Data exchange in distributed mining systems by OPC Unified Architecture, WLAN and TTE VLF technology.

David Horner[1], Friedemann Grafe[2], Tobias Krichler[1], Helmut Mischo[1], Thomas Wilsnack[2])

[1] TU Bergakademie Freiberg
[2] IBeWa Consulting

ABSTRACT

Mining operations rely on effective extraction policies, which base on concerted management and technical arrangements. In addition to commodities, mining of data is the increasingly matter of subject in mining engineering. The Horizon 2020 project – Real-Time-Mining supports the ongoing paradigm shift of pushing mining activities from discontinuous to continuous operation. In this respect, the partners TU Bergakademie Freiberg (TU BAF) and IBeWa Consulting tackle the issue of physical and logical data acquisition in underground mining.

The first aspect of the project addresses the 'logical' provision of data. Mining technology is increasingly interacting among each other and integrated into globally distributed systems. At the same time, the integration of current mining devices and machineries into superordinated systems is still complex and costly. This means only a few number of mining operators is capable to integrate their operation technology into a Supervisory Control and Data Acquisition (SCADA) system. TU BAF presents the middleware OPC Unified Architecture, which is a platform independent middleware for data exchange and technology interconnection among distributed systems. By installing a SCADA demonstrator at the research and education mine Reiche Zeche, TU BAF intends to present the technical feasibility of a SCADA system basing on OPC UA even for SME mining operations.

The second aspect of the project addresses the 'physical' provision of data via wireless transmission. The targeted use cases are mobile machineries and the surveillance of remote mine sites. Mobile machineries in underground mining are increasingly equipped with data management and autonomous operation systems. Correspondent data exchange to superordinated systems is mostly realized via Wireless Local Area Network (WLAN). A comprehensive WLAN signal coverage, however, is generally not maintained in underground mines due to lacking technical and economic feasibility. With the intention to increase the coverage/expense ratio at underground WLAN installations, TU BAF and IBeWa Consulting installed a WLAN test loop at Reiche Zeche mine basing on leaky feeder cables. Simultaneously, IBeWa Consulting pushes forward the surveilability of remote and/or hardly accessible mining sites by Through The Earth (TTE) data transmission. Current test performances present an enhanced stability for data transmission at ore / gneiss formations beyond 200m, primarily basing on a better alignment of the system to the isotropic characteristics of the bedrock.

1 Motivation

Small to medium scale enterprises (SME) present the majority of Europe's mining operators. This a consequence of Europe's geology being characterized by small and distributed deposits for many raw materials. Certain raw materials, like Indium, Germanium, Galium or Rare Earth Elements, are not produced within Europe at all. In both cases, Europe's mining operators are exposed to global competitors, often times sitting on geological bulk deposits. In the last decades, those competitors managed to lower production costs by exploiting the economy of scales effect; introducing larger machineries into operation. This approach, however, is not transferable to Europe's small and complex deposits, rather flexible and intelligent solutions are required to enhance competitiveness.

One driver is to enhance the information flow along planning and production activities, the aim of the EU Horizon 2020 project – Real-Time-Mining. Within this project, TU Bergakademie Freiberg (TU BAF) introduces a method for the alignment of data acquisition, data transmission and data processing in mining. By now, these instances are engineered individually by device and machine manufacturers as well as system integrators. While functionality of mining technology advances rapidly, connectivity and compatibility across multi-vendor systems lags behind. The lack of a uniform language and software architecture across industrial applications hinders the implementation of interactive solutions. With the aim of engineering a Supervisory Control and Data Acquisition (SCADA) system suitable for SME mining operations, TU BAF identified this weakness as one of the key issues at digitalization in mining.

Simultaneously, IBeWa Consulting together with TU BAF deals with the integration of wireless data transmission solutions in underground mining. Basing on the underlying frequency, data transmission through the earth (TTE) or data transmission through the air is fostered. Particularly, attention is paid to underground ore mines with stratified gneissian host rock and isotropic environment, as can be found at the research and education mine "Reiche Zeche" at TU BAF. TTE is of particular interest for monitoring hardly accessible parts of a mine. Basing on very low frequency (VLF), the amount of transferable data, however, is limited to binary encoding in the range of Kilobytes. Larger messages are transmitted via WLAN technology, which is gaining ground in underground mining. In general, such infrastructure is set-up to allow data transmission at defined hot spots. The installation of a comprehensive network within an underground ore mine is mostly considered disproportional. At this, the intrusion of autonomous mobile machinery in underground mining makes such continuous monitoring crucial.

2 Supervisory Control and Data Acquisition in Mining

SMEs in mining are predominantly equipped with low labor and limited budget. This means employees are generally responsible for multiple tasks and capabilities for investment are restricted. To push SCADA services into SME environment, convincing solutions must address the key factors mobility, intuitiveness and economic feasibility. Mobility is crucial; with no exclusive dispatching capacities on site and the managing engineer not being positioned at a defined placed permanently. Intuitiveness comes along, as a managing engineer cannot be expected to manage complex or multiple user interfaces besides its daily business. Lastly, feasibility is subjected to the required engineering for implementation and subsequent mode for maintenance.

The operation of a SCADA system is performed on diverse systems depending on the technique applied. Technically, SCADA systems are realized as Web Application, Desktop Application or Smart Client Application. Lastly, the transmission of information and control to an operator can become provided from local such as cloud based applications, being entirely detached from the hosting automation site.

A Web Application is a Client-Server application, in which the client (or user interface) runs in a web browser. This allows to access a system globally, as no installation is required on a local operating platform. To realize and run corresponding applications, various web development techniques, like Ajax, are applied. HTML 5, at this, provides explicit language support for web-based applications, which can store data locally and remain functional even while getting offline.

A Desktop Application is an application running on a stand-alone desktop computer. It is designed to high performance with quick response times in conjunction with high functionality. A Desktop Application is aligned to a particular platform, providing a stable embedded run-time environment.

A Smart Client Application brings the two approaches together by simultaneously capturing the benefits with so called “thin-“ and “fat-clients”. A “thin-client” is the operators interface to the SCADA system, a “fat-client” a performant server running the system. The “thin-client” does not require installation, as the application is delivered over a web Hypertext Transfer Protocol (HTTP) connection. Parallel, it automatically updates without user action. The “fat-client” performs its operations independently, allowing to provide its services to multiple “thin-clients” parallel at once. At this, the system provides the look and feel of desktop applications.

Depending on the application, SCADA systems are provided from

- Industrial manufacturers to make the proprietary functionality of their devices or machineries available
- System integrators for interconnecting multi-vendor solutions and the provision of superordinated services
- In-house developments for covering specific on-site prerequisites and/or technology

Manufacturer solutions are usually most effective at the illustration and handling of proprietary applications. Generally, they have their own platform definition, which is applied on the entire product range. This allows an effective integration of technology to a proprietary SCADA solution. By designing correspondent SCADA solutions as closed environment, they are easy to roll-out across diverse client sites. This approach is effective to the manufacturers, as the provision of additional information on the devices’ status and operation presents a lucrative, additional business. The disadvantage of this solution is its proprietary architecture, which is not designed to integrate third party technology from the ground up. Thus, such services are mostly provided with poor quality.

System integrators provide solutions for integrating multi-vendor technology into superordinated control and information applications. Their quality of service is defined by the effectiveness of technology integration, the quality for provision of functionality such as the level of intuitive operability. System integrators ground their capability for integration of 3rd party technology on multi-standard IO devices, programable logical controllers and device / machine type libraries. The general set-up of these SCADA systems is realized as Editor, allowing to customize the system easily to the clients’ on-site condition. Mostly, system integrators provide open interfaces to their systems from a technical perspective. The Client, however, is bound by concerted license models, charging the client with significant license fees for the implementation of third party solutions.

In-house developments are specifically built around the mining enterprises' demands. They are commissioned for the universal surveillance of the operational mining process. In contrast to available market solutions, such systems are particularly aligned to the operators' requirements. However, such a development requires significant inhouse resources and is a costly single shot investment. Being particularly designed to the on-sites' technology and mining methods, a transfer to other sites is mostly hardly feasible.

3 Today's Challenges of SCADA Systems in Mining

SCADA systems base on the developers' selected communication architecture. Interfaces, protocols and data formats are particularly aligned to realize particular services. This approach enables excellently performing systems with high functionality and robustness. The developers' background, at this, decides on the systems pronunciation for functionality or interoperability, which is mostly a balance among each other. While the first generally presents the decisive sales argument for newly launched products, the latter receives increasingly awareness particularly for mining sites with high technological penetration. Devices and machineries in mining are never stand-alone solutions. In practice, this causes the operation of multiple SCADA systems parallel to each other at many mining sites. Alternatively, a resource intensive in-house development for a proprietary SCADA system is triggered. Both cases are not feasible for SMEs with restricted labor and capital and are losing their justification for larger enterprises with expanding technological penetration, too. Rather, SCADA systems must become capable to surveille and link ongoing processes across multi-vendor limitations.

Causal problems are broken down to the level of functionality, connectivity and implementability. Functionality describes a SCADAs' ability to represent a devices' or machines' capabilities. This point is crucial, as it decides how much of their particular skills can be made use of. Functions not being covered are lost investment to the enterprise; they are not available for operation. It does not only limit the capabilities of the particular technology itself, but opportunities for collaboration with other units, so called smart mining activities. Lastly, the transferability of a SCADA solution to other sites is of importance in order to minimize the effect of sunk investment costs. A single shot investment for only one particular mining site will barely become economical feasible.

Connectivity penetrates the lower level, dealing with the fundament of logical data transmission. Machines, devices and superordinated systems must talk the same language in order to interact with each other. This does not mean there is only one valid language for all fields of application, but like at society with its cultural heritage of thousands of languages, there must be one common denominator to exchange one another. Interoperability describes this level of technological readiness for interaction. It requires the definition of industrial standards. For local, on-site implementations such standards are available, mentioning Industrial bus systems like ProfiNet or EtherCat. Such bus infrastructure provides high robustness and quick response times. Such systems are so called tightly coupled systems with

- A strictly defined communication model – Communication between the systems is deterministic and tightly regulated.
- A strictly defined data model – The data (I/O for most of these systems) model is predefined and limited
- Strictly defined data types – Data types transported by these systems are limited, predefined and supported by both sides.

A loosely coupled, multi-system platform is hardly integrated into available SCADA solutions. At this, such a platform would provide more flexibility to link technology and software applications. In fact, such architectures are available, mentioning i.e. OPC Unified Architecture, but have not arrived the 'consumer' market, yet. The integration engineering of technology into SCADA solutions is aggravated by this; lastly, each site has to apply technologies from range of manufacturers. Add to that system demarcation is a present method of manufacturers to prevent external access on their technology's data for two reasons:

1. Technically: Guarantee of compatibility for multi-vendor operation. For access and control, i.e. from external programmable logical controllers (PLC), there is no industrial or legal definition for liability in case of malfunction.

2. Economically: The provision of information and smart services becomes a lucrative additional business. It allows enhancing the mining operators' productivity aside the provision of the device or machinery itself.

Table 1 Selected Problems of SCADA Solutions by Developer

	System Integrator	**Manufacturer**	**House Production**
Functionality			
Capture of 3rd Party Solutions	x	x	
System Transferability			x
Connectivity			
Interoperability	x	x	x
Platform Fundament	x	x	x
Integration Engineering	x	x	x
System Demarcation	x	x	
Implementability			
Expenses	x		x
Liability	x	x	x
Data Sovereignty		x	

Implementability deals with the clients' capability to integrate a SCADA solution on site. The more complex such implementation, the more specific and costly it gets. As soon as it is not up to a read-only SCADA version, the just mentioned liability is a crucial factor for mining enterprises. Like at the automotive industry, it is not within the interest of the client to become responsible for a malfunctioned automation decision. At the same time, however, provision of technology data for external systems must not cause the loss of sovereignty on these data for the manufacturers. It must remain within their decision which data are going to become published openly, which data are published i.e. by licensing and which data remain in an enclosed environment.

4 Middleware OPC Unified Architecture

TU Bergakademie Freiberg pushes the implementation of a Mine Control System (MCS) at its mine "Reiche Zeche" within the Horizon 2020 project – Real-Time-Mining. Based on the above-mentioned business models, TU BAF pursues the development of an open, non-discriminating platform for SCADA systems. For this, a communication architecture, also called middleware, is required, which is capable to connect applications and technologies uniformly. Lastly, it must be possible to cover the interests equally; only an approach involving all stakeholders has promising chances to find acceptance on the market.

TU Bergakademie Freiberg selected the middleware OPC Unified Architecture (UA) to realize the project. The decision for OPC UA fell due to its neutral position and openly designed technical fundament. To this day, the global OPC Foundation holds 529 members from authorities, industry and research institutions. Just the mining sector is only represented by RAG Mining Solutions within this consortium for now [6]. Unified Architecture is a platform independent, scalable middleware, which allows comprehensive information modeling and enables the realization of multi-vendor compatibility. In addition, as existing standard it is expectable to have a promising solution developed within a reasonable timespan.

OPC is a familiar industrial communication standard among the automation industry. OPC is a powerful platform to link the shop floor with Human Machine Interfaces (HMI), Supervisory Control and Data Acquisition systems (SCADA), Distributed Control Systems (DCS) and Manufacturing Execution Systems (MES). It replaces product specific drivers and Dynamic Data Exchange (DDE) among PC based automation technology since the 90s. OPC is the standard interface for the access on windows based applications in automation. However, exactly this point is the well-known limitation OPC brings along [8]:

- Platform dependence on Microsoft – It is built around Microsoft's Distributed Component Object Model (DCOM) for communication between software components on networked computers.

Additional familiar problems of OPC are

- Insufficient Data Models – For certain kinds of data, information, and relationship between data items and systems OPC lacks the ability for adequate representation.
- Inadequate Security – The security model of OPC is not sufficient to protect a system in a connected world with sophisticated threats from viruses and malware.

So why to choose OPC as communication platform? Simply, because these restrictions are attributed to the original version of OPC, called OPC Classic in the meanwhile. It is important to point out this fact, as OPC is still mostly linked to this Classic instead of the nowadays valid Unified Architecture (UA) version; even though UA got released already in 2009.

Unified Architecture is a communication technology designed to keep track with the vision of Internet of Things. It is a fundamentally redesigned architecture of OPC in order to address interoperability in Industrial Automation and related domains. It allows to shift from the commonly applied pyramidical thinking in automation towards a decentralized cloud based. Nowadays, data must traverse firewalls, specialized platforms and security barriers to arrive at a place where they can be turned into information. UA is particularly designed to connect databases, analytic tools, Enterprise Resource Planning (ERP) systems and other enterprise systems with data from the shop floor, like low end controllers, sensors, actuators and monitoring devices that interact with real processes. For having such a sophisticated objective realized, the OPC Foundation has been actively collaborating with industrial organizations to facilitate modeling of their data. Unified Architecture shall provide a unified mechanism for transporting their complex Information Models seamlessly between disparate systems. Thus, UA is capable to communicate anything from simple downtime status to massive amounts of highly complex plant wide information. [8]

In contrast to the above mentioned tightly coupled systems, OPC UA is a loosely coupled system basing on [8]

- widely used, standards-based transport layers – TCP and HTTP / HTTPS
- an open, platform independent data encoding – eXtensible Markup Language (XML) can be processed by any other computer platform
- a highly extensible operating interface – Simple Object Access Protocol (SOAP) provides a highly flexible mechanism for messaging

5 Design of OPC Unified Architecture

OPC UA is a service oriented architecture for Client / Server communication. It is not built around the concept of a centrally located Server, but a distributed system of scalable Servers which are an integrated component of the particular devices and machines. Such a Server manages one or multiple sensors, actuators, or other devices and runs the connection to the parent network. In turn, the Client is the prospective of the acquired data in order to process raw data into information. The connectivity between Server and Client is realized as many-to-many instead of one-to-many; so a server is not exclusively source feeding a single Client, but can provide its data to an 'infinite' number of Clients. The Information Model of OPC UA is designed around the concept of Objects to make it flexible and allow for modularization. At this, OPC UA is platform independent, so a developer is not tied to a certain operating system or programming language. OPC UA also fosters to enable the Plug and Produce qualification within its systems. In this context, two services are provided

- Discovery Server - allowing a Server to register at a central spot, like a company in a business directory.

- Certification - an optional validation process for OPC UA Profiles by independent institutions.

To point out the concept of OPC UA and its capabilities for the establishment of a SCADA solution, its basic set-up is explained in the following:

5.1 OPC UA Server

An OPC UA Server consists of an Address Space and a Communication Stack. The Address Space is kind of the centerpiece of the UA philosophy, presenting the structural framework for a devices' control. The UA Address Space is organized around the concept of an Object. Objects are entities that consist of Variables and Methods and provide a standard way for Servers to transfer information to Clients. An Object, at this, can be a simple piece of data or a sophisticated process. A set of aligned Objects can get clustered to a Profile. Such Profiles can become easily duplicated and implemented on any other Server. The Communication Stack runs the Servers' transport with the superordinated network, considering message encryption and authentication. Usually, a Server does not provide a single mechanism for connectivity, but a selection of which a Client can chose the most appropriate to its requirements; lastly, a Server is not intended to serve a single Client, but to operate in a loosely coupled network with no strictly defined hierarchical structure. Such a Server, at this, does not necessarily require a powerful hardware. [7] [8] Dependent of the application profile, a single board computer can be totally sufficient for providing the requirements of an OPC UA Server.

5.2 OPC UA Client

The OPC UA Client is the interested party on the Server's data. A Client is set-up by a Service Set and again a Communication Stack. The Service Set holds the Client's ability to invoke methods, trigger actions and to retrieve data from a Server. OPC UA enables a Client to register its individual subscription mode at a Server's Address Space. Finally, the requirements of Clients are manifold. The Communication Stack runs the Clients' transport with the superordinated network. Much more, it negotiates the communication procedure with the Servers by retrieving their provided communication methods. This approach lowers as well the amount of data transferred via a network. The Client pulls (in standard mode) the required data from the Server, not the Servers pushes its data into the network, requested or not. [7] [8]

5.3 OPC UA Information Model

Message transmission is realized by a multi-layer architecture. For each instance, like data serialization, data security and data transmission various protocols are supported parallel to each other. Important to mention, the supported protocols are not exclusive; OPC UA is designed to be capable to integrate newly emerging or even proprietary protocols. Like this, a software engineer can select the most suitable methods and protocols to have a Server / Client communication realized. [7] [8] [10]

5.3.1 Layer: Data Serialization

There are reasons to send data already structured or just binary. OPC UA supports both cases. Complex data structures are generally compiled to XML files, being platform independent process- and transferable. Binary data are generally send in case of time critical applications with comparable low amounts of information to communicate.

5.3.2 Layer: Security

Security is an elementary component of OPC UA. A loosely coupled system provides naturally way more targets for attacking in comparison to tightly coupled systems. In addition, sovereignty on data is crucial to gain trust from the manufacturers for a certain communication architecture. Hence, the security model of OPC UA is accomplished by multiple instances

- Security Protocols - OPC UA supports the security protocols UA and WS Secure Conversation by default. The selection is made upon the underlying serialization layer, binary or web-based.
- Authentication - OPC UA allows to request authentication for each Object within the Address Space. Such a gate can be established on application, client and user level. Hence, a manufacturer is able to define access rights on its device or machine absolutely fine grained. Even IO devices, popularly used by system integrators, are not capable to circumvent this gate.
- Encryption - Encryption of the message itself can be already realized before transportation by the Server. Like this, the original data are not accessible by any unauthorized party without holding the associated key.

Due to the open structure of OPC UA, security mechanisms must be implemented and activated at OPC UA by default. However, it is free to the developer to select the most appropriate option for the individual system. For certain, in particular very time critical applications within an enclosed environment, it is possible to deactivate security in order to reduce processing effort. However, it should be kept in mind, that lastly the reliability of an entire system depends on the security of each single unit.

5.3.3 Layer: Transmission

OPC UA allows to transmit data from the level of an individual machine up to operations of global scale with remotely located recipients. For complex data structures, such as XML, transmission is realized by the web-based protocols HTTP or HTTPS. Like XML for serialization, these protocols allow a platform independent visualization of the data. For on-site communication with time critical information exchange the means of choice is usually the UA TCP protocol. However, as mentioned before, OPC UA allows the integration of proprietary protocols to same extent.

5.4 OPC UA Discovery Server

The OPC UA Discovery Server is the business directory of an OPC UA system. Discovery Servers are implemented on several levels from on-site to global in order to enable interactivity within system units. A Server registers at the Discovery Server of its level as soon as it is connected to the system. It registers its Endpoint description, which are basically core information of its Address Space and Communciation Stack as well as its IP. A Client looking for a Server holding a certain information or service can place a request to a Discovery Server. With the Endpoint description returned, the Client is capable to initiate a communication session with this particular Server. These processes run automatically, without the requirement for manual intervention by a software engineer. [7] [8]

5.5 OPC UA Certification

A major challenge of automation is the provision of compatible multi-vendor solutions. The OPC Foundation implemented a certification process for OPC UA Profiles in order to ensure a flawless interaction of OPC units. Independent certification labs provide manufacturers to have their OPC UA Server integration checked, providing a digital certificate in return to an impeccable performance. This certificate is registered at the particular OPC UA Server, proofing its conformity to third party units. An OPC UA Client can become instructed to exclusively connect to certified units. Like this, systems are set-up with entities allowing for a robust operation independent on their vendors origin. [7] [8]

6 Wireless Data Transmission

Wireless data transmission in underground mining is complex, too. The available adjustment screws are radio frequency and antenna technology essentially. These are highly dependent the on-sites' mine conditions, like geology, metal installations, roadheading, etc. It has to be distinguished between very low frequency (VLF) and high frequency applications in mining. VLF is applied for Through The Earth (TTE) communication for remote and / or badly accessible sites. High frequency applications there are competitive, primarily distinguishable between the Wireless Local Area Network (WLAN) and the 4^{th}/ 5^{th} Generation (4G / 5G) Wireless Systems technology. Both are applied for high performant data transmission. The most significant difference between the first (VLF) and the second approach is the transmission medium, bedrock for the first, air for the second.

For the high frequency technologies, 4G and in particular 5G is the more sophisticated compared to WLAN. However, 4G / 5G has high integration barriers, by making external network operators necessary and holding high costs for network operation. "Private" solutions are only at the development phase, yet. [11] Hence, TU BAF and IBeWa Consulting chose to have a WLAN installation realized at Reiche Zeche mine with the objective to enhance this approach for underground mining operation.

The frequency of WLAN is set to 2.4 and 5.7 Ghz. To choose the most more appropriate frequency among, is a controversial decision at the moment. Physically the rule applies, the lower the frequency, the better the signal distribution. In return, however, the data transmission rates increase with higher frequencies. As this argument receives a higher priority among the network technology manufacturers, it causes a slowly down turning support of the 2.4 Ghz transmission standards. Nevertheless, 2.4 Ghz is still considered by TU BAF and IBeWa Consulting to be more suitable for underground mining; with economical network coverage being more crucial compared to extremely high data transmission rates today.

The second adjustment opportunity are the antenna parameters. In particular while talking on SME mining activities, narrow cross cuts and highly uneven drifts make it challenging to cover an entire mines' infrastructure with a comprehensive WLAN signal. The installation of classical WLAN (omni-) directional or sector antennas is only feasible to realize a hotspot infrastructure at certain defined points. For ordinary status transmission, it is mostly sufficient to provide such transmission hotspots for mobile machineries i.e. at a dumper place or an intersection. The operation of autonomous machineries, however, requires a comprehensive online surveillance. For this, TU BAF and IBeWa Consulting decided to go for leaky feeder antennas, which are spread around the entire mine site, by simultaneously allowing a drastically reduction of WLAN Access Points.

7 Implementation at Reiche Zeche Mine

The Mine Control Station developed for Reiche Zeche mine will have to proof effectiveness at transmission and provision of operational data for small to medium scale mining activities. For this, the practical part of this project is split into two components

1. Economic data acquisition and processing aligned to low capital mining operations
2. Wireless data transmission aligned to meet increasing mobile applications and guidelines for remote site monitoring

7.1 Economic data acquisition and processing

Administration of Information Technology is whether a core competence nor a core task of a mining operator. Simultaneously, with its increasing complexity it preoccupies the mining entrepreneurs' resources to increasing extent. This effort shall become reduced by linking the communication architecture OPC UA to a SCADA system. Such a platform shall relieve the mining industry and is defined by TU BAF as Industrial Operating Platform (IOP). The IOP links the field level OPC UA Servers with cloud based computational resources and a Smart Client / Web Client SCADA application.

The first building block, the OPC UA Servers, are actually realized on Single Platinum Computers (SBC). These became powerful in the recent past and are expected to fulfil the requested performance for most small-scale mining applications. SBC products like "Revolution Pi" (referred to in the following) are capable to provide most services of a Programmable Logical Controller (PLC) in the meanwhile. At this, the underlying Operating Systems (OS), an industrial version of Raspbian OS, is open source; thus it is non- discriminating to any third party automation technology. Interestingly, the industrial OS even holds a real-time-patch of the kernel. For hardware integration Revolution Pi provides comparable IO interfaces as conventional PLC solutions. Such flexibility offered at prices from 150,- € is a promising starting point to have the project's objectives realized at the shop floor level. [12]

The second building block is the central IT infrastructure of a mining enterprise. Computational power and databases can generally be located wherever the customer likes to. This can be on-site, the classical approach, or off-site in a cloud. OPC UA is not designed to have to stick to the classical pyramidically approach of automation any longer. Rather, entities are entirely distributable among multiple sites or a global infrastructure of an enterprise. The decision to which extent outsourcing of IT infrastructure is feasible, depends i.e. on the on-sites' internet connectivity such as the real-time requirements for operational performance. Computational power with high performant response times is crucial for the operation of a mine site as soon as it is equipped with automation technology. Therefore, it is rational to remain such competences on-site. Databases, however, are not necessarily providing time critical, vital information for the performance of an operation. Accordingly, databases can become outsourced into a cloud easily. Accompanying, this allows to make data available by long observation periods, as required for certain information by mining authorities. At TU Bergakademie Freiberg, Server and Database will not be located at the mine site itself, but at the central data centre of the university providing a high performant and reliable connectivity. At this, the Server is just a virtual machine (VM Ware) with the ability of a real-time swap in case of a machine failure. With this approach the mine operator does not have to care for its IT any longer.

The third building block presents the Smart Client / Web Client SCADA application. All computational tasks and storage are performed on central or distributes IOP Servers. The Smart Client / Web Client, finally, is the human-system-interface of a SCADA application. Their design is decisive, as it decides on the efficiency of a mine dispatcher to have the operations handled. The Smart Client and Web Client approach are chosen, as there are strong arguments to have a SCADA solution running stationary and mobile simultaneously. The Desktop Client application is discarded, as its design is primarily constituted to have the classical, pyramidical automation approach illustrated. The Smart Client version must be designed with a high performant, reliable connection to the IOP Server(s). It must ensure flawless controlling of a SCADA system in a cloud based environment. Complementary to this, engineers are increasingly requested to monitor and control their processes remotely. Mobile devices for such tasks are mostly running on the operating platforms Microsoft Windows (Mobile), Android or iOS. To realizate and maintain a client application for each of these platforms is expensive. In addition, these platforms partially do not fulfil industrial data privacy policies. Consequently, it is more effective to set-up a platform independent, web-based visualization with HTML 5. The redundant development of a Smart Client application is necessary, as Web Clients are not performing such highly reliable, yet.

7.2 Wireless data transmission

7.2.1 Installation of WLAN at Reiche Zeche mine

Underground WLAN coverage is mainly limited by intervisibility of a mobile WLAN Client and the radio antenna of the WLAN Access Point. This is caused by very high attenuation of radio waves at frequencies in GHz range at rocks. Therefore, underground WLAN installations are usually installed in large, linear drifts in combination with beam radio and/or a lot of access points, in order to allow for intervisibility. However, in case of small and intermediate mines like Reiche Zeche, this might be impossible due to small and curvy roadheading.

Figure 1: Installed WLAN equipment (left: RF-Technology – Radiating Cable [3], right: Outdoor Access Point[2])

To make WLAN accessible for demonstration activities in a larger area of the Research and Education Mine “Reiche Zeche”, a drift distance of about 600 m was equipped with RF radiating cable from Kabelwerk Eupen AG being optimized for 2.4 GHz with a diameter of 15.5 mm and a longitudinal loss of 14.7 dB/100m. The two leaky feeder antennas were connected to an outdoor access point from Cisco Systems (Figure 1)

After installation, comprehensive measurements were performed to determine the WLAN coverage, spatial and time-dependent signal strength as well as transmission rate. As a result of an antenna optimization, a WLAN coverage of about 5/6 of the installed leaky feeder antenna was obtained by only one Access Point (Figure 2).

However, there was an instability in signal strength observed which reached an absolute amount of about 10 dBm to 15 dBm and led sometimes to spontaneous signal loss at lower signal strength. Consequently, a mismatch of access point settings to the particular requirements for leaky feeder antennas were supposed to be responsible for signal instability. Especially interference of its own signals by logic optimization algorithms (e.g. MIMO technology, IEEE802.11ac) might be a source of signal stability (Figure 3).

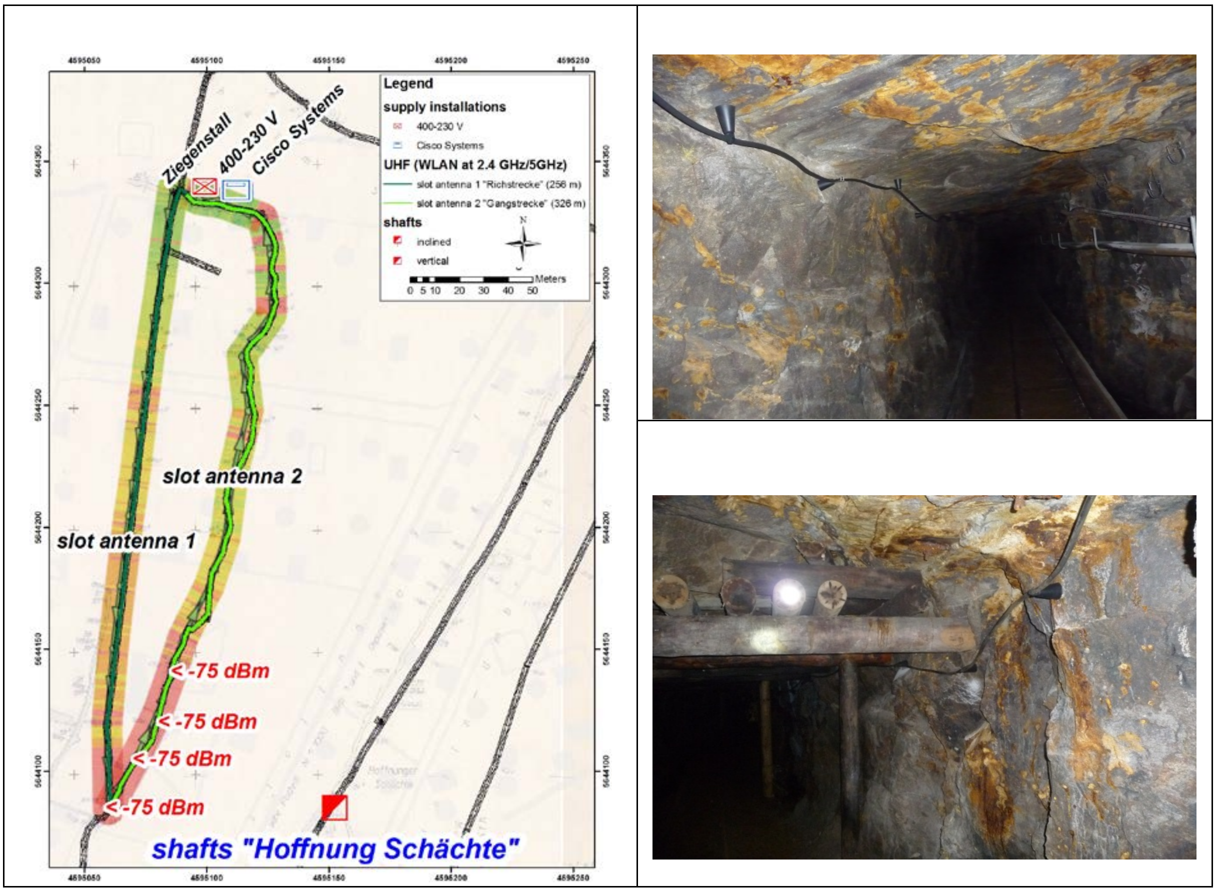


Figure 2: Results of coverage tests of WLAN system at 2.4GHz – heatmapping at the site "Wlhm-Std.-S (upper right: situation in the "Richtstrecke" – slot antenna 1, lower right: situation in the "Gangstrecke" – slot antenna 2)

Figure 3: Fluctuation in signal strength at the site "Wlhm-Std.-S

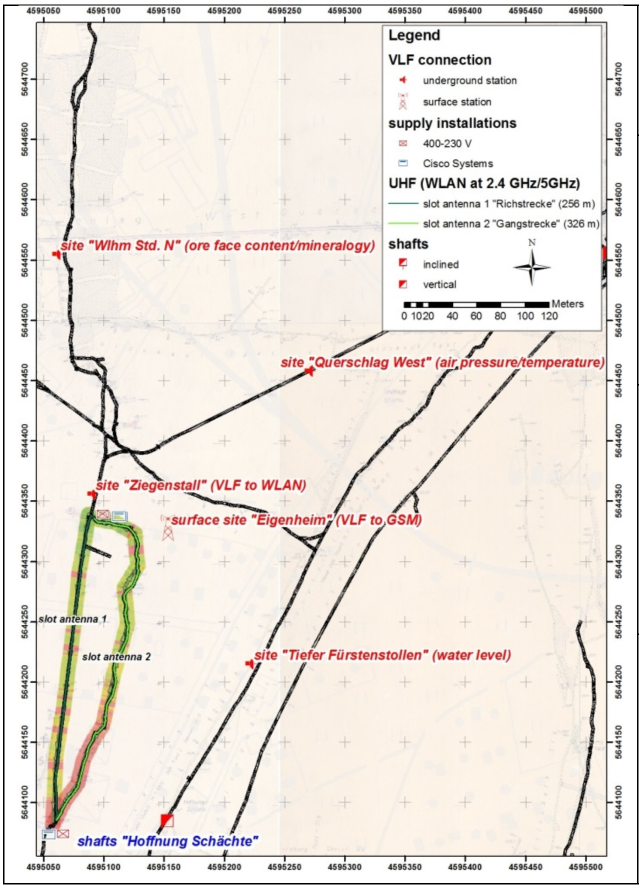
The actual objective is the realization of channel bundling at the 2.4 Ghz "n-standard", which is not provided by CISCO for the installed Access Point, yet. Interferences by channel bundling among Access Points is not an issue in underground mining. After this stage, it will have to become checked to which extent an installation of a second Access Point is required reach full WLAN coverage at site “Wilhelm-Std.-Süd” at substantial transmission rates.

7.2.2 Coverage Tests of TTE data transmission via VLF

As demonstration activity within the RTM project, it is actually planned to link a TTE data transmission via VLF technology with the WLAN test site, in order to feed local monitoring data from abandoned, safety relevant but difficult accessible mine sites to the central mine control station. Figure 4 shows a possible scenario for such an installation.

Freibergian Gneiss is inhomogeneous and anisotropic rock. Furthermore, several mineralized ore veins are cutting the gneiss which were on focus of mining activity in the past. The mine air conditions are hard for any electronic device. There is a temperature of almost constantly 11 °C and a relative humidity between 97 % and 98 %.

Several underground tests of VLF coverage were performed in drifts and stopes with the aim to optimize the transmission technology in this particular environment and to test transmission out of boreholes, especially the antenna configuration and the electromagnetic connection to the rock. For the tests a frequency range between 40 kHz an 132.6 kHz, different antenna configurations and handheld devices (Figure 5) were applied.

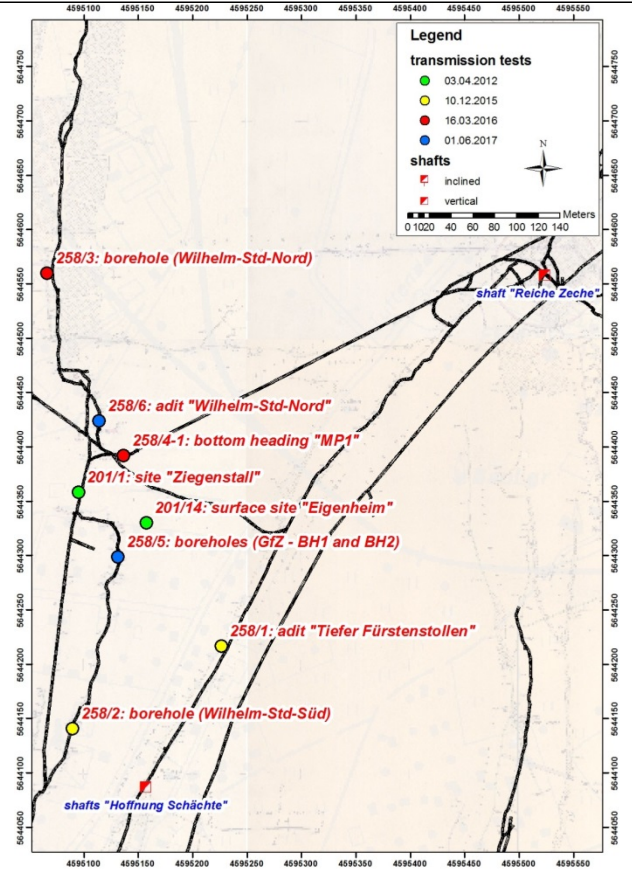


Site	Distance [m]	Monitoring Parameter
stope “Whlm Std. N”	220	ore content / mineralogy
adit “Querschla g West”	220	air pressure / temperature
adit “Tiefer Fürsten-stollen”	190	water level

Figure 4: Recent planned RTM demonstration activity linking VLF with WLAN (note topographic base from TU-Bergakademie Freiberg)

Figure 5: VLF tests in research mine “Reiche Zeche”

Applying VLF technology at different sites of the Research and Education Mine “Reiche Zeche” Freiberg transmission distances between about 140 m to 220 m were successfully tested (Figure 6). Whereas, the test from 04/03/2012 is a permanent demonstrator sending air pressure and temperature data continuously from an underground to a surface station across 120 m through the rock and the later tests were simply transmission tests with the focus on transmission out off a borehole. This might be a great goal, especially in sense of safe installation in active and abandoned mine environment.



Date	Distance [m]	Drift con-tour	Bore-hole
04/03/2012	120	yes	no
12/10/2015	194	yes	no
03/16/2016	220	yes	no
06/01/2017	140	yes	yes

Figure 6: Results of coverage tests of TTE data transmission via VLF (note topographic base from TU-Bergakademie Freiberg)

As Figure 6 reveals transmission was always successful when the antenna was directly installed at the drift contour. However, transmission almost failed when the antenna was installed in a borehole. Only in large boreholes BH1 and BH2 from German Research Centre for Geoscience (GfZ) transmission over 140 m succeeded. According to [4] both borehole have a diameter of $8^{1/2}$’’ (216 mm), a length of 20.4 m and 30.6 m and explore several water-bearing anisotropies (e.g. crevasses, fissures).

Due to the specific VLF transmission technology using predominantly the electric field component of the electro-magnetic field, coverage is dependent on low resistivity and high dielectric constants or with other words on wetness of rocks. Since the resistivity of gneiss differs from $6.8{\cdot}10^{-4}$ Ωm (wet) to $3{\cdot}10^{-6}$ Ωm (dry) and the dielectric constant is with around 8.5 about 10 times lower than water [5], the transmission is mainly controlled by higher conductible wet anisotropies (e.g. crevasses, fissures). This, together with the geometry dimension of the boreholes, might explain the successful tests in GfZ boreholes BH1 and BH2. Future tests in nearly water saturated opalinus clay at Swiss underground laboratory Mont Terri [1] may reveal better results in boreholes coursed by lower resistivities of shale to argillitic rocks (about $2{\cdot}10^{-3}$ Ωm to $1{\cdot}10^{-1}$ Ωm, [5]).

8 Conclusion and Outlook

Data handling and provision are long-dealt industrial topics; whether it is the logical instance for data acquisition and control, or the physical by wireless data transmission. There are many solutions already available for mining industry, providing high functionality and services. Particularly, system integrators think beyond the pure provision of automation solutions, but drive forward the development of intuitive handling systems. There are strong arguments why multiple approaches for data provision are in place. TU BAF presents in this respect a method to enhance connectivity among distributed, multi-vendor systems from shop floor to the global level. Within the Horizon 2020 project - Real-Time-Mining, it is the aim to have data platform independently integrated into one holistic SCADA system. For this, the middleware OPC Unified Architecture is a powerful software architecture, meeting excellently the demands of a globally acting mining business. TU BAFs vision is to provide a Plug and Produce capability for the integration of mining devices and machineries into superordinated data management systems. The related technical demonstrator, a Mine Control Station at Reiche Zeche mine, is expected to be in place until the end of 2018.

Similar effort has to be made in the future for the enhancement of wireless data transmission in underground mining, too. An increasing introduction of mobile devices and machineries with (semi-) autonomous capabilities, such as increasing demands for surveillance of remote sites in underground mines, require more comprehensive wireless networks in underground mines. In this respect it must be taken into account, that underground facilities put higher requirements on transmission technologies in order to obtain a comparable performance as industrial applications on the surface. Both radio transmission media, air and bedrock, are applied in order to provide certain services. Partially, data are transferred through the bedrock by TTE VLF technology, which is a great approach for remote and/or difficult accessible mine areas. For operational processes, which require high performant data transmission for mobile machineries, WLAN is still the means of choice at the moment. In order to still improve this transmission technology for the application in underground mining, TU BAF and IBeWa have realized a test site with WLAN and leaky feeder antennas at Reiche Zeche mine. By aligning a range of parameters and introducing channel bundling, it is intended to increase the coverage/expense ratio for underground installations.

Declaration:

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 641989.

REFERENCES

[1] Bossart, P., Thury, M., 2008. Mont Terri Rock Laboratory. Project, program 1996 to 2007 and results. Wabern: Reports of the Swiss Geological Survey no. 3

[2] Cisco, 2016. Cisco Industrial Wireless 3700 Series Access Points. Datasheet, datasheet-c78-734968.pdf at site www.cisco.com

[3] Eupen, 2014. RF Cables for Radio Transmission in Confined Areas. Catalogue EUCARAY, RF_Radiating.pdf at site www.radiating-cables.com

[4] GfZ, 2016. GFZ Underground Laboratory in the Research and Education Mine “Reiche Zeche” Freiberg, Journal of large-scale research facilities, 2, A68 (2016), 6 p.

[5] Telford, W., Geldart, L., Sheriff, R., 1990. Electrical Properties of Rocks and Minerals. Applied Geophysics, 283-292. Cambridge: Cambridge University Press. doi:10.1017/CBO9781139167932.009.

[6] OPC Foundation, 2017. OPC Foundation Members, https://opcfoundation.org/members, retrieved September, 11th 2017

[7] Lange, J., Iwanitz, F., J. Burke, Thomas, 2013. OPC: Von Data Access bis Unified Architecture, 5th edn., VDE Verlag, Berlin, 489pp.

[8] Rinaldi S. J., 2016. OPC UA – Unified Architecture; The Everyman’s Guide to the Most Important Information Technology in Industrial Automation, 1st edn., CreateSpace Independent Publishing Platform, 170pp.

[9] OPC Foundation, 2017. Unified Architecture – Part 1: Overview and Concepts, Version 1.04.07

[10] OPC Foundation, 2017. Unified Architecture – Part 5: Information Model, Version 1.04.15

[11] PIMM, 2016. Pilot for Industrial Mobile Communication in Mining, PIMM presentation March 2016, https://www.sics.se/projects/pimm

[12] Kunbus GmbH, 2017. Open Source IPC auf Basis des Raspberry Pi, https://revolution.kunbus.de/, retrieved September, 1st 2017