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Master Thesis

Constructing a position finding system model in underground installations

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keywords:
underground
indoor positioning
smartphone

short summary:
Following document investigates position finding system model based on network of reference points using Bluetooth Low Energy technology and consumer grade smartphones as a system clients.

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Contents

Streszczenie

Celem pracy jest stworzenie modelu systemu ustalania pozycji w instalacji podziemnej z poziomu osobistych urządzeń mobilnych klasy smartphone. System jest dedykowany osobom znajdującym się wewnątrz tej instalacji. W pracy omówiono kwestie wymagań wydajnościowych, niezawodności i precyzji systemu ustalania pozycji. Na bazie analizy dostępnych rozwiązań została zaproponowana koncepcja modelu wykorzystująca kilka źródeł danych dostępnych w korytarzach poziemnych obejmująca koncepcję nawigacji inercyjnej na bazie odczytów z sensorów urządzenia klasy smartphone oraz jej korekty na bazie odczytu mocy sygnału RSSI modułów radiowych w technologii Bluetooth Low Energy będących punktami odniesienia. W ramach pracy przeprowadzono próbną instalację zaproponowanego modelu w korytarzu dawnej kopalni węgla w Wałbrzychu i przeprowadzono testy.

Abstract

The purpose of the work is to create a model of position finding system for underground installations accesible from the level of personal smartphone devices. System is dedicated for people using customer class smartphone inside this installations. The paper discusses the issues of performance requirements, reliability and precision of the positioning system. Based on the analysis of available solutions, the concept of the model using several data sources available in the aboveground corridors has been proposed. Concept include inertial navigation based on smartphone device sensorics and signals strength analysis of Bluetooth Low Energy radio modules that are used as a reference points. As part of the work, a trial installation of the proposed model was carried out in the corridor of the former coal mine in Wałbrzych. Results from tests confirm correctness of assumptions stated in requirements.

Chapter 1

Goals and thesis scope

Following document investigates position finding system implementation basing on consumer grade smartphone and network of reference points using Bluetooth Low Energy technology.

As part of the work, there are presented currenty known position finding solutions within underground environment, available technologies and a method of position finding for consumer grade smartphones in underground installations is proposed. There are presented test cases and experiments supported by data analysis from measurements of given factors of the solution. Experiments are focused on stability, repeatability, accuracy and reliability factors. The work do not discuss the mining model representation but general architecture and data exchange model. but there are proposed soluin terms of the location of the reference points, the location of the miner (system user), the safety points and the evacuation exits. The model should allow both the user to navigate to the nearest safety point, taking into account the current state of the corridors, and to allow presentation of the current position in graphical form. As part of the work, a complete model of the solution are be proposed along with the prototype of application for the mobile device. Finally, there are proposed future works that would base on a concept of integration of the location system with the function of remotely updating corridors. There are be provided example use cases.

Chapter 2

Underground envioronment description

Description of:

- Construction (very briefly):
  - how can look like: from complicated (room and phillar) to simple (tunneling)
  - distances
  - how big it is: corridor diamensions, room diamanesions, etc.
- Conditions in therms of light and air.
- What wireless communication methods are available?

Answer questions:

- if we need the navigation in whole installation? if yes, why?
- if we need the navigation only in some places inside installation? if yes, why?
- what factors may require from navigation system its extensive lifetime?

2.1. Underground installation characteristics

This section covers a short description of underground installations in general that are the environment for the positioning system.

Underground installation therm is a general description of places such as tunnels and shafts that were digged into the earth in purpose of valuable material extraction, transportation, touristics or other reasons. The common phase in those installations is the phase of their creation. There is a need to digg tunnel or shaft at first in order to reach buried ore deposits or just remove not needed rock. Tunnels and shafts are used in this phase to supply material needed to perform exchavation, for personel transportation and rock transportation to the surface. Mining installations are about continous rock exchavation process (creation phase) while the others, like designed for transporation, ends creation phase and moves to the phase of use and maintenance. Underground installations that can be descibed as a gorup of laneways (main and branch tunnels) and in case of mine: mining areas and mined-out areas.

What is the common in underground installation is that there are no reference objects like plants, horizon or sun. Corridors and chambers are almost identical, in particular if there is room-and-pillar extraction method used. For orientation special numbering is introduced in order to identify corridor and given meter of the corridor.

Symbols are painted on the walls with reflective paint and are regurally repainted. Dust combined from moisture deposit himself on a substrate, the walls and ceiling covering symbols describing the hallways. It worsens the orientation.

As the purpose of underground installation may be different, there are also different environmental characteristics such as diamensions, type of material (rock), amount of dust, how freqent is in use, what means of communication are placed into, what machines (if any) are being used inside. Along greater depths, the work conditions are decreasing. The probability of coal and gas outbursts increases because of bigger gas emission on deeper levels. Underground installations can be affected also by water leaks, coal dust explosions and rock bursts [12]. That is why underground installations are prepared for such disasters as floods, fire, high/low pressure, presence of gas, big carbon monoxide (CO) level, or enormous amount of dust. The another risk is connected to people and material transportation. Poor light and narrow working space causes underground car accidents.

Underground mines, which are characterized by their tough working conditions and hazardous environments, require reliable underground installation-wide communication systems in order to prevent from accident if possible or provide means of early warning of possible disaster [1]. Besides safety purpose, both analog and digital communication is used in order to ensure smooth functioning of workings. For example it is possible to save the machine breakdown time thanks to immediate messages passing from the vicinity of underground working area to the surface for day-to-day normal operations.

With respect of the areas of the underground working activity there are different communication system used. Communication technology in underground installations use wired transmission media (twisted pair, coaxial, trolley, leaky feeders, and fiber optic cables), wireless and through-the-earth (very low frequency radio methods) transmissions. In most cases the communication solutions are based on wired technologies. Wireless communication techonologies are used in places that are inaccessible or in places affected by disaster where wired communication got broken. It is also havily used for communication purposes with modern underground equipment such as self-propelled mining machines. Wireless communication is installed also in underground installations where probability of disaser is low as an extension to wired technology. Commercial tunneling equip thier corridors with wireless communication technologies such as GSM and WiFi in order to speed up communication between executives on tunel construction site and on surface. Tunneling is about digggin a corridors for transportation purposes in difficoult terrains such as mountains or bellow the water. Operations that are performed it high latitudes where gas is not present are safer then in mines which operates deep under the surface.

2.2. Hardware and environmental constratins

State of the art in underground navigation solutions. Theoretical topic.

Phisics related to waves propagation in underground corridor

- Waves difraction, <tłumienie>
- What are known issues related to wireless communication in underground installations

*TO be adapted; book-wcin Requirements stated for communication system for the undeground operations:

- must be intrinsically safe and explosion proof
- should adhere to the ingress protection (IP) standards;
- must be rugged in structure
- must be size flexible
- must have totality in design including cables, power supply unit, base stations, etc
- must be value-added priced;e stations, etc
- must be robust, inexpensive, easy to expand, and enable fast and secure connections

*** The wireless communication systems used on surface cannot be applied straightaway in underground mines due to high attenuation of radio waves in underground strata. Undergorund radio waves propagation envioronment differ also because of

- presence of inflammable gases,
- hazardous environment,
- complex corridors topology (mines case),
- complex geological structures,

2.3. Positioning systems

Position finding in underground installations is a problem that arrised along with the advance in the available technologies. Demand for such functionality comes from two main reasons:

- safety of mine workers,
- the need of tool that will support human and equipment resource planning and distribution.

2.3.1. Safety aspect

Protecting and rescueing people lifes are one of the most important challanges for the underground construction and mining industry since many years. In case of accident there is need to perform appropriate search and rescue actions immediatley as the survival rate decreases rapidly as time passes. As for underground construction and mining industry positioning systems are rather in research stage then in real use, executives doesn't know exact position af miners before accident and how many of them are trapped and how big is the scale of destruction. Currently used techniques for rescueing people after an accident requires to count people that came out to know how many people are trapped and then digg though the falled corridors and perform searching operations that rely on old low frequency technology like GLON. GLON is a polish old low frequency radio solution for finding signal emmited from miners lamp, allowing on detection from a few meters [11]. Personal safety equipment consists of oxygen masks enabling to survive 50 minutes, and lamps with GLON transmitter. In case of accident in copper mine "Rudna" in Poland that had a place on 29'th November, 2016 [10] rescue action started 20 minutes after rock mass movement. Part corridor with chamber for mobile machines and excavation got collapsed. After 1,5 hour it was discovered that there are trapped miners. Rescue team had to dig fallen rocks from both sides of corridor without knowledge where trapped miners are because steel elements from collapsed corridor housing influenced the GLON system measures. Positioning system with online underground monitoring would give immediate information who and were was in time of accident and speed up rescueing operations. Unfortunately there was no such system. Current safety regulations does not take new technology into account. Mines do not know where exactly their miners are, they know only the region.

Modern emergency systems for underground installations provide a set of functions that improves safety and minimise loss in case of accident. Besides the means of emergency situation prevention like preditions of mass movements or presence of gasses, lots of them provide functions that help coordinate miners if they are in the isolated areas to meet each other, guide them to the emergency equipment, exit points or safe areas and ensure that nobody was left in danger place [7]. All of those functions requires good position finding solution in order to provide fast and realiable information even if connectivity is broken.

Positioning system can be used also by people working underground directly from their personal digital equipment[7] as a kind of navigation system which can help to evacuate from underground installation. It could provide information about their current position within mine and there would be given informations about dangerous areas and recommended escape paths in case of emergency.

2.3.2. Business aspect

Another use case for positioning system is that stakeholders want to know where the equipment is placed, how many time it needs to do it's operations, if there are some unplanned breakes in machine work. Delays in case of any underground operations are very costly. Resources monitoring can depict bootlenecks in machine operations may provide informations how to balance the workload in order to make operations smoother and more efficient. Data gathered by positioning systems can be also used in time and cost estimations. Mine stakeholders can see in real time what is the current distribution of equipment what enables them to perform real time coordination of ongoing process parts. In day to day operations information where are located operators and machines can increase production efficency because of less time needed to spend on gethering information about machines position from reports. [9] The positioning systems are mainly used to deliver information to systems that operates above ground. Todays underground operations are partly or fully automated. The process of the operations is monitored and managed remotely from operation centers on surface. Supervior and control of such operations are similiar to that known on above ground process plants which are controlled by SCADA – Supervisory Control And Data Acquisition software systems [7].

Underground construction industry use automation technology heavily in nearly all aspects: safety, work automation, work and environment monitoring, internal and external communication, transport, maintainig ventilation, power or fresh water supply and others. Automated solutions are also used for example to control access to mine like entries for cars and mobile mine machines or for safety purpose to quickly cut off rooms where petrol oil are stored in case of accident or fire detection. Those automated systems can be configured and controlled from places they are mounted under ground or from central systems located above ground where central monitoring and work control take a place. Such centers collect informations distributed by systems and provide information about envioronmental parameters or work performance. Devices and mobile machines that work underground are also connected to that system through means of onboard microcontrollers or computers and wireless network. Thanks to it it is possible to provide to central system work performance information or device health status that can be usefull for service during periodical device checks or repairs. Positioning systems implementations may work togehter with these devices which allows underground operation executives to have a up to date map of current works and processes being in progress. Positioning information can be used also by mobile devices by themselves. Example of devices that make use positioning data are modern mobile machine gateways devices [7] which are kind of black-box devices for big mining machines like loaders. Those devices can use positioning information as a trigger for reports of work efficiency expressed in load - unload cycles (IREDES Performance Profile report).

Nowadays there are available positioning systems for underground installations that can provide aproximate localization of people or equipment.

2.4. Usage of mobile devices in underground installations

Define 'mobile device'

Answer questions:

- If mobile device (smartphone class) can be used in undergorund installations?
- How usage of mobile device in underground installations may differ from usage in normal conditions (outside underground installation)?

Chapter 3

Position finding solutions and applications

* What features should have the model in order to be used for navigation?

3.1. Known solutions analysis

- List of known positioning system in underground installations
- Characteristics of known positioning systems
  - Their concept Advantages and disadvantages
  - How can be used
  - How they perform the communication (physic/hardware aspect)

There are known solutions for location and monitoring people in undergorund installations. They are together named as LAMPS systems - Location and Moinitoring for Personal Safety systems. Those systems use three components in general: *

Positioning systems with respect of the what is the target of acquired data. There can be defined three categories of positioning systems: positioning systems that are dedicated to acquire and transfer information about objects position to systems on surface, systems that are dedicated for on site usage to locate the device inside the underground installation and systems that combine both approaches.

Computer recognise loading and dumping points by data provided by positioning system. It acumulates data about machine speed, distance traveled, time, amount of load that is carring and put into the report which creation is triggered by positioning information.

- Advantages and disadvantages of solutions
- How the solutions fulfil given criteria (ex. how accurate given solution can be)

Possible subsections that will discuss in detail given technologies. Inertial system https://en.wikipedia.org/wiki/Inertial$_navigation_system$

Considering reference points:

- communication technology:
  - Bluetooth - the availability, supported by modern mobile technology,
  - ZigBee,

   - WiFi
   - RFID
   - ... others
- system architecture
   - server - client
   - client - server
   - WSN and IOT
   - Peer-to-Peer

3.1.1. WiFi access points and WiFi fingerprinting

WiFi network infrastructure is a one of the available solutions that can be used as a source of information about current position of the device. The basic solution for positioning with use of this technology is about recognising wireless lan network access points by thier SSID or physical address of network cards [4]. As there exists working position finding solution that base on that technology the accuracy of the solution is about 100-300 meters [9].

What is specific for radio waves attenuation at 2,4 GHz frequency is that their signal is present from relative large distances in mine in compare to the same devices signal range in the open space environment. What is also characteristic is that the signal strength, after its peak close to the WiFi transceiver antenna its going to stabilize in distance about 10m from source and then the signal strength is residing on similiar level up to distance arround 300 meters from its source when it goes down [7].

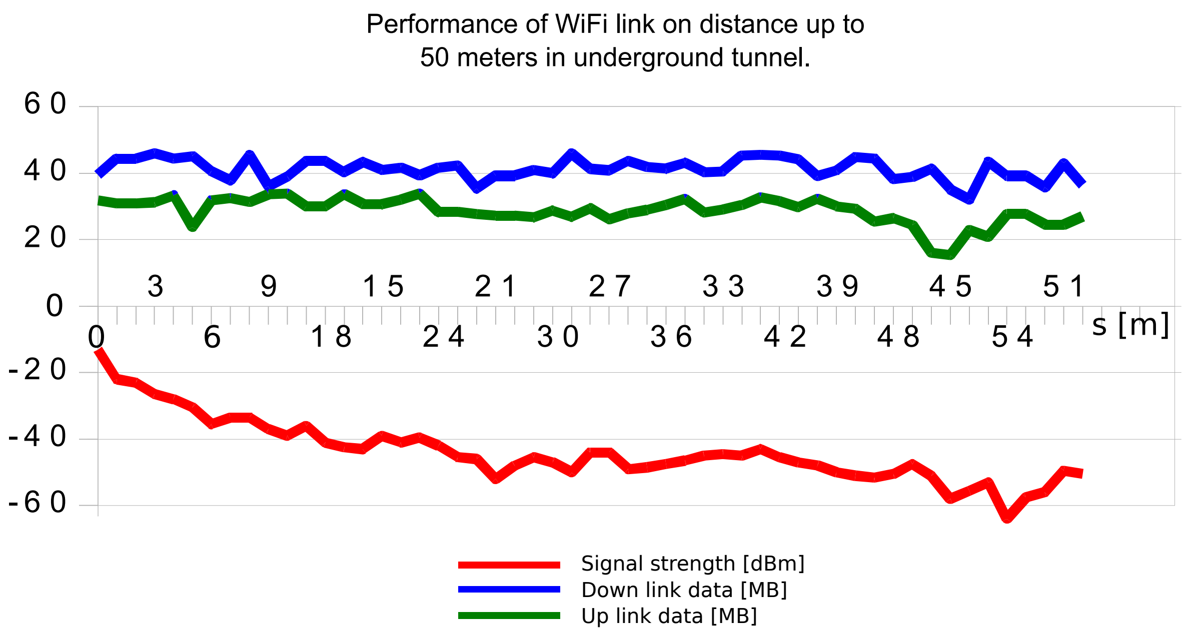

Figure 3.1. Wireless lan throughput and signal strength with respect of distance from the signal source (wireless access point) [7].

On figure 3.1 it is presented how wireless lan link parameters differs with respect of distance between client device and the network access point. Measures presented there are taken from 0 up to 50 meters from signal source. In case of this chart there were presented uplink and downlink throughput measured by amount of data gathered on each testing probe taken each meter distance from the signal source and the related signal strength expressed in dBm units. Values presented on chart are medians of all gathered values and factors for given distance. Test was caried out in straight underground tunnel in the biggest coal mine in Slovenia: Premogovnik Velenje. Connection throughtput between client and server remains nearly the same for distances in range from 0 up to 50 meters. Signal strength is presented in logarithimc unit dBm. Signal strength falls significantly in first 10 meters from 0 to -40 dBm. After distance of 10 meteres value of signal strength is ranged in between -40 and -50 dBm with small and not regular diviations. After 45 meters from source the value drops slightly bellow -50 dBm.

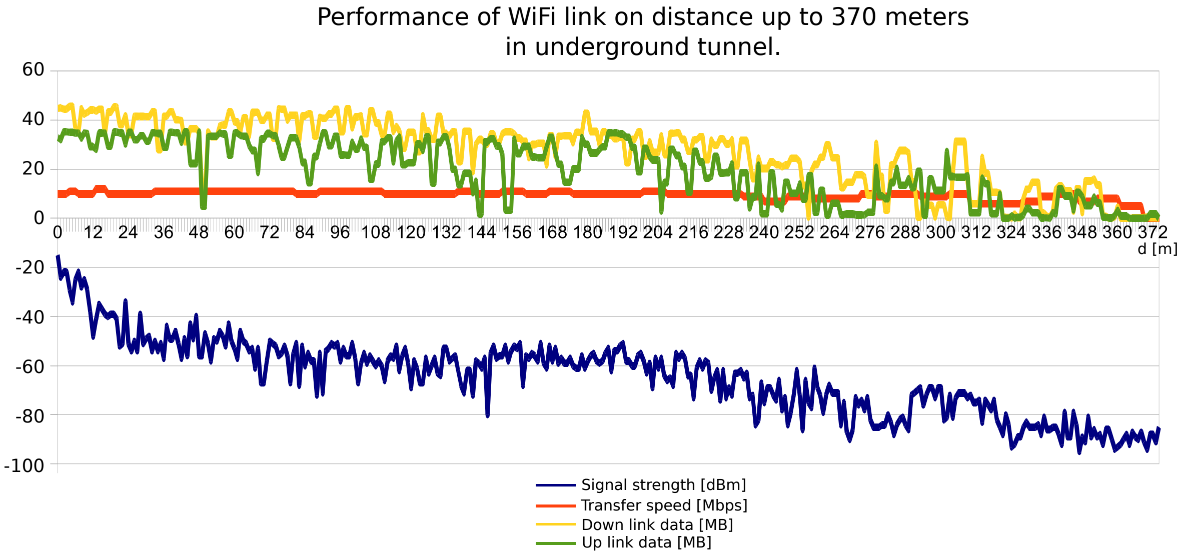

Figure 3.2. Wireless lan range [7].

Figure 3.2 presents tests results performed on longer distance till connvectivity was not possible due to too low signal strength. On distances from 50 up to 240 meters parameters of link are similiar. Down link data remains at 40 MB and at 38 after 140 meters with drops to 20 MB. Up link data measurments are more unstable than in case of down link in therms of drops in delivered amount of data, but trend seems to be steady on range from 50 till 220 meters from access point. Then both data uplink and down link drops by 10 MB. Speed of data transfer between access point and client device remain similiar from very beggining till distance around 370 where signal is not enogh to conduct connection. Signal strength is characteristic only for first 10 meters from signal source. Then signal strength oscilates between -40 and -60 dBm on distances 10 – 50 meters, between -50 and -80 dBm on distances 50 – 240 meters, between -60 and -90 on distances 240 – 320 meres and between -80 and -90 on longer distances. Following data does not represent any straight forward solution to adjust positioniong information to make positioning more precise and accurate. Only on distances close to the signal source it is possible to estimate more precise position while signal strength values differ significantly from the values that occures on the rest of distances. There can be identified following range zones with respect of WiFi signal behaviour [7]:

1. near field zone: 0 – 40m distance from signal source where wave attenuation curve is similiar to that in free field distribution,
2. coverage zone: 40 – 200m distance from signals source where can be identified symptoms of waveguide propagation and signal strength remain to be arround -50 dBm,
3. monitoring zone: distances since 200m from signals source where signal starts to vary from -75 up to -85 dBm and becomes to be unusable for communication purpose but client and access point are visible for each other,
4. out-of-range zone: where signal is too low and both client and access point are not visible for each other.

One of the approaches for the Wireless LAN based positioniong system is to assume that given client is present in given area of underground installation if it is in coverage zone of one of Wireless LAN access point. Client can be registered by access point software and followed until he leave coverage zone. As the coverage zone is about 200 meter distance from access point then total accuracy of this solution is about 400 meters. Second approach assume positioning accuracy improvment by signal strength interpretation and recognistion if client is in near field zone. This approach is easy to be implemented as signal strength values in near field zone differs from values from the rest of zones. Such solutions are implemented in mines in Germany [7] and in Swedish Boliden's mines [9].

3.1.2. RFID tags

RFID technology make use of electromagnetic field phenomena that allows to transfer information to reader from special component, RFID tag. Passive RFID tags are powered by readers though electromagnetic field; they do not use batteries or wired external supply. In order to acquire information from tag readers have to propagate electromagnetic waves. Tags cumulates power from electromagnetic field in capacitor. When tag have enough power then it transmits the response with tag's data to the reader and goes to sleep for a given time. Reader get signal from tag and perform filtering and decoding operations on it in order to get tag's data. There are also available variants of active RFID tags wich use it's own power supply.

RFID technology is used in underground installations in certain locations to serve as check points. In this manner are monitored underground trains or dispatch of materials is being monitored. Passive RFID modules are installed on containers or mobile machines like trains. Those modules can be read by passive RFID readers that are connected to the mine network via dedicated control unit like Mining Infrastructure Computer [7]. Control unit is responsible for RFID reader configuration and translation of its readings into standarized positioning information format. It also supplement data from RFID reader with its identificator or coordinates which express position of a reader on mine model. RFID can operate at 868MHz band. RFID with 8dBi antenna is able to detect RFID passive tags at range of up to 3 meters.

3.1.3. WSN based position finding systems

There are proposals of position finiding and tracking systems based internet of things (IOT) soultions [6, 12]. The idea is to create means of wireless communication to locate miners during their daily basis. It is proposed to create a network of wireless nodes (WSN) that read signal from tag devices (RFID) carried by miners and transfer it through nodes network to sink nodes that are directly connected to the mine core data transfer installation such as industrial Ethernet. Miners position data is sent to acquisition server. Intermediate and nodes are directly connected one or more nodes laying in the range of their wireless communication module. They form together ad hoc, multi-hop, self-organizing network of nodes that is able to transfer data, reorganise its structure in case of mailfunction of one of the nodes and allow to configure nodes remotely due to the implemented wireless communication technology and dedicated routing protocol. Network of nodes can be easily expanded by adding new nodes. Due to the fact that communication is wireless, nodes can be placed also in danger or new areas where wired network devices are not allowed or the related infrastructure doesn't exists.

WSN and RFID based positioning system is designed to serve such functionalities as querying miner information, locating miner, tracking miner and managing tag and reader. It is proposed to use this system along with simillary implemented monitoring system that measure safety parameters in mine [12]. This positioning system is dedicated to used by production monitoring, production scheduling and emergency rescue mine departments located on surface. Bigger precision can achived by adding more nodes into the network. Technology that is used for wireless communication between WSN nodes can be a Bluetooth Low Energy, ZigBee (IEEE 802.15.4 based) or WiFi (IEEE 802.11). ZigBee technology is the most popular in WSN's as it supports variety of communication modes, contain out-of-box solutions for network topology management and support low energy solutions like sleep modes [2]. ZigBee protocol which is dedicated for ZigBee technology uses energy and computational efficient solutions for data collision avoidance which includes CSMA/CA techniques and time division concept [12, 8]. There are three main topologies forced by ZigBee technology that can be used in the WSN network: star topology, tree topology and mesh topology. Star topology limits the network to have all nodes directly connected to sink. Tree topology enables multihop functionalities but litmits network flexibility in therms of adopting routes in case of filure (doesn't support redundant connections between nodes). Mesh topology requires to store routing tables in each node but provides means of redundancy in therms of routing what makes the WSN network reliable and fault resistant [8]. The WSN positioning network proposal base on ZigBee technology and it's mesh topology. Placement of WSN nodes should guarantee signal coverage of RFID readers modules build into nodes. On order to achive that there are proposed variety of topologies that can be used on site during network installation. On image 3.3 it is presented the network topology proposal that introduces intermediate nodes – routing nodes – that gather information from sensor nodes and transfer it through network of routing nodes to server via sink node [12]. Due to the fact that WSN nodes are limited in energy supply, systems that base on that technology needs to be designed with aware of energy management and fault management. Idea of routing nodes deployment along the tunnel in two simmetrical lines comes from the need of link redundancy between nodes. Thanks to that even if some of routing nodes are down the information from sensors can be passed out through the other routing nodes that are in range. In order to limit power consumtion of reader nodes they were designed as Reduced Function Devices

(RFD). These nodes do not take a part within information passing process. Reader nodes are designed only in purpose of reading signals from RFID tags and to send the information to the nearest routing node. In order to achive that the information will be sent only to the nearest reouting node there is performed initial configuration process that involve both reader nodes and route nodes in its signal propagation range. The process is such: reader node send the testing signal to all of the nodes. Nodes that were able to reiceve the signal, send responce with value of Received Signal Strength Indication (RSSI). Reader node limit its sending power according to the responces. Thanks to it power consumtion of reader node and interference with neighboring nodes are reduced.

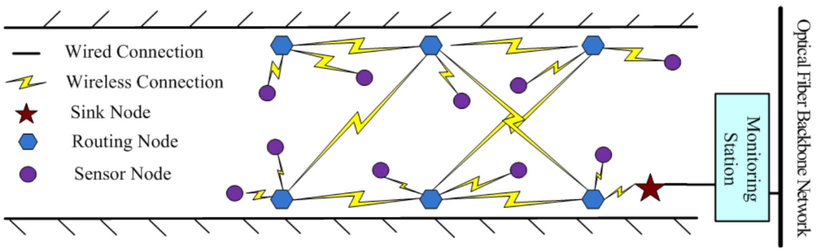

Figure 3.3. Wireless Network Sensor topology in underground corridor example [12].

Network of wireless connected nodes needs be designed with respect of its maintability. There is need to assume that some nodes may fail during their operation. As the network consits of many nodes, where the number of nodes can be changed during thier operation, there is need to implement actions that will allow them to organize their topology automatically. Even if particural nodes will fail, the rest of nodes should be able to work and maintain communication with remote services. It is the role of implemented routing protocol. There are available solutions that allow network to adapt quickly to the changing environment [3], but in case of statically placed network elements the environment is not changing havily. As it is in common practise, routing nodes stores information about nodes that are used for network purposes in the routing tables. Rounting tables are created with the manner that there are promoted link to nodes that ensure the lowest cost (distance) of packet travel from given node to the sink node. Routing table can have many entries. In case of topology for underground installation there are suggested 3 entries: parent route, minimum route, backup route [12]. Parent route points to the parent node, minimum route points to the best node in therms of the most energy efficient way to the sink node and backup node that points to the second to the best routing node. Each entry consists of elements such as: number of hops (routing nodes from itself to the sink node), value expressing quality of link of the last communication, flag that describe the role of the entry (parent, minimum, backup route). Routing tables and interconnections between nodes are created during network installation process. The idea is that the sink node that is directly connected to external communication medium creates at first 1-node WSN. Rest of nodes organize themselves in manner that nodes broadcasts their physical and network adresses. Basing on information gathered during installation they are able to determine their position in the network, obtain network address, assign routing table entries and obtain hop number. The network topology can be build up and maintain after WSN installation process [2]. Nodes are able to pass information to sink node that contains it's routing tables. Thanks to that sink node is able to recreate network topology and then pass the information to the external server. In order to maintain the network there are implemented status messages that contain information about changes in nodes routing tables. They are usually pass through WSN along with data from periodic sensor readings.

Nodes are equiped with batteries that makes them independent from external power source. In order to save the energy and in order to prolong device live on the battery nodes works in energy efficient modes. In these modes nodes are turned into sleep for certain time. They woke up in order to perform tag readings and transfer the data to the external resources. In order to synchronize their operation, in each cycle the sink node broadcasts the initial message which is used to synchronize all of attached nodes. Power level of nodes batteries are monitored. Nodes can send information about their power level as a repsponce for appropriate request. There can be implemented special routines inside node that can cause sending the information about the low battery level in emergency mode, without any request from the sink node.

The crucial for the positioning system is to determine accurately exact position of given reader node inside the underground installations. Without information about readers placement positioning data obtained from them are not usefull. Solution for this problem in WSN positioning systems are solved by manual configuration. Each node have it's own identification number that is a part of it's initial configuration. This number is atteched into their housing also so given nodes can be identified directly during the installation or maintenance work in tunnel. As nodes deployment is regular it is assument in advance what will be the position of the node within the tunnel. In case of sudden failure of some node it is possible to determinate which of the node is broken by it's ID information, and check were the node is placed. WSN network should have possibility to report failure of its nodes. That is why WSN positioning systems are equiped with failure detection and reporting mechanism. Parent nodes like routing nodes against reader nodes, checks if child nodes responds to the requests. In case of having no response from given node for a given amount of subsequent requests then parent node issue status request command to the child node and wait given amount of time. If child node give an answer then it is assumed that the given child node is working correctly. In case of no response from child node, the parent node send information about failure to external service. As the readers nodes are connected stright to the parent node with no routing options then different policy for borken parent node must be applied. If the child node does not reiceve acknowledgement (ACK) frame from it's parent given amount of times then the node increase it's sending power and retrainsmits it's data again. If there is no result of increasing the power then node goes into network setup mode and scan channel to rejoin the network.

Positioning algorithm in WSN positioning system base on mine layout and assume fixed position of nodes. Information about mine layout and nodes position wihin mine is stored in database on server above ground. Data transferred from nodes into acquisition server is a combination of three values: ID of a node, ID of acquried RFID tag in range of RFID reader module of that node, signal power of this RFID tag, and timestamp. Data is being stored in simplified relational database. This positioning system uses algorithm for finding exact position of RFID tag in dwo diamensional space (x, y).

In order to do that algorithm search in database for 3 nodes that acquired given tag sinal with the biggest power. Then it uses simple free space electromagnetic waves propagation model (3.1) to compute distance between node and tag.

$$P_{ri} = \frac{P_t \cdot G_t \cdot G_{ri} \cdot \lambda^2}{4\pi D_i^2} \tag{3.1}$$

Parameters P_t (signal power generated by tag), G_t (tag antenna gain), G_{ri} (node reader antenna gain) and λ (electromagnetic wave length) are constant and known. Parameter P_{ri} (received signal power on reader's input) is the only variable in the equation that is needed to compute distance from tag to reader. Maximum likelihood estimation method that base on data from three nodes and thier values of reiceved signal power from given tag produces relative position of given tag in (x, y) coordinates. Suggested implementation [6] assume that nodes look for RFID nodes each 10 minutes.

3.2. Mobile device dedicated positioning systems

Todays smartphone class mobile device contains set of sensorics that can be used as a base for interial positioning system. In underground oprations industry this idea is not the newest as there were tryies of this technology implementations inside hand-held devices for people working underground with use of semiconductor based MEMS gyroscopes [7]. Such devices were connected to the underground wireless network through access points which was responsible for transfering positioning information to the central systems above ground.

3.2.1. Mobile device sensorics

- Why mobile device is good for positioning purposes? What are the factors?
- What sensorics are present in mobile device.
- Which of them will be useful to increase positioning accuracy

3.2.2. Abilities and limitations of mobile device in context of available positioning methods

- What means of communication (ex. wireless) can be used in context of positioning system
- Battery limitations
- Sensitivity of receivers

3.2.3. Position finding basing on localization system and mobile device model

Localization system choise (system based on beacons)

- Motivation
- Prototype system description
- Mobile device - system interaction description
  - Method of detecting reference points description
  - What are the possibilities to improve positioning on your mobile device?

- How could the process of installing a localisation system in a mine look like?
- How the parameters of the environment (corridor height, corridor width, type of rock, type of corridor corridors, presence of other networks operating on similar frequencies (WiFi, GSM (harmonic frequencies)), others) affect reference point signal quality.

3.3. Solution requirements

Requirements as the position of the mobile device will be determined by the environment model.

Define criteria that will be used to compare position finding solutions (existing or conceptual):

- How to save a corridor model in computer memory
- wireless communication
- resistance to power outages and communications
- Do I need the ability to change configuration of reference points (configuration of devices that perform role of reference points)?
- What parameters can be read from the reference points (range, distance, ?)
- How long should the network work properly?
- How to detect irregularities in reference points?
- How to fix problems in reference points?
- What problems may occur with points of reference?
- If there are restrictions upon existing network topology (ex. in order to get access to servers located on surface)
- Can the mobile device be useful in case of lack of signal (GSM/Wi-Fi/BLE)?
- example: accuracy, durability, cost, maintability (energy, fault)

Safety purpose of position finding system is very important for many countries [5]. European Union encourages to search for a good solution for the miners localization, which, in one of the postulates of its set of recommendations for the coal and steel sector ('Personnel Tracking' task). There are solutions for underground localisation but they allows only to approximate miner's position (error can be range from 300 m (range of a single radio receiver) to the distance to the next transmitter).

Underground position finding system must be compatible with mobile devices of smartphone class. Special mobile devices that were prepared to work in bad conditions like in coal or salt mines differs mainly with their housing in compare their non-commercial, personal-use equivalents. This assumption limits the range of available technologies that can be used in order to provide means of communication between mobile device and the enviornment.

Position finding system bases on idea of interaction between mobile device and the undeground envioronment. In case of the nessesity of extension that enviornment by electionic devices that will provide positioning data or means of connection with mine network there is need to state that such devices must be safe. Safety regulations in this matter differs with respect of the type of underground installation, the regional, country, or even association of countries [7]. The goal of this paper is not to provide solution that will be adjusted to each installation type or safety regulation, but to investigate possibilities and propose state of the art solution. As the enviornmental restrictions for devices and related infrastructure that can be needed for given solution there will be assumed general rules that are being in use in commercial tunneling [7].

Chapter 4

Mobile device position finding algorithm

* Algorithm that will make use of chosen localization system and mobile device internal sensors.

4.1. Position finding requirements

- Should repeat and answer requirements stated for localization system.
- example:
  - Reading signal and its parameters from reference points;
  - Identification of reference points
  - Current location presentation on the environment model

4.2. Simple position finding algorithm implementation

* Simple algorithm will use localization system only (no internal sensors)

4.3. Extended position finding algorithm implementation

* Algorithm will use localization system and internal sensors

Chapter 5

Localization system tests

5.1. Tests criteria and assumptions

- Define factors that are important to state if solution is good or not
- Will allow to check if system fulfills requirements
- Test features stated in 'Localization system choise section'

5.2. Tests metodology

- Testing environment descipription
- Equimpent used during tests. Example:
  - using a representative wifi router, 801.11g techonology, simple circular antenna (eg Minetronics MMG) - for charts.
  - using a representative beacon
  - dBm signal strength depending on the distance and polarity of the mobile device from the signal source
- Pictures

5.3. Tests of system and basic algorithm

- Check if system works with basic algorithm
- Tests in few configurations
- State if some factors have impact on signal quality
- State if some factors have impact on position finding

5.4. Tests of extended algorithm

Capture data that will be base for comparison between simple and extended position finding algorithm accuracy.

5.5. Experiments results

Resluts with analysis.

5.6. Tests summary

Chapter 6

Conclusions

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