Case Study: Underground Real-Time Locating System Selection Criteria

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Abstract

As technology advances, mines are looking for more ways to harness emerging methods of increasing production, worker safety as well as reducing operating costs. Real-time locating systems (RTLS) are one of the many tools which are becoming increasingly popular as a means to these ends. In order to successfully select a real-time locating system for use in underground mines, it is crucial that the correct tracking system as well as the appropriate system components are selected. While commissioning products which integrate with these tools, BESTECH has had the opportunity to gain valuable experience in ensuring that tagging and tracking systems are successfully deployed. This paper will discuss some of the various challenges encountered and draws conclusions about the critical requirements that other potential tracking system implementers should be considering for their own sites.

Biographies

Sarah Paajanen has been employed as Project Manager/Senior Software Developer at BESTECH for almost five years. She holds an Honours Bachelor of Mathematics degree from the University of Waterloo and has obtained over 7 years of progressive industry experience. Over the years, Sarah has developed capabilities in the areas of project management, product development, software development, business analysis and sales support. Additionally, Sarah has acted as Subject Matter Expert and Technical Lead on a number of critical projects, both for internal and external clients.

Trang Tran has been employed with BESTECH for the past seven years, where she currently holds the position of Manager, Research & Development and Commercialization. Trang is a Professional Engineer, having graduated from the University of Ottawa’s Computer Engineering program with the Business Management Option. Over the years, Trang has lead a number of innovative projects including custom software development for the mining and insurance industries as well as process control automation for mining clients throughout Northern Ontario. Trang possesses widespread knowledge in the areas of Energy Management (mines), Ventilation-On-Demand, Software Development, Air Quality Monitoring, Engineering and Automation.

Pat holds a MBA and an Honours Bachelor of Arts in Psychology with a Minor in Business Administration. Before moving to Corporate Services and Marketing, Pat successfully implemented and spearheaded the Technical Support & Services division at BESTECH as well as managed and supervised the daily operation of the Sudbury Community SO2 network under BESTECH’s environmental monitoring division. In his current capacity, Pat effectively seeks business development opportunities and strategic alliances in order to educate mining industry professionals on Ventilation-On-Demand/Energy Management (NRG1-ECO), Air Quality Monitoring, and Hoist/Winder (RopeInspector) technology as well as Automation and Software Interface Development service capabilities and products.

Introduction

Due to the nature of its operations, the mining industry faces numerous challenges related to health and safety, supply and demand for materials, escalating hydro prices and the ability to attract skilled workers. As such, the industry is constantly looking for new methods to increase worker safety, increase production volume and reduce operating costs. As advancements in technology continue to be made public and the price for such technologies decreases, more tools are becoming available to assist mines in achieving these goals. Real-time locating systems (RTLS) allow users to find employees at a moment's notice in the case of emergency. As the popularity of tracking systems within mines grow and the options available to potential purchasers increase, a question presents itself: How does a mine select an appropriate tracking system?

In order to address the challenges in the mining industry, BESTECH, a Canadian firm specializing in the areas of engineering, automation, software development and environmental monitoring, has developed a mine wide energy consumption optimization system, NRG1-ECO™. This system employs multiple complimentary control strategies in order to achieve: energy savings, increased productivity and improved worker safety.

In particular, a tagging control strategy has been designed as part of the NRG1-ECO™ system in order to facilitate automatic equipment setpoint changes when required based upon the presence/absence of personnel or vehicles in specific areas of the mine. When applied to the ventilation process, if a running vehicle is detected within an area of the mine, a specific amount of airflow is required in the area based on government legislated regulations or site/company policies. By detecting the vehicle, the system could automatically alter the ventilation in the area to meet the new airflow requirements.

In order to achieve this functionality, there is a need for a method of tracking personnel, vehicles and any other assets with ventilation requirements in real-time within the mine (i.e. a tracking or real-time locating system).

The two most widespread RTLS (real time locating system) technologies being used in the mining industry are based on RFID (radio frequency identification) and Wi-Fi technology. Some examples of such systems include Aeroscout MobileView, Becker Varis, MRS Helian, ActiveMine, Ekahau, Cisco MSE, VisorTrac Zebra Technologies, NewTrax, Northern Light, PBE, MineAx™ Bird Dog (Laliberté, 2009).

This case study investigates the requirements of an effective tracking system for use in mines by taking into consideration the experiences gained by BESTECH when commissioning and utilizing two distinct tracking systems as part of the NRG1-ECO™ system; an RFID solution and a Wi-Fi solution. Based on the findings with each solution, conclusions were drawn about the critical requirements and attributes of tracking systems within underground mines. Thus, allowing mining operations to make informed decisions when selecting a tracking system for their own environments.

Background

It is important to note that there are multiple types of asset tracking systems aside from RFID and Wi-Fi systems available to prospective tracking system implementers. Other such options include, Global Positioning System (GPS), Near Field Electromagnetic Ranging (NFER), Ultrasonic, and Optically

Enabled tracking systems. However, these technologies currently represent the minority of selected tracking systems within the mining industry, and thus were not included in this case study.

BESTECH has gained experience commissioning and interacting with several tracking systems over the years; therefore, the practices implemented by this firm are applicable for this case study. Throughout this case study, the following two systems will be examined: RTLS #1 (RFID) and RTLS #2 (Wi-Fi).

RTLS #1 (RFID – radio frequency identification)

RTLS #1 utilizes RFID tags, networked RFID tag readers and a server running proprietary software. The system uses a presence/absence algorithm to determine tag position, and correct setup requires that tag readers have minimal or no overlap of coverage areas. When the server software is notified that a tag reader has detected a tag within its antenna range, it assigns the detected tag the position of the tag reader.

RTLS #2 (Wi-Fi)

RTLS #2 utilizes combinations of exciters and networked Wi-Fi access points in conjunction with a server running proprietary software. Exciters are designed to be installed at choke-points or critical gateways dividing isolated areas. The exciters use low frequency signals to trigger tags as they pass within their range. Once triggered, the tag signals are received by an in-range access point. The described setup using exciters guarantees that no critical gateway or choke-point will be missed by the system as the tagged asset moves into a new mining area. RTLS #2 uses two location algorithms depending on the number of overlapping access point areas: TDOA and RSSI.

TDOA, which stands for Time Difference of Arrival, is a location determining algorithm which infers position based on comparing the clock timestamps at which tag signals are received using multiple accurately time-synced access points.

RSSI, which stands for Received Signal Strength Indicator, is a location determining algorithm in which position is inferred by the server based on the signal strength of the tag signals received by the relevant access points.

The determination of which algorithm is used by RTLS #2 depends on access point coverage for the specific location in question. If there are 3 or more overlapping Wi-Fi coverage-areas in a specific location, TDOA or RSSI is used. RSSI is used when there are 2 overlapping access point coverage-areas. In the case where only one access point has coverage in an area, a primitive method of RSSI is used in which either the coordinates of the access point through which the tag was detected is used, or the coordinates of the exciter which triggered the access point detection is used.

For the test site where RTLS #2 was used, the latter scenario of singular access point coverage areas encapsulates the vast majority of the system setup.

Real-Time Locating System Analysis

Critical Requirements

Certain criteria have been identified as the crucial metrics for distinguishing an effective RTLS system. Due to the inherent safety-centric nature of tracking systems, it can be inferred that these criteria will be vital for any underground tracking system installation. The following is a list of the critical system requirements which will be used to measure RTLS #1 and RTLS #2:

Accuracy
Within a tracking system, accuracy is the concept that the correct position is being reported the majority of the time.

Consistency
Within a tracking system, consistency is the concept that the system components will behave identically and deliver the same results under similar circumstances. For example, if a vehicle with an installed tag is detected and reported when moving under an exciter or tag reader configured using a specific process, similar vehicles with similar tags installed should experience the same detection and reporting when moving under comparably configured exciters or tag readers.

Real-time Delivery of Data
Real-time delivery of data implies that an effective tracking system must be capable of reporting tag/asset movement detection from the received underground node (potentially a tag reader or access point) to the end user within five seconds.

Equipment/System Life
Equipment/system life refers to the endurance of the product. Tracking system equipment must be able to tolerate an underground mining environment for long periods of time without replacement or maintenance. At a minimum, the equipment should not require modifications for at least one year, including wiring repairs, enclosure maintenance and battery replacements.

RTLS #1 (RFID) Observations

The following depicts the RTLS #1 (RFID) observed behaviour related to the above mentioned critical requirements.

Accuracy
The study showed that RTLS #1 performed extremely well in terms of accuracy; any detected issues were easily resolved by antenna tuning within one day of work.

Consistency
The study showed that RTLS#1 displayed high levels of consistency. When a tag reader was responding well in reaction to tag movements from one particular tagged asset, it did so across the board.

It is important to clarify that the high level of consistency should not be attributed to the use of RFID within RTLS#1, but rather to the manufacturer's method of tag design and installation. The vehicle tags were manufactured to be housed in enclosures attached to the hood of the vehicle, and it is this highly accessible positioning which yields the high consistency in tag movement data. The rugged enclosure design allows the tag to be in such a location without risk of damage. Similarly, the tag readers used by the tracking system manufacturer are typically equipped with sufficiently strong antennas whose range could span the entire length of standard mine levels.

Real-time Delivery of Data
RTLS #1 has been observed to perform with high data availability and performance between underground tag readers and the surface server. End to end response time (underground tag movement to detection by server software) is recorded as less than five seconds.

Note that the above performance observation does not imply that all RFID systems are capable of near real-time data availability. Although it has not been thoroughly investigated, there exists another RFID tracking system (referred to as RTLS#3 in this case study) which falls severely below the acceptable benchmark of five seconds when implemented over a leaky feeder network. In the test environment hypothesized, it was expected that an underground network consisting of 50 tag readers in RTLS#3 would result in data latency measured one to two minutes end to end.

Equipment Life

RTLS #1 returned with mixed reviews in terms of equipment life. The tag readers are housed in industrial panels which protect the electronics without over-shielding the antennas. Similarly, the vehicle tags are housed in a rugged metal enclosure, which not only protects the tags from environmental hazards, but makes it possible to position them in the middle of the vehicle hoods. It has been observed that in general, the vehicle hood is an ideal location for tag reader detection, allowing the tracking system to maintain a high level of accuracy and consistency. Along the same vein, the personnel tags can be conveniently installed anywhere on cap lamps, since they are not restricted by the requirement of hard wiring to the cap lamp batteries. This setup ensures that the personnel tags can be easily detected without additional shielding. Contrasting these points, both personnel tags and vehicle tags have been observed to have extremely short battery life, on the order of months. Although it is possible to extend this battery life by ensuring that vehicles are parked away from tag readers, the solution is unrealistic to be employed consistently. If the batteries could be easily changed, the short battery life would be a minor issue. Yet this is not the case because, the tag batteries are soldered into the tags and the tag compartments are sealed. This design increases the complexity of battery replacement and tag maintenance.

It is important to note that since this deployment, a new tag design for RTLS #1 has been developed with vibration sensors. These vibration sensors enhance the tags in such a way that they will only communicate with tag readers, and consequently consume battery power, when they are in motion. This new development would omit scenarios where tags are signaling continuously while parked vehicles are in range of a tag reader.

<u>RTLS #1 Conclusions</u>

Overall, RTLS#1 proved to be an accurate tracking system, with easy to install equipment. The biggest encountered issue was battery life within the RFID tags and the inability to easily change the batteries. In hindsight, it would be optimal to enable powering of tags through the vehicle engine or cap lamp, ensuring the design does not introduce any additional shielding or installation location changes.

<u>RTLS #2 (Wi-Fi) Observations</u>

The following depicts the RTLS #2 (RFID) observed behaviour related to the critical requirements.

Accuracy

Initial stages of commissioning resulted in multiple accuracy issues within RTLS#2. The first issue encountered was due to interfering signals caused by the custom designed metal backplates installed on exciters. The exciters are essentially a copper coil creating an electromagnetic field, and the choice of material for the backplate caused the exciter's electromagnetic field to be significantly reduced. This reduction in exciter range caused tags to fail to communicate with access points when moving through crucial gateways. In order to overcome this issue, the metal backplates were replaced by polycarbonate backplates which did not interfere with the exciter's functionality.

The second issue encountered with RTLS #2 in terms of tagging accuracy was due to the triangulation algorithms used with the selected equipment setup. The setup uses singular access point coverage areas (no overlap) which trigger the server engine to use a primitive RSSI algorithm, generating location positions anchored to either the access point's position or the triggering exciter's position. Tag behavior can be configured to be passive or active, as illustrated in Figure 1. A passive tag is one that only "chirps" or communicates with nearby access points when it has been "excited" or triggered by a nearby exciter. An active tag consistently chirps at a set rate (example: 10 chirps every 10 seconds). An active tag placed in an environment where exciters are present will result in both passive and active tag location reports.

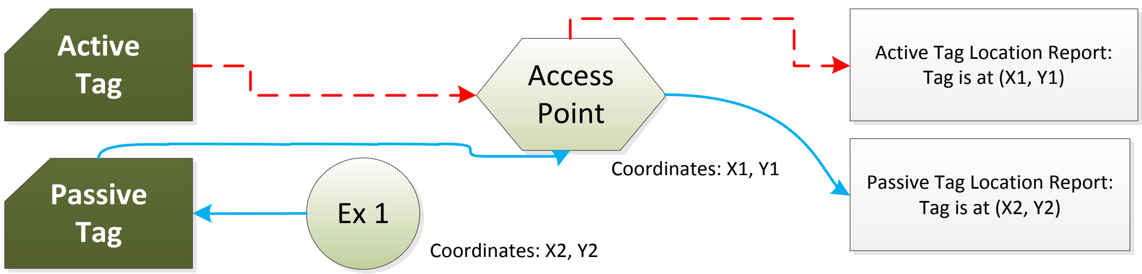

Figure 1: Active tag behaviour vs. passive tag behaviour in singular access point coverage setup

In , *Ex 2* is located in *Area 2*. A tag in range of *Ex 2* will be detected by the access point which is located in *Area 1*. When the exciter triggers the tag, location *Area 2* is reported; however, when the tag performs its timed "chirp" as per its active tag configuration, the location *Area 1* is reported. The result of this is that the tag's reported location continuously bounces between the two isolated *Areas 1 and 2*.

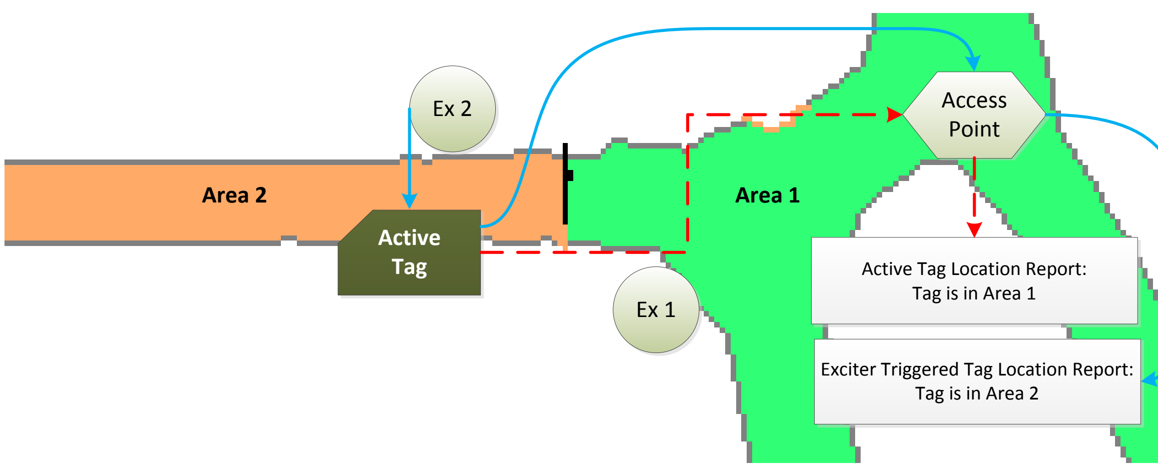

Figure 2: Illustration of problems encountered using active tags in conjunction with exciters

In order to determine a static location, logic is required to recognize this tag movement pattern within the RTLS system and filter out active tag location reports.

A third issue encountered in terms of accuracy is related to location noise, or lack of signal stabilization. When a tag moves into an area where it is transitioning between two exciters, it will be in flux. If the system setup is one where singular access point coverage areas are used, the tracking system will report the static exciter location, instead of triangulating a midpoint between the exciters. This once again results in a continuous bounce between the two static positions (two exciters). When exciters represent gateways between two distinct mining areas where the location data is being used to generate airflow demand, this bouncing would result in continuous changes in airflow equipment setpoints. In order to overcome this obstacle, noise cancellation algorithms were required to stabilize the fluctuating tag location signals.

The final issue related to tag location accuracy within RTLS #2 was found when areas of the system setup allowed for multiple access point coverage overlap. In these scenarios, triangulation algorithms, such as RSSI and TDOA, were attempted by the tracking system. However, due to signal interference within the harsh underground mining environment, inaccurate data was reported. Some examples of such interference include large equipment and vehicles, as well as dense areas of electrical cabling (all of which generate strong electromagnetic signals). Additionally, dense rock faces throughout the drifts can either reflect or dampen a signal. In order to overcome these issues, RTLS #2 is capable of identifying "blacked out" or impossible locations, such as within rock faces. This feature, along with fine tuning of the access point antennas, allows for signal stabilization of the tagging data.

Consistency

Once accuracy issues were mitigated, RTLS #2 also faced multiple issues in terms of consistency. The first issue encountered is one of tag shielding. The tags provided with RTLS #2 allow for the option of hard-wiring them to the vehicles for power, instead of installing batteries which must be replaced occasionally. The issue became one of tag installation location. The most convenient installation location, which also provided tag protection, typically meant that the tag was surrounded by the body of the vehicle. This choice of installation results in tag shielding, where the vehicle body blocks the tag signal as it moves past mining area gateways monitored by combinations of access points and exciters. In order to overcome this issue, guidelines were created for the tag installation positions per type of vehicle.

Table 1: 1 week of tag position testing results comparison

Vehicle Description	Original Tag: Detection Count	Optimal Tag: Detection Count	Original Tag: Missed Gateways	Optimal Tag: Missed Gateways
Jeep	168	631	24%	1%
Scoop	10	278	40%	0%

As Table 1Table 1 illustrates, by simply repositioning the tags on the vehicle, the system experiences a drastic improvement in detection consistency. The tests were performed by leaving the initial tag on the vehicle, and installing a second tag in a researched, optimal position. The tags were left for one week and the vehicle was utilized as normal.

The second issue in terms of consistency observed within RTLS #2 was exciter range. The exciters are cited to have a range of six meters. In practice within an underground mining environment, the actual exciter range was observed to be approximately three meters. Adding to this difficulty, the exciter field, which determines its area of effect, is in the shape of a cone directionally one way out of the exciter at a an observed angle of approximately 45 degrees . The site in which RTLS #2 was setup in typically required exciters installed in a drift with average dimensions of six meters wide and five meters high. The difference between the exciter's range and the drift size leaves a large margin of error even in an ideal situation.

To further increase the challenges, the exciters themselves have been manufactured for commercial use, not industrial. In order to avoid critical damage, they must be mounted high on drift walls, requiring a lift to tune them. The small range of detection and specific shape of the activation area requires that the exciter be precisely tuned and positioned. Accomplishing this precision tuning for a single exciter requires repeated attempts using trial and error. As previously stated, the nature of the exciter's design is that a copper coil generates an electromagnetic field. This field is highly sensitive to external factors, the consequence of which means that even after gaining experience of perfectly fine-tuning one exciter in one drift, the requirements of fine-tuning the next exciter in a different area can vastly differ(i.e. the effort required to tune each exciter does not decrease with experience).

Real-time Delivery of Data

RTLS #2 has been observed to perform with high data availability and performance between underground access points and the surface server. End to end response time (underground tag movement to detection by server software) is recorded as less than five seconds.

The only issue encountered in terms of location reporting performance was due to the tracking system server database density. In order to overcome this issue, specialized database indices were created and data retrieval stored procedures had to be meticulously optimized.

Equipment/System Life

The equipment included with RTLS #2 has been observed to have some issues with durability. Namely, as mentioned above, the exciters are manufactured for commercial use, not industrial. They are tolerant to some amount of dust, but are vulnerable to any physical bumps, moisture as well as other elemental situations commonly found in an underground mining environment. Additionally, they cannot be enclosed for protection due to consequential signal damping/interference.

In terms of battery life, RTLS #2 was observed to have extremely long running time as long as they are wired to a power source. The tags do not come encased; therefore, it is the responsibility of the user to select casing and power sources. This setup allows a flexible solution, but can also create vulnerability since changes to wiring are being done after-market.

<u>RTLS #2 Conclusions</u>

Overall, implementing RTLS#2 required overcoming many issues. However, once the issues mentioned were addressed, the core issue became clear: the choice to use exciters. Exciters may be a valuable component of a tracking system in a commercial, indoor surface environment; yet, in an underground mining environment, they have proved to be inaccurate and ineffective. If a site feels compelled to use exciters, then the choice of tag behaviour should be closely examined. Exciters are intended to be used in environments employing passive tags, and using active tags can produce conflicting tag information within the tracking system.

Installing tags vehicles with any RTLS must be done following tested and verified guidelines based on vehicle type to avoid missed location reports.

In general, the Wi-Fi tagging system RTLS #2 is capable of producing highly available and accurate location reports.

General Conclusion

BESTECH's energy management system, NRG1-ECO^{TM} , requires accurate and consistent tag location data in order to achieve potential energy savings through the tagging control strategy. The open platform nature of NRG1-ECO^{TM} allows it to integrate with multiple tracking systems; however, experience has shown that it is important to select not only the correct system for a site, but also the correct setup of that tracking system within the site. The design and layout of the system is as crucial as the selection of the system itself.

The current options for mining operations interested in implementing an RTLS system within an underground option are dominated by various Wi-Fi and RFID systems. With this in mind, multiple arguments can be drawn from the information put forward in this case study. There is no clear dominating technology between Wi-Fi systems and RFID system. Both technologies are capable of producing accurate, consistent and timely location data.

Exciters are not suitable for underground environments. Exciters add unnecessary complexity for systems which generally only require basic presence/absence algorithms. A similar point can be made for systems which utilize RSSI, TDOA, or other triangulation algorithms. The density of equipment required to achieve usable levels of triangulation is excessive and costly for an underground mine environment. In exchange for highly optimized triangulation algorithms, purchasers should look for systems which offer accurate basic position reporting when minimal detection equipment is installed.

External charging power sources for tag batteries are essential. If tags are not powered, the tracking system is ineffective. Although personnel tags may be in a better position for maintenance and battery replacement, vehicles tags are much more difficult to alter and maintain once they are installed. Similarly, vehicle tag position selection is a key step in the system commissioning process. If tags cannot be detected, due to shielding or being out of range, the tracking system is once again made ineffective. If a site is left with no option but to use battery powered tags, serious consideration should be put towards the choice in tag signaling behavior, since the more frequently a tag is communicating, the faster the battery will be drained. Technologies such as vibration activation can assist with this effort.

Whether choosing Wi-Fi, RFID, or a new upcoming tagging technology, potential users must carefully analyze the selected system for its ability to succeed in all of the critical metrics: accuracy, consistency, real-time data delivery and equipment/system life.

References

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