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An Application of the IoT in Belt Conveyor Systems

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Abstract: The Internet of Things and Big data these days means big business. Monitoring Belt Conveyor Systems used to be performed by means of inspectors and off line. These days the developments are towards fully automated inspection systems. The IoT enables that more information from sensor systems becomes available that was not available in the past. Theoretically this means that monitoring Belt Conveyor systems 24/7 should become reality and downtime and unexpected maintenance a thing of the past. All these sensor systems produce a vast amount of information. Big data implies a combination of databases too large and/or too diverse to maintain by regular database management systems. Big data plays an ever-increasing role these days. This paper discusses an application of the IoT in bulk solid handling and transportation systems and the utilization of big data. It discusses recent developments and a case study.

1. THE INTERNET OF THINGS

In literature the term the "Internet of Things" (IoT), which is multi-disciplinary, is defined in a number of different ways reflecting this multi-disciplinary nature [1]-[4]. In [5] for example, the IoT is defined as "things or objects, which through addressing schemes interact with each other and cooperate with their neighbors to reach common goals". In [6] the IoT are "interconnecting physical objects with computing and communication capabilities across a wide range of services and technologies". Finally in [7] the IoT is perceived as "Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework...with Cloud computing as the unifying framework". The first definition comes from a networking perspective, the second uses physical attributes as the base for the IoT definition and the third definition emphasizes the use of platforms and the cloud. This paper is party based on [2].

The IoT holds several disciplines and consists of multiple technologies. The technologies are structured in such a way that they form a value chain between a SO and an end-user, and they are (also se Figure 1):

- Data acquisition
- Identification and tracking
- Communication and networking
- Middleware
- Data storage and analytics
- Applications (will be discussed later)

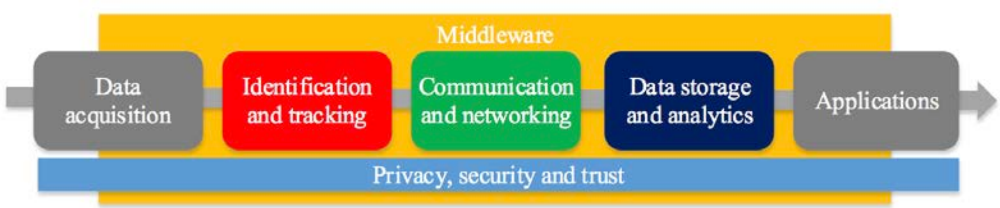

Figure 1 Value chain of IoT [2]

Atzori et al. [5] identified three different definitions or visions on the IoT. The IoT can only be useful in application domains where these three visions intersect [7], see Figure 2. These visions are called:

- ‘Internet oriented’ vision
- ‘Things oriented’ vision
- ‘Semantic oriented’ vision

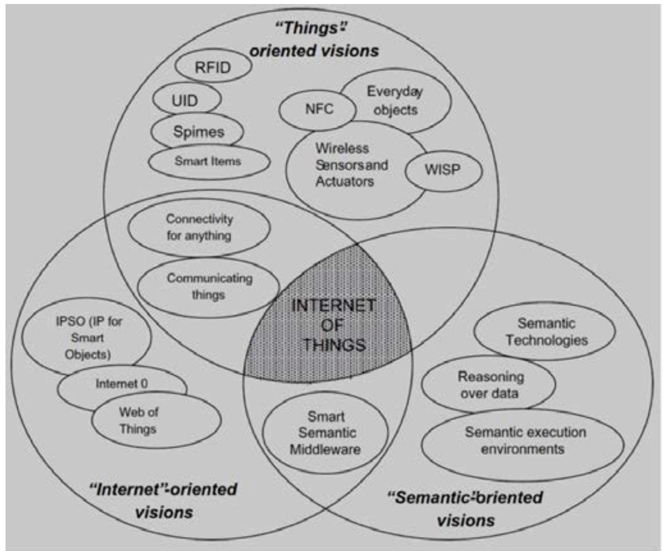

Figure 2 The IoT as a result of different visions [5]

1.1 The ‘Internet Oriented’ Vision

The ‘Internet Oriented’ vision incorporates the requirement for a standardized communication architecture that allows the IoT to become widespread. Several researchers have studied this requirement and they all aim for the Internet Protocol (IP) to be used as the network technology for connecting objects in the IoT. According to Gershenfeld et al. [8], the costs and complexity of setting up a global network out of heterogeneous local networks are currently too high and have to be dramatically reduced. For this purpose the ‘Internet-0’ (I0) was introduced and devices, which are a part of it, embody seven principles [8]:

- Each I0 device uses IP as the connection standard, which removes the need for costly and complex translation interfaces.
- Communication protocol software is simplified and non-segregated.
- Each set of I0-deviced is able to work independently, thus there are no client/server relations.
- An I0-device keeps track of its own identity.
- I0 uses bits, which are bigger than the network.
- Big bits allow data to be represented in the same way, no matter what medium conveys them.
- An I0-device will use open standards in order to make optimal use of available resources

These seven principles allow physical and virtual objects, given that they are equipped with the required technology, to seamlessly connect to a data network with communication, computation, sensing and storage functionalities. By allowing objects to share information in the same ‘language’ in any network, locally or globally, the system can be designed based on the required functionality rather than constrained by boundaries.

1.2 The ‘Things Oriented’ Vision

The ‘Things Oriented’ vision sees the IoT as a network of smart physical or virtual objects with extended Internet technologies and at the same time with a set of technologies that realizes this [5], [6]. The focus lies on the physical embodiment of the IoT. According to this vision the IoT concept has three characteristics, which apply to all the active objects in the network:

- Anything identifies itself: smart objects are identified with a unique digital name to establish relationships in that domain.
- Anything communicates: smart objects form ad hoc networks of interconnected objects.
- Anything interacts: smart objects interact through sensing and actuation with their environment.

Developing the solutions and technologies to realize these three characteristics is the basis of the 'things oriented' perspective.

The 'things oriented' vision differs from known networking visions in that everything should be able to interact based on its own decision-making. Each single object is called a Smart Object (SO) and these SO's have at least basic communication and computation functionalities. A SO is also uniquely identified with one name and address within the network and it may possess means to sense physical phenomena. This is the key feature, which distinguish SO's from nodes normally used in networking systems. A system containing a large number of SO's is seen as a dynamically distributed network. These SO's produce and use information and are able to trigger actions that have an impact on the physical realm [6]. Challenges lie in how these functionalities and resources can be integrated in multiple services spanning the network, which should result in an "always responsive service" for the end-user. Key system-level features, as identified from the 'things oriented' perspective, are:

- Connected devices should be heterogeneous
- Scalable addressing and information management
- Data exchange should be ubiquitous through proximity wireless technologies
- Energy-optimized solutions, minimizing the energy spent for communication and computation
- Devices should be track- and traceable
- Device should be autonomous, the network should distribute intelligence
- Data formats should be standardized
- Adequate security and privacy mechanisms

1.3 The 'Semantic Oriented' Vision

The 'Semantic Oriented' vision deals with representing, storing, interconnecting, searching and organizing information generated by the IoT [5]. It promotes the use of smart connectivity and context-aware computation features. These features should allow the technology to 'disappear' from the consciousness of the user. Raw sensor data obtained through data acquisition has no real value if there is no understanding of its context and meaning. The challenge lies in the translation of the collected data into information [9]. In the IoT an enormous amount of sensors will be connected to the Internet. It is however not feasible to process all the data that is being collected in real time, which ultimately leads to the generation of large and diverse databases or 'Big Data'. Therefore, within the IoT a shared understanding of the situation of the users is required, as well as solid software and communication architectures and analytic tools that aim for autonomous and smart behavior [7].

2. BIG DATA

Today, an overwhelming amount of data is generated and analyzed by enterprises, Social Media, Multimedia and the IoT [10]. Questions may arise however whether or not this data is useful. Individually it may be considered valueless, but when accumulated data is exploited, useful information can be identified and potential forecasts can be made [11].

The subject of Big Data concerns the need for real-time analysis of enormous datasets and masses of unstructured data, which are gathered in various fields [12]. The data is numerous, it cannot be categorized within standard relational databases and the capturing- and processing processes are executed rapidly. The underlying engine of Big Data is supported by Cloud Computing. With Cloud Computing a much larger scale and more complex algorithms can be employed to meet the, continuously growing, demands of Big Data. However, the rapid evolution of Big Data left little time for the subject to mature in academic literature and there exist little consensus of the fundamental question when data is qualified as Big Data [14]. Still a substantial part of the found literature (multiple authors, cited in [12]-[14].

Big Data the can be characterized by the following four V's:

- Volume : the massive data volumes that are processed
- Variety : the data is collected from a great variety of sources in multiple formats
- Velocity : data is acquired, sent and analyzed with high data transfer rates
- Value : value is found in, first considered, unstructured and uncorrelated data

The growth of Cloud Computing and Big Data further promote the growth of the IoT [13].

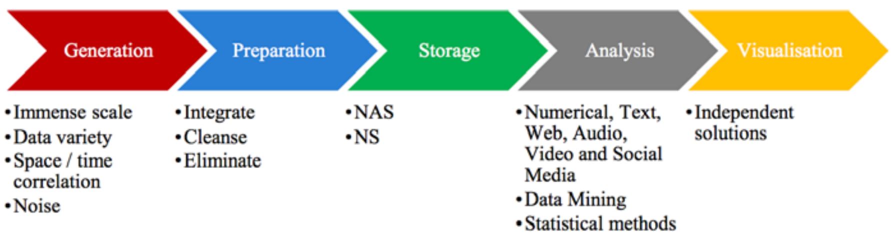

Figure 3 The Big Data Value Chain [2]

The steps that are used in order to extract information from Big Data fall under the Big Data Value Chain, see Figure 3, and are as follows [13]:

- Data generation
- Data preparation
- Data storage
- Data analysis
- Data visualization

Data generation

Data can come from anywhere, enterprises, social media, the IoT. The generated data from the IoT can be characterized as: (1) being immensely scaled since the IoT is deployed in a distributed manner, (2) having a great variety in data types, due to the variety in IoT devices, (3) being correlated in both space and time, and (4) having only a small portion of valuable data, due to potential noises in acquisition and transmission of the data.

Data preparation

Data preparation stands for all the necessary steps that need to be taken before data can be stored in the cloud. These steps are: (1) data collection, (2) data transmission and (3) data pre-processing. Data collection and -transmission in the IoT happens at component level and the different enabling technologies were introduced in the previous paragraph. The data which is sent by the SO´s varies in consistency and the amount of noise. It is therefore considered a waste to store all this data in the cloud and pre-processing of the data is required. Various techniques and steps for pre-processing are proposed [13]:

- Integrate correlating data from multiple sources to provide a uniform view of the data
- Cleanse data from inaccuracies and incompleteness by either deleting or modifying this data set

- Eliminate redundancies via recognizing repetition or surplus of data

Data storage

Prepared data is send towards a Data Storage center. Data storage systems for Big Data are classified as Direct Attached Storage (DAS) or Network Storage (NS). In DAS data is connected through peripheral devices and is commonly used in small sized data storage centers. NS provides, via a network, ubiquitous data access via a union interface and is characterized for a strong expandability [12]. Most storage systems are limited in their computational- and/or storage capacity and should not be considered useful for Big Data. Instead Cloud Computing may be the right alternative.

Data analysis

The Data Analysis functionality refers to the information extracted from Big Data by applying complex algorithms and tools [10], [13], and [14]. There exists a general consensus that multiple intelligent learning tools exist which can derive information from (un)structured data within numerical- and text files, web and mobile data, recorded audio, video and social media. If these learning tools do not show direct results, complex data mining models will be created which will further analyze the big data for new associations, behavior and classifications.

Data visualization

Data Visualization is the graphical representation of the learned knowledge via analysis in a more intuitive and effective way [13]. To have the necessary effect of the visualization, the information has to be conveyed graphically in both aesthetic- and functional form. Current known data visualizations are done separately and these serve only their own purposes. The main challenge of creating a general solution lies in the immense size and dimension of Big Data.

3. APPLICATION OF THE IOT IN BELT CONVEYOR SYSTEMS

In this paragraph an example of the application of the IoT and Big Data in belt conveyor systems as used in the Bulk Materials Handling and Transportation (BMHT) industry will be given. The example is not intended to be exhaustive or representative for all developments that are going on. On the contrary, the introduction of components that are connected to the Internet in the BMHT world is very slow and their numbers rather low. Rather, this paragraph will illustrate the development of technology that allows the combination of the IoT within belt conveyor systems. In the BMHT industry there seems to be a hype surrounding the IoT and the apparent endless opportunities that come with it. This paragraph is intended to look beyond the hype and illustrate what needs to be done in order to develop a true IoT application for the BMHT.

This paragraph follows the discussion in the previous paragraphs and sections. Firstly, the general idea of the application will be introduced. Secondly, the multidisciplinary character of the IoT application will be discussed by revisiting the three visions introduced in paragraph 2. Thirdly, the technology required and developed for the application will be discussed. Finally, the Big Data aspects in particular will be reviewed.

3.1 Introduction

In the mining industry, large-scale belt conveyors are often the main means for long overland transportation, see Figure 4.

Figure 4 Long overland belt conveyor in South Africa (courtesy Conveyor Experts B.V.)

These belt conveyors have many components. Some components are clustered in one location. For example the belt drive system, head pulley and take-up system may all be fairly close to each other at the head of the conveyor. Other components like the tail pulley, the belt loading station and/or brakes may be clustered at the tail of the conveyor. That makes it relatively easy to inspect them and to determine whether or not maintenance or replacement is required to maintain the reliability of the conveyor. Other components like the conveyor belt itself and the idlers are spread-out over the length of the conveyor. For the belt that is not really an issue. Since the belt rotates through the conveyor it suffices to place a conveyor belt monitoring system either at the head or at the tail of the conveyor. Inspection of the idler rolls is a different issue. In current systems an inspector physically has to walk/drive along the system to inspect/monitor the performance of the idler rolls. The question is whether we can ease the monitoring of the idler rolls keeping in mind that there may be 10,000 to 100,000 rolls in one conveyor.

In 2003 the concept of automated maintenance and intelligent monitoring in belt conveyors was introduced [15] and further extended in 2005 [16]. One of the ideas was to provide the idler rolls with wireless sensor technology and see what benefits could be gained by hooking them up to the IoT. This idea, called the smart idler concept, has been first introduced in 2007 in [17]. Since then it has been further developed together with Rulmeca rolls from Italy.

In general the idea seems simple; connect all the idler rolls to the Internet and one has information available 24/7 at any location. This has a couple of advantages:

- The maintenance department of the company that operates the belt conveyor may be on a different site and can now gain insight into the 'operational health' of the idler rolls 24/7. If an abnormality is observed then the mine can be notified and a inspector can be send to the location. By centralizing the data from the rolls a database can be build up that enables building a knowledge based inspection system.
- There is a tendency to lease belt conveying systems instead of owning one. In that case the lessor might want to have insight into the performance/use of the system. This IoT application allows for that.
- If a maintenance contract is in place between an operator of a belt conveyor and a component supplier then the supplier needs information of performance of those components. Having the IoT application allows suppliers to send replacement components to site even without the operator knowing it.

However, there are also quite a few questions. The first question was how to assess the technical health of an idler roll. The second question was how to get information on the technical health at the right place, for example at the desk of the maintenance manager. The third question was what should the maintenance manager do with the information, in other words how to interpret the information. A fourth question was what else, or who else, can do something with the gathered information. The next sections will provide answers to these and more questions.

3.2 Three visions revisited

As was explained in paragraph 1, the IoT can only be useful in application domains where these three visions intersect. These visions were called:

- 'Internet oriented' vision
- 'Things oriented' vision
- 'Semantic oriented' vision

In order to structurally look at the development of the smart idler concept, aspects of these three visions relevant for the concept will be discussed.

The first vision is the "Internet oriented" vision. This vision is relevant because the question is whether the smart idlers should really be connected to the Internet as such. What about the privacy of data and the risks of someone hacking the system? It should be realized that not only maintenance personnel of the user of the belt conveyor has benefits of being able to assess the data. The same holds for the owner of the system (in case it is leased) and the original manufacturer of the idler rolls. Therefore, a full fledge Internet connection was deemed appropriate. This does not mean that each roll needs to able to be online 24/7. In order to reduce the amount of data send through the IoT application, a careful selection of relevant data should be made.

The second vision is the "Things oriented" vision. Since the idler rolls have to be online, a platform with wireless sensors and a means for communication is required. In principal, each roll can be wired and connected to a databus. However, a wired system makes it vulnerable for theft of wires, which makes the system useless. The same holds for a system with (wired) routers. With the routers stolen the system would not work anymore. Therefore, the original idea was to install an RFID wireless sensor node in each roll that would allow the determination of its technical health. RFID has the right range and costs for this application.

The third vision is the "Semantic oriented" vision. This is related to the third question mentioned in section 3.2. Having data from the smart idlers means that this data needs to be translated into information. Even having information on the technical health of idler rolls does not mean that the conveyors reliability is ensured. Still questions remain on the amount of time there is available till a roll stops functioning.

3.3 The Technology behind the Application

In this section the technology behind the smart idler concept will be discussed.

3.3.1 Data acquisition

In order to assess the technical health of an idler roll it should be realized that in most cases it are the bearings of a roll that malfunction/get stuck so that the roll stops rotating. Before a bearing fails the roll will experience vibrations and the bearings starts to make noise (audible vibrations). In theory it is possible to equip each roll with either an acoustic sensor or an accelerometer to pick up vibrations that indicate potential bearing failure. Both an accelerometer and a microphone measure data as a function of time. In order to translate that data into information, to find the root cause of the failure, it needs to be transformed into a signal in the frequency domain via an Fast Fourier Transformation. This would mean that every sensor node needs to have processing power. This is not feasible. Therefore, the collected data has to be transmitted to a central monitoring unit and processed there. This process means that the central monitoring unit has to 'tune in' with a specific roll and take a measurement based on a certain inspection protocol. The measurement has to be long enough to allow detection of the vibrations in the relevant frequency spectrum. Although it is technically possible to equip each roll with sensors to pick up vibrations, this was deemed too complex and economically not viable.

An alternative way of assessing the 'technical health' of the roll's bearings is by measuring their temperature. Normal operating temperatures range between 20° C and 50° C depending on the ambient temperature. If the temperature of a bearing increases to higher temperatures, ranging from 80° C to 120° C, then that is a clear sign of potential bearing failure. The time between picking up irregularities in bearing behavior and bearing failure using vibration detection sensors is significant larger then when using temperature sensors [18]. However, if the temperature of the bearings can be measured on-line or if the rolls have the ability to notify the central monitoring unit in time in case of temperatures over a certain threshold value then there is still enough time to replace a roll with potential bearing failure before it actually fails.

Figure 5 Idler roll equipped with RFID sensor node

Each roll is supported by two bearings. However, if one of those bearings fails then the total roll is considered broken and needs replacement. If a bearing is about to fail and its temperature increases then also the temperature of the shaft that supports the bearing will increase. Since both bearings are supported by the same shaft it is sufficient to measure the shaft temperature instead of the temperature of both bearings to assess the condition of the bearings. Therefore, the smart idler concept needs an RFID sensor node for each roll, where the sensor is a thermocouple to measure directly measure the temperature of the shaft, see Figure 5. The thermocouple data does not need post processing; there is a direct and linear relation between the output voltage of the sensor and the temperature of the shaft. The accuracy of the thermo couple does not have to be very precise. An accuracy of +/- 2 degrees C is deemed sufficient.

3.3.2 Identification and tracking

Identifying a specific roll is not difficult since each roll is equipped with an RFID sensor node and therefore has a unique number. The biggest challenge is to keep track of which roll is installed where. This asks for a certain discipline during installation of the rolls in terms of administration. On the other hand, identification and tracking can be done automatically by sending a signal for request of identification from the head and the tail of the conveyor to the roll and time the amount of time it takes to get a response. Timing this from the head end and the tail end should give sufficient accuracy on the location of a specific roll.

3.3.3 Communication and networking

If each roll could measure its own temperature and/or give a temperature overload warning (temperature too high) then that information still needs to be transmitted to the central monitoring unit and be made available to the Internet. Each roll is equipped with a RFID sensor node that can communicate with the interrogator, see Figure 6. The above-described nodes have one drawback and that is that the range over which they can communicate with the interrogator is relatively small caused by the internal power limitations. Typically this range is smaller than 10 m. Since the envisioned applications are large scale belt conveyors, see Figure 6, an alternative way of transmission is required.

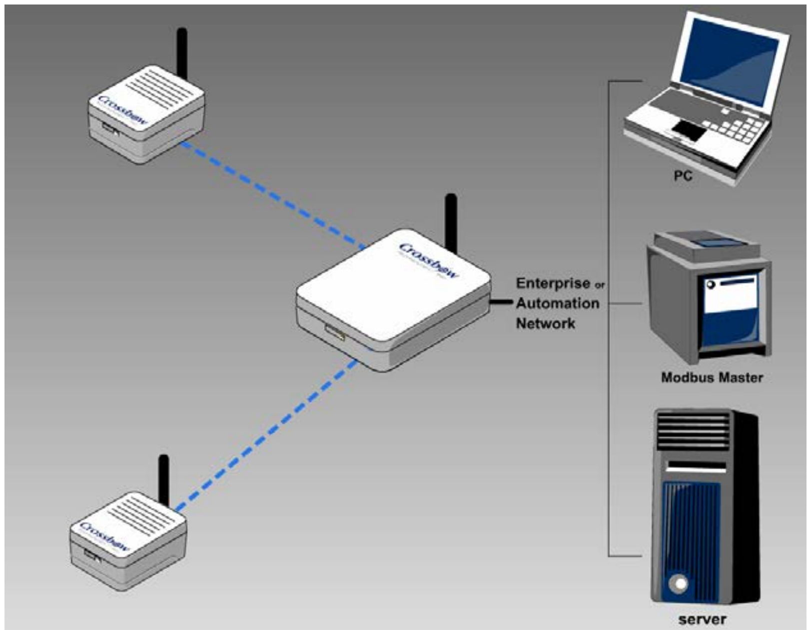

Figure 6 Nodes, interrogator and systems used in the central monitoring unit (courtesy Crossbow, Inc.)

Typically the idler pitch varies between the 2.5 and 4.5 meters for the carrying belt and between 5 and 10 meters for the return strand. Assume that the temperature of roll A, see Figure 7, exceeds its threshold value. At that time the node is activated and starts to transmit its identity (number) and, if required, its temperature. Since the distance between roll A and the interrogator at the central monitoring unit is far more than about 10 meter, in fact it may be over 10 kilometer, it needs assistance for the data transmission. Knowing that the system needs to be purely wireless, all nodes need to be able to not only send data but also receive data. In that case direct roll-to-roll communication is possible. The path used for data transmission is not fixed. The network is build up every time a roll starts to transmit data. Examples of data transmission routes are given in the Figures 8 and 9. The configurations shown in these figures are so-called Hybrid Star (ZigBee) configurations. In principle each roll can participate in the data transmission route. If the node in one of the rolls fails then the network can reconfigure itself. This feature ensures a self-healing LAN network. This concept is shown in Figure 10.

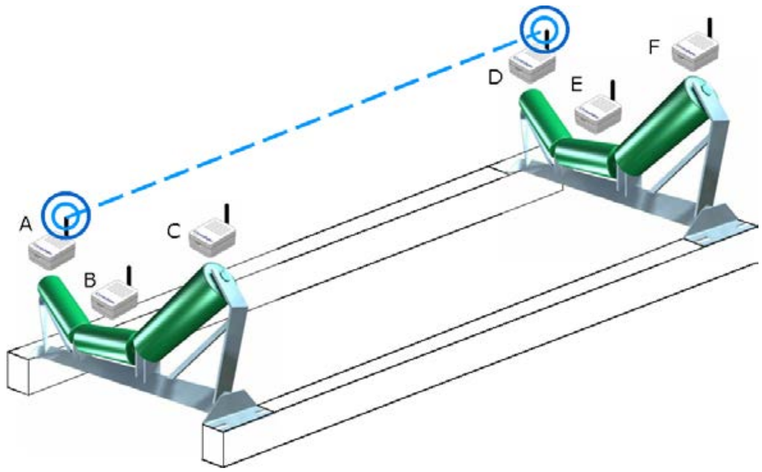

Figure 7 Direct roll-to-roll communication (in reality the nodes are placed inside the rolls)

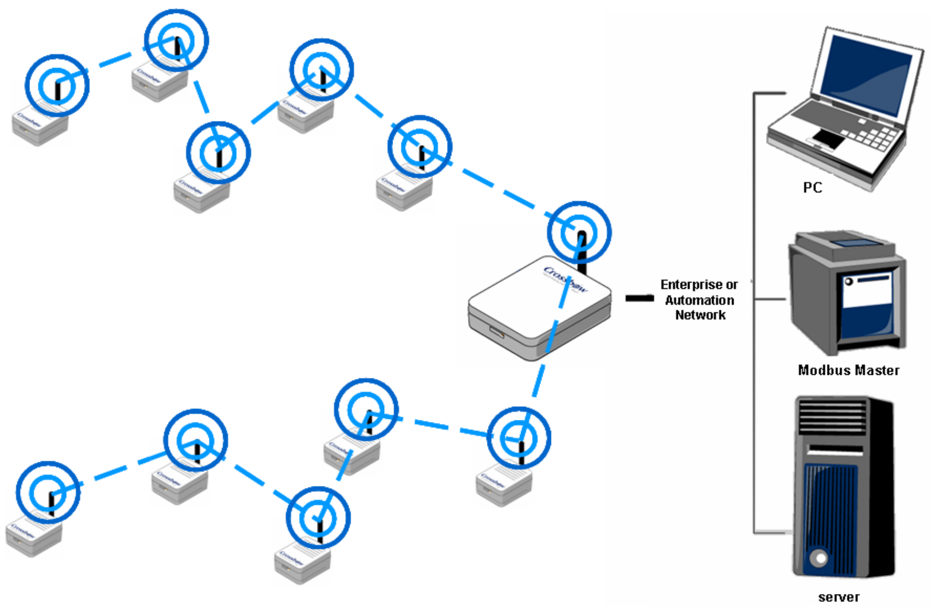

Figure 8 Communication through the network from nodes through interrogator to automation network

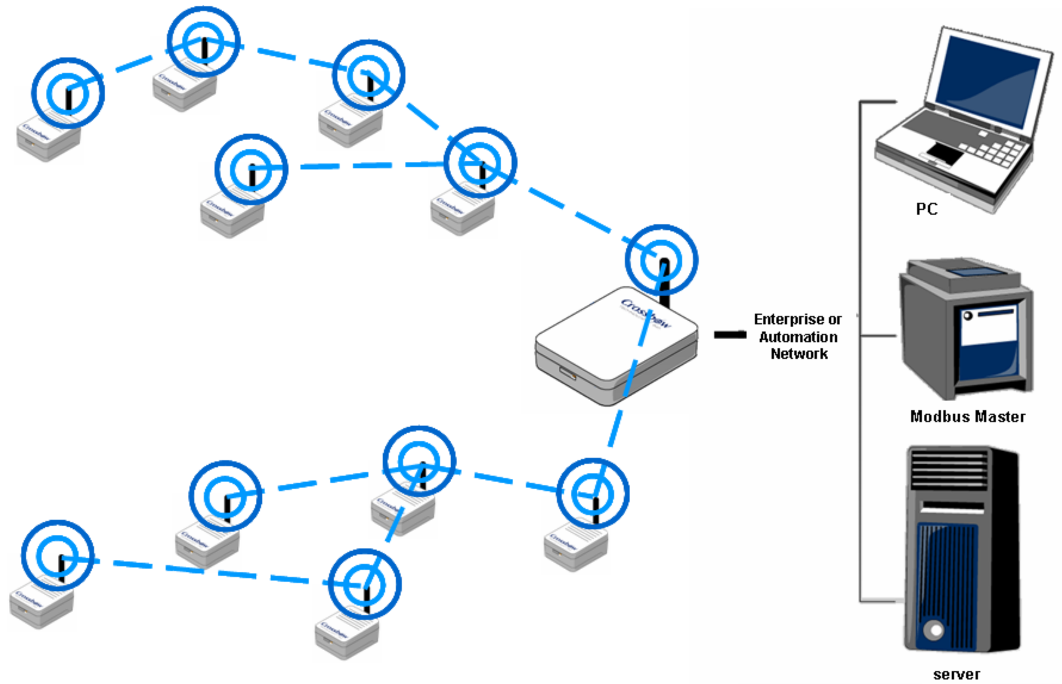

Figure 9 Alternative data transmission route.

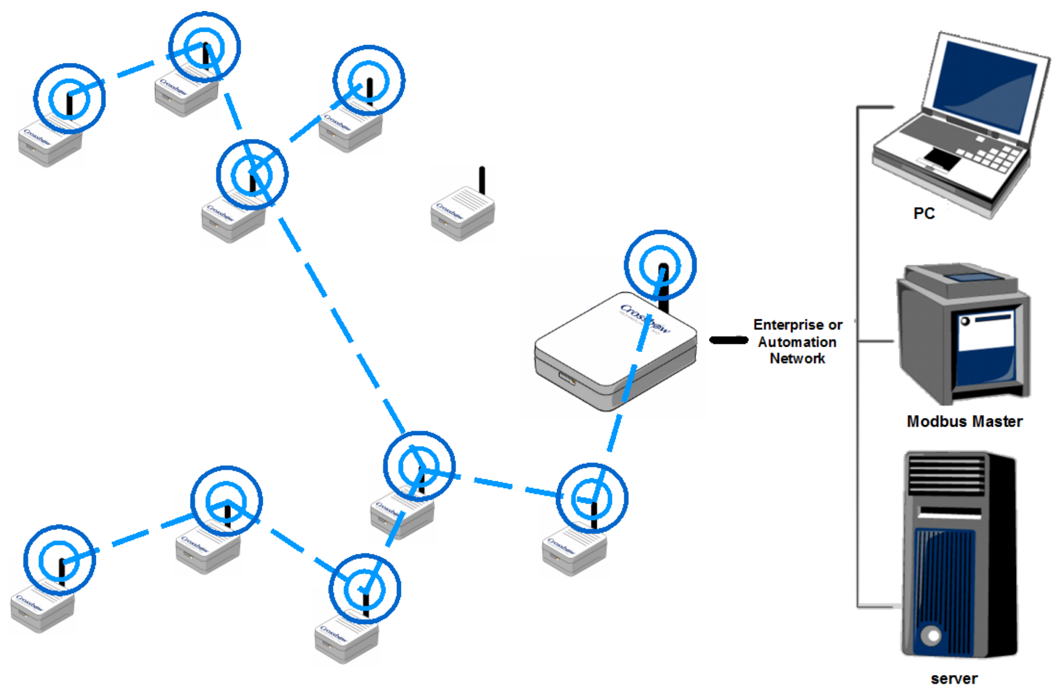

Figure 10 Self-healing network after node failure

The rolls have three operational modes:

- *Internal activation mode*; when the temperature of the roll exceeds the threshold value then the node is activated and starts to transmit its identity. If required it can also transmit its temperature and battery status. This option will be used initially to determine the correct threshold value for the bearing and roll temperature. The threshold value depends partly on the application and ambient conditions.

- *Central external activation mode;* if a roll does not transmit its identity it can be assumed that the roll temperature is below the threshold value. However, if for whatever reason the node in the roll is malfunctioning or it does not have power then it will not be able to transmit data. Therefore it is possible that the roll temperature is above the threshold value without the node transmitting data. To periodically check whether the nodes are functioning or not the central communication unit can request each node to identify itself and report its temperature and battery status. If a roll does not respond then it can be considered broken and needs replacement [19].
- *Local external activation mode*; if a neighboring roll is transmitting data then the node in the roll is activated to transmit the same data. This mode is used to either support the central request for identification of specific rolls or for the transmission of the identity and temperature of a roll whose temperature exceeded the threshold value.

Currently Rullmeca is testing a set-up where each roll transmits its temperature and rotational speed every half an hour so that a history of the development of the technical health can be build up. This set-up however requires considerably more power and need a more expensive node. They also consider the utilization of routers to ease the data transmission.

3.3.4 Middleware

For the smart idler concept no special middleware was designed from the point of view to support interoperation. Till now middleware software has been developed that allows monitoring all the rolls in the system. The context detection for the system is simple; the temperature of a roll is either below or above a threshold value. Device discovery and management have been discussed above. Basically, a roll can be automatically detected by sending a detection signal from the head and from the tail of the conveyor. Security and privacy are no real issues in the smart idler concepts. It’s basically a one-way system from the point of view that the rolls inform the system. The system however does not control the rolls in any way. Privacy is also not an issue in this application since it does not contain any private individuals information. It is envisioned that the middleware will be extended in the future and that a translation from the acquired data, via information, into a maintenance plan will be possible.

3.3.5 Data storage and analytics

Depending on what data or information is stored the smart idler concept may lead to Big Data. If every now and then, for example every five minutes, each roll in the system is asked to provide it’s temperature then that will lead very fast to a large data base that may need to stored in the cloud. The advantage of having this Big Data is that it will be possible to detect deterioration of rolls over time. This will give insight in the time available between a roll’s temperature passing the threshold value and the roll stopping rotating. On the other hand, if only the ID’s of those rolls are stored that of which the temperature passed the threshold value, then a small data set will be build up. The latter data can also be deleted as soon as a roll has been replaced. The analytics of the data set is primarily to answer the question at what rate rolls deteriorate. This information is essential for the planning of (preventive) maintenance activities.

Looking at the characteristics of Big Data, the following notes can be made for the smart idler concept:

- Volume : the data volume can be very large or relatively small depending on what data is stored (see above).
- Variety : data is collected in one format only.
- Velocity : data is acquired, sent and analyzed with low data transfer rates (868 MHz) to safe energy.
- Value : value is found in structured data.
- Data generation : data is generated by the thermocouples in the RFID sensor

nodes.

- Data preparation : is not necessary. There is a direct correlation between the output of the thermocouple and the roll's temperature.
- Data storage : in the Cloud when large amounts of data is stored. May be on a local server when small amounts of data is stored.
- Data analysis : Is easy, temperature over the threshold value requires action.
- Data visualization : On the screen (for triggering) and in Excel datasheets.

4. DISCUSSION

In the previous paragraphs it has been shown how an IoT application for belt conveyor systems like the smart idler concept can be developed using the characteristics of IoT systems and Big Data. Although the concept has been developed, and still is under further development, it has not yet been implemented in a large-scale belt conveyor. The main reason is the worldwide situation of the mining industry. The smart idler concept has been tested extensively under laboratory conditions in all kind of different configurations and the system works fine. The RFID sensor nodes in the meantime have been further developed to an economical viable concept. However, in practice it is not always easy to convince the procurement department of a mine to invest in technology on forehand. Unexpected downtime of a large-scale belt conveyor may costs up to $300,000.- If the idler rolls where the cause of this downtime then this could have been prevented by using the smart idler concept.

The IoT application described in the previous paragraphs only concerned the idler rolls. There are however two other examples of a combination of the IoT and a BMHT system; a belt scraper system [20] and the conveyor belt inspection system [21].

Where the mining industry in general is not seen as a particularly technology intensive industry, it is a capital-intensive industry that justifies the application of advanced technology in order to reduce costs and increase safety. Even when the utilization of Internet connected equipment in the mining industry is very small, the outlook and possible future benefits of systems like the smart idler concept seem to be there. So, where the current role of the IoT in belt conveyor systems is still very small, it may be expected that this will change in the future with a change of tides in the mining industry [22], [23].

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