FEASIBILTY STUDY OF RFID / Wi-Fi / BlueTooth WIRELESS TRACKING SYSTEM FOR UNDERGROUND MINE MAPPING – OKLAHOMA[1]

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Abstract. Underground mine mapping using GPS technology is not an easy task because satellite signals do not penetrate through earth strata down to the underground mine works. In most cases, the use of GPS data collection for underground mines is limited to capturing the point locations such as mine entry, shaft locations and approximate mine location and then using traditional underground mine surveying techniques to capture spatial data. In order to capture accurate spatial information for underground mines, we need to explore new ways of collecting spatial information where satellite GPS technology is not applicable. The Radio Frequency Identification (RFID) is a method which relies on storing and remotely retrieving data via transmitting radiowaves using devices called RFID tags or transponders. In our daily lives, we see this technology being used by mail/package delivery system, medical devices reading vital information off of implanted medical chips in humans and animals, and cashiers at retail stores checking items for purchase. This technique has been successfully used in facilities management such as airports. The use of RFID and other wireless technologies will enable us to collect accurate spatial data in cases where conventional satellite GPS technology is not feasible.

The purpose of this paper is to illustrate the possibilities of utilizing RFID, Wi-Fi and BlueTooth wireless technologies in personnel/equipment tracking and mapping mine works of Pollyanna No. 8 underground mine in Oklahoma. Also, cost analyses associated with installation of RFID or similar wireless tracking systems at this mine site and the benefits of having such a system will be evaluated and addressed. In addition, this paper will provide a number of case studies where RFID/Wi-Fi/BlueTooth technology has been applied in mining and other industries.

Additional Key Words: RFID, Wi-Fi, Bluetooth, Radiowaves, Underground Mine Mapping, Spatial data, Tracking systems, Transponders

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Introduction

The purpose of this feasibility study is to address the applicability of several Radio Frequency Identification (RFID) methods; local positioning systems (LPS) and location based services (LBS) or real-time location systems (RTLS), for underground mine mapping. The use of global positioning system (GPS) has been well standardized; however, it does not work indoors. GPS receivers determine their positions by computing relative times of arrival of signals from several GPS satellites. LPS use a centralized server application to track a variety of clients such as personal digital assistants (PDAs), laptops, handsets, and tags. LPS have already found their use in applications such as people/asset management tracking, healthcare and mobile patient monitoring, security, emergencies, location based network access/security, games, retail, post-analysis of shopping behavior, shopping, advertisement, marketing, and tour guides. To illustrate the applicability of current technology in RFID for underground mining, several LPS and LBS are considered using the conditions at the Pollyanna No. 8 underground room-and-pillar coal mine.

Mining at the Pollyanna No. 8 was approved by the Oklahoma Department of Mines (ODM) under permit OK4243F. Pollyanna No. 8 underground mine (Figure 1) is located near the town of Spiro, LeFlore County, Oklahoma (Lat~N35°13' Lon~W95°33', NAD 1983, WGS 1984). A site survey was performed by the authors of this feasibility report during a single-day visit to the mine. The survey results were used for describing the site condition in questionnaires sent to a number of vendors of LBS, two of which provided their recommendations.

Also, different LPS alternatives will be discussed with the focus on the current RFID, Wi-Fi (Wireless Fidelity) and Bluetooth technologies. The conclusion will summarize the evaluation of alternatives and identify a system that would be the best or most feasible at Pollyanna No. 8 Mine.

Figure 1. Pollyanna No. 8 underground mine

Mine Setting

The setting in which the wireless equipment would need to operate are the rectangular enclosed tunnel-like underground mine rooms formed from mineral extraction (i.e. coal). The room openings are about 6 feet high and 20 feet wide. The total length of these rooms, which also serve as a primary escapeway route, is 3.3 miles and forms the interrogation zone or RF (radio frequency) coverage area (Figures 1 and 2). LoS (line-of-sight) distance ranges from 100 feet to 600 feet as shown in the chart below (Figure 3) and is defined as an unobstructed straight line between two transmitting devices.

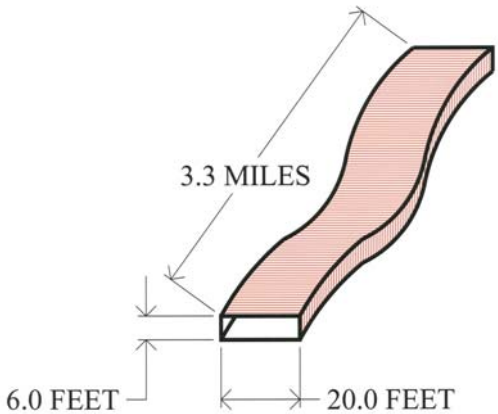


Figure 2. Worst-case design proposition.

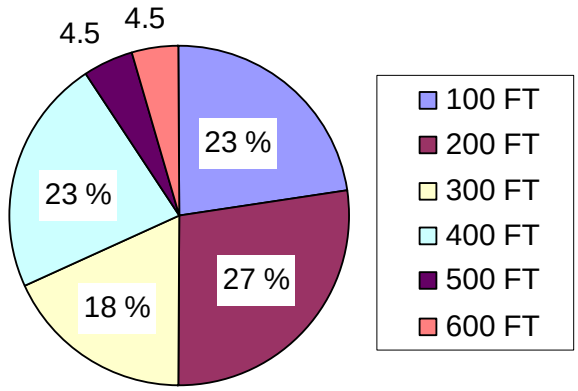


Figure 3. Line-of-sight distribution.

Temperature Extremes

Temperature conditions in the underground mine works average and stay approximately constant throughout the year at ±79°F. They are almost never less than 32°F or more than 100°F as long as the mine ventilation system is operating.

Levels of Humidity

Humidity increases during the summer months, but the conditions allow for the mine employees to perform their duties normally. Constant air movement from the mine ventilation system significantly reduces the potential for humid work conditions.

Possibility of Water Intrusion

The mine in question is an underground mine located near a river. The overburden and adjacent rock is saturated with water which has constant seepage of water into the mine. The site visit revealed that the floors were wet, causing difficulty for the miners when walking around the muddy floors of the rooms. Water flow seeping from the coal pillars near the active coal removal area was observed.

Electrical Diagrams

The mine has a high-voltage electrical cable (∅4”, 4160V) grid initiating at the mine entrance and following the proposed coverage area almost to the end. There is a concern that various elements of the electrical grid could cause interference with the RF signals of the tracking

antennas or access points, since almost all of the proposed coverage area and major access areas have high-voltage equipment. A representative portion of the electrical plan of the mine is provided and shows the mine entrance or portal area (Figure 4). Mine entries from the mine portal area are represented with numbers 1, 2, 3, 4 and 5 in Figure 4. If the Wi-Fi or RFID equipment is installed, the spacing between the high-voltage cables and the access points or the antennas would be anywhere from 6 feet to 21 feet. 400 kVA power transformers are at the average spacing of 1,000 feet within the proposed 3.3 mile tracking coverage area.

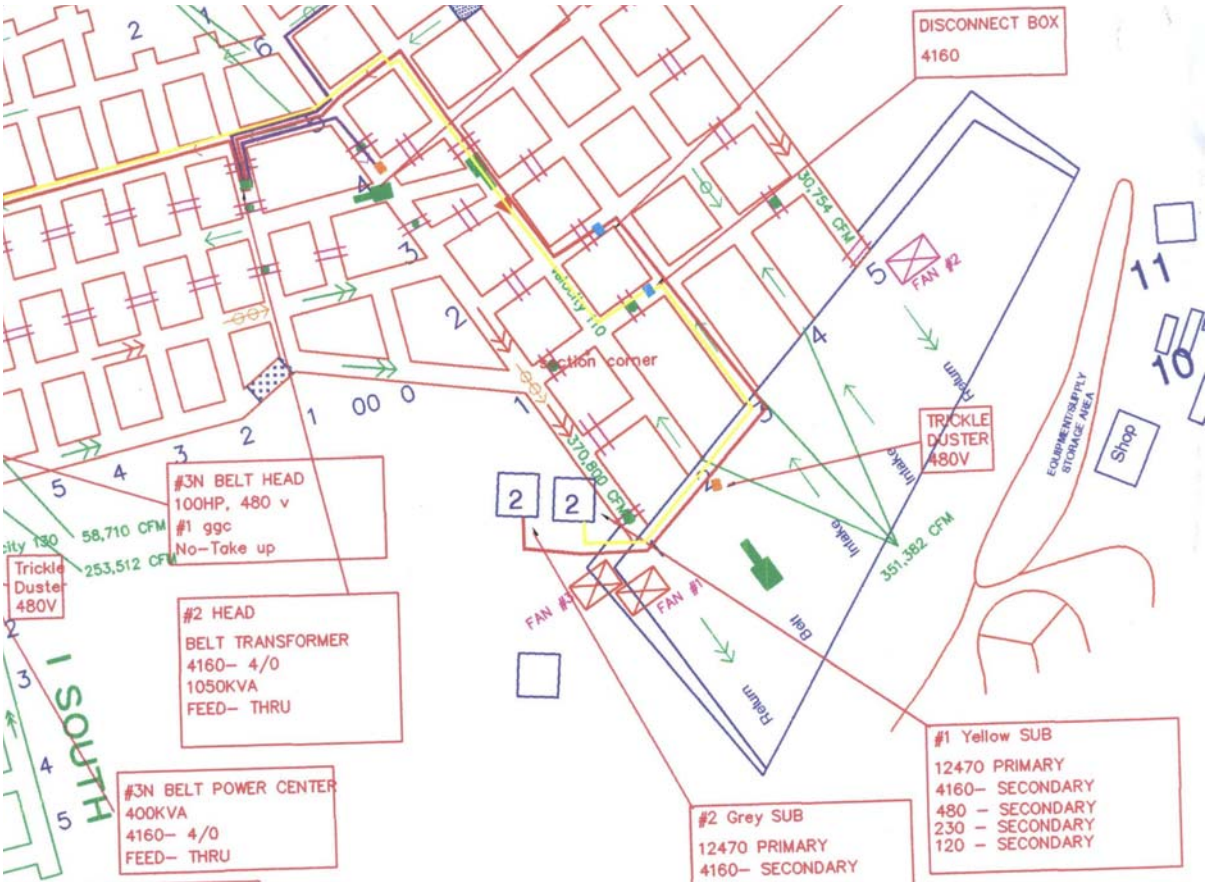


Figure 4. Underground mine's electrical, ventilation and mine plan map.

Mine Ventilation System

Approximate maximum air velocity within the coverage area was determined to be 33 miles per hour (mph). Three (3) mine fans located at the entrance to the mine are characterized as shown in Table 1. The fans are located at a distance of more than 50 feet from the nearest proposed access point or RFID antenna.

Table 1. Ventilation data

Item	Fan #1	Fan #2	Fan #3
Horsepower	800 HP, 3 PH	50 HP, 3 PH	50 HP, 3 PH
Volts	4160V, 60Hz	460V, 60Hz	460V, 60Hz
Amps	95 Amps	60 Amps	60 Amps

Vibration

Vibration is caused primarily by the continuous mining equipment at the location of the coal removal site. Vibration levels shouldn't significantly affect the mounted or attached antennas or access points.

Dust

Coal dust may be a significant factor. Because of the air flow created by the mine ventilation system, there is continuous wind-tunnel effect, causing accumulation of the coal dust on the objects in the underground mine works. Even during the 2-hour visit to the mine, noticeable amount of coal-dust accumulated on the faces and clothing of the visitors. In addition, in order to prevent ignition of the coal right after mining, the areas are regularly coated with a thin layer of non-ignitable small-particle material such as the dust coming from the rock crushing operation.

Chemicals

Two main chemicals are found in the mine: Sulfur from the coal, which has the potential to form acidic water within the mine, and methane gas. There are no other chemicals that would cause deterioration of the equipments. Acid water flow usually causes deterioration of the metallic and concrete materials. Methane concentrations less than 2% are expected in the underground mine. Methane and other mine gas levels are continually inspected and regulated by Mine Safety and Health Administration (MSHA) to comply with the regulations and to allow for the safe work environment of the miners.

RF-Emitting Devices & Network Cabling

Other than the paging that may occur from time to time, there are no RF - emitting devices. Communication systems such as 'leaky feeder', Ethernet, Wi-Fi, RFID and WLAN (wireless

local area network) systems are not available. Cordless phones are also not available. The only communication system currently used in the underground mine is the Pyott-Boone Mine Pager ('Page Boss') System (Figures 5 & 6), which is the quickest way of communicating between mine workers and the mine office located on the surface. There are several interconnected nodes located near the beltline in the underground mine works. The mne utilizes a paging system through the speakers at the locations of these nodes; however, the paging system is not audible when the belt conveyor operates.

Figures 5 & 6. Mine superintendent demonstrating the use of an existing communication system

Conveyors & Heavy Machinery

The mine has belt-driven equipment, conveyor line stands and mining machinery utilizing electrical power. This equipment includes feeders, roof-bolters, scoops and shuttle cars. The range of voltage at which the mining equipment operates is 440 VAC to 950 VAC.

Traffic Data

Transport of crews between the active coal removal location and the mine office is provided by mantrip/golf carts (Figure 7). The velocity of the carts is highly dependent on the floor conditions and vertical slope of the coverage area, but it appears to be never more than 20 mph.

Thus, the tracking system would need to be designed so that it is capable of showing positions of several mine vehicles in a row with a total of 22 workers moving at a velocity of at least 20 mph. This worst-case design scenario is based on the information received from the mine superintendent about the maximum number of workers in the mine at any time.

Figure 7. Mine vehicle.

Local Positioning Systems (LPS)

Many indoor positioning systems have been developed to demonstrate that indoor positioning is possible, and can be done with good accuracy. A number of these systems utilize some form of the RFID, Wi-Fi, or Bluetooth radio standards shown in Table 2. Most of these LPS are network based rather than terminal based (sensors are integrated into the mobile device), meaning that the network calculates the position of the mobile device as opposed to a receiver inside the device calculating its own position and using the network to notify others of its location. Because most common positioning systems available today are built upon the WLAN 802.11b or Wi-Fi infrastructure, the primary focus will be on those systems utilizing that technology because it is currently installed. Even so, it may be important to note that some

existing positioning systems combine RFID, WLAN, Bluetooth, and other technologies to enhance or improve certain positioning applications. It is recommended that references specified at the end of this feasibility study report are consulted for more information on the other systems.

Table 2. Some of the local positioning systems (Kolodziej and Hjelm, 2006)

	MIT Cricket	**Ekahau**	**AeroScout**	**BLIP Systems BlipNet**
Deployment Range	Building	Building/local area	Building/local area	Building
Position Calculation	Mobile Device	Server (Ekahau Positioning Engine)	Server (AeroScout Positioning Server/Engine)	Server (BlipServer Positioning Engine)
Position Method	TOF Lateration & proximity (with one beacon)	Location fingerprinting using signal strength	TOF Triangulation (TDOA for absolute location; RSSI for symbolic location	Inquiries and pagings
RF Signal Used	RF (418-MHz) + ultrasound	802.11	802.11	Bluetooth
Transmitter	Beacon	Existing Wi-Fi nodes	Active RFID tags or Wi-Fi devices	Mobile device
Receiver	Listener	Ekahau Client	Aeroscout Location Receiver (TDOA), AeroScout Exciter (choke-point); standard Wi-Fi AP (RSSI)	BlipNode (Bluetooth AP)
Accuracy	1-3m (3.3-10ft)	1-3m (3.3-10ft)	1-5m (3.3-16ft)	10cm-10m (4in-33ft)

RFID Systems

RFID (radio frequency identification) involves technologies that use electromagnetic (radio) waves to identify individual items, places, or people (Figure 8). The most common use of RFID is detecting numbers that uniquely identify objects, places, or persons. The number is stored on an integrated circuit (IC) that is attached to a tiny antenna. Together, the IC and the antenna are

called an RFID transponder or tag. The tag is attached to objects, places or persons to be identified. A device called the interrogator or reader communicates with the tag and reads the identifying numbers from tags. The reader feeds the numbers it reads into an information system, which stores the numbers in its database or searches its database for a specific number and returns information stored therein about the object, place, or person.

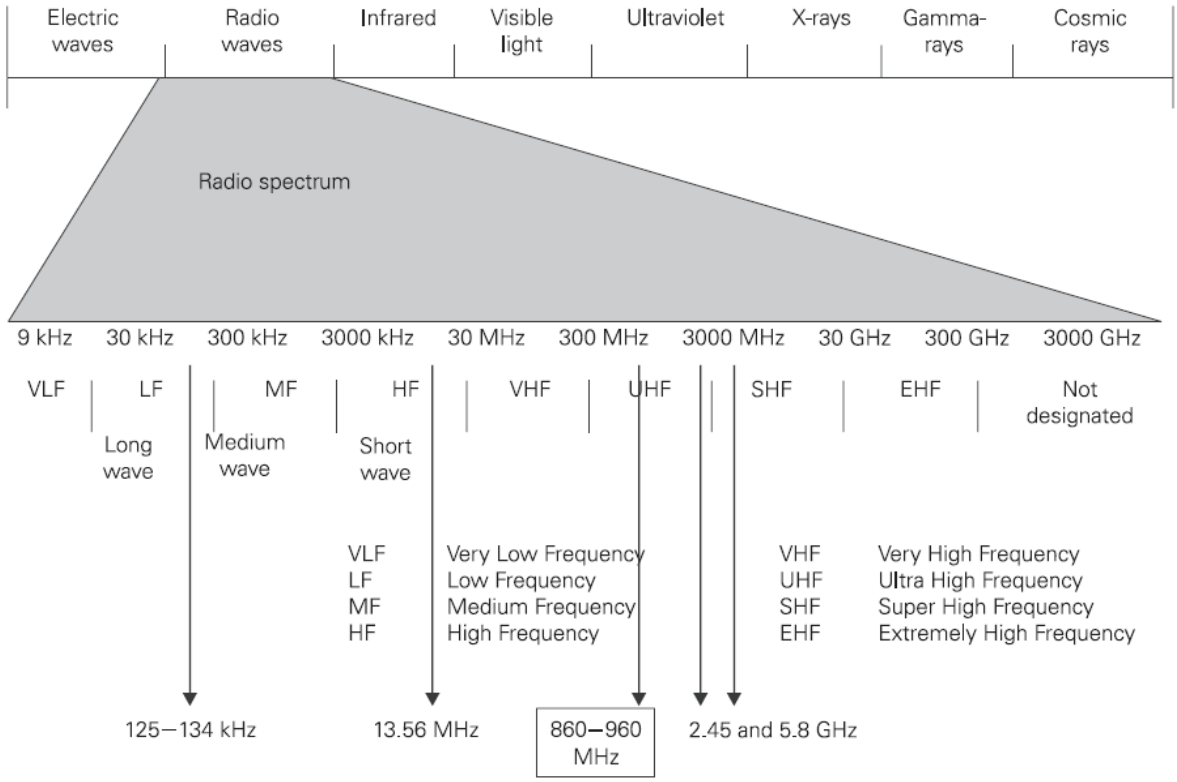


Figure 8. RFID frequencies (Brown et al., 2007).

Four major components of RFID tags are integrated circuit (IC), antenna, interconnection between IC and antenna, and substrate (Figure 9). IC is a small microprocessor which requires power in order to operate. The power for IC is provided from a battery (active tag), or from the radio energy generated by the interrogator antenna (passive tag). The memory of IC is divided in blocks, called banks. The banks are of four types: read-only (ROM), write-one-time-only or write-once-read-many (WORM) and write-many times. Smaller ICs decrease the overall cost of the tag, because these tags require less power to operate. IC is also called an electronic circuit, chip or microchip, and is produced by semiconductor manufacturers. Some of the latest ICs

consist of 40,000 to 50,000 transistors. The antenna is designed for a specific frequency to receive the signals from the interrogator and transmit (for the active tags) or reflect (for semi-passive or passive tags) the signals. Antenna can be formed as a spiral coil, single dipole, dual dipoles, or a folded dipole. The antenna is usually made out of copper, aluminum or silver. Substrate is used to hold the components of the tags together. It is typically in the form of flexible material such as plastic, but can also be made of rigid material. Polymers, PVC, polyesters, styrene, paper, phenolics and polyethylenetherephtalate (PET) are all used as the substrate material. Protective overlay of the tags usually consists of the PVC lamination, epoxy resin, or adhesive paper.

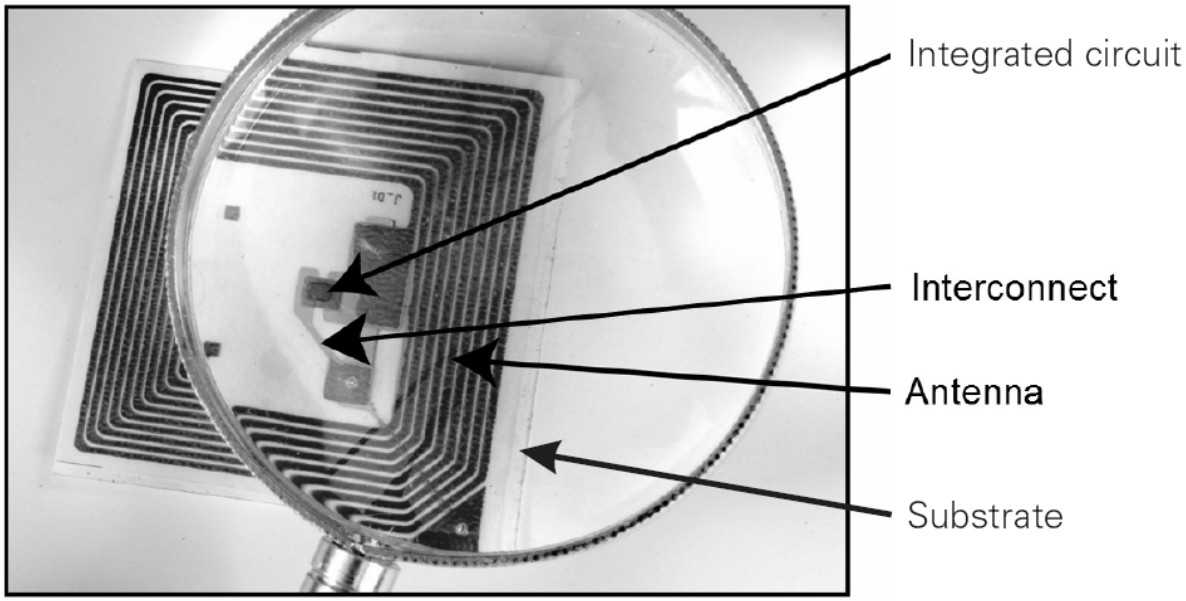


Figure 9. RFID tag components (Brown et al., 2007).

With respect to how tags obtain and use power, classification schemes involve passive tags, semi-passive tags, or active tags. Passive tags don't have a transmitter but rely on the inductive coupling for operating at low to high RF, and radiative coupling for operating above high RF. These tags have a read range of up to 20 feet. Like the passive tags, semi-passive tags don't have a transmitter but reflect the signals from the interrogator because the presence of interrogator is required for both of these tag types to operate. Semi-passive tags have an on-board battery which allows them longer read range. Active tags have an on-board power source, such as a battery which allows them to operate without the presence of an interrogator. It can

also communicate with other active tags without the presence of an interrogator. Because active tags have much more processing power, they may collect and process data prior to sending the data. Active tags typically have read and write functions. An active tag's memory size depends on the application requirements. The read range of the active tags is usually up to 750 feet. RFID tags can operate at low frequency (LF), high frequency (HF), ultra high frequency (UHF) and microwave frequency.

For real-time location service applications using RFID, the system employs an active microwave tag which is powered with an internal battery to assist a back-end system and a server for calculating its position relative to known antenna locations. RFID tags and readers are designed to operate at various frequencies and protocols. Each reader needs to connect to the network (Figure 10). The accuracy of an RFID LBS system depends on the number of readers and their placements. RFID systems use relatively simple approaches to determine which reader is used or accessed.

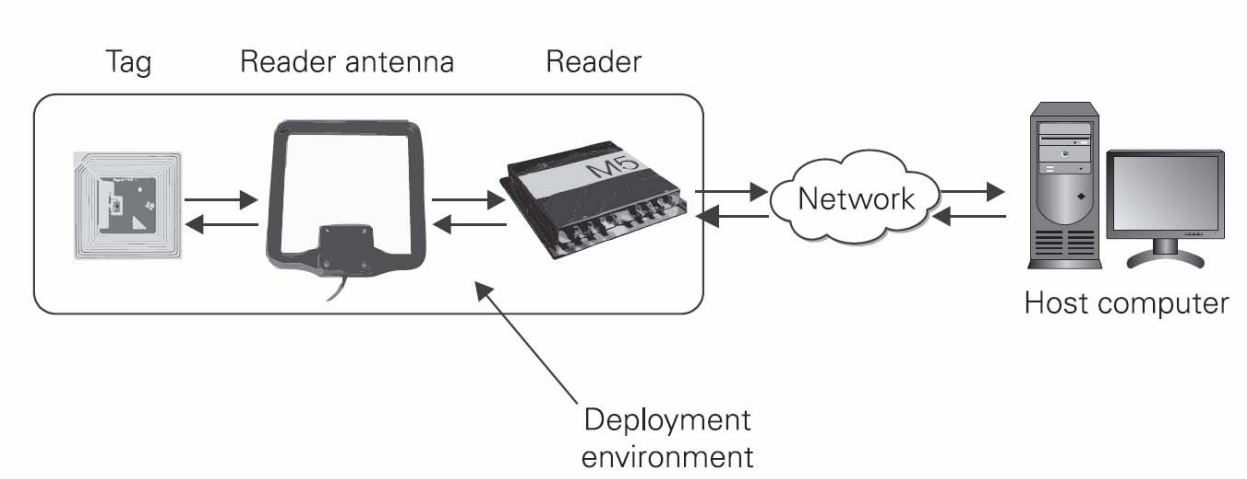


Figure 10. Typical RFID system (Brown et al., 2007)

One of the RFID LBS systems in use is differential time of arrival (DTOA) or time difference of arrival (TDOA) which employs a tag attached to an object that beacons on a given interval or is awakened upon an event and then beacons. When a tag transmits signals, receivers within the range of the tag record the specific tag's ID. This information is then passed to a location processor that determines the difference among the receipt times of at least three receivers. This allows the processor to triangulate the position of the tag (Figure 11).

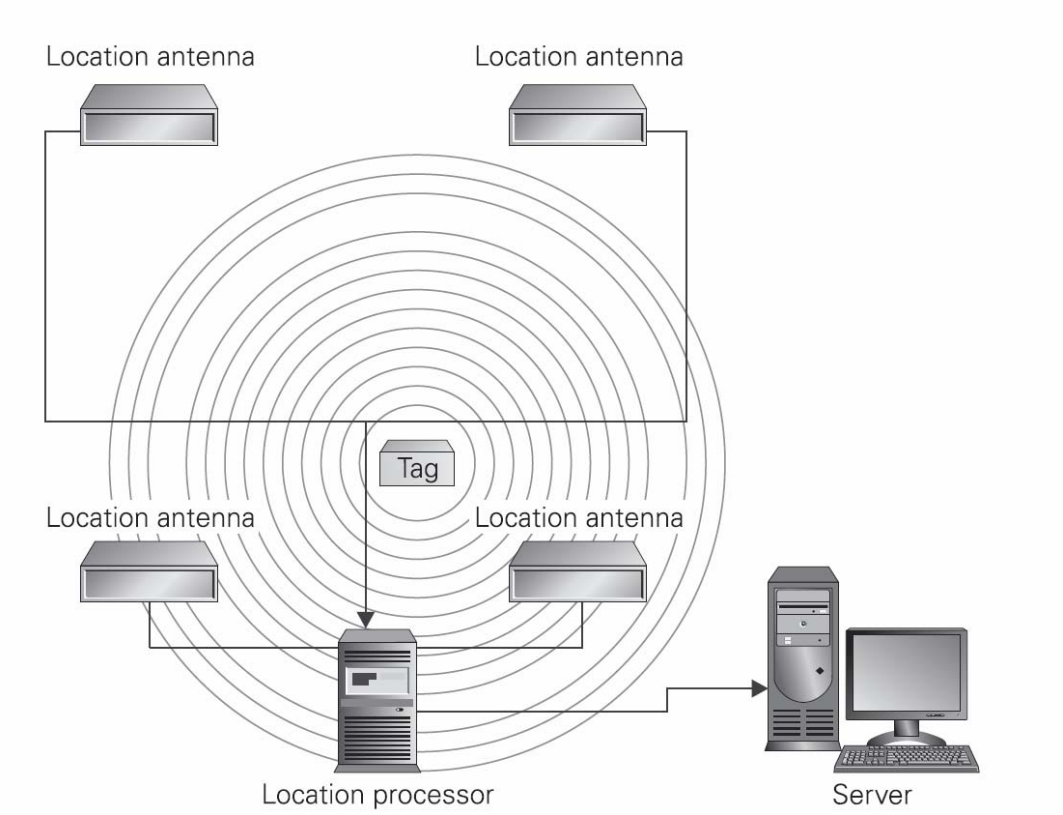


Figure 11. Differential time of arrival system (Brown et al., 2007).

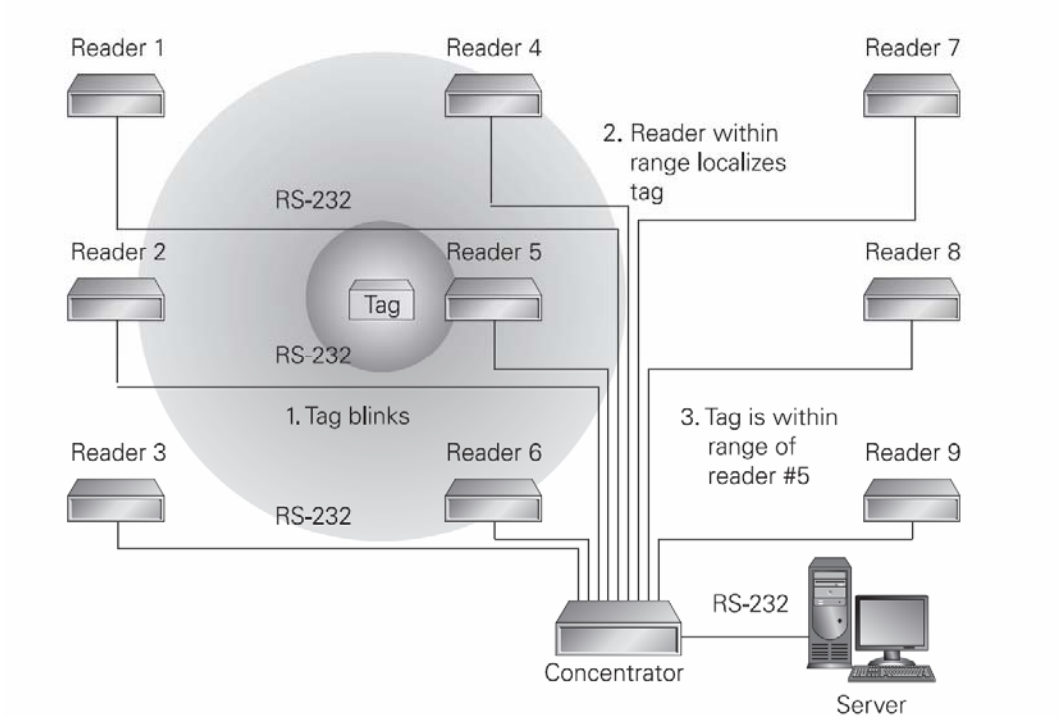


Figure 12. Received signal strength indicator system (Brown et al., 2007).

The other system commonly used is received signal strength indicator (RSSI) which is commonly used with Wi-Fi (IEEE 802.11) wireless networks. Based on signal strength, the system determines to which receiver is the closest and then provides an approximate location. The accuracy of this type of system depends on the granularity of the receivers upon installation. Closest access point (AP) or reader provides users with the granularity equal to the total coverage area of a single AP or reader. It is generally the simplest and coarsest way to locate a device of user (Figure 12).

Time-of-flight (TOF) ranging systems operate by waking up tags on a given frequency, and measuring how long it takes the tag to respond on a different frequency which gives the system an approximate distance from the tag to the antenna.

These systems may be used in combination with triggering devices such as proximity sensors which typically use ultrasonic waves to detect the presence of an object in the area. An object which passes close to the proximity sensor will reflect the ultrasonic waves back to the unit which can then derive the approximate distance based on the time of travel of the waves. To achieve greater accuracy, MIT Cricket also uses combination of RF and ultrasound hardware to enable the listener to calculate the distance to the beacons, from which the closest beacon can be determined.

In hospitals, staff may attach small RFID tracking devices to all newborn babies that are born. This device is very difficult to remove, and sensors within the area of the hospital track the location of the babies. This makes it difficult for anyone to steal babies, which does happen in some hospitals. At the airports, active tags have been introduced to track ground service equipment and people. Passive RFID tags are also used for baggage handling and tracking. These are only few of the many applications of the RFID tracking systems.

802.11b (Wi-Fi) System

RF-based systems mostly use IEEE (Institute of Electrical and Electronics Engineers) 802.11 wireless local area networks. The 802.11 family of standards is the basis for wireless access network technology based on the Ethernet. 802.11, and has a number of substandards. 802.11b or Wi-Fi is a standard for wireless LANs operating in 2.4 GHz spectrum with a bandwidth of 11 Mbps. 802.11a is a different standard operating in the 5 GHz frequency range with a maximum

data rate of 54 Mbps. 802.11g is for WLANs operating in the 2.4 GHz frequency with a maximum data rate of 54 Mbps. Both 802.11b and 802.11g operate in 2.4 GHz ISM (industrial, scientific, and medical) band enacted by the United States Federal Communications Commission (USFCC). Although the standard of the measurement technology for which positioning was developed is 802.11b or Wi-Fi, these positioning technologies should work for all 802.11 substandards. 802.11 networks can be configured using an access point that bridges to the fixed network, usually Ethernet (IEEE 802.3).

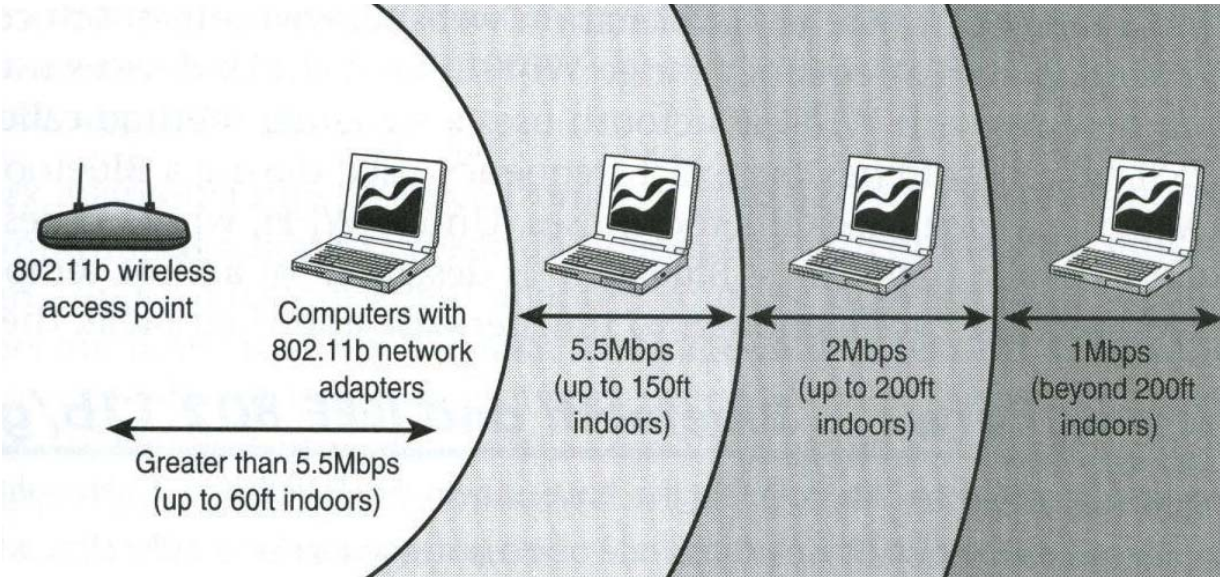


Figure 13. Reduction of signal strength and rated speed with distance (Mueller, 2006).

At short distances, as shown in Figure 13, 802.11 devices can connect at top speed (up to 11 Mbps); however, as distance increases, speed decreases because the signal strength reduces. The strengths of the radio signals arriving from more AP's can be related to the position of the mobile terminal and can be used to determine the location of the users. The AP's are configured to determine the signal strength and pass the information onto a back-end system for processing. The higher the signal strength, the closer the transmitting device is presumed to be to an AP. Changes in the signal strength as the wireless device moves about the area allow for the real-time tracking. It is possible to track the positions of multiple locations in the defined space using a single access point; however it significantly reduces the accuracy. Roaming between the AP's is generally supported. Typically, the AP's are coupled to one or more network servers which manage the traffic flow. The range of communication between the AP and the mobile device

typically depends on the product type, multipath, and number of users. A typical coverage range ranges from 100 to 300 feet. In open areas, access range from Wi-Fi access point is approximately 980 feet. In most WLANs, it is very unlikely that users will be within range of more than four or five access points as they roam through the facility. A higher density of access points will cause a significant amount of inter-access-point interference which negatively affects optimization of the wireless network. Both Ekahau and Aeroscout allow integration of their products with the existing Wi-Fi infrastructure.

Bluetooth

Bluetooth is a short-range radio standard that allows various wireless equipment to communicate over relatively short distance (up to about 100m). Bluetooth functions in the free ISM 2.4 GHz band which is also applied to other technologies such as 802.11b/g and microwave ovens. Unlike Wi-Fi devices which stick to a predefined channel, Bluetooth devices hop though 1600 frequency channels per second, of which 800 channels are transmit channels and other 800 channels are receive channels. The channels span 79 MHz with 1 MHz spacing between the neighboring channels. Thus, Bluetooth is designed to be functional even in very noisy RF environments. The goal of adaptive frequency-hopping (AFH) is to allow Bluetooth to coexist with other non-frequency-hopping technologies and interferers in the ISM band. The Bluetooth devices keep static to a minimum over good and bad channels. For example, Bluetooth channels located at the same frequencies as an 802.11 channel will be marked as bad to prevent further interference. Studies show that there is some interference with 802.11b devices, and that 802.11a devices might be an alternative to alleviate this issue.

By integrating Bluetooth positioning technology, BLIP Systems can also provide messaging and web content. Since Bluetooth uses a relatively short-range RF, devices at unknown positions can estimate their positions by proximity to devices with known positions, which means that Bluetooth is able to share the position information with other information. Because Bluetooth works in a relatively short range, the system is limited in accuracy and may not be sufficient for certain applications. In broadcast-based wireless LANs like 802.11, the network topology is determined by the physical distance between nodes, but in Bluetooth, an explicit topology formation process is needed because nearby devices need to discover each other and establish point-to-point link.

AeroScout

AeroScout Wi-Fi positioning technology uses WLANs to locate laptops, PDAs, and AeroScout tags attached to people or any objects or equipment (Figure 14). The AeroScout system uses both TDOA for large indoor environments and RSSI algorithms for tight indoor environments to determine locations accurately.

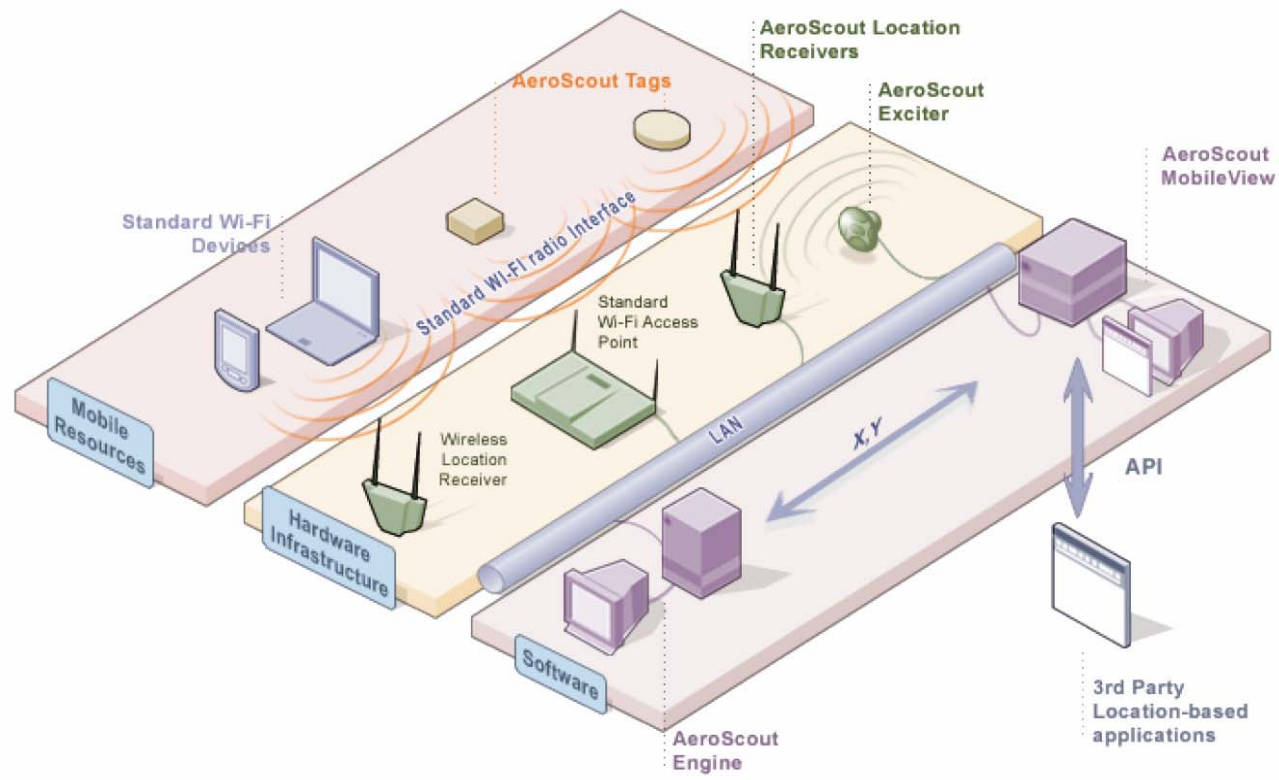


Figure 14. AeroScout architecture (www.aeroscout.com).

AeroScout Wi-Fi tags are long-life active RFID tags. These tags have a battery life of up to 5 years. Battery life of tags can be extended by turning them off when they leave a defined area. Unlike traditional passive RFID devices, AeroScout architecture doesn't require dedicated readers but allows WLAN to act as a long-range reader locating wireless devices and active RFID tags anywhere in the Wi-Fi network. These tags can be located by AP's or readers at a range of several hundred feet. Tags can be triggered at short range by an AeroScout Exciter. This gives an instant knowledge that a tag passed through an area where the exciter is located, and therefore allows for the greater positioning accuracy. Exciters have up to 20-ft range, but up

to eight exciters can be chained and operated as one exciter thus allowing a large gate area or 275 ft to be covered. The tags can be programmed remotely since they support telemetry functions, and exciters may be used to modify tag behavior wirelessly.

AeroScout Engine is a software application which incorporates sophisticated algorithms to reduce multipath-induced inaccuracies. In open area locations, TDOA mode of the Engine eliminates the need for a radio map calibration. The main components of AeroScout Engine are AeroScout Positioning Server, AeroScout System Manager, AeroScout positioning API and AeroScout analysis and design tools.

Ekahau and Location Fingerprinting

Ekahau is a software-based Wi-Fi location platform which uses standard Wi-Fi data network to work. It is the preferred choice for environments with obstructions and multipaths. Ekahau Positioning Engine or EPE (Figure 15) is Java-2 platform that calculates the position of the client device and a center of the Ekahau system. The Ekahau Tracker is an end-user application for monitoring the locations and movements of people and assets. It provides a real-time view of the tracking area with selected objects displayed as icons on a map of the tracking area. The Ekahau Logger is used for storing the historical location information to a log file or database. Other component applications are Ekahau Client which is a network agent program that runs on a client device such as a laptop, PDA, and Wi-Fi tag, and Ekahau Manager which is an application for creating positioning models of the area. Ekahau is also a provider of Wi-Fi location tags which, unlike RFID-based tags, don’t require being in the close proximity of a reader or scanner. This allows tags to be used for continuous tracking as long as the tag is within the Wi-Fi coverage area.

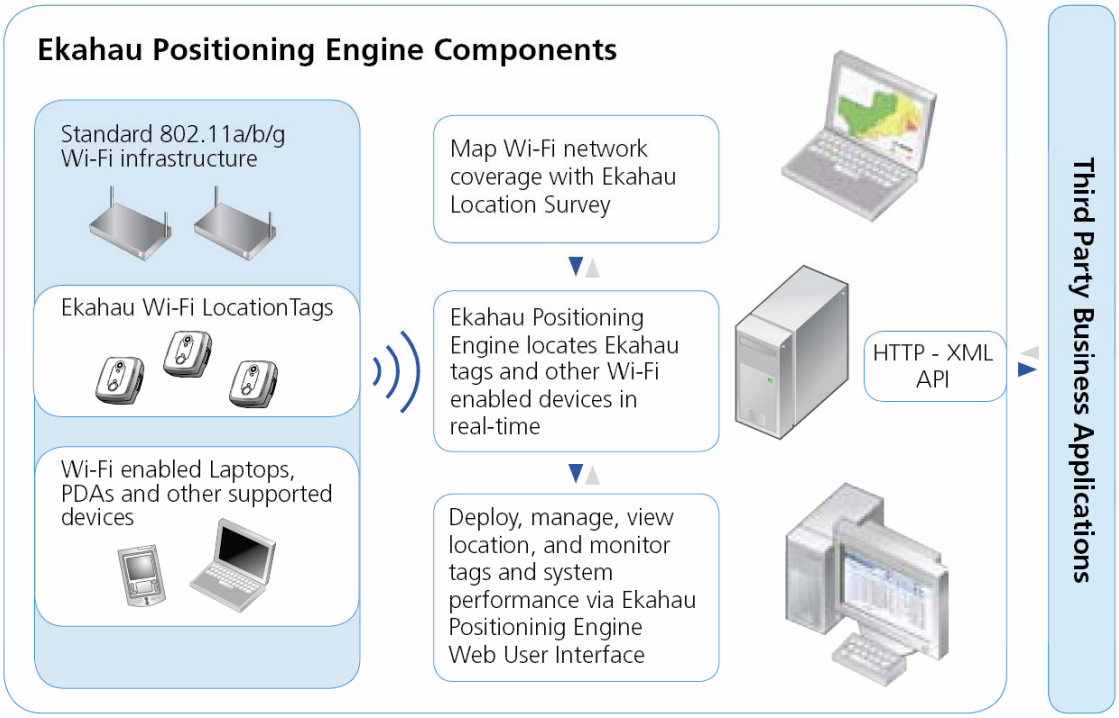


Figure 15. EPE architecture (www.ekahau.com).

Ekahau technology was used in Personal Shopping Assistant (PSA) application which utilizes Wi-Fi networks, and can pinpoint the location of the customer in an aisle at a grocery store. To deploy a PSA to a grocery chain, it costs about $150,000 per store, and this includes hardware, software (PSA and the positioning system), training and implementation. Products like the ones from Ekahau don't ship with any radio maps and may require time-consuming site and system calibration. To perform system calibration and achieve desired accuracy through location fingerprinting (pattern matching), this system requires a detailed site survey to be performed before the positioning system is placed into operation. RF fingerprinting determines how a signal will be received at every grid point within a coverage area, and results in the so-called radio map. A grid point can be as granular as half a foot. Whereas triangulation techniques don't rely on pre-existing database search, the signal strength propagation and path-loss conditions of the surveyed site are measured to compile a location fingerprinting database of received signal strength (RSS) values used for the database correlation and pattern-matching algorithms. The measured RSS values are compared with the database to obtain the mobile device's location. Location fingerprinting methods account for the modified signal strengths in

different locations of the RF coverage area due to reflection, diffraction, and scattering (Figure 16). The fingerprints of different locations are stored in a database and matched to measured fingerprints at the current location of a mobile device.

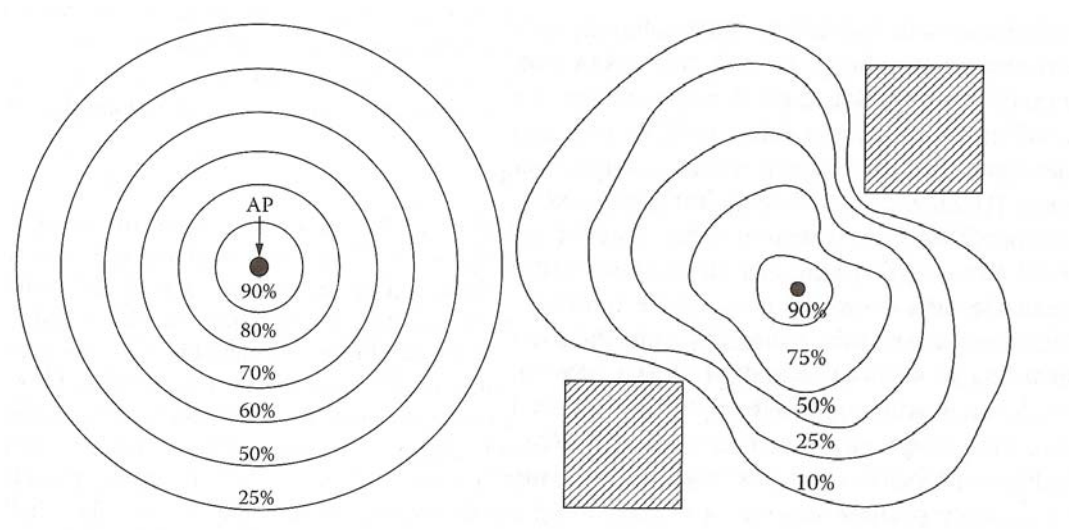


Figure 16. Signal strength pattern without (left) and with (right) interference (Kolodziej and Hjelm, 2006).

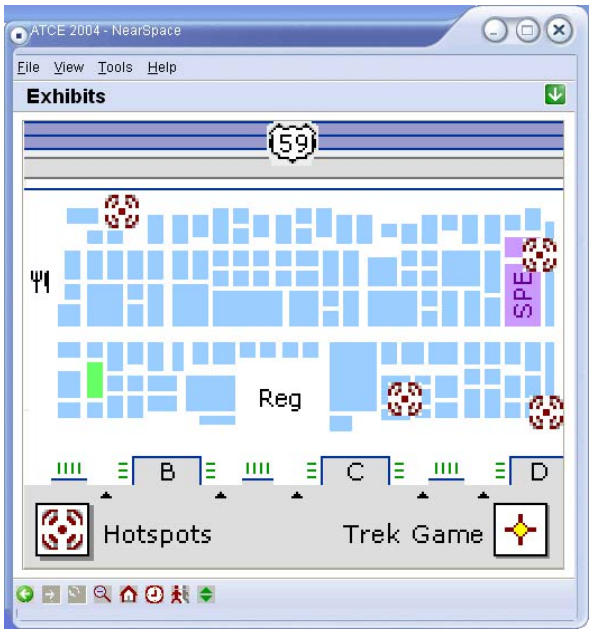
Positioning methods based on location fingerprinting achieve accuracy within 10 ft (Ekahau system achieves 3-foot accuracy). AP's use RF fingerprinting technology to collect information about RF topology in any part of the proposed coverage area via a site survey, which creates a database containing information about how every part of the coverage area appears to all AP's. When there is high multipath environment within the proposed coverage area, other techniques that use triangulation and trilateration can yield highly erroneous results. Although it is generally recommended that at least three AP signals are provided at each location, location fingerprinting techniques allow Ekahau Positioning Engine to locate a device with only one AP, but a minimum of three signals are needed to achieve better than 5m (15 ft) average accuracy in locating the client device. Location fingerprinting methods don't require specialized hardware at the mobile devices, but they do require specialized hardware in every access point to correlate the multipath characteristics. Both AP's and the handsets or the mobile devices can scan the environment, determine the signal strength and match it to the database in order to determine the position of the client or handset.

Using the Ekahau system in a dynamic environment requires recalibration. This may incur a significant cost in the comparison of stored and measured information, especially if the area to be covered is large. An advantage of the system is high accuracy, however disadvantages may include high overhead since site survey and measurements have to be repeated every time the facility environment changes. Ekahau site survey and calibration generally requires up to 1hr/10,000 ft^2 (Kolodziej and Hjelm, 2006).

Mapping and Data Management

Personal digital assistants (PDAs) have been successful as a handheld platform of choice, typically using Wi-Fi as the connectivity method. Handset-based hardware in the handset will usually be freely accessible to a local application, allowing a mobile client application to access the position data as frequently as desired.

The mapping infrastructure is needed for exploration and navigation of the place. We generally talk about two types of the mapping and modeling of user's position: geometric and symbolic. When available, geometric maps are the best means of depicting location information, but alternative way may be presenting location data based information by text (i.e. in a symbolic way). In Wi-Fi infrastructure-based positioning system, the central task of middleware is to deal with the data management. This means that application servers are situated between the communication network, GIS databases, and the end user or client. Spatial GIS servers provide data about static or mobile objects and users, and upon request are set to return their location. Databases are used to store static information such as building layouts and coordinates of access points. Typically, once a digital form of the space is formed, a statistical strength model of different locales is defined. An indoor spatial information database might be created from digital maps such as CAD drawings of the facility. A set of tools is generally required to allow the data conversion to create maps from CAD files which would be useful for navigation. NearSpace Workshop contains a variety of tools for importing and creating a combination of raster and vector data. Figures 17 and 18 show some of the applications by NearSpace. Kolodziej and Hjelm (2006) are providing more information on how to create indoor maps from CAD data.



Figures 17 & 18. Examples of NearSpace mapping applications for PDA and laptop (www.nearspace.com).

The positioning information that is obtained from the local positioning systems is managed within databases, from which the application server will access the data. Relational database management systems (RDBMS) are typically used to store location data. Alternatives to RDBMS exist, in the form of object-oriented databases and XML databases (which may be adapted to RDBMS). In cases where there is a central engine that manages queries and tracks distributed data, the Structured Query Language (SQL) can support all database management operations as well as object related data modeling. These enable users to store and manage location data, as an object, with data from sources such as computer-aided design (CAD) in the same database. Oracle 8 Spatial and ESRI ArcSDE are examples of spatial databases that store geometric objects as abstract data types (ADTs) in feature-based tables within the RDBMS.

Wi-Fi WLAN Site Surveying

The purpose of the site survey is to collect sufficient information to locate, install and configure RF parameters of the AP's and antennas. It is performed by walking the proposed coverage area of the planned network. Results of the site survey are the site survey report which describes in detailed RF coverage characteristics of the site as well as the recommendations for

the proper placement of the AP's in order to avoid inadequate RF coverage and poor signals in some areas (i.e. dead spots). Site survey utilities, like the one shown in Figure 19 may be loaded on a pocket PC or a laptop and allow for walk-through of the site and spot-checking of the RF signal strength, quality, and loss. Some of the advanced site survey systems are also available from AirMagnet, Netgear, Intel Centrino, Ekahau, etc.

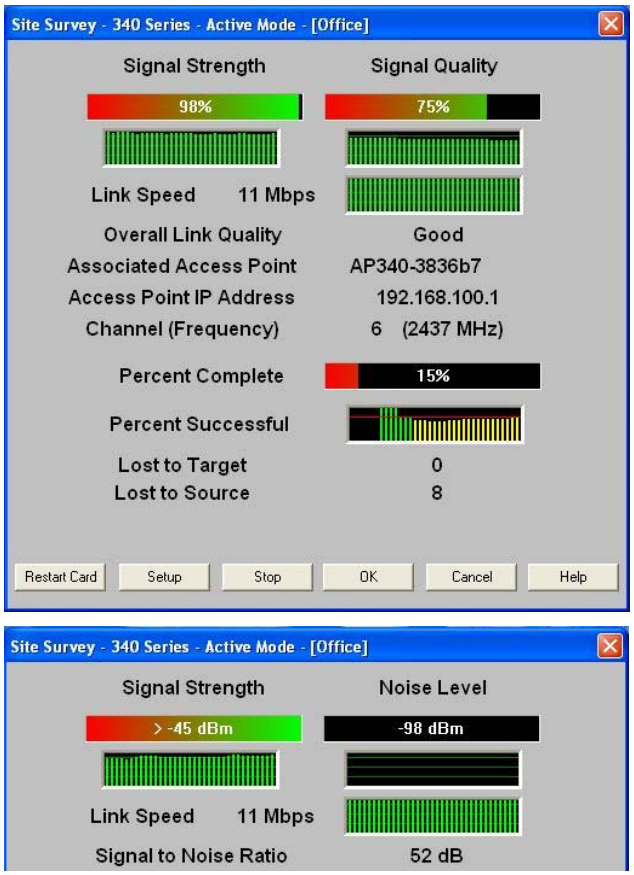


Figure 19. Cisco Aironet site survey utility (www.cisco.com).

As shown in Figure 19, the important result from the site survey is a signal-to-noise ratio (SNR). Ambient RF noise or noise floor occurs in the atmosphere and increases as the electronic devices are added to the environment. To properly receive a signal, signal strength must be greater than the noise level. It can be compared to trying to listen to another person speaking in a noisy environment. The speaker would have to raise the voice to a level strong enough to be heard over the surrounding noise.

The steps involved in the site survey related to the creation and maintenance of the local positioning system (LPS) usually consist of (1) performing the site survey by deploying AP's by trial-and-error (in case of the non-existing Wi-Fi infrastructure) and checking the resulting RF characteristics of the site (this step involves the creation of the signal strength model, also called the radio map); (2) creating a positioning model by overlaying the measured data or radio map with the map image or the site plan (e.g. in BMP, PNG, JPG or some other format); (3) calibrating the positioning model (training process); (4) AP placement and configuration when there is no existing infrastructure already in place; (5) tracking and (6) periodic accuracy tests or maintenance.

Recommendations

This section presents the results of questionnaire responses received from two vendors of the LPS for mining environments – Mine Site Technologies and Extreme Endeavors. The vendors were provided with information about the current conditions of the Pollyanna No. 8 underground mine, and goals and requirements of the tracking system described in the introductory part of this report. Their systems are custom built for the rugged conditions. The responses are provided in this report in a similar format as they were received from the Mine Site Technologies and Extreme Endeavors.

Mine Site Technologies

Mine Site Technologies was established in 1989 with the focus on the underground communications and has also become increasingly active in open pit communications. Mine Site Technologies have their technology used in over 350 mines in Australia, Canada, United States, China, Peru, Sweden, Chile and Tanzania. Mine Site Technologies recommends implementation of the Wi-Fi version of their Tracker Tagging System (Figure 20):

- Installing Mine Site Technologies' ImPact Wireless Access Points at strategic locations. This creates zones in the mine, and depending on the resolution of location required determines the spacing between APs.
- Issue Wi-Fi RFID tags to employees. These are available in two versions:
    - ✓ Incorporated into the miner's cap lamp (the ICCL cap lamp), and

- ✓ Self Contained Tags with their own battery pack that can be carried in a small pouch by miners.

- Software to process and display miners location in zones underground. This can be shown in graphical form on a mine map as well as lists for reports, etc.

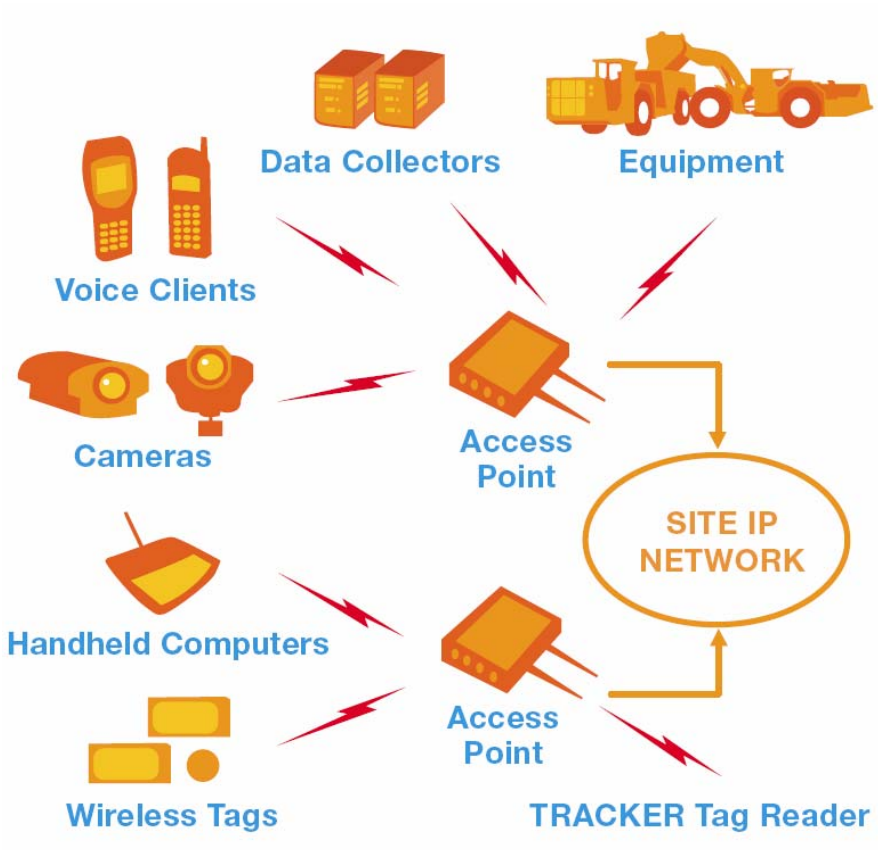


Figure 20. Mine Site Technologies system (www.minesite.com.au).

The solution uses 802.11b/g RFID tags and 802.11b/g ImPact access points (Figures 21 and 22). The AP's link to a mine's fiber optic system already in place or uses its own fiber optic back-bone with specially made composite cable that contains not only optic fibre cores, but also power cores to carry 24 VDC to power the AP's. It is proven in use at coal and non-coal mines already. Though the basic elements use open Wi-Fi standards, critical system components (such as the AP's and tags) are specifically designed for underground use to ensure their reliability and, most importantly, ease of installation and maintenance. Also, the composite data/power cable greatly simplifies installation and maintenance. The only drawback currently is that AP's are not approved Intrinsically Safe (IS) when mine ventilation system is disrupted. This hasn't stopped

mines from installing them because there are distinct benefits in the day to day operation of the mine, and knowing whereabouts of people at the time of an incident is still a vast improvement. Mine Site Technologies have the APs submitted for approval and hope this will be completed by May 2008.

Accuracy depends on AP spacing. Mine Site Technologies can also add a device known as an Exciter at critical points that gives accuracy down to 2 to 4 feet around the device. Due to the linear nature of mines, the ability to triangulate more accurate locations is limited, if not ruled out. According to Mine Site Technologies, installations to date do not need accuracy down to feet, and as long as the area where the workers are located is known, it is sufficient for the mine's management and emergency preparedness requirements. Mine Site Technologies' data sheets, brochures and specifications provide information about the ImPact APs and Composite Cable, and RFID T3 tag (based on AeroScout T3, though is housed in Mine Site Technologies' approved power supply pack).

Figures 21 & 22. ImPact AP and RFID tag (www.minesite.com.au).

Mine Site Technologies also supply VoIP phones to mines for communication with miners underground. Mine Site Technologies also supply a range of other communication devices to complement the Wi-Fi based systems to ensure system redundancy in all circumstances. VoIP phones would be adequate but they do rely on the infrastructure to be operational, something which is certainly not guaranteed after a major incident underground. Mine Site Technologies also recommend the installation of their PED System to complement the two-way, infrastructure dependent Wi-Fi system. PED is currently a one-way pager that transmits signals directly through rock strata (through-the-earth or TTE) to a miner underground. To date, PED is the only

TTE system in actual use at mines. PED is being installed at most coal mines in Australia and is their primary emergency warning system. Where surface access allows, the PED antenna system can be set up on the surface to transmit text messages to miners underground. Mine Site Technologies are currently developing two-way PED as an upgrade to the current system. This will allow miners to communicate with people on surface by signals being sent through-the-earth between the miners and the surface and vice versa. The system is planned for release in 2009.

Extreme Endeavors

Extreme Endeavors is a small business, located in rural West Virginia and is currently designing a communications system allowing a stand alone communication device for independent deep miner position tracking system. They have formed a partnership with Comtech Mobile to enhance their system with 900 MHz communication system, providing a full complement of communications technology, which can provide a safer and more effective operating environment for the mining community.

Extreme Endeavors' solution to the Pollyanna No. 8 underground mine involves a tracking system by Extreme Endeavors coupled with a communication system provided by Comtech Mobile. Extreme Endeavors was selected by the National Institute of Occupational Safety and Health (NIOSH) to develop the next generation miner tracking system. In this work, Extreme Endeavors has integrated advanced Reverse RFID (RRFID) tag and inertial sensor technology to create a dependable wireless location tracking system for underground applications. The basic approach of this technology is as follows:

- Miners are equipped with inertial sensors (i.e., accelerometers and gyroscopic inertial measurement units);
- Install RRFID tags in the mine to maximize the coverage and accuracy of the positioning and store very accurate location (coordinate) information along with other necessary information in the tags;
- Equipment such as mantrips, loaders and haul vehicles are equipped with RFID tags. When these RFID tags are detected the tracking system will move to vehicle motion mode and track the motion of the vehicles;
- Use the location information provided by the RFID along with inertial sensors to produce highly accurate location information.

The RFID system uses a tag database which stores information such as exact location, tunnel zones, nearest exit, etc., corresponding to the tags available in the mine and part of a digital map of the mine. The low cost RFID tags are installed in the mine as opposed to costly readers where the operational environment is very harsh due to low temperature, humidity, dusts, etc.

Extreme Endeavors utilize non-proprietary communication interfaces on the equipment to promote integration of multiple types of systems to provide the proper redundancy. For example, if miners must use an emergency shelter and their primary communications system is down, a through-the-earth communication system can be tapped into at the emergency shelter, thereby ensuring constant communication. This system is compatible with the NIOSH reference design communications system and supports automatic failover in the event of an explosion or other degradation of the primary communications link.

Because all of the position calculations would be performed on the miner's mobile unit, Extreme Endeavors can develop additional products to display the miner's location. For example, the miner could pull a small computer screen out of the pocket to show his location within the mine. Furthermore, a heads-up display could be constructed that would direct the miner out of the mine if all the passages have been filled with smoke from a fire. This heads-up display may also be useful for a mine rescue team. Some of the benefits to Extreme Endeavors system are:

- All data processing is done on human worn processors, thereby reducing bandwidth requirements to transmit data out of the mine;
- Communication independent architecture allows switching communication systems to, for example, 900 MHz data link, and if 900 MHz fails it is possible to switch to a through-the-earth communication system;
- This system is compatible with the NIOSH reference design communications system, and supports automatic failover in the event of an explosion or other degradation of the primary communications link;
- Compact, lightweight;
- Ease of maintenance and installation;
- Fits with mine's existing methods of work;
- Designed in the middle of coal country (Philippi, WV).

The main disadvantage of Extreme Endeavors tracking system is a larger upfront cost. While it may have greater accuracy and reliability over other systems, it will be an investment in equipment up-front. However, once the equipment is purchased, maintenance and additional cost should be minimal. As the mining team advances, new RFID tags must be attached to the heads of roof bolts. Attaching these tags requires some manpower and change in regular roof bolting procedures as well as updates to the miner tracking computer system due to the newly added tag locations. Although Extreme Endeavors has been working to ease this burden, some amount of system maintenance and upkeep will be required.

The accuracy of the Extreme Endeavors tracking system is based on how many RFID tags are secured to the roof. Every time a tag is encountered, automatic correction occurs. The tags are being developed to attach to roof bolts. It is recommended to put the tags at every 100 feet to achieve good accuracy.

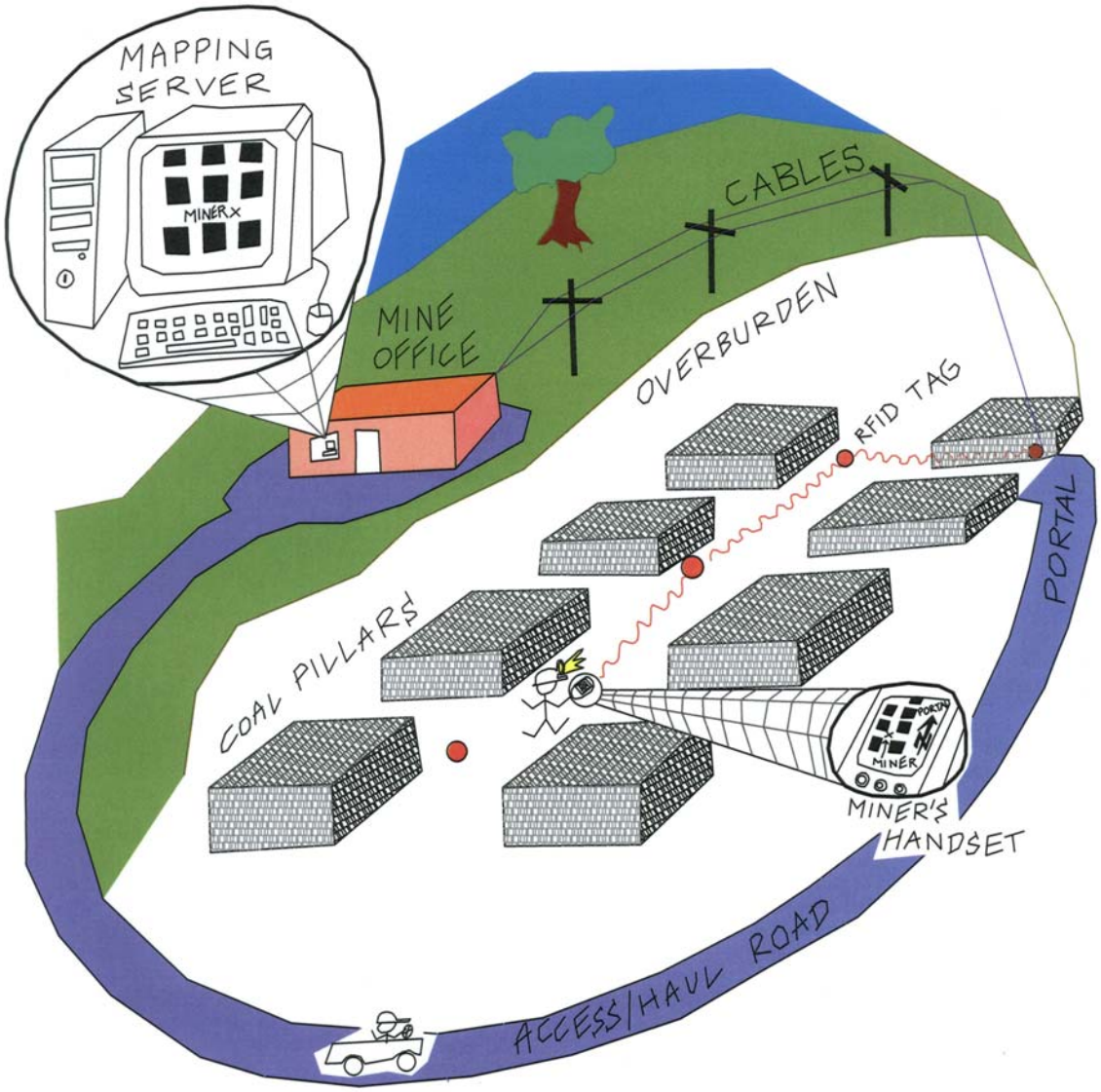


Figure 23. Illustrated reverse RFID (RRFID) system

The tracking system would communicate throughout the mine and transmit data to a standard PC that can be located either at the mine office or monitored remotely (Figure 23). The PC would show a map of the mine and dots on that map will indicate the miners' location. Data will be updated to this PC every second to thirty seconds. This stand-alone PC would not run any other software on site.

A software package is under construction to run on a Windows platform and display the location of multiple miners on mine maps. This software will use DirectX controls to allow the mining companies' AutoCAD maps to be imported into the program. As a miner enters the mine,

his name will appear next to an indicator showing his/her location. As the miner moves, the dot and name will move across the map on the screen. The user will be able to click on the dot and see a live display of information such as the direction he is traveling and any additional data transmitted from instrumentation (e.g., the future plans include physiological information). The software will have "emergency button" that resets everything and shows the entire mine and the miners' locations. The software will allow selection and display of particular miners or classes of miners (for example, shift foremen or electricians). An additional feature of the software is being able to send corrected location data to the miners. For example, the software could observe that the dot is crossing through a coal pillar and send corrected information to the miner's tracking device, thereby providing the correction at the source.

The Extreme Endeavors system is a communications independent system that can show the location of the miner at any time. This is one of the primary benefits to this system. An inexpensive PDA or small ruggedized tablet computer would allow each miner to view his/her location when necessary while in underground mine works.

The proposed solution is failover compliant on a mine explosion and implements a mesh topology via duplicated, self-connecting communication paths. It consists of 900 MHz wireless nodes at 100-foot intervals. This implies a total of 175 nodes for the 3.3-mile long passage in the Polyanna No. 8 Mine. These nodes tie to a fiber optic data cable for normal communications, and high-frequency (HF) transceiver (a device that has transmitter and receiver, in this case tags) for the failover case.

Conclusion

This feasibility report evaluated the current advances in the real-time location services (RTLS) technology in order to determine their applicability and limitations to the room-and-pillar underground mining at the Pollyanna No. 8 Mine in Oklahoma. Results are summarized in the following paragraphs.

RFID systems may be the best choice when the area to be monitored is relatively small and can be instrumented with readers at a moderate cost or if the requirement can be met by monitoring just a small number of key locations. In the case of Pollyanna No. 8, it is highly desirable to have as high coverage as possible. RTLS reader costs about $3,000 (Year 2004

figure). A significant disadvantage is that RFID reader devices do not have a communication network that supports exchange of positioning information.

In terms of infrastructure costs, the IEEE 802.11 systems that use an existing WLAN infrastructure could yield very low incremental cost if the accuracy requirements can be achieved with existing infrastructure and minimal interference level. Costs associated with Wi-Fi are minimal (especially if using existing hardware) and affordable for Bluetooth and dedicated RF. Even in the case of Pollyanna No. 8 Mine which doesn't have an existing infrastructure in place, from an economic standpoint, it may be preferable to employ Wi-Fi or IEEE 802.11 WLAN networks to determine the position of users. Because Wi-Fi is widely used across a broad variety of mobile devices, this positioning technology is more available and standardized on the market and allows for upgrades of the wireless infrastructure if needed. Wi-Fi networks, if properly installed and configured also support a wide variety of client devices such as laptops, PC tablets and PDAs. Wi-Fi tags are slightly more expensive than RFID tags at $100 a piece. The costs of RF tag location systems generally consist of three components: the tags, the infrastructure, and installation. Since pricing is somewhat commercially sensitive most vendors of wireless networks and local positioning systems were not in a position to release such information. Based on the Wi-Fi-based solution recommended by Mine Site Technologies, and depending on final system specifications and configuration, the total cost of a system by Mine Site Technologies to track miners in Pollyanna No. 8 Mine would be between $60,000 and $100,000. The cost includes all system hardware, software, installation and training. For 22 users in the mine which is a part of the worst-case scenario this would result in the investment of around $2,700 to $4,550 per user.

Projects by AeroScout which is partially funded by the Cisco Systems and Intel Corporation include Wi-Fi networks and usually run in the several hundred thousand dollar range. The current cost of their RFID tags is approximately $65 for AeroScout T2 tags and $75 for AeroScout T3 tags. Since the requirement of the LPS is generally high-update rate, occuring in real time, power consumption and battery capacity may be an important consideration in selection of tags. Other important consideration is the overall cost of the positioning application. For example, the cost of Ekahau Positioning Engine software is about $6,000.

Site pre-survey was performed by the authors of this report to determine if interferences would present significant issues in the existing mine. As described in the discussions about the

existing local positioning systems and the site surveys, there are developed systems which measure and account for interferences through the use of site surveys and creation of radio maps. However, it is believed that the high-voltage line running through the underground mine would not cause the tracking system to become unusable or function poorly. Electromagnetic radiation of 60 Hz which is associated with the normal alternating-current (AC) electricity or any other low-frequency radiation with frequencies in the range of 1 to 1000 Hz should not cause the site survey measurements to result in non-permissible signal-to-noise ratios (SNR). Signal strengths produced by the wireless equipment have much higher strength than noise produced by the high-voltage lines.

Other than use of Wi-Fi networks, the solution recommended by Extreme Endeavors appears to be promising in obtaining low-cost and effective RTLS solution. This solution is still in the development phase under the vendor's contract with NIOSH. However, once developed, it may be highly desirable for the use in the mining industry, including Pollyanna No. 8 Mine.

In conclusion, it is believed that the technology developments have allowed the installation of sufficiently accurate LPS in the underground mines such as Pollyanna No. 8 Mine. The solutions described in this report are technologically feasible. From an economy standpoint and addressing the question of financial feasibility, as time brings new developments, the technology and mining community becomes more interested in the LPS technologies. It is highly probable that the lower costs associated with these systems will allow the average and small-scale mine operators to adopt the technology as part of their already accepted geospatial technologies and applications.

Acknowledgements

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