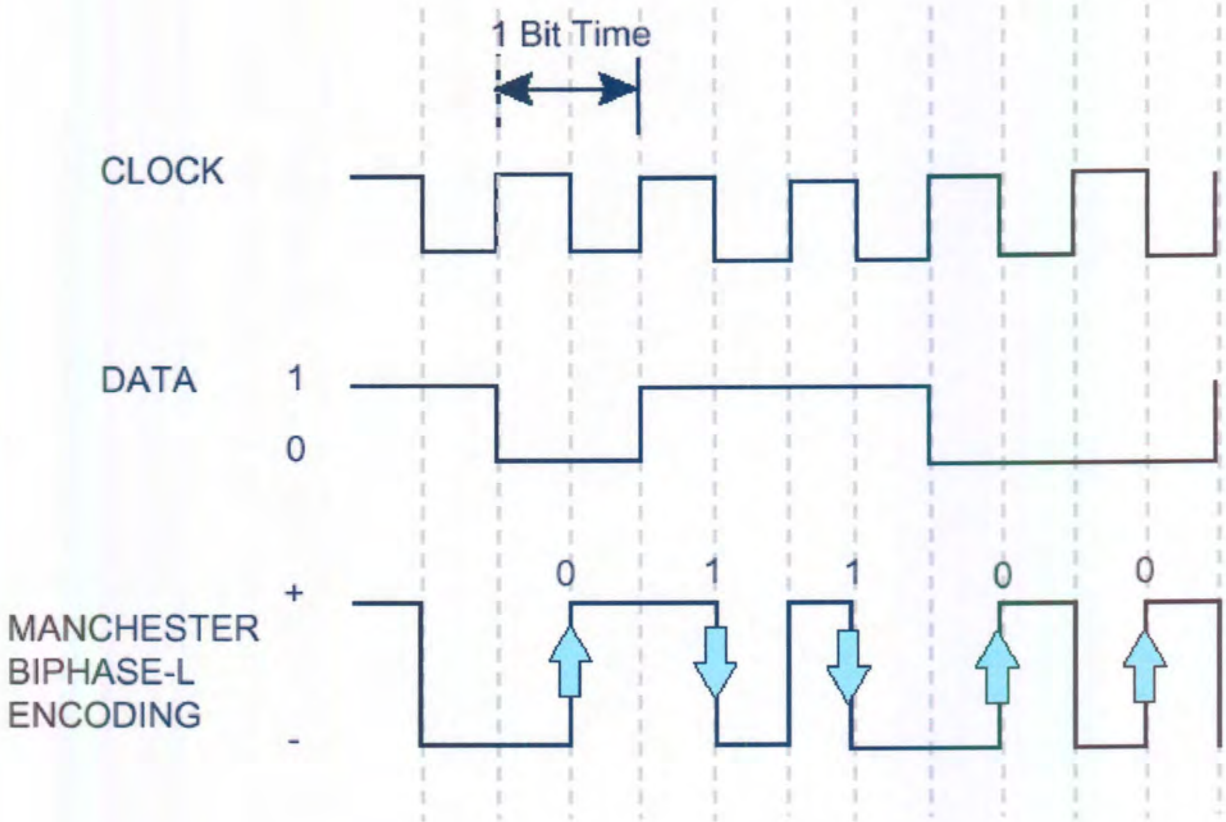

Figure 37: Manchester Encoding

The standard has two versions: H1 the 31.5 Kbps version, and the high speed Ethernet option H2 presently being developed.

H1 transmission is implemented using Manchester encoding as illustrated in Figure 37. With this scheme the signal is encoded as a high-low transition for a one and a Low for a Zero. The receiver looks for the transitions to interpret the data.

H1 transmission is done via current change control as shown in Figure 38.

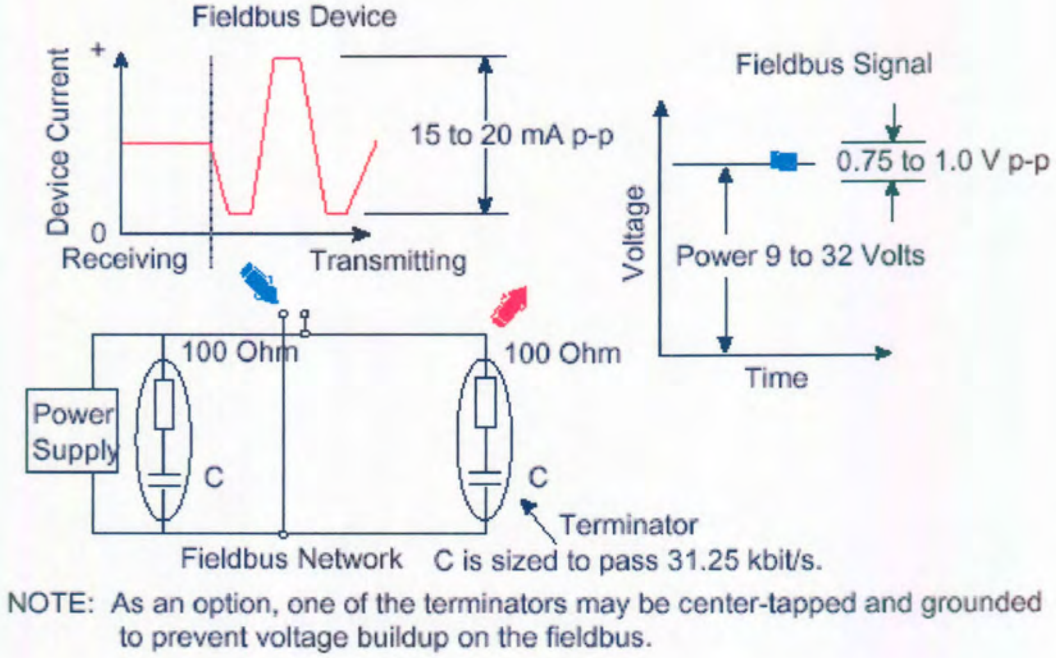

Figure 38: H1 Fieldbus Signalling

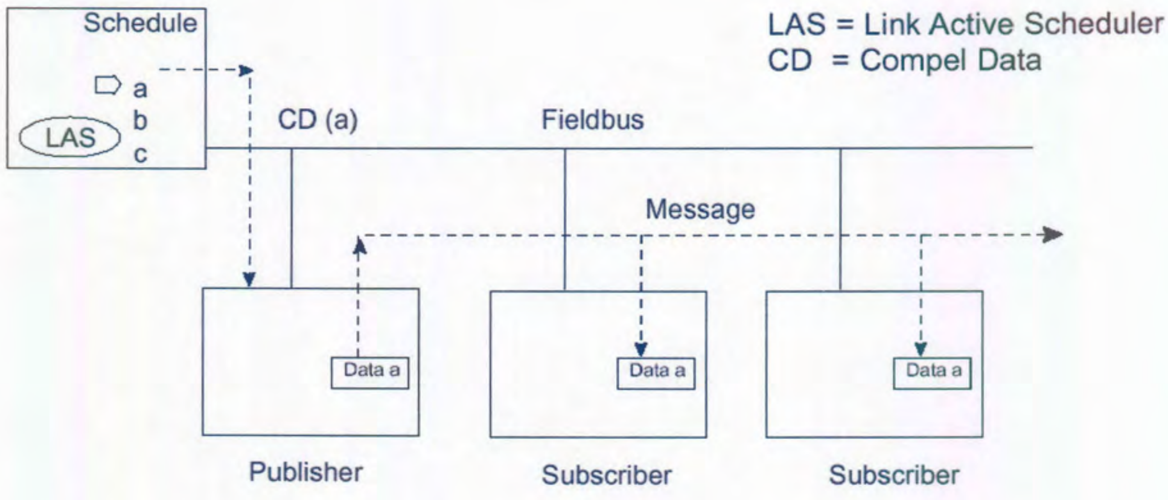

Figure 39: Scheduled Communications Bus Control Illustration

A.4.3 Current Status of the Standardisation Process

The current status on the H1 and H2 standards are as follows:

H1: The Final Draft International Standard (FDIS) for IEC 61158 was passed and it only remains for the IEC Action committee to review voting results and implement as a standard. This draft of the Data Link layer and the Applications layer however contains 8 parallel sections for 8 different protocols which accommodate most of the major protocols (e.g. Profibus, CAN etc..). This choice of eight different protocols is negative with respect to interoperability and has caused some discontentment. The idea the Fieldbus Foundation has is that the market will determine which protocol implementation of the standard is the most effective. As of August 1999 there were 33 registered H1 devices (see reference[26].)

H2: This High Speed Ethernet standard (HSE) is expected to be completed in 2000. The HSE 15 stage testing program is progressing with stage 2 completed, and 3 Prototypes delivered for stage 3 from National Instruments, Smar, and Softing.

The organisation of the Fieldbus Foundation is explained with reference to Figure 40. There are 5 classes of membership having both individual and corporate members, and a total of 130 members. There is an elected Board of Directors that appoints a president who controls an Executive Committee and sub-committees as shown in the chart. The current chairman of the Foundation is John Berra, President of Fisher Rosemount Systems.

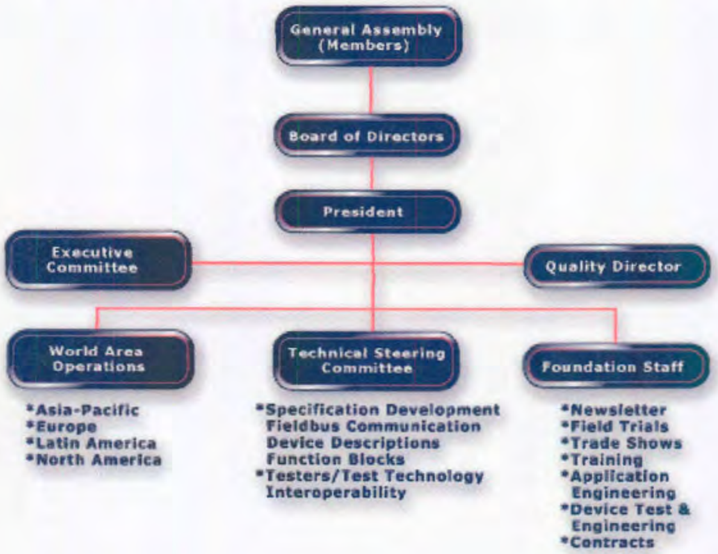

Figure 40: Fieldbus Organisational Chart

A. 5. RADIO FREQUENCY CODE OF PRACTICE GUIDELINE FOR ANGLOGOLD

A.5.1 Definitions

RF: Radio Frequency

COP: Code of Practice

A.5.2 Scope

Radio transmission underground is not subject to legislation regulating RF emission on surface. However it is necessary to manage the use of the RF spectrum underground due to safety and technology management reasons. This COP guideline is intended to cover the important issues in this regard. It is intended that Business Units adopt this as policy to manage their RF usage underground.

A.5.3 Related Standards

IEEE 802.11: For RF LAN Equipment

ETSI 300.325: Spread Spectrum Standards

SABS 1069 (1985): General RF Equipment

SABS 549 (1987): Intrinsically Safe Issues

SABRE: South African Telecommunications Bandwidth Reservation. [27]

A.5.4 Reserved Frequencies

Frequency reservation underground should in all cases be aligned with surface regulations. The latest version of the SABRE project gives detailed guidelines. Incorporating this into the Underground management plan, the following table summarises the reservation required in underground mines.:

Frequency	Application	Comments
100 – 128 kHz	Ecam plus PED system	
300 – 800 kHz	Rescue radios	
150 – 175 MHz	Leaky feeder	Typically for voice transmission and low bandwidth radio modems
404 – 406 MHz	Man Tracking & Asset Tracking	
433 – 440 MHz	Loco Driver to Guard signal	
915 – 950 MHz	Loco remote control/Winch control	*existing cordless phones*
1,2 GHz	Video	Suited to cells of line of sight Communications
2,5 GHz	Spread Spectrum Radio LANS	Suited to cells of line of sight Communications

This table is to be reviewed when the SABRE II project is complete.

A.5.5 Critical Measures

- Safety critical systems must have digital encoding to authenticate point to point transmission. Suppliers remain responsible for the proper safety interlocking involved with the system. A risk assessment should be done by the supplier in liaison with Anglogold regarding the application of safety critical RF systems.
- ·Radio transmission must be limited to within the maximum transmission power as defined by the pending SABS specification regarding electronic detonation devices and RF. In the interim suppliers must ensure that their systems are safe by means of testing and risk assessment and usage guidelines communicated to the mine.

A.5.6 Prerequisite Standards

- ·Leaky feeder systems should be properly engineered and planned before implementation. This involves documenting the future system on the BU communications plan and presenting this to the Anglogold Communications User Group Forum. Arrangements for the presentation of this plan should be made with the Anglogold CIC Manager.

- RF LAN systems should comply fully with SABS 1069, IEEE802.11, and ETSI300.325

A.5.7 Preferred Standards

- Digital radio are preferred systems. A future architecture of a roaming TCP/IP system is envisaged but this currently requires further R&D before implementation.

A.5.8 Implementation and Controls

- Before any system involving RF generation is purchased this must be authorised by the appointed CIC person on the business unit.
- All systems must be recorded on the communications plan showing RF spectrum emission, area of coverage, and number of potential RF nodes (mobile and fixed).
- A record of RF devices must be held by the business unit. This should include the identification number of the device, the RF reception and transmission bandwidth and frequency specification, supplier, model, and responsible person.

A. 6. CONFERENCE ON "EMERGING AND CONVERGING TECHNOLOGIES AND STANDARDS FOR INDUSTRIAL COMMUNICATIONS"

A.6.1 Agenda

8h30 – 9h00: Registration

9h00 – 9h10 : Welcoming and Introduction:

Prof. Ian Craig, University of Pretoria, Electrical and Electronic Engineering Dept – Group Head of the Measurment and Control Department

Web: http://www.ee.up.ac.za/ee/profiles/craig.html

Fieldbus

9h10 to 10h00 Unscrambling the Omelette by Eric Carter

From a user's point of view, there is a confusing selection of communications systems which fall under the 'fieldbus' label. Most implementers of control systems wonder why there is this plethora of available bus types, and why there is not a 'one size fits all' type of bus.

This paper looks at the available bus systems to explain what distinguishes one from another, and why one bus may not in fact be suitable for any application. The paper will cover the ways in which emphasis is placed on the different 'layers' of the modified OSI 7-layer model (reduced to three layers in most industrial buses).

Eric Carter has been involved in control systems for many years, and previously edited Pulse, Sparks Electrical News and Quantum. He is currently an instructor with the well-known training company, Instrument Data Communications. Courses currently presented include Fieldbus, Data Communications, Process Instrumentation, Power Quality, Variable Speed Drives, Power Quality and Intrinsic Safety.

10h00 – 10h30 Profibus: A more detailed Look at Profibus by an International presenter of Profibus International (Siemens Communications Engineer)

This paper covers the more important Technical points of Profibus as a Standard. It simplifies the Organisational Relationships driving the Standard, as well as exploring the Value adding opportunities the Technology presents.

10h30 – 11h00 Fieldbus Foundation: A Solid Alternative by *Alex Jukes of Alpret Control Specialists*

This paper covers the more important Technical points of Profibus as a Standard. It simplifies the Organisational Relationships driving the Standard, as well as exploring the Value adding opportunities the Technology presents.

11h00 to 11h30 Lontalk – an Emerging Communications standard for Rugged Domains by Professor Alwyn Hoffman, Potchefstroom

The Lontalk communications technology and standard has emerged from the building industry and the USA as a significantly beneficial alternative for communications on inferior quality mediums including Power Line borne communications. It also gives good advantage in the free topology it offers network engineers. The paper reviews the main aspects of the technology and illustrates its use in industry.

11h30 to 12h00 Tea and Coffee

The Core Backbone Alternatives

12h00 to 12h30 Fibre Optics as core Backbones by Ben Hayen of Siemens OTN, Belgium.

The paper gives a perspective on emerging standards for fibre optical backbones. It explores SDH as one alternative and relates opportunities where multi-interfaced fibre backbones have secured Value Add in Industry.

12h30 to 13h00 Engineering Aspects behind Fibre Optics by George Hughes, Fibre Optics System Engineer from Fibre Optical Systems.

A review of choices engineers are presented with in installing the fibre backbone. This covers issues such as Multi-mode/ Single Mode, Loose-tube/Tight Buffer, Attenuation, Splicing and many more.

13h00 to 14h00 Lunch

14h00 to 14h30 ATM verse FDDI – The Battle for the Optical highway by Chris Caddick of Anglogold

A paper examining the differences between these two Fibre Optics Standards. The paper highlights the main technical points behind the standards and some important history in the formation of these. It then highlights the strengths and weaknesses of each.

Chris Caddick is a well experienced telecommunications professional having worked in the field for 17 years. Chris currently heads the Vaal River region Telecommunications Systems Support of Anglogold.

Radio Frequency Domain

14h30 to 15h00 Tetra an Emerging Digital Radio Standard by Robin Goodwin (founder member and Secretary of the Southern African TETRA Association)

The paper will review the review the creation, development, current status and evolution of TETRA (TErrestrial Trunked RAdio) as the only open standard, digital technology for Professional Mobile Radio, with particular reference to its use for remote transmission of multi - media information for control and measurement in industrial applications.

Robin is currently Simoco's Regional Director - Sub Saharan Africa, he has spent his entire working life in technical, commercial and strategic roles in the professional mobile communications industry. Previous positions include Managing Director of Simoco's systems business, Strategy Director of Philips Mobile Radio before it was acquired by Simoco, a member of the initial Philips strategy team for digital mobile communications and General Manager of Philips Mobile Radio in South Africa. He has travelled widely in his career including periods of work in Botswana, South Africa, India, Australia, Canada and most countries in Europe.

General

15h00 to 15h30 Technology Management via Domains – An Underground Mining Perspective. By Mark Miller (Control, Instrumentation and Communications – CIC - Manager for Anglogold)

The paper examines the mining process's communications needs in terms of data, voice and video. The total communications infrastructure in a mine has been classified into 4 domains within which Anglogold manages technology for the synergised application of communications systems.

Mark Miller has been active in the CIC field for 10 years managing technology and standards for Anglogold. He is a member of the SACAC executive council. He has travelled to Europe, USA, Canada and South America in various technology searches. Mark has a BSc. Elec. Eng (C&I) from Wits University and is currently completing his M.Eng. in Control Communications with Pretoria University.

15h30 to 16h00: Debate: What does the Future Hold

An open debate on future trends in the field chaired by Francois Laubscher (Executive member of SACAC).
Leading Questions:

- Will Standards converge – Market pressures, Supplier Strategies?
- One Communications Standard for all services or Mutli-domains?

- What is the best practice for users in technology management to maximise Return on Investment?

A.6.2 Summary of Debate

An open debate was held with the questions above as catalysts for discussion. The following summarises some of the more important points made:

- Technology convergence is a joint result of Supplier "Push" and Consumer "Pull". Most communications standards were in the past de-Facto standards resulting from market domination by one or a few suppliers. The establishment of a sufficient population of systems leads to future suppliers conforming to the de-facto standard and bringing their product ranges out on the dominant standard. Today there is a greater role played by the user as more and more users realise the benefits from inter-operability and insist on this when deciding where their money is spent.
- Significant manufacturers are sitting back and waiting the result of a number of competing standards before committing themselves to development of support for a major contender. Where this is most evident is in the support for the new Fieldbus Foundation Standard.
- A single standard for all purposes is not expected to emerge in the medium term future.
- Tetra as a protocol is not supported at frequencies where most underground mining leaky feeder Systems operate.
- General consensus was that TCP/IP was leading the way as a unifying protocol.

A. 7. COST AND BENEFIT ANALYSIS

Table 3: Lost Blast Cause Analysis

Attributing Costs to Total Working Cost	Benefit available if a communications system is implemented in conjuction with other initiatives	Lost Blast causes avoidable with a Comms system and resulting improved management: Qualitiative Assessment (%)
Labour	Flexible Use of Spare Capacity gangs for Cleaning or Support in closely situated panels.	20%
Services	The ability to address Uitlity deficiency quickly. e.g to contact a responsible person to increase air or water pressure.	5%
Material	The ability to order Material immediately and avoid losing a shift waiting for an order.	10%
Equipment	The ability to order equipment immediately and avoid losing a shift waiting for an order.	5%
TOTAL		40%

Table 4: Stope Panel Advance Analysis

Current Stope Advance per month (m)	10	
Blue Sky Potential per month (m)	20	A qualitative assesment of a typical stope advance with no external contraints, i.e. only the capacity of the team holding production back and not avoidable incidents
Assume half of Blue Sky improvement is achievable	15	Assume that with error we can only achieve half full potential. This is a conservative estimate to allow for non-follow through of management effort even when the Comms system is in place.

Advance if avoidable Incidents are eliminated with a Comms system	12	

Table 5: Cash Cost Calculation

Current Stoping Labour Cost per sqm mined		137.5	
Current Total Cash Cost per sqm mined		1898	Based on the 1998 Annual Report forcast for SA Operations R/m2
Current Anglogold Sqm mined per year		4200000	Based on the 1998 Annual Report forcast for SA Operations Sqm Mined
Cash Cost before Comms Systems	R	7,971,600,000	

Table 6: Increased Profit Analysis

<u>Strategy to increase Gold Production</u>

Current Gold per year (tonnes)		185.8	
Current Gold Price per Tonne Gold	R	58,022,388	
Current Revenue	R	10,780,559,701	

If we can mine and extra Xm ontop of Ym in every stope = X/Y% increase in production

Conservatively assume that only the stope labour cost comes down but the rest of the cost remains fixed per sqm

Stope Labour/ Total Labour (%)	7%	

Hence after Comms Systems:

Stope Labour	R	577,500,000	Remains fixed for improved Gold
Other Cost	R	8,872,920,000	Increase proportionally to Tonnage/Gold Output
New Cash Costs	R	9,450,420,000	

New Revenue	R	12,936,671,642
New Profit	R	3,486,251,642
Old Profit	R	2,808,959,701
Increased Profit per Year	R	677,291,940

Table 7: Approximated System Cost

Typical Costs of a System (PER LEVEL)

	Per Unit	Total Units	Totals		
Base Equipment			R	500,000	
Leaky feeder/m (Installed)	50	15000	R	750,000	
Per stope	60000	10	R	600,000	
Engineering and installation			R	1,450,000	Approx R30000 per stope; R10/m Leaky feeder; R20,000 per RF LAN RTU
Hi Bandwidth Haulage	10000	50	R	500,000	One RF LAN RTU per 100m
TOTAL (per level)			R	3,800,000	

Estimated Yearly Cost of Communications System Maintenance (Running Cost)

Technicians	R	200,000	
Spares	R	190,000	5% of installed capital
TOTAL	R	390,000	

Table 8: Cost for Anglogold

TRANSLATING TO ANGLOGOLD SOUTH AFRICAN OPERATIONS

Levels Per Mine	8
Mines in SA Operations	13

COST OF THE COMMS SYSTEMS

Capital Per Level	R 3,800,000
TOTAL CAPITAL	R 395,200,000
Running Cost/Level	R 390,000
TOTAL RUNNING (Per Year)	R 40,560,000

Table 9: IRR on Comms Systems

IRR:		-39%	113%	146%	156%	159%	160%	161%	161%	161%
	1	2	3	4	5	6	7	8	9	10
	R -395,200,000	R 241,531,940	R 1,273,463,881	R 1,273,463,881	R 1,273,463,881	R 1,273,463,881	R 1,273,463,881	R 1,273,463,881	R 1,273,463,881	R 1,273,663,881
	R -395,200,000	R 636,731,940	R 636,731,940	R 636,731,940	R 636,731,940	R 636,731,940	R 636,731,940	R 636,731,940	R 636,731,940	R 636,931,940
Purchase Cost	R -395,200,000									
Maintenance		R -40,560,000	R -40,560,000	R -40,560,000	R -40,560,000	R -40,560,000	R -40,560,000	R -40,560,000	R -40,560,000	R -40,560,000
Replacement										
Benefit 1		R 677,291,940	R 677,291,940	R 677,291,940	R 677,291,940	R 677,291,940	R 677,291,940	R 677,291,940	R 677,291,940	R 677,291,940
Final Value										R 200,000

IRR:		61%	131%	151%	156%	158%	159%	160%	160%	160%
	R -395,200,000	R 636,731,940	R 6,731,940	R 636,731,940	R 486,931,940	R 636,731,940	R 636,731,940	R 636,731,940	R 636,731,940	R 637,031,940
Purchase Cost	R -395,200,000									
Maintenance		R -40,560,000	R -40,560,000	R -40,560,000	R -40,560,000	R -40,560,000	R -40,560,000	R -40,560,000	R -40,560,000	R -40,560,000
Replacement					R -150,000,000					
Benefit 1		R 677,291,940	R 677,291,940	R 677,291,940	R 677,291,940	R 677,291,940	R 677,291,940	R 677,291,940	R 677,291,940	R 677,291,940
Final Value					R 200,000					R 300,000

A. 8. SUMMARY STANDPOINT ON AUTOMATION APPROACH FOR ANGLOGOLD OPERATIONS

A.8.1 Background

Productivity improvement demands, stemming from the need to ensure the extended life of mines and to improve profitability for our operations, have seen the drive for automation and improved decision support systems for operational management. The major Tramming control systems implemented at Kopanang and Great Noligwa were installed in relatively great haste in an effort to take advantage of immediate productivity improvement opportunity, and also as a result of the reduced risk initially offered by the contract negotiated with the Supplier.

Similar projects but with systems of lower functionality have been implemented at Tau Lekau and Tshepong mines (TDS projects).

Recent increased interest in these types of automation systems has caused us to rapidly review communications technologies and automation needs in an effort to more rationally choose future communications infrastructure and specify levels of automation.

In this light an overseas visit was undertaken to review current technology trends in these areas. This involved visits to the UK, Sweden, Canada, and the USA. Mines, Technology Development Centres, and Suppliers were visited. A full report on the visit is available.

Prior to this audits have been carried out on the Kopanang Modular/Centrocen System where some degree of benefits analysis was done and where the functionality of the system was relatively thoroughly examined.

A.8.2 Conclusions Drawn

The activities to date have exposed us to numerous technologies, systems, system developers, system integrators and users. We have obtained a broad overview of what the major users and suppliers of communications and automation systems are implementing and the trend for future developments. We believe we are now in a better position to assist the Anglogold Operations to formulate a vision and best practices for automation and communications infrastructures and standards for the future of Anglogold mining operations.

A.8.3 Automation Drivers

Discussing approaches with mining houses in Sweden and Canada, it is apparent that their mining methodology is a big driver behind their level of automation. They essentially follow methods similar to block cave, and the danger of roof collapse at the mining front is so significant that Tele-remote loading vehicles are necessary. Also the high cost of labour has also made automation alternatives feasible.

Our operations have narrow tabular ore bodies requiring smaller equipment. However our operations have far more people underground and great opportunity exists in maximizing their productivity, increasing face time, managing material ordering, reducing human error/inefficiency. Our solutions call for more logistics control than autonomous equipment operation. In the Tramming scenario with the amount of people we have underground it is extremely difficult to implement driver-less trains but we should consider going for less but bigger autonomous trains supervised by a single person on board, supported by video at the remote end of the train.

A.8.4 Methodology of Introducing Automation

Discussions with users and developers confirmed that peoples "resistance to change" is a major inhibitor to technology implementation.

Major reasons for people's resistance to technology are sighted as:

- The lack of a champion
- The fear of the unknown.
- To a lesser extent the "nothing in it for me" attitude.
- The "not invented here" syndrome.

To ensure smooth technology acceptance and transfer the following points need to be taken care of:

- Clearly identify the technology champion, his/her role, responsibilities and commitment to the technology. Above all ensure that he/she is in the position for the duration and for some time after implementation.
- Keep all the users involved with development through to implementation. This will enable one to evaluate the training requirements, get user buy into the technology, through their involvement and contribution to the technology the not invented here and fear of the technology is eliminated. It will also identify to the user "what's in it for them."

- The single biggest contributor to the fear of technology is trying to do too much at once. By phase technology in small incremental steps one ensures:
- All users are familiar with and train on each phase of the implementation program.
- Each phase is fully functional and debugged before the next phase begins
- The cost benefit of each phase is properly measured and evaluated before the next phase begins. This will facilitate the optimisation of systems.

The following phases are definable:

Level	Communications Infrastructure	Control
1.	Voice over leaky feeder	None, drivers control themselves, requests from those in need of transport directly to the drivers or alternatively from a designated person in the operations
2	Voice, with a monitoring system giving end of shift reports on traffic activities for reactive action	Reactive/Disciplinary/Corrective actions at end of shift
3	Voice, with real time monitoring of traffic over hardwire or radio network or combination	Dispatcher takes decisions on which vehicles must go where. Instructions relayed by voice. Voice recorder if necessary
4	Same as 3	Computer expert system does dispatching. Dispatcher monitors for exceptions.
5	Same as in 3 . Higher bandwidth hardwire Communications backbone to stationary video cameras at loading points. High bandwidth Radio network in cells of automation requirements	Same as in 4 plus driverless trains. Zones of restricted access required while autonomous operations in progress. Obstacle detection technology might develop as an alternative but it is not there yet. Tele-remote operations for loading. Expand to autonomous operation of mining equipment, most likely drilling, with human intervention for charging and blasting

One needs to ask what the optimum level of automation is for our mining scenarios. A single rail or even dual rail system does not require high intelligence software to control. One can argue that the complexity of control is not too great for a central dispatcher with visuals of where traffic is and a good indication of box status. For this reason it is recommended to implement **Level 3** in shafts with Tramming infrastructure pressure, but to do this with a vision of extending to level 4 when we have consolidated on Level 3. Conquering the phase 3 level also allows us to work through the management and control issues of the system before handing this over to an expert system, where we trust the black box approach so much that we do not notice the shortcomings of the automatic system.

A.8.5 Communications Backbones

Leaky feeder has advantages in the way it reduces the complexity of engineering the radio wave propagation requirements underground. A disadvantage however is that delay sensitive real time data in analogue form, such as video, is deteriorated due to multi reception paths. Alternatives exist to convert the video signal to digital and overcome this. The approach some mines have taken is to go for fixed antennae also gaining bandwidth. Considering the advantages of leaky feeder we believe this continues to be the solution for our operations for voice purposes. To be supplemented by cells of high bandwidth point antennas (e.g. the Elequip "Stope Antenna"), and high bandwidth cells as appropriate where demands call for it (typically future type autonomous development loading etc…)

Current projects hence should continue to roll out leaky feeder, however transmission technology on top of this media should preferably be digital transmission. The Tetra standard will now be investigated further as an option together with the Elequip Baseband developments. It now becomes a matter of striving for planned communications backbones for all our shafts, each case with its specific requirements derived from its envisioned automation and monitoring visions.

Fibre as a shaft backbone standard seems already entrenched in our major shafts. The multi-interface standard of Siemens OTN seems most appropriate to interface to our current systems.

Major PLC networks still support their own process field bus standards however it is not too far off where we believe a truly open standard will emerge. Foundation Fieldbus seems likely that it will be that standard. Presently the most practical method of implementing a process field bus is the Profibus PA technology. At least it is on the same physical standard as Foundation Fieldbus.

A typical communications backbone as envisioned is given below and consists of the following: Siemens OTN Fibre as a Shaft Back Bone, Fibre(preferred)/Copper interface to the shaft specific PLCs. An inter-PLC bus (Ethernet preferred), a process control fieldbus of preferably Fieldbus Foundation (when the IEC standard is approved) alternatively Profibus PA . Interfaced to leaky feeder for tunnel type Communications application and cells of stope antenna. For future type high video demand applications then cells of high video bandwidth interfaced to OTN and/or leaky feeder. Echelon for medium or inferior quality such as power lines and fire detection cable.

A generic communications backbone obviously needs application to each shafts specific needs. At times it might make sense to hook on a device, or set of devices, onto an alternative leg of the backbone, e.g. fire detection onto leaky feeder, as opposed to the Echelon network segment. In such a case, if we manage the communications backbone as a utility then this flexibility becomes possible. The key point being that we manage the Communications utility i.e. plan it, document it and train personnel to maintain it.

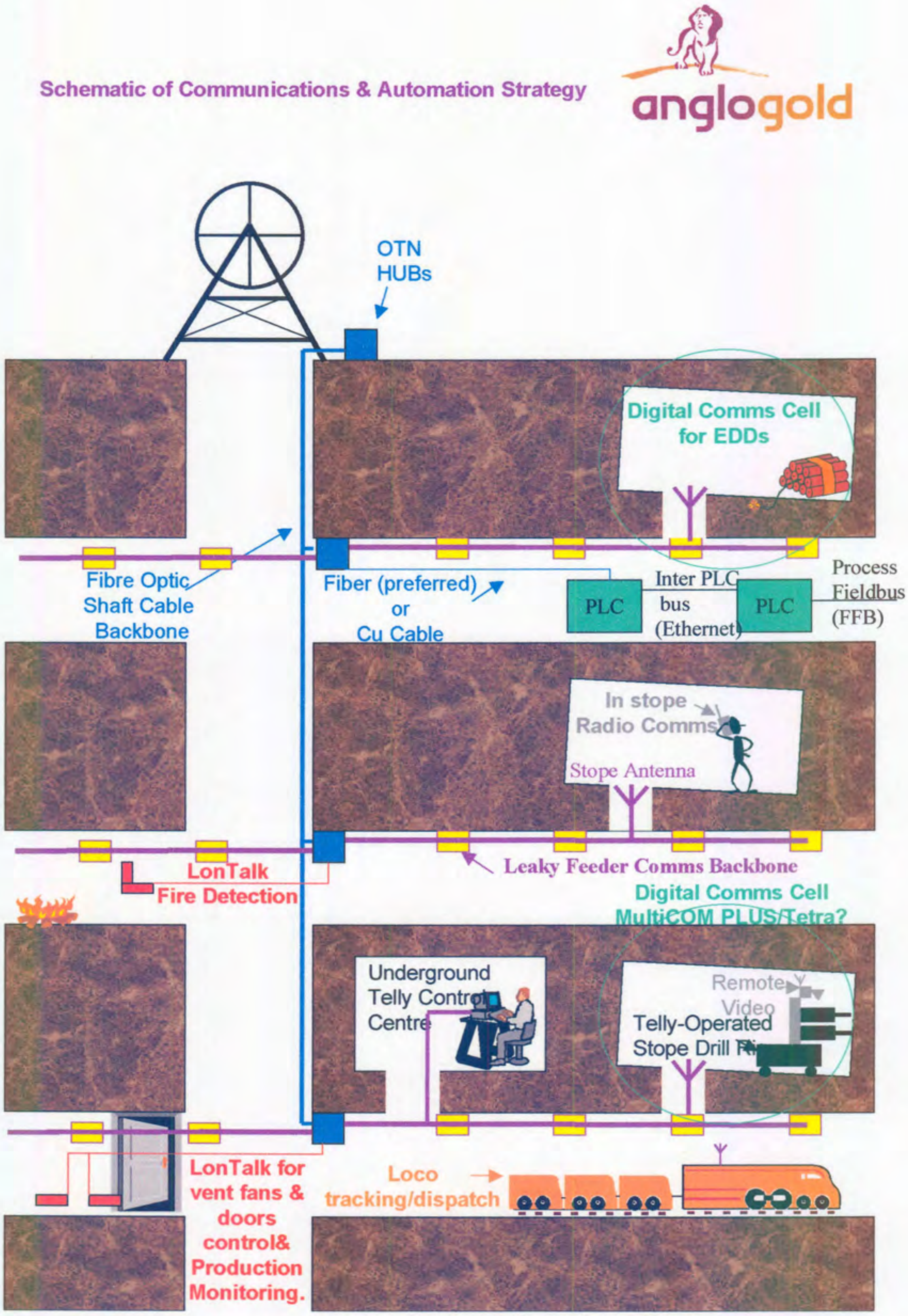

Figure 41: Communications Domains for Automation Standpoint