Industrial Ethernet for Control and Information Interconnectivity in Automated Longwall Mining

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ABSTRACT

This paper describes the adoption of the Ethernet/IP standard in the development of a specification for the interconnection of mining equipment as part of an industry-sponsored *Landmark* longwall automation project. Longwall mining is used extensively worldwide and accounts for the majority of underground coal production in Australia and the USA. Full automation of the longwall mining process is being driven by issues of occupational health and safety and increased productivity. The *Landmark* project targets a step change improvement in productivity and safety in longwall mining by combining new enabling technologies and high-level control with existing equipment control systems. The existing proprietary control systems are practically self contained and prior to the *Landmark* project had little or no provision for external communications. In order to achieve the *Landmark* automation goals across all commonly used equipment it was first necessary to achieve interconnectivity between existing equipment and the *Landmark* specific components. Ethernet/IP shares a common application layer with DeviceNet and ControlNet and levers benefits from widespread and rapid developments in Ethernet technology. Distributed wireless Ethernet technology has been employed to provide a reliable Ethernet/IP link to a moving longwall shearer. The *Landmark* project has secured the support and cooperation of the major longwall equipment manufacturers who are now providing *Landmark* compliant interfaces to their equipment.

1. INTRODUCTION

Recent advances in longwall coal mining automation have been made by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia, Mining Automation group. Longwall mining is used extensively worldwide and accounts for over 80% and 50% of underground coal production in Australia and the USA respectively.

Modern longwall mining operations have been optimized to the point where manual operation of the process limits the future development of this mining method. In addition, the necessarily hands-on approach to the mining process exposes the operators to hazardous working conditions. In 2001 the Australian coal industry provided major *Landmark* funding to the CSIRO to develop a longwall mining automation system to the level of “on-face observation”. This project builds on previous successes in highwall mining automation [1]. More *Landmark* details can be found at the project website [2].

In this automation system the *Landmark* process controller interfaces with a number of proprietary control systems each associated with a major component of a longwall mining system. Each of the existing control systems is practically self contained and prior to the *Landmark* project had little or no provision for external communications. In the early scoping stages of this project it was determined that the issue of reliable interconnectivity between existing equipment and the *Landmark* specific components was central to the project’s ultimate success.

A brief overview of the longwall mining process and the need for automation are presented in Section 2. Section 3 discusses longwall equipment interconnectivity and in particular Ethernet/IP; the selected information and control protocol for all *Landmark* compliant mining equipment.

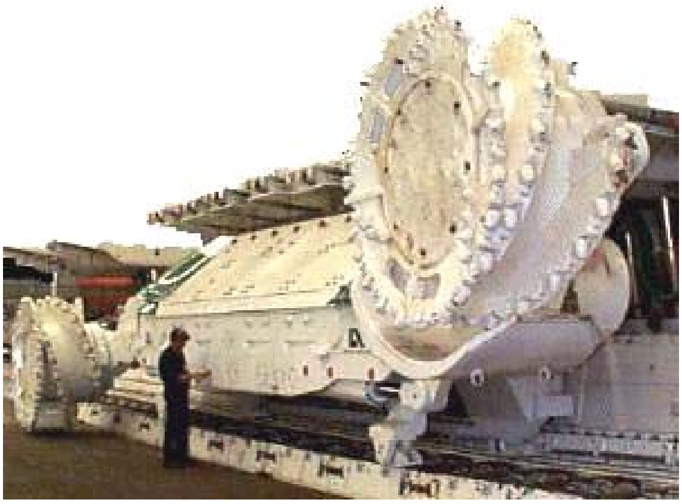

Figure 1: A longwall shearer showing the leading and trailing cutting drums. A portion of the roof support canopy and armoured face conveying is also visible.

2. LONGWALL AUTOMATION

Longwall coal mining is a full extraction mining process in which large panels of a coal seam up to 5m thick are completely mined. An indicative longwall panel is 250m wide by 2000m long. The longwall mining system used in this process is comprised of three main equipment components: a shearer, an armoured face conveyor (AFC) and a roof support system.

A longwall shearer as shown in Figure 1, is up to 15m long, weighs up to 90 tonnes and typically extracts a one metre slice of the coal seam as it travels back and forth across the panel along rails integral to the AFC structure. The scale of this equipment can be seen in Figure 1 which shows a shearer and a portion of the roof support system and AFC. Figure 2 depicts a portion of a working longwall operation with the coal seam (hatched edge) and floor and roof material visible. A group of the roof support modules adjacent to the shearer has been removed for clarity.

The roof support system is comprised of individual hydraulic support modules typically spaced at 1.5m centres across the full width of the longwall face. Collectively, these hydraulic supports provide temporary support of the roof material above the extracted coal seam. The load capacity of each support can exceed 1000 tonnes.

As the shearer moves across the coal seam, large hydraulic rams attached to the roof support modules progressively advance the AFC and associated shearer rails behind the shearer in a snake-like manner. The AFC is then held in place while each support in turn is pulled to the new alignment by means of the same dual-action hydraulic ram previously used to push the AFC. As the longwall equipment progresses in this manner, the roof material collapses into the void left behind the advancing system.

The complete longwall system is a mobile semi-autonomous underground mining machine weighing in excess of 700 tonnes. Currently, each of the three main equipment components operates under proprietary and largely independent control systems.

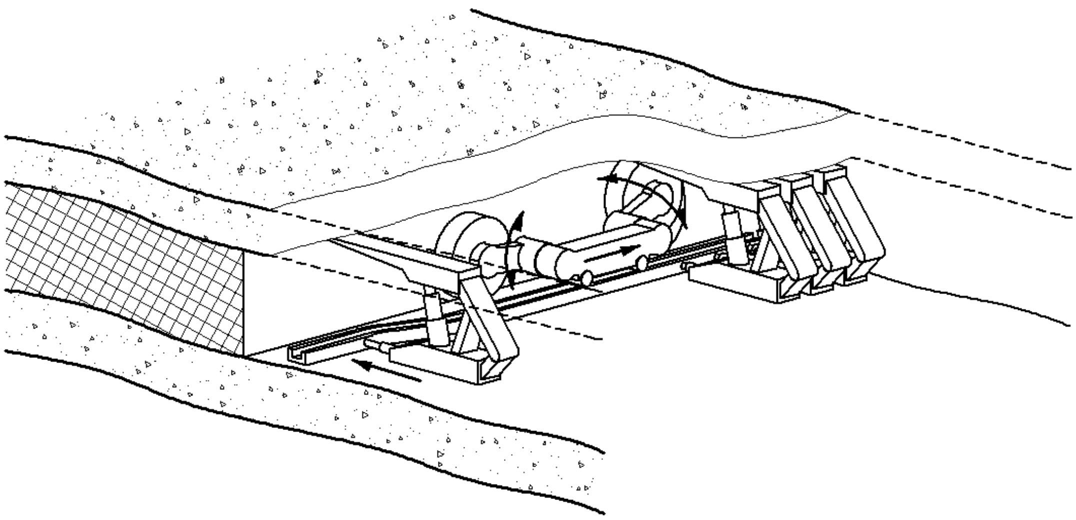

Figure 2: Representation of a small portion of a working longwall operation with the coal seam (hatched edge) and floor and roof material visible. A group of the roof support modules adjacent to the shearer has been removed for clarity.

2.1 The Need for Automation

Full automation of the longwall mining process has always held the lure of increased productivity but more recently is being driven by issues of occupational health and safety. The presence of hazardous gases, respirable dust and the inherent danger of personnel working in close proximity to large mobile mining equipment is becoming increasingly unacceptable.

There have been many attempts worldwide over a number of decades to achieve full automation of the longwall mining process [3]. Equipment manufacturers have invested heavily in ongoing development of their respective proprietary control systems and yet, to date, personnel are still required to routinely work in hazardous production areas and to manually control the mining process.

The *Landmark* goal is to provide the enabling technology, data communications and control system needed to achieve a step change improvement in longwall automation. This is being achieved with the cooperation of the major equipment manufacturers to the benefit of the project sponsors; the Australian coal industry. The *Landmark* project offers a new automation strategy build around patented inertial navigation techniques [4] for accurate measurement of the three-dimensional position of the moving longwall shearer. A detailed presentation of this new enabling technology is given in [5].

2.2 Longwall Automation Equipment

In addition to the new enabling technologies and advanced process control, the *Landmark* longwall automation strategy integrates the existing proprietary control systems associated with the shearer and roof support equipment. As depicted in Figure 3, the primary input to the *Landmark* system is the INS-derived three-dimensional position of the moving shearer. The primary outputs provide control of the position of the shearer cutting drums and AFC movement via the roof support system. The *Landmark* Process Controller generates the high-level information necessary to close this automation control loop.

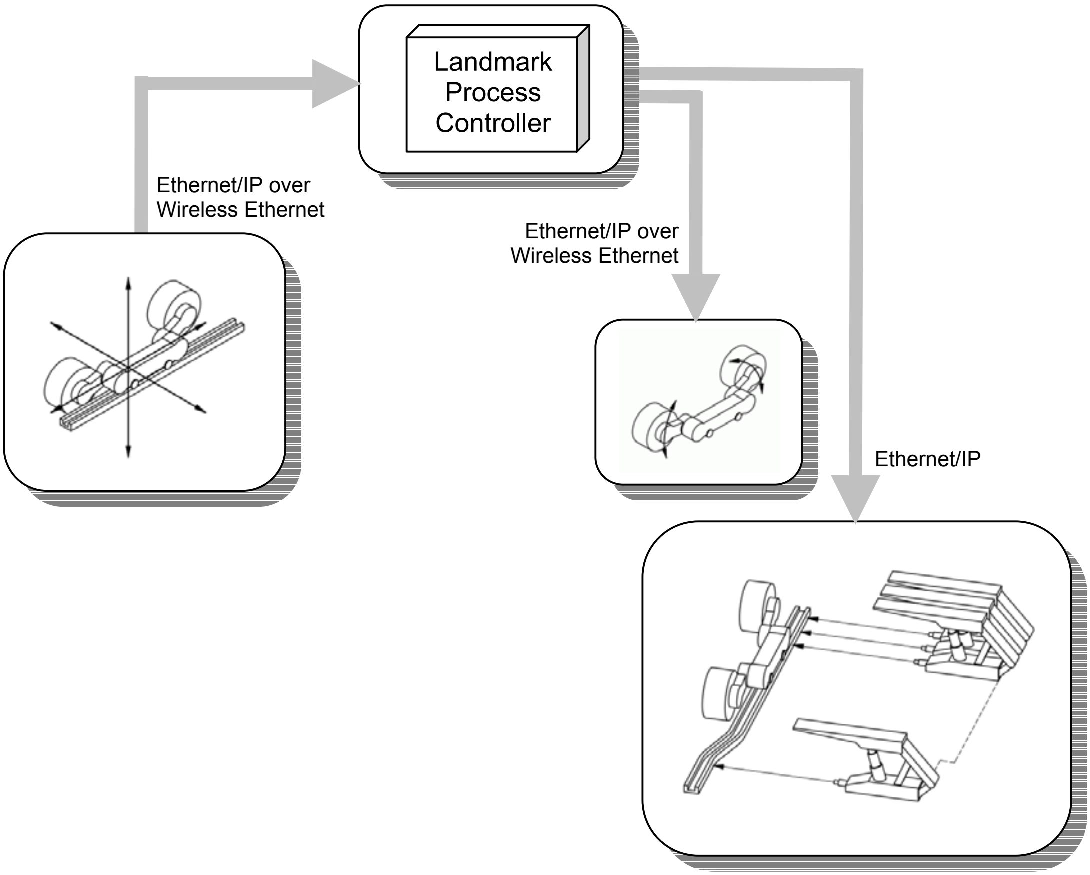

Figure 3: Block diagram showing the primary inputs and outputs of the *Landmark* control system.

3. EQUIPMENT INTERCONNECTIVITY

Longwall equipment is produced by two major and several smaller manufacturers worldwide and it is common for mine sites to mix and match longwall equipment from different manufacturers in order to best suit their particular mining conditions. Prior to the *Landmark* project there was little or no provision for data communication between equipment from different manufacturers. Mine sites and third party vendors devised ad hoc solutions for accessing only limited data from longwall equipment and were restricted by low data rates. Given the fundamental role of the proprietary control systems in the Landmark automation system it was imperative that reliable interconnectivity be established across all commonly used longwall equipment. Furthermore the coal industry sponsoring the Landmark project mandated an open-architecture approach to avoid introducing any new proprietary 'black-boxes'

Statutory regulations greatly restrict the manner in which electrical equipment can be used in underground coal mines so as to prevent the ignition of naturally occurring explosive gases. In hazardous zones, electrical equipment needs to be either intrinsically safe, storing insufficient electrical energy to cause an explosion, or housed in heavy flameproof metal enclosures to contain any internal explosion and naked flame.

Because of these restrictions and the extremely harsh environment, underground coal mines tend to lag general industry in the uptake of new developments in computing and data communications. Despite this, an increasing number of sites in Australia are installing fibre optic Ethernet links between the underground and surface operations. This communications backbone satisfies the ever increasing bandwidth requirements and conveniently integrates the surface and underground data networks.

The availability of existing broad band Ethernet links underground, the requirement for open-architecture and the increasing use and acceptance of industrial Ethernet in process control, greatly influenced the selection of Ethernet for the *Landmark* project.

The choice of Ethernet provided only half the connectivity solution. It is perhaps not widely understood that Ethernet only describes the physical and data link layers of a data communication network as represented by layers 1 and 2 of the well-known Open Systems Interconnection (OSI) seven layer model. OSI layers 3 and 4, the network and transport layers describe how the network data packets are addressed to the destination device, how large blocks of data can be broken up into smaller packets and reliably reassembled by the destination device and how packets are routed across large and complex networks such as the internet. IP (Internet Protocol) and TCP/UDP (Transport Control Protocol / User Datagram Protocol) are layer 3 and 4 specifications respectively and are commonly used in Ethernet based networks.

In combination, network layers 1 – 4 describe a reliable method for transporting packets from one device to another over local or large and complex networks. However these layers don't specify the format of the information actually being transported within the packet or how the destination device should interpret this information once it is extracted from the packet (as the saying goes, "just because you can make a phone ring in Beijing doesn't mean you can speak Mandarin"). The information interpretation is described by layer 7, the application layer. Commonly used layer 7 standards are FTP (for transferring data files), Telnet (for connecting remote terminals) and HTTP (an internet transfer protocol).

Each of these layer 7 standards has been developed to suit a particular application. However none of these is generally suitable for industrial control systems. To meet this growing need, industry is promoting an open-standard known as Control and Information Protocol (CIP)[1]. This protocol allows for both the control of low-level devices on the factory floor and exchange of high-level control system information. Although CIP is intentionally independent of the underlying network (layers 1 – 4), it is ideally suited for use in combination with Ethernet using IP and TCP/UDP. The combination of Ethernet (as the physical layer), IP (as the network layers), TCP/UDP (as the transport layers) and CIP (for the higher layer) to form a complete industrial control and information network is referred to as Ethernet/IP. The IP in Ethernet/IP stands for Industrial Protocol which is an unfortunate choice given that IP commonly stands for Internet Protocol.

3.1 Ethernet/IP

In simple terms Ethernet/IP describes the verbatim encapsulation of CIP application layer frames into TCP/IP and UDP/IP packets for transmission over Ethernet physical networks. CIP is also common to DeviceNet and ControlNet and has been used extensively for industrial control worldwide prior to the development of the Ethernet/IP standard. The commonality between Ethernet/IP, DeviceNet and ControlNet and the network independence of CIP is illustrated in Figure 4 in terms of the OSI seven layer model. The CIP specification is now openly available and is being managed and promoted by the Open DeviceNet Vendor Association (ODVA), a cooperative association of more than eighty automation companies worldwide including Rockwell Automation, Omron and Cutler-Hammer. CIP incorporates many of the features expected in a modern application layer industrial control protocol – network independence, object oriented device models and electronic data sheets. Development and support of CIP is ongoing with the recent announcement of real-time and safety critical extensions to the CIP standard.

Ethernet/IP builds on the benefits of Ethernet – open specification, low cost and readily available hardware, maintainability, versatility and most importantly exponential improvements in technology driven by the office and enterprise markets. The real and/or perceived disadvantages of Ethernet, which largely centre on the non-deterministic nature of the protocol, can be overcome in most industrial applications by network management and segmentation.

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[1] Recently CIP is being redefined as Common Industrial Protocol to better reflect its network independent industrial application

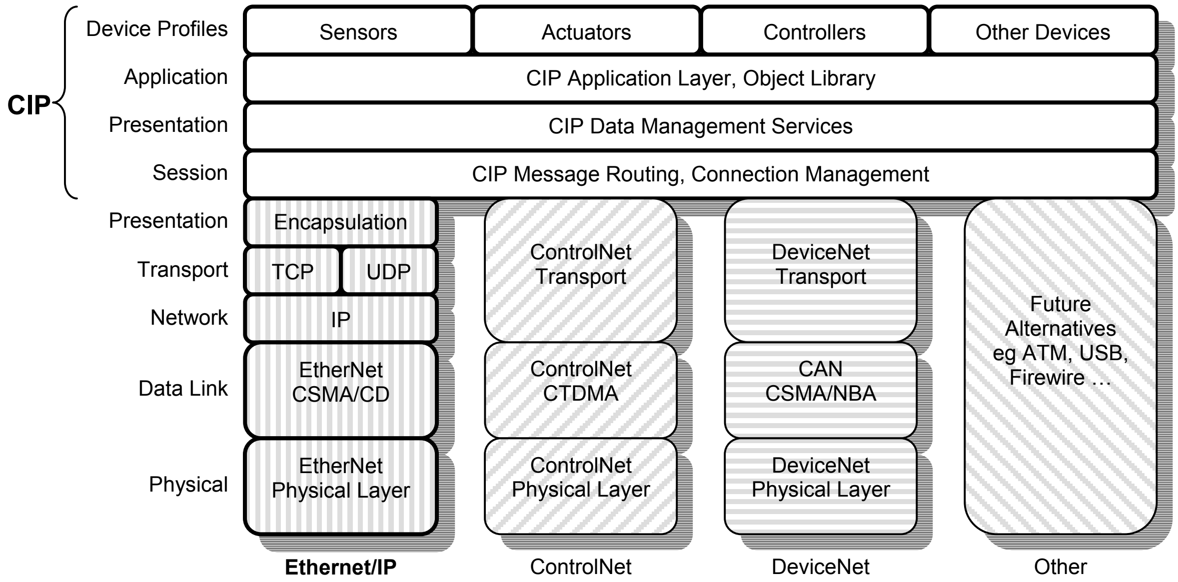

Figure 4: Comparison of Ethernet/IP, DeviceNet and ControlNet in terms of the OSI seven layer model. Each of these industrial control protocols shares a common application layer.

In the *Landmark* project the control system response time requirements are quite long compared with likely network delay times. Furthermore the *Landmark* control system has been intentionally designed to act in an advisory role to the existing proprietary equipment controllers and therefore does not subsume any safety critical functions.

As envisaged, the choice of Ethernet/IP in the *Landmark* project has allowed the project to lever benefits from widespread and rapid developments in Ethernet technology. A case in point is the establishment of the *Landmark* communication link to the moving shearer. Typically, shearer communications has been provided by a slow serial data link over the shearer main power cable. Because of the harsh environment and the specialised Bretby-type cabling handling mechanism it is not practical to install a separate communication cable.

As part of the *Landmark* project, broadband Ethernet/IP communications with the shearer has been achieved using off-the-shelf CISCO wireless Ethernet hardware with minimal modification. A reliable wireless Ethernet link across the complete longwall face is achieved using distributed wireless access points and a wireless workgroup bridge installed on the shearer. This solution takes advantage of the dual-antenna space diversity and signal strength management facilities integral to this equipment to overcome severe multipath propagation problems and to provide redundant paths in the wireless link. A more detailed description of this wireless Ethernet application can be found in [6].

4. SUMMARY

Longwall mining accounts for a large portion of underground coal production worldwide. The industry is seeking ways to improve productivity and safety for mining personnel. Significant advances in longwall automation are being achieved through the industry sponsored *Landmark* project. This project has provided a focus and motivation for longwall equipment manufacturers to enhance their proprietary control systems to take advantage of the new enabling technologies.

A standard for the interconnection of *Landmark* equipment has been established based on Ethernet/IP. This standard ensures that the longwall automation system will operate correctly with any mix of *Landmark* compliant equipment. Ethernet/IP shares a common application layer with DeviceNet and ControlNet and is rapidly gaining acceptance for modern industrial control applications.

The *Landmark* interconnection standard takes advantage of existing mine network infrastructure and levers benefits from widespread and rapid developments in Ethernet technology. A reliable panel-wide distributed wireless Ethernet link to the moving shearer has been established using off-the-shelf hardware with little modification.

The *Landmark* longwall automation project has secured the support and cooperation of the major longwall equipment manufacturers who are providing *Landmark* compliant interfaces to their equipment. The project promises to deliver a step change in productivity and safety improvement to the sponsoring coal industry and offers an interconnectivity standard for the mining industry in general.

References

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