Localization issues in Wireless Sensor Networks in Underground Mines

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Approval

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Dedication

I dedicate this thesis to my father whose constant encouragement and push for tenacity has always led me to believe in myself. Also, my siblings, especially my brother who helped me in every way whenever I was in need and of course, a special feeling of gratitude to my loving husband whose support and appreciation has never left my side.

Certificate of Originality

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any degree or diploma at NUST SEECS or at any other educational institute, except where due acknowledgement has been made in the thesis. Any contribution made to the research by others, with whom I have worked at NUST SEECS or elsewhere, is explicitly acknowledged in the thesis.

I also declare that the intellectual content of this thesis is the product of my own work, except for the assistance from others in the project's design and conception or in style, presentation and linguistics which has been acknowledged.

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Acknowledgment

I am extremely grateful to Allah Almighty who provided me the opportunity to learn and to educate myself, for bestowing me with a mind to think and ponder.

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List of Abbreviations

WSN	Wireless Sensor Network
RFID	Radio Frequency Identification
WiFi	Wireless Fidelity
GSM	Global System for Mobile Communications
LOS	Line of Sight
RSSI	Received Signal Strength Indicator
EMI	Electromagnetic Interference
VF	Voice Frequency
VLF	Very Low Frequency
LF	Low Frequency
HF	High Frequency
UHF	Ultra High Frequency
TDOA	Time Difference of Arrival
DTOA	Differential Time of Arrival
PSTN	Public Switched Telephone Network
ISDN	Integrated Services Digital Network
TDMA	Time Division Multiple Access
AP	Access Point
LAN	Local Area Network
WAP	Wireless Application Protocol
MAC	Media Access Control
CDMA	Collision Detection Multiple Access
TOA	Time of Arrival
AOA	Angle of Arrival
APIT	Approximate Point in Time
DV-HOP	Distance Vector Hop
GND Signals	Ground signals

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Abstract

Wireless sensor networks (WSNs) are a vital projection of wireless networks that are capable of opening a world of possibilities in wireless domain. Many of wireless sensor applications are being utilized for military, environmental, health and other commercial purposes. One such purpose of wireless sensor networks can be sought in research associated with location sensing in underground mines. Underground mines are not an easy environment to study; they are expansive, complicated and extensive labyrinths. The tunnel terrain is often longer than it is wider with width ranging from few meters and length to several kilometers. Miners are personnel working in mines under extreme conditions. Mines are prone to have a highly risky work environment and due to this very reason, thousands of miners face accidents in mines every year. Those accidents range from extreme injury to death. It is imperative that a safety net must be established in mines in order to ensure safety and performance coordination of workers. Such a safety net would deploy a location sensing infrastructure in underground mines which can help in routine and timely rescue operations.

However, there exist various challenges to the existing research due to which localization remains an unsolved issue in mines. Therefore, there is a need of developing a reliable location-sensing infrastructure built on top of wireless sensor networks that would respond well to the underground mining settings. The purpose of this research is to establish such a WSN-based location sensing system that would be robust against the mine's difficult environment. The research aims to increase the localization accuracy with a novel localization algorithm. The research would be helpful in prospective cross-disciplinary research in the fields of technology and mining.

Chapter 1

1. Introduction

This chapter gives the essential idea of the concepts involved in this proposal. It also presents the background and motivation for this study. Moreover, it also entails objectives that are to be achieved and the scope of this thesis. Finally, it explains whats more to come in the thesis document.

1.1 Introduction to the Domain

There has been an increasing demand for miner's safety that requires the development of location sensing infrastucture. WSN are a potential solution that can provide the vital localization information. However, there is a need to develop fast and reliable localization algorithms that can work with a WSN based sensing infrastructure. Localization algorithms rely on the existing technologies like RFID, WiFi, UWB, GSM etc. But these technologies have their limitations. For example, in the case of RFID the card reading time causes delays if applied for multiple personnel, the localization accuracy is low and it requires an additional RFID antenna in the existing WSN motes to make such an algorithm workable. Similarly, in case of WiFi, the signal attenuation is remarkably prominent in an underground environment; hence the signals can never be relied to be accurate in case of a mining incident. There is also high computational cost involved while working with WiFi signals that is undesirable for a wireless motes working underground. GSM signals are not known to be reliable underground and hence localization accuracy would be greatly compromised for a GSM based localization algorithm. In case of UWB, although the signal penetration is high that can reduce localization error but the computational cost makes the system unfeasible. Also it involves large communication delays. ZigBee is one such technology that is more suited to the underground environment due to its inherent characteristics.

ZigBee based WSN have recently emerged as a flexible power capacity system that offers low energy consumption, small size, can reliably work in an underground environment and provides ease of use and deployment. Many localization solutions based on WSN already exist. Pico-Radio [1], WINS [2], Smart Dust [3], SCADDS [4] all worked on the node localization with energy management at ZigBee. Work has been performed in node localization at the application layer [5]. Some national projects in China that are currently working on disaster relief systems in underground mines [6] are employing WSN coupled with ZigBee for improved location accuracy and efficiency. Therefore, ZigBee based WSN can be considered as a potential solution to the miner's localization issue in underground mines.

1.1 Problem Statement

In order to efficiently carry out the rescue operation or monitoring of the miners in the mine tunnel, the localization algorithm should be designed in such a way as to overcome the shortcomings that are associated with exisiting research on the subject. Since the existing literature on the localization techniques in wireless sensor networks is either energy inefficient or require complicated adjustments to the required infrastructure which adds to the cost or becomes complex enough to cause delays in the performance. We are looking for an algorithm that does not require any modification to the existing wireless sensor motes, is simple and easy to perform and has reduced communication delays. While keeping all these factors in focus, this novel algorithm should be designed to be energy efficient and must function on the basic routing communication system so there should not be the need of a new routing protocol or a modification of a present one. Besides this, it is imperative that the new localization algorithm must provide highest precision in localization of the unknown node and the application must have smooth performance. The aim of our research is to provide such a novel algorithm that works on simple principles of localization, works on lower stack level yet provides efficient and precise localization coordinates.

1.2 Purpose

The purpose of this research is to improve the precision of the existing localization algorithms and its application performance, while reducing communication delays, energy consumption and cost of the equipment employed.

1.3 Scope

The scope of our research is to improve localization error while simultaneously working with low cost equipments that do not require any modification to the existing infrastructure. The localization algorithm should be adapted to the underground mine environment and should be faster and efficient in terms of delay and energy.

1.4 Objectives

Our proposed scheme should meet the following objectives

- Improvement in localization error compared to traditional techniques
- Reduction in communication delays
- Low computational cost
- Energy efficiency

1.5 Thesis Outline

Rest of the thesis report is structured as follows

- Chapter 1: It gives the introduction of research domain, describes the problem statement, purpose, scope and objectives of this thesis.
- Chapter 2: It describes theoretical background related to the study of underground localization. Major topics under discussion would be the characteristics of an underground mine environment, the available technologies to choose from, the currently available localization algorithm and their comparison.
- Chapter 3: It reviews several related Weighted Centroid localization algorithms with their pros and cons.
- Chapter 4: It explains our proposed architecture.
- Chapter 5: It presents the simulation setup for the validity of proposed algorithm and the results.
- Chapter 6: It provides the conclusion of entire work and provides direction for further research.

Chapter 2

Theoretical Background

2.1 Introduction to Wireless Sensor Networks (WSN)

In the past few years, wireless technology has seen a sharp inclination towards low power wireless motes, micro sensor chips and microprocessors which are not only energy efficient but also have significant improvements in distributed signal processing, pervasive computing and ad-hoc networking. These low-powered multi-functional sensor nodes are capable of integrating vast information, faster data computation, optimal storage and efficient wireless communication. In other words, wireless sensor networks are low cost, low power, short ranged, small size nodes that are deployed for data collection specifically at inaccessible places for sensing and processing information.

These nodes are autonomous devices and can be deployed either at the site of the phenomenon or very close to it. They monitor the activities of the area under observation and report their sensing information to a central node that is capable of receiving the messages from a cluster of nodes. This centralized node is called a sink node. The information thus obtained can then be used to ascertain the status of the observed region. More often than not the centralized node is connected to a monitor or a server, which captures the information and processes it for further computation. Figure 1 shows a typical wireless sensor network with an operating sink node collecting data from the sensor node.

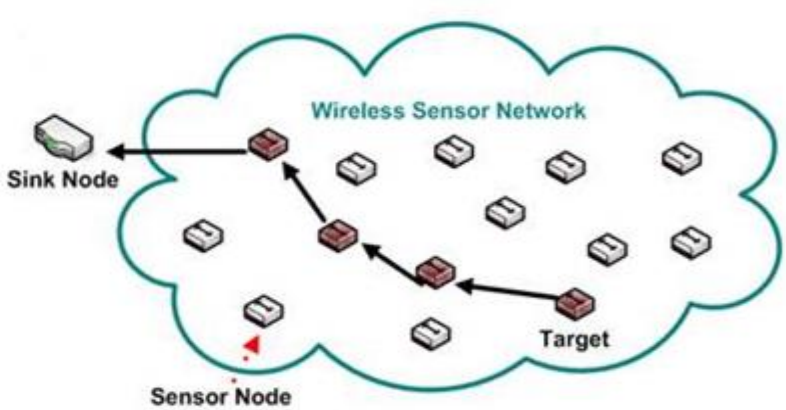


Figure 1 Wireless Sensor Network

2.2 Wireless characteristics in different environments

Wireless transmission is the propagation of an electric signal representing the desired information, from a transmitter, through space to a receiver that estimates the transmitted information from the signal thus received. The transmission path between a transmitter and a receiver can either be completely unobstructed i.e. Line of sight (LOS) or severely obstructed by mountains, trees and buildings. The signals reaching the receiver after passing through such environments can greatly deviate in the actual signal strength that was originally transmitted due to many phenomenon occurring in the free space. [7]

Figure 2: A typical coal mine tunnel

2.2.1 Unobstructed environment

For areas where there are no significant obstacles in the way of free line of sight communication, the antennas can be placed with a relatively free choice of location. However, the farther the receiving antenna is from the transmitter, the more signal will disperse with distance. Because of signal spread in large area and distance, the signal will experience attenuation over distance even if no other source of impairment is observed. This form of attenuation is called free space loss.

Also, atmospheric absorption takes place due to the presence of water vapours, oxygen, fog and rain in the atmosphere, which leads to attenuation. Another phenomenon called scattering refers to the signal loss due to change in direction or frequency when radio waves encounter matter in space. Thus, in areas of significant precipitation, the distance between receiver and the transmitter have to be kept short and lower-frequency bands should be used.

2.2.2 Obstructed environment

For areas having many obstacles in the way of free line of sight communication, the signals can be affected by such obstacles. By interacting with the obstacles by the phenomenon of reflection, multiple copies of a signal with time delay is received by the receiving antenna. In some severe cases, there might be no direct signal and all the antenna receives is multiple versions of the same signal in different time intervals. In some cases, the signal might follow a curved path through the atmosphere due to refraction and the signal also reflects from the ground. Refraction refers to bending of signals when they propagate through the atmosphere. Normally, with the speed in signal increase, the radio waves are bent downward.

2.2.3 Underground environment

In underground environment, a signal undergoes much greater attenuation as compared to that in the air due to the non-uniform structure of the mine surface which makes communication un-reliable. The walls are rough and the floors have uneven surface. Parts of roof and walls contain wood and metal grids and sometimes water is seen running at unusual spots in the mine.

1. **Topographical differences of underground environments.**

   i) **Shifting of Walls:** As a consequence of cutting of minerals, the geometry of walls in underground tunnels differ greatly on day to day basis. [7]

   ii) **Temperature extremes:** The temperature range in the underground mines or tunnel remain average over the year ranging from 32°F or more than 100°F [8]. However, the ventilation system is still required to keep the temperature conditions in control.

   iii) **Humidity:** The rise in water vapour is observed more during the summers but the ventilation system keeps the mines airy [8]. At 28 degrees of temperature, relative humidity with respect to earth's stratosphere is 90%.

   iv) **Water Intrusion:** Sometimes the mines have constant seepage of water causing muddy floors. It makes the mines more exposed to electric field charge and accidents.

v) **Limited LOS:** Since the structure of the underground tunnels is uneven and contains many obstacles like pillars and grids in the room, there is very limited LOS available. The constant everyday undulations and cuts also pose a threat to the existing LOS if any.

vi) **Low loss dielectric medium:** Underground communications get greatly disturbed when at some frequencies, the mine would act as a low loss dielectric.

vii) **Ionized air:** Due to fire and blaze incidents, the air inside the mines gets ionized as a result of exothermic reactions of coal and oxygen. If there is a high concentration of oxygen (greater than 3%) in the mines, it may lead to the release of oxidation heat in the coal mines and leading to fire. [8]

viii) **Vibration:** There is continuous vibration observed at the coal removal sites. The level of vibrations are not enough to significantly affect the working of an access point or antennas.

ix) **Chemicals and Gases:** The most important gas to come out as a by product of the extraction of coal is Methane. It is due to the high level of methane in the mines that lead to explosions and gas blasts [9]. That is why a good ventilation system is required in a mine to keep the mine airy and dispose off the excess Methane. Another chemical found specifically in a coal mine is Sulfur which has the potential to produce Methane and acidic water. This acid water thus formed, on contact with mine equipments, can often cause fast deterioration and rusting. [8]

Keeping in mind the topographical differences of the underground environment, we can classify the signal loss by the following factors.

(i) **Path loss:** Path loss is severe in underground tunnels in higher frequencies than that observed in the lower frequencies due to material absorption. With increase in humidity, the rate of attenuation would increase.

(ii) **Multipath fading:** Fluctuation is observed in signal strength with position and frequency and in case when the transmitters and receivers are mobile, the fluctuation is also observed with respect to time.

(iii) **Reflection/refraction:** Waves refracting off the walls of the underground tunnels lead to a waveguide effect. Waves that impose on the walls of the tunnel get partially reflected back to the ground and partially refracted into the surrounding dielectric medium creating a waveguide and result in significant signal losses.

Information can also be lost as a result to change in pattern in the electric signal due to reflection.

(iv) **Reduced propagation velocity:** When the temperature at the underground mine rises, the dielectric property of the medium would reduce the propagation velocity of the medium, greater than that observed in the air. With the decrease in velocity, the signal will undergo a considerably high attenuation than that of air.

(v) **EMI Noise:** Clouds have electric charges with respect to eachother as well as the surface of the earth. During the lightning storms, these charges are electrified as lightning strokes of tremendous voltages striking the earth. These lightning charges allow EM waves to be formed and travel thousands of miles in the vicinity of the area and interfere with the performance of electric devices in the near vicinity [11]. Therefore, the choice of equipment used in such a harsh environment setup should be carefully made. These EM waves interfere with the radio communications observed in the form of noise in extremely low frequencies (ELF), voice frequencies (VF) and very low frequencies (VLF). Also, this noise can also be the result of electric motors and appliances running underground which comes under the category of Man-made noise [8]. This form of noise can be considerably reduced by using higher frequency bands and it varies with the location. But unfortunately, the man-made EM noise occurs mostly in the frequency bands most suitable for underground communications. [11].

2.3 Wireless Communication Technologies

2.3.1 Radio Frequency Identification

Radio Frequency Identification is a technology that allows the identification from a distance without requiring a clear line of sight. An RFID system consists of a group of wireless readers connected through leaky feeder, WiFi, coax cable or other systems. It is most employed in a tracking system. RFID tags use a large set of IDs and can include data such as manufacturer, product type and can even measure environmental factors such as temperature. It also has the ability to detect different tags which are located in the same area as the RFID detector without any kind of human intervention.
RFID technology exists in two forms: having active tags and passive tags. [12]

i. **Active tags:** Active tags in RFID are usually powered by a battery source or a powered infrastructure and is used for long range communication. Since these tags are powered by a source, they may collect data and process it before sending it to the receiver. Active tags have usually both read and write functions. Active tags can be read upto 750 feet.

ii. **Passive tags:** Passive tags are limited by the power supply and can only perform a restricted number of readings before expiration. They are more popular and high in demand due to small size, less power cost and maintenance. However, passive tags cover relatively shorter range than the active tags and can only read upto 300 ft away [11]. A passive tag includes an antenna, a semi-conductor chip and some sort of encapsulation which provides covering to the chip and the antenna from environmental changes. The tag is read by the tag reader by calculating energy level and transferring the tag's ID. The reading of the tag can be done either by EM waves or through magnetic induction. These tags can operate at low frequency (LF), high frequency (HF), ultra high frequency (UHF) and microwave frequency.

The use of RFID in asset tracking is ever so popular but lately, this technique is also being used in the harsh environments due to its unparalleled characteristics. Since the techniques like GPS cannot be used in underground mines, the use of RFID in estimating the in-mine positioning is known to be a promising research area. RFID in underground mines can be used to monitor the entering and leaving of mine workers, control of traffic to hazard zones, vehicular identification and tracking inventory/supplies and production units.

In real-time localization systems using the RFID, an active tag is used which is driven by an internal battery and communicates with a backend server for estimating its position with respect to the known antenna points. These tags and readers can work with a variety of frequencies and protocols. Each reader node connects with the network. The more the readers in a localization system, more accurate are the results. This RFID system can either use the differential time of arrival (DTOA) or time difference of arrival (TDOA) that requires the object to be tracked to send a beacon after a fixed time interval. The reader in the tags range, receives the beacon and records the tag's ID. The information thus obtained is sent to a processor via a twisted pair cable. The processor calculates the location estimation via TDOA of three beacons received by the same tag to calculate the nearest accurate results by the triangulation scheme. One of the limitations of this system is in case of mine accidents, we can lose all forms communication as one of the main components of this system is a twisted pair cable which is susceptible to disasters. Also, the tags require maintainence all the time so they must be equppied with self-diagnostic system that should run at pre-defined intervals in order to be synchronized with the monitors.

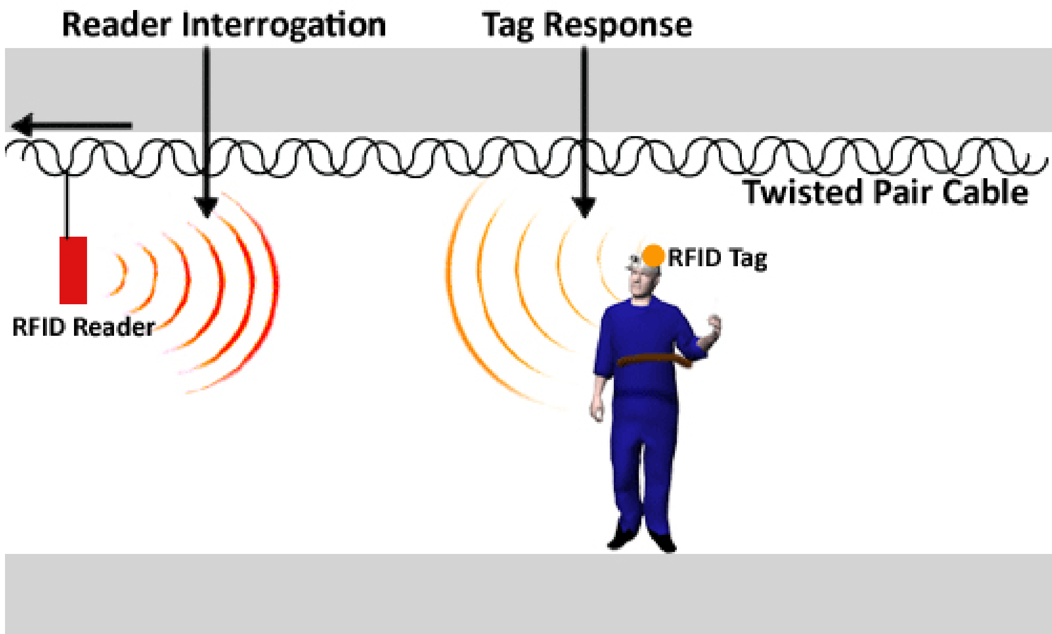


Figure 3 RFID based tracking system

2.3.2 GSM

GSM employs the Time Division Multiple Access (TDMA) technology to allow the digital transmission of asynchronous/synchronous data between the ISDN terminals. GSM handles voice, data and internet applications traffic. Just like it used to happen in PSTN, GSM establishes the data connection in just the same way as a regular call, user dials in and a circuit switched connection is established for the entire session. In case, the user disconnects, the entire session is again to be re-established. Speech which is analogue in nature has to be digitized and sent. ISDN employs the Pulse coded modulation (PSD) scheme for multiplexing the voice lines over high speed cables and fibre optics.
GSM operates in the 900 MHz and 1.9 GHz frequency bands.

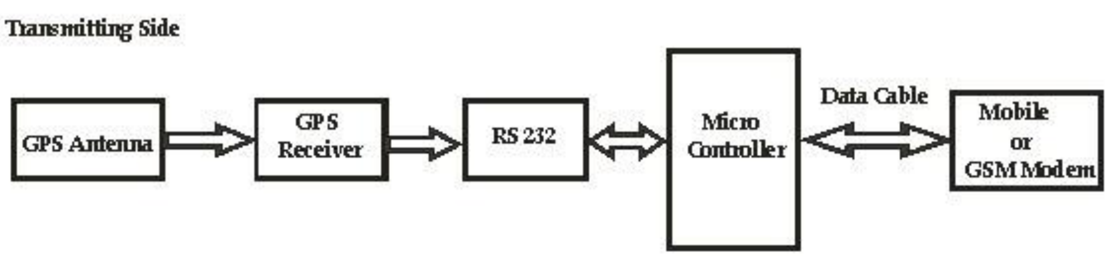


Figure 4 GSM transmitting side

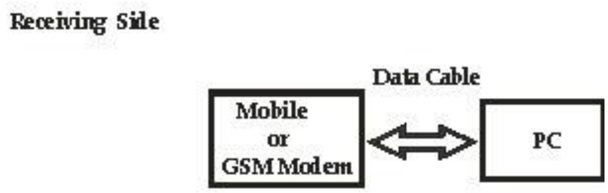


Figure 5. GSM receiving side

GSM underground tracking systems are not common but a typical localization system on ground would require GPS embedded system which is connected via a micro-controller and a data cable to a GSM device which reads the information of the coordinates via GPS. GPS working feasibility in underground environment is not established hence GSM technology gets completely ruled out while considering available technologies for mine environment.

2.3.3. WiFi:

WiFi is short for wireless fidelity and belongs to the 802.11 wireless local area networks. It implies a term for wireless local area communication networks which utilize the protocol in IEEE 802.11b, g standards. In lieu of hard wired LAN, the WiFi is quickly pacing up the communication demands and offering people many services in public places to log on to the Internet and receive emails at anyplace at anytime. HotSpot WiFi-based communication systems are also available for underground mines.

WiFi communicates by creating a network configured using access point that bridges to the fixed network, usually Ethernet. Since the strength of the signal received from an AP is associated with its proximate distance from the mobile terminal, it can be used to estimate the position of the users. Hence, the signals are read by the APs and the readings are passed to a back end server for processing. The closer a device is to an AP, the more would be the signal strength,. As the user moves away from the AP, a fluctuation in the signal strength is observed which allows real time tracking of the object. A single access point can track the position of many nodes in a specific area. However, the localization accuracy may be compromised. Typically, an AP covers around 100-300 feet range while in open areas the range is almost 980 feet. [9]

The reason why WiFi seems to work best for locating mobile equipment in the underground tunnels is because it is almost always a pre-deployed setup and does not require new specialized equipments. It is relatively inexpensive as compared to inertial navigation systems (INS) and laser range finders [13]. The most common approach to localization in a WiFi system is to measure the delay of the packet transmission to the WiFi client from an access point and use the difference in the signal strength from WAP to client [11]. The other approach is also referred to as time-of-flight localization model which uses the accurate clock synchronization in transmitter and receiver which is somewhat impractical. Because of having low level information which would not be available from standard radio interfaces, this communication system is rendered unfeasible in real time environment [13].

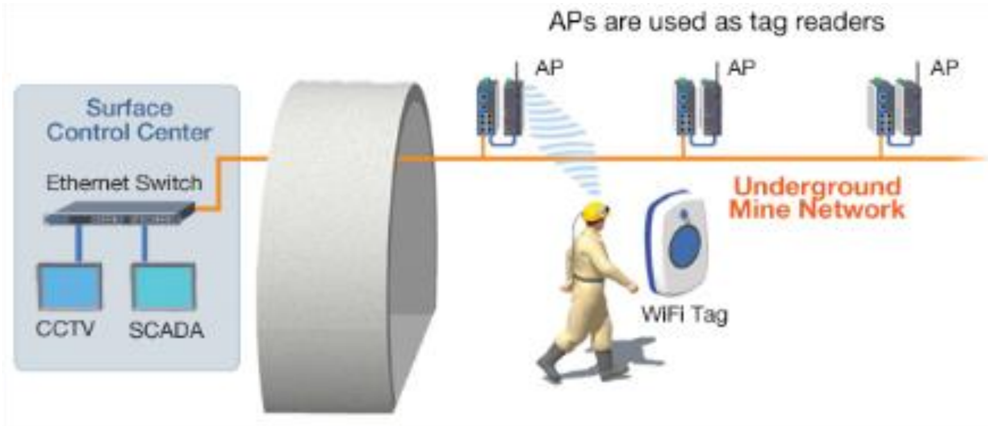


Figure 6 WiFi based tracking system

2.3.4. ZigBee

ZigBee is a wireless networking standard just like WiFi. It operates in the same spectrum as Wifi i.e. 2.4 GHz. ZigBee is known for its self healing properties in wireless networks, low cost devices and limited throughput. Same battery power can make ZigBee devices to work for years and support 100-250 kbps transmissions [14].

There are many standards like Bluetooth and WiFi that are good for high data rates and video transmission etc. However, there exists no wireless network standard that meets the requirement for sensing and control networks. Sensors and controllers do not require high bandwidth or data rates rather they are more interesting in longer battery lives and latency in data rates. ZigBee works best for such sensor networks as it has high power source, one that lasts longer than any other technology and also, provides medium latency.

The most accountable reasons for selecting ZigBee technology for sensing are:

i. ZigBee's physical layer is considerably low cost and also provides an excellent integration capability. The use of direct sequence makes the analog circuits simple and tolerant to implementation designs.
ii. MAC layer is designed in such a way as to allow many topologies without difficulty. The MAC allows a reduced functionality device (RFD) that does not require flash or large amount of RAM or ROM.
iii. The network layer allows for the growth of the network without utilizing high-power transmitters. It can handle many nodes inside the network with latency.

iv. ZigBee based RFID is perfect to uniquely identify objects and people. It can be a mean for storing and retrieving information through electromagnetic transmission to RFID compatible device. ZigBee complaint RF readers use tags at certain radio frequency and protocol for the data transmission. [15]

v. ZigBee has only two operational modes as compared to Bluetooth's many different modes and states of operation, namely, active and sleep modes. In this way, it saves up much power as compared to any of the other technologies.

2.3.5. Bluetooth:

Bluetooth is considered for short ranges. It is a personal area network standard. It uses 2.4 GHz and 5 GHz bands for communication [16]. Bluetooth is extensively used for short distance communication like head phones, cell phones etc. Although Bluetooth has low power consumption as its transmission power is very low so Bluetooth has coverage area even shorter than WiFi. Hence, Bluetooth can never be considered for underground localization as the area covered in mines is large and Bluetooth technology is not meant to work in such environments.

2.3.6. UWB:

UWB stands for Ultra-Wide Band and has been used in the last ten years for digital data communication in military applications. It has a large bandwidth compared to other conventional technologies. It has an absolute bandwidth of 500MHz and relative bandwidth is greater than 0.2. The transmission of signals takes place in pulses and these pulses are in nanoseconds transmitted over a wideband of 3.1 to 10.6 GHz.

UWB can be considered a desired medium for localization as it is a safe system for wireless transmission. It can co-exist with other technologies hence many hybrid technology algorithms can also be designed from it. As it has an extremely wide bandwidth, we can measure precise distances but only in a situation when the transmitter and the receiver are highly synchronized. It also offers high penetrability due to which it is suitable for both indoor and outdoor environments. A localization algorithm [17] combines the TOA and TDOA techniques along with Sequential Bayesian Filtering in order to localize miners in underground mine but the results can be remarkably improved as communication system poses delay and it requires hardware customization which is not cost effective.

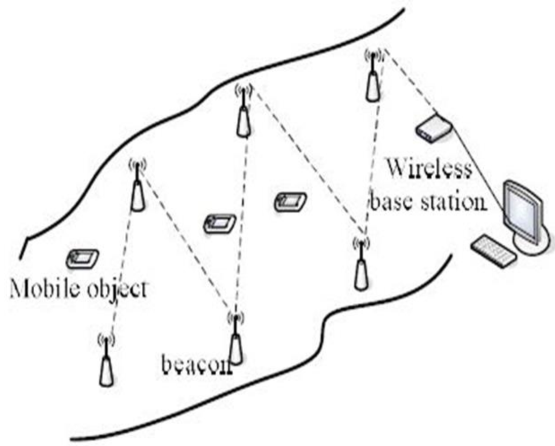


Figure 7 A typical localization system based on UWB

2.3.7. Comparative Summary

Comparative summary of the above-mentioned technologies is given below.

Wireless Technology	Range	Dedicated Infrastructure	Power Consumption	Disadvantages
RFID	1m	Yes	Low	Cover range is limited
GSM/CDMA		No	Unknown	Highly patented
WiFi	35m (indoor)	No (for most places)	High	High signal variance
ZigBee	30 ~ 60 m	Yes	Low	Dedicated infrastructure is required.
Bluetooth	10 m	Yes	Low	Limited cover range.
UWB	few meters	Yes	Low	Limited cover range.

Table 1 Comparisan of Wireless Technologies

2.4. Physical Measurements

It is important to have the information of the physical world when considering localization approaches. For all sorts of localization techniques, physical geometric elements have to be measured by the sensor nodes. These physical measurements can be classified for convenience into different types e.g. position estimation, distance, angle, area, hop count and neighborhood proximity measurement. The most important of all these measurements required for localization is the position measurement which can be obtained by employing the technology of a GPS. However, the GPS infrastructure can not work for certain environments like underground mines where other methods or physical attributes are utilized to perform localization. The other five measurements become the choices for positioning an unknown in a complex environment. Throughout the text, the term "unknown” would be employed for such a node the position of which is unknown while the term "beacon" node would be used for nodes which are assigned known coordinate positions and they would be used as reference points for localization.

2.4.1. Distance measurement

Distance measurements are crucial if localization is performed through Trilateration or Multilateration. In a trilateration technique, three reference or beacon nodes are employed. The node to be localized calculates the distance between itself and the three reference nodes. Three overlapping circles are drawn by assuming the unknown node to be at the center relative to the reference nodes. The intersection of the circle provides the estimated location or area of the unknown object. Same technique is modified in the form of multilateration as the specific mathematics of its implementation vary according to its application in sensor networks. Much depends on the methods utilized to measure the distance between the nodes. There are a number of ranging techniques common in localization algorithms including RSSI based distance measurement and time based ranging.

i. Radio Signal Strength based Distance Measurement:

RSSI stands for Received/Radio Signal Strength indicator. This ranging technique relies on the radio signal strength received at the unknown node. The strength of the signal diminishes during propagation and while the signal arrives at the receiving node, it is important to understand the attenuation of the signal while mapping its received strength to distance. RSSI distance measurement does not require hardware modifications as most of the times the sensing motes come equipped with the chips that provide software access to the amplitude of the signal. [18]

$$P_r\,(d) = \frac{p_t G_t G_r \lambda 2}{(4\lambda)^2 d^2},$$

Where Pt = transmitted power, Gt = transmitter antenna gain, Gr = receiver antenna gain, and λ= wavelength of the transmitter signal in meters.

In existing literatures, received signal strength is represented by RSS values. As the distance increases, the fading of the signal strength is observed. We can reverse this to find the distance through received signal strength. A simple RSSI based triangulation requires 3 or more than 3 base stations to locate a user's coordinates. Multitrilateration combines 3 base stations to predict the results by using different measurements to weight the result. The important thing for this kind of trilangulation to take place is that the beacon nodes and the user should be in Line-of-sight. Otherwise, the RSSI would not give the accurate results. High accuracy in RSSI is not possible as beacon nodes and the user are seldom in LOS as obstacles and hindrances are common in an underground mine.

ii. Time Based Measurement:

Since RSSI technique can be inaccurate due to RF signal irregularity depending upon the environment, another technique employed to get better results is through the use of ultrasound/acoustic and radio signals to calculate distance. Time based triangulation also measures distance for triangulation but this distance is calculated through time used from beacon to user and through this time, the distance is calculated. The travelling speed of wireless signal in a said amount of time also helps us to calculate the range of the distance. There are two methods based on time. ToA (Time of Arrival) and TDoA (Time Difference of Arrival)

Time of Arrival (ToA)

ToA measures the direct transmission time from beacon to the user. The user notes the time the beacon frame arrives at it and transmits a packet with a timestamp on it. This method assumes that the time required for a packet to reach from beacon to user is the same as the user to the beacon. For this assumption to hold true, the beacon and the user (the transmitter and the receiver) have to be highly synchronized which makes it super hard to achieve in real time especially in underground mines where the interference is high. [16]

TDoA (Time Difference of Arrival)

The difference in time of arrival of the wireless signals helps in calculating the range of distance. For this purpose, the nodes must be equipped with a speaker and a microphone to calculate audible frequencies.

The TDOA technique is simple in that it involves a transmission of a radio signal from a transmitter. Then the transmitter waits for a fixed interval of time delay and then produces chirp through its speaker. The receiver upon receiving the radio signal records its time of arrival and then turn on its microphone which detects the chirp pattern and again records the current time sound. Through delay, radio and sound, receiver calculates the distance between the transmitter and itself through the following equation. [19]

$$d = (s_{\text{radio}} - s_{\text{sound}}) * (t_{\text{sound}} - t_{\text{radio}} - t_{\text{delay}}).$$

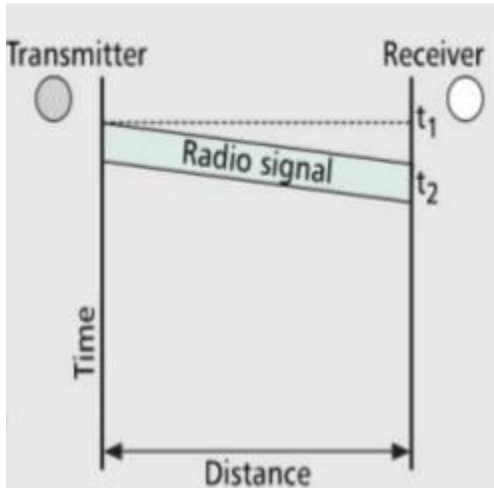


Figure 8 Time Difference of Arrival

iii. Angle of Arrival (AoA):

AoA is defined as the angle between an incident wave of its propagation and some reference direction, which is term as Orientation. One of the ways to find out the indicent angle is to measure it in degrees in a clockwise direction from the North. If the orientation is 0 or pointing towards the North, then the incident angle is considered as absolute otherwise it is taken as relative.

In a WSN, the beacon nodes are equipped with antennas to measure the angle of the signal arriving at them. There are other ways discussed in [23] and [24]. Several localization algorithms have been proposed that work with angle of arrival but again such algorithms require twerking with the existing equipment. And the computation involved can be cost ineffective when it comes to energy consumption.

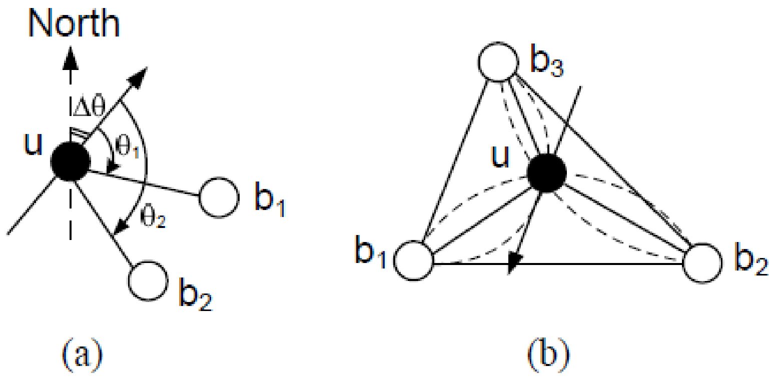


Figure 9 Triangulation in AOA localization (a) Localization with orientation information; (b) Localization without orientation information

Chapter 3

Literature Review

To address the fundamental issues related to localization, some schemes are proposed which combine the ZigBee technology with RSSI based location algorithms to improve the location precesion. Some of the recently proposed localization systems for WSN have been discussed in this section. Their main focus is improvement in location precesion, reducing localization error and improving cost efficiency.

3.1. Localization Algorithms

3.1.1. Centroid Systems:

Centroid systems are proximity-based algorithms that utilize multiple beacon nodes who broadcast their location coordinates (X, Y). After receiving the beacon frames, the unlocalized “unknown” nodes estimate their positions accordingly. Beacon nodes can be randomly deployed or arranged according to the workstation terrain. The nodes localization takes place through the following formula.

$$(X_{\text{est}}, Y_{\text{est}}) = \left(\frac{X_i, + \cdots +, X_n}{N}, \frac{Y_i, + \cdots +, Y_n}{N}\right),$$

Where Xest and Yest are the estimated coordinates of the unknown node.

Centroid algorithm also comes with a variation where weights are assigned to each beacon node according to its respected distance from the unlocalized node. Such algorithms are called Weighted Centroid Algorithm. More weight will be assigned to a node which resides nearer to the unlocalized node and less weight for the beacon node farther away from the unknown node.

3.1.2. APIT

APIT (Approximate Point in Triangulation) is another arrangement in which nodes get their positions from GPS. Unlocalized nodes localize themselves by forming an overlapping triangle. In APIT, an unknown maintains a table which extracts the ID, location and signal strength from the receiving beacons. Unknown would then select any 3 nodes from its table and perform PIT (point in triangulation) to check whether these 3 nodes lie in a triangular position or not. After that the PIT test is repeated until such perfect 3 nodes are found. A center of gravity is calculated by the intersection of the three triangles formed by the 3 nodes and that centre is calculated to be the estimated coordinate of the unknown node. [20]

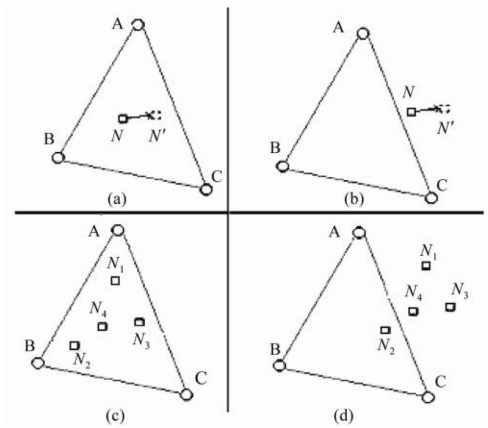


Figure 10 Mathematical and network forms of APIT algorithm

3.1.3. DV-Hop:

This scheme uses the neighbour's information like hopcount to find the distance between nodes. The beacon nodes broadcast their coordinate's information along with their hop counts across the wireless sensor network. The information is routed from one node to another until it reaches the unknown node. As the information is received by each beacon node, the hop count is increased by one [20]. This way, unknown nodes gets to know how many hops away are its neighbours. The beacon nodes calculate the shortest hop count from other nodes and so does the unknown node.

$$hopsize_1 = \frac{d_{1,2} + d_{1,3}}{hop_{1,2} + hop_{1,3}}$$

Where d1,2 is the distance between the beacon node 2 and node 1, d1,3 being the distance between node 3 and node 1, hop1,2 being the hop count between node 1 and 2, and hop 1,3 is the hop count between node 1 and 3. [21]

An average hop-distance formula is applied which is distance between two nodes/number of hops [22]. Triangulation is applied to get the final coordinates.

$$d_{i,x} = hopsize_i \times hopcount_{i,x}$$

Li Juan et al. proposed a new weighted centroid localization algorithm in coal Mine wireless sensor networks [30] that uses RSSI algorithm for distance measurements combined with weighted centroid algorithm for node localization. The improved algorithm used Multi-hop transmission and power control devices which means that if any beacon node was damaged in the network, the beacon node next to it would increase its transmission power to communicate with the unknown node in order to participate in the localization process.

Juan Li [30] proposed that since the underground environment is harsh and electromagnetic wave propagation becomes complicated in such a medium, the wireless signals face scattering attenuation. The surface roughness and sloping of the tunnel walls can be responsible for this attenuation. Li [30] described the transmission of electromagnetic waves in the underground mine includes vertical polarization wave mode and horizontal polarization wave mode. In order to take these polarization factors into account, the following formula was devised to calculate the total pathloss.

$$PL = PL_{Eh} + PL_{Ev} + PL_r + PL_t$$

Where PL_{Ek} is the propagation loss for vertical polarization, PL_{Ev} is the propagation loss for the horizontal polarization, PL_r is the loss due to roughness of the walls, PL_t is the signal loss due to wall sloping. When the unknown node archives the average RSSI received from each beacon node and selects three best RSSI values which are the highest values received from the network, these values are converted into distance by formulas that include propagation loss in the underground mines. Weights are applied next to improve the results. The least localization error recorded was 4.87m from this improved version which still needs considerable improvement.

In the reference [39] Fan, Hongbo, et al proposed a new scheme of weighted centroid algorithm based on improved RSSI ranging. This algorithm used the distance as well as RSSI values, corrects the distance between the beacon nodes and the RSSI and selects the reciproval of the distance as the weight of the algorithm. Hongbo et al [39] used the Free-Space model for the simulation environment to apply the traditional principles of weighted centroid algorithm.

In order to improve the RSSI measurements, the signal strength and the distance between the beacon nodes whose coordinates are known by the system is utilized.

$$P_{ij} = 10^{RSSI_{ji}/10}$$

Where $RSSI_{ji}$ represents the average signal strength of the beacon node B_i received from the beacon node B_j. This value is then used to compare the distance between the two beacon nodes through the following equation.

$$\frac{P_{ij}}{P_i} = \left(\frac{d_{ij}}{Bd_{ij}} \right)^{\beta}$$

The schematic diagram of the RSSI ranging correction is shown in the figure below.

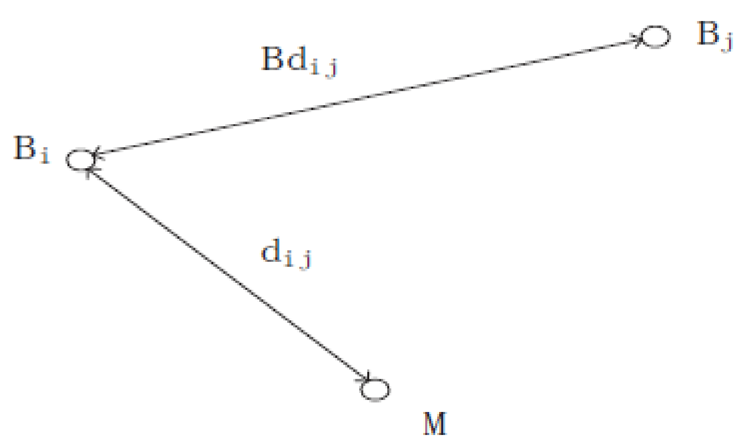


Figure 11 the schematic diagram of RSSI ranging correction

It is shown in the results that compared to the traditional centroid algorithm, the centroid algorithm with improved RSSI ranging has smaller positioning error and higher positioning accuracy. When the simulation results were compared of the two algorithms, the position accuracy improved by 10% which was better than that obtained by the traditional prinicpies of weighted centroid localization.

Another simple scheme has been proposed by Shaoguo Xie [40] where none of the complexities related with pathloss and distance between the anchor nodes is considered. It just relies on the RSSI information received to localize the unknown node. Xie [40] established the relationship between the received power at the unknown node (P_{RXi}) from the i-th anchor node and the transmission power of the two nodes placed one meter apart (P_{Ref}) through the following equation.

$$RSSI_i = 10 \cdot \log \frac{P_{RX_i}}{P_{Ref}}$$

By using the equation from the pathloss in a Free Space model shown below, Xie [40] devised another equation to be used for distance calculation.

$$P_{RX_i} = P_{TX} \cdot G_{TX} \cdot G_{RX} \left(\frac{\lambda}{4\pi d_i} \right)^2$$

From the above equation d can be expressed as

$$d_i = \lambda \sqrt{\frac{P_{TX} \cdot G_{TX} \cdot G_{RX}}{4\pi P_{RX_i}}}$$

After the distance calculation, the weights are assigned to the least distant nodes. The weights would get normalized through the following equation:

$$w_i = \frac{1}{d_i^g} = \frac{1}{\left(\lambda \sqrt{\frac{P_{TX} \cdot G_{TX} \cdot G_{RX}}{4\pi P_{Ref} \cdot 10^{\frac{RSSI_i}{10}}}} \right)^g}$$

And the position of the unknown would be calculated based on the above equation as follows.

$$P = \sum_{i=1}^{n} W_i a_i$$

Where a_i indicates the coordinates of the anchor nodes selected $a_i = (x_i, y_i)$.

The average localization error as shown after the experimentations [40] improved as compared to the traditional WCL. The least error recorded by a WCL was 4.32m while the improved version [40] had the least localization error of 3.75m. The scheme also claimed to be faster and efficient than traditional methods of localization as it does not calculate β the pathloss factor and the distances between the beacon nodes hence saving time and energy. But this scheme can reasonably fail in the underground environment as pathloss factor can not be ignored in such harsh settings and avoiding the pathloss in calculations can result in erroneous measurements.

Although all the above mentioned schemes claimed to perform better than the traditional weighted centroid algorithm, their results can still undergo significant improvement to achieve more accuracy in localization.

2.6 Comparison of Localization Errors of Different Localization Algos

i. RSSI based algorithm:

	Name of the Paper	Localization Algorithm	Results
1.	Zigbee Based Miner Localization System [25]	RSSI based distance calculation Trilateration	LE increases with the RSSI ranging error
2.	A coal mine environmental monitor system with localization function based on Zigbee Compliant Platform [29]	RSSI with trilateration	2.2m with 20.5% ranging error
3.	A new weighted centroid localization algorithm in coal mine wireless sensor network [30]	Weighted centroid	3.87m with 20% ranging error
4.	A Novel real time coal miner localization and tracking system based on self organized sensor network [31]	RSSI verification	i. Weighted centroid performs better than

			RSSI. ii. Centroid performs better than weighted centroid
5.	Study on Localiztion algorithm of Mine Personal Positioning System based on Zigbee [32]	Weighted centroid with RSSI	Better results of weighted centroid with RSSI than without RSSI

Table 2 Comparison of RSSI based Algorithms

ii. Time of Arrival algorithm:

	Name of the Paper	Technology deployed	Results
1.	A UWB mixed positioning method based on the pattern matching in the underground mines [33]	UWB ranging	95% of the localization error is less than 0.4 meter square.
2.	Simultaneous sensor localization and target tracking in mine tunnels [34]	UWB with Round trip TOA	Better results of RT-TOA than TOA

Table 3 Comparison of ToA algorithms

iii. Time Difference of Arrival:

	Name of the Paper	Technology deployed	Results

1.	EKF (Extended Kalman Filter) localization based on TDOA/RSS in underground mines using UWB ranging [35]	UWB ranging +RSS and TDOA	Localization error of EKF with RSS&TDOA is less than EKF with only TDOA.

Table 4 Results of TDoA localization algorithm

iv. Angle of Arrival:

	Name of the Paper	Technology deployed	Results
1.	Research on Mine Tunnel Positioning technology based on the oblique triangle layout strategy. [36]	AOA with RSSI	Localization accuracy improves upto 25%

Table 5 Comparison of AoA algorithms

v. APIT algorithm:

	Name of the Paper	Technology deployed	Results
1.	Novel PIT localization algorithm based on coverage of anchor nodes in WSN [37]		Novel PIT increases the localization accuracy upto 20% as compared to APIT

***Accuracy of APIT algorithm only reaches about 35%**

Table 6 localization accuracy of APIT algorithm

vii. DV-Hop algorithm:

	Name of the Paper	Technology deployed	Results

1.	An improved DV-Hop localization algorithm for WSNs [38]	IDV-Hop vs DV-Hop	Localization Precision: IDV-Hop = 0.65% DV-Hop = 0.50% (when connectivity of the network is higher than 5.6)

Table 7 Localization accuracy of DV-Hop Algorithm

Chapter 4

Proposed Scheme

This chapter describes problem statement and the detailed description of our research methodology that we are using in our thesis. Solution is also explained in detail. The terms and parameters used are explained in order to understand the solution.

4.1 Quadrants Based Weighted Centroid Algorithm for Localization in Underground Mines

We are proposing an improved localization scheme that is founded on weighted centroid algorithm discuused in the previous chapter. Figure (13) depicts the system design of our porposed localization algorithm. The design involves a set of static beacon nodes whose coordinates are fixed at the time of deployment. The deployed system is used to track an unlocalized node carried by a mobile target. The network is designed in a way that the beacon nodes are programmed to send beacon frames at regular interval of time in the network. The unlocalized nodes receive periodic beacon frames transmitted by the beacon nodes. These beacon frames contain information such as beacon node ID and its coordinates (X,Y) of each sending beacon node. The RSSI (received signal strength indicator) values are calculated at the receiving node. These values are the signal strength values in the unit dBm.

As explained in literature review, Weighted Centroid Algorithm coupled with RSSI distance measurement provides acceptable results in an underground environment. We propose a localization algorithm that takes two important aspects of the node localization in underground mines into account; the pathloss factor and an improved weighted centroid algorithm that both work together to give improved localization results as compared to other techniques.

Our proposed scheme can be divided into four phases

a. Pathloss Calculation
b. Distance Estimation
c. Position Estimation
d. Quadrants Calculation

Figure 12. Traditional Weighted Centroid Algorithm

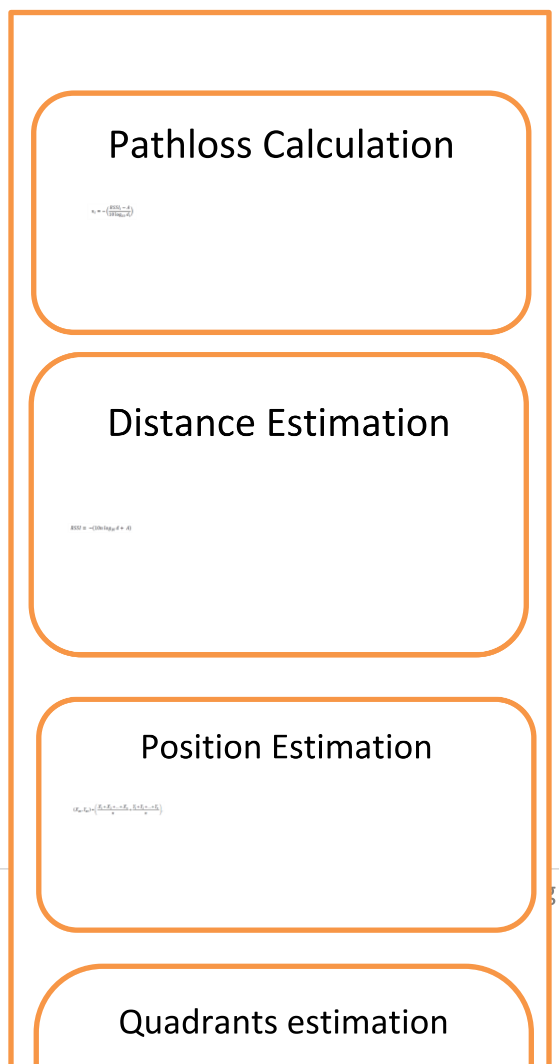


Figure 13. Quadrant-Based Weighted Centroid Algorithm

4.1.1. Pathloss Calculation:

Pathloss calculation phase involves finding the path loss in the vicinity of each beacon node. Existing literature on radio propagation model [26, 27] in different environments suggest that a non-isotropic path loss exists beacause of the variation in the propagation medium and direction. Neglecting the pathloss factor while considering underground environments can lead to highly erraneos results as such a constant directly reflects the propagation environment. The feasibility of any localization algorithm largely depends on the correct estimation of this constant which varies based on the enviornment. Most of the models assume the pathloss to lie between 2~4 when considering the underground environment but such assumption does not always hold true due to varying and harsh underground environment. Therefore, it is required that in order to analyse the radio propagation pattern, the irregularity of the pathloss must be defined.

A series of calibrations perfomed in [28] show that uniform computation of the pathloss constant in order to determine the distance exhibits drawbacks. This verified that various mediums such as walls, obstacles, glass, free space etc affect the signal attenuation differently so using a uniform signal propagation constant neglects the interference properties of these materials. So, if only a single pathloss factor is calculated for all beacon nodes then that may lead to high errors in localization process.

In our scheme when an unlocalized node receives the beacon frames at predefined intervals, it calculates the RSSI values. This RSSI value is used to approximate the distance from each beacon node by using the pathloss factor. Clearly any error in pathloss factor estimation would result in erroneous distance estimation. This first phase aims to improve the pathloss factor estimation process.

The beacon nodes are already aware of their coordinates as they are fixed at the time of deployment. The idea is that beacon nodes can exchange beacon messages with each other and calculate the RSSI of received beacon messages. Now as the actual distances between the respective beacon nodes are already known, RSSI can be easily related to actual distances to calculate the actual pathloss factor involved in the beacon message transaction. Each beacon node can calculate and advertise this pathloss factor in its future beacon messages. The unknown node once receives this beacon message with pathloss advertisement, can improve its distance estimation based on RSSI and the prevelant pathloss factor.

When the beacon frames are exchanged, the beacon nodes calculate their relative distances compared to other beacon nodes by the following formula.

$$d_{relative(a\ \&\ b)} = \sqrt{}(X_a - X_b)^2 - (Ya - Y_b)^2 \qquad (1)$$

Where $d_{relative(a\ \&\ b)}$ is the relative distance between beacon node a and beacon node b, X_a and Y_a are X and Y coordinates of the beacon node a and X_b and Y_b are the X,Y coordinates of the beacon node b.

These distances are stored at each beacon node such that every beacon node in the network is aware of its neighbour's coordinates and their respective distances from each other. After determining each other's distances, beacon nodes calculate the pathloss factor by the measured RSSI values and the relative distances by reversing the linear RSSI equation.

$$RSSI = -(10n\, log_{10}\, d + A) \qquad (2)$$

Where n is signal propagation constant or exponent, d is the distance from sender and A is the received signal strength at 1-meter distance.

$$n_i = -\left(\frac{RSSI_i - A}{10\log_{10} d_i}\right) \qquad (3)$$

The value of A is an absolute value calibrated by determining the signal strength between two nodes set at 1m apart. In this phase, the pathloss factor is calculated to be used in the distance estimation. After pathloss calculation by each beacon node, we proceed to the distance estimation phase.

4.1.2. Distance Estimation:

Since each beacon node in the network has estimated the pathloss factor, it would propagate this information to other nodes within the beacon frame advertisement. The unlocalized node can now receive beacon frames that would have the information of their transmitted beacon nodes ID, coordinates and the pathloss factor calculated alongwith the RSSI values calculated upon the arrival of each beacon. The unlocalized node upon receving this information stores this information and averages the multiple pathloss values received from various beacon nodes to obtain an average pathloss factor value.

Once the average path loss factor value is available, an unlocalized node is capable of converting its RSSI measurements into distance through the use of this average pathloss factor. However, the main challenge in using raw RSSI values is that it is prone to high sensitivity of its environmental variations. The fluctuating nature of RSSI measurement limits the accuracy of the distance estimation, in other words, if radio propagation signals are highly dependent upon the distance between the transmitter and the receiver, then it would be easier to use the raw values of the RSSI but in practice RSSI values are largely fluctuating because of the environmental interference hence distance calculated through such wavering values would be faulty. This happens even when the mobile target is not changing its position and the whole network is static, RSSI values vary over time for the same distances. This is the nature of the signal's behavior. Therefore, RSSI smoothing is required to reduce this dynamic wavering of the radio signals received from each beacon node more so when the unlocalized node is mobile.

In order to smooth the RSSI values while the user moves arbitrarily in the network, we calculate the simple moving average of measured RSSI values for each beacon node.

$$RSSI_{avg(i)} = (\text{rounded } RSSI_{prev} + RSSI_{new})/2 \quad (4)$$

Where $RSSI_{avg(i)}$ is previously averaged and $RSSI_{new}$ is the newly received RSSI from beacon node i.

Averaged RSSI values obtained using equation No 4 are then converted in to distances using equation (1) with estimated pathloss factor derived from the phase 1 of our algorithm. The unlocalized node now has distance estimation to each beacon node from whom it has received a series of beacon messages. The information of neigbour beacon nodes are then stored at the unlocalized node according to the calculated distance in ascending order.

4.1.3. Position estimation

In order to assess the position of the unknown node, at least three reference nodes are selected. These three nodes selected are the three least distant beacon nodes from the unlocalized node. A traditional weighted centroid algorithm is applied which determines the position of the moving object based on simulateous range measurements from the three beacon nodes. The algorithm requires the coordinates of these three reference nodes (xi, yi) and the distances d_i between the unlocalized node and the beacon nodes, which have already been calculated in the last phase and stored and sorted according to the distance.

$$(X_{est}, Y_{est}) = \left(\frac{X_1 + X_2 + \ldots + X_n}{n} + \frac{Y_1 + Y_2 + \ldots + Y_n}{n} \right). \qquad (5)$$

Now weights are applied according to the distance from each beacon node. From the weighted centroid principle, we can use the equation (6).

$$(6) \qquad = \frac{\frac{x_1}{d_1} + \frac{x_2}{d_2} + \cdots + \frac{x_n}{d_n}}{\frac{1}{d_1} + \frac{1}{d_2} + \cdots \frac{1}{d_n}} \qquad X_{est}$$

Where x_1, x_2, x_3 ….x_n are the X coordinates of the beacon node 1, 2, 3 … n respectively and d_1, d_2, d_3….dn are the distances of the beacon nodes 1, 2, 3 … n from the unlocalized node respectively.

$$Y_{est} \qquad = \frac{\frac{y_1}{d_1} + \frac{y_2}{d_2} + \cdots + \frac{y_n}{d_n}}{\frac{1}{d_1} + \frac{1}{d_2} + \cdots \frac{1}{d_n}} \qquad (7)$$

Where Y_1, Y_2, Y_3 ….Yn are the Y coordinates of the beacon node 1, 2, 3 … n respectively and d_1, d_2, d_3….dn are the distances of the beacon nodes 1, 2, 3 … n from the unlocalized node respectively.

The weighing factor used is

$$\omega_i = 1/d_i \qquad (8)$$

In other words, we can say that the closer the distance is, the greater would be the value of the weight. In this way, a node closest to the unlocalized node would have more influence on the position estimate than a node that is farther away than the closest node.

After this phase has completed, we have an estimated position of the unlocalized node.

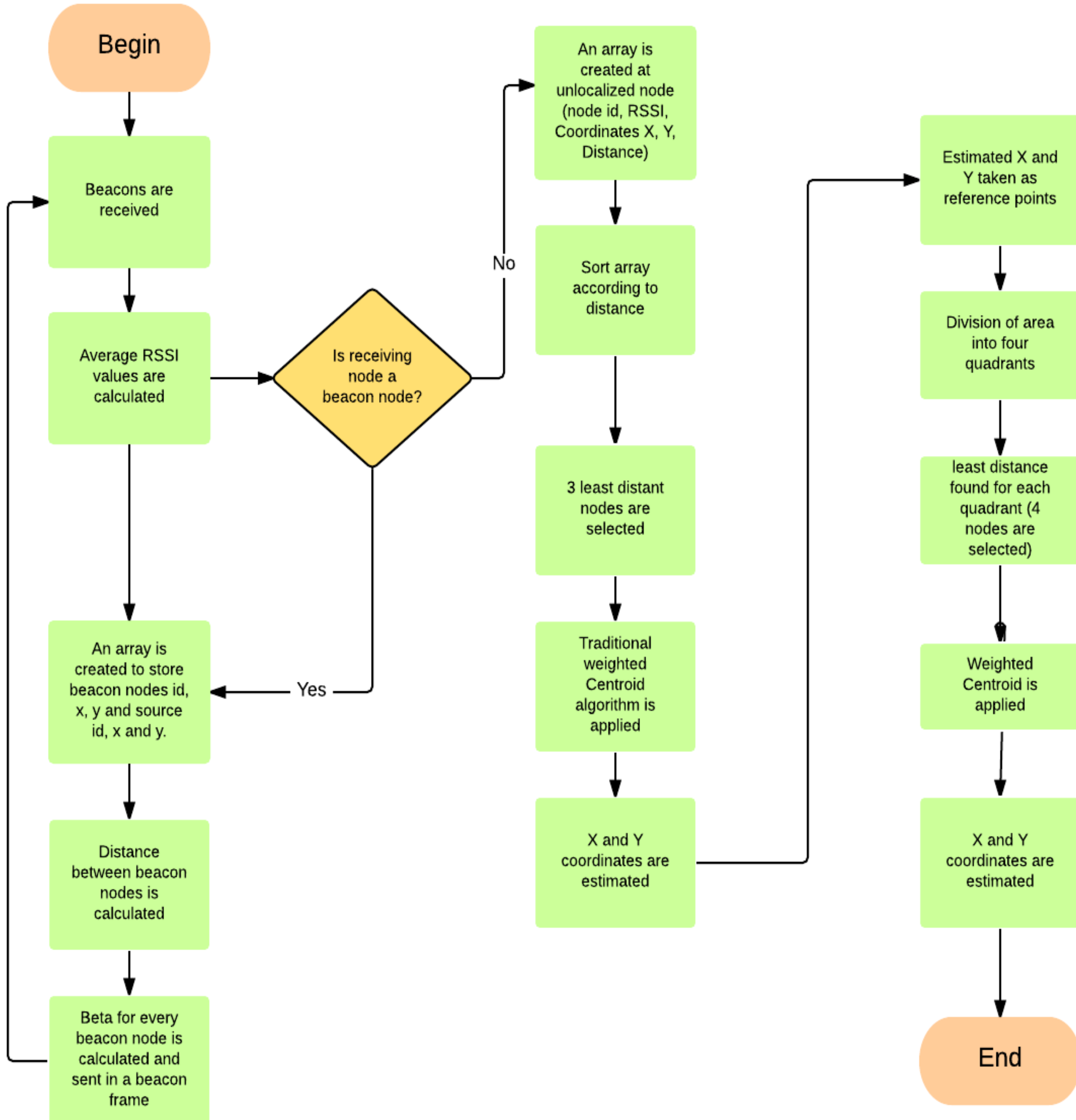
4.1.4. Quadrants estimation

Once this estimated position is calculated, the unlocalized node would use this position to divide its network into four quadrants. Each quadrant would be a mathematically calculated area based on the coarse calculation of X and Y of the unlocalized node. These quadrants are calculated by the unlocalized node through sorting the X and Ys of the neighbouring beacon nodes into four squares from four directions. For this purpose, it would run a query on its existing beacon information to separate $X_{beacons} > X_{est}$ and $Y_{beacons} > Y_{est}$ into first quadrant, $X_{beacons} > X_{est}$ and $Y_{beacons} < Y_{est}$ into second quadrant, $X_{beacons} < X_{est}$ and $Y_{beacons} < Y_{est}$ into third quadrant, and $X_{beacons} < X_{est}$ and $Y_{beacons} > Y_{est}$ into fourth quadrant respectively. After this division, the unknown node would select least distant node from each quadrant so that now it has four nodes from each quadrant to perform the weighted centroid algorithm.

The four nodes selected would undergo the position estimation again in which weighted centroid algorithm would be applied to get a new estimated position.

The idea behind the division of the wireless sensor network into four quadrants is that the un-localized node should get localized from four directions in a 2D tunnel. A node which is going to be located through the information received from all directions would achieve better accuracy in localization as compared to a node using three least distant nodes as is the usual practice of a typical weighted centroid localization algorithm.

4.2 Flow chart of Quadrant-based Weighted Centroid Localization Algorithm



Chapter 5

Performance Evaluation

5.1 Simulation Setup

Setup for simulation was installed on a VMware machine running Linux – Ubuntu as an operating system having version 12.04. Simulations were performed in Network Simulator-2 (NS-2) and the version used is NS-2.35. VMware offers a complete isolation of the operating systems. Overall simulations were performed at the MAC layer due to which no significant changes were made to the application layer. The work was performed on Mac 802.11 and no routing protocol was involved in the implementation of the setup. So, in order to implement our algorithm at the lower stack level, the modifications of the existing Mac 802.11 were done in pre-exisiting Mac files in the NS-2.35 setup. Further details are discussed in the following sections.

5.1.1. VMware Workstation

VMware software offers a completely virtualized set of hardware to guest operating system. Also, multiple virtual machines with different operating systems can be setup in such a way that they are simulated as connected through a LAN whose settings can be customized by the user as per the requirement. Advantage of using VMware is that backup of these machines can be copied from one place to another thus supporting mobility. Vmware can be run over Windows, Mac and Linux etc. NS-2 can be installed through Vmware in Windows and Linux both. As for Windows is concerned, it is necessary to install a UNIX emulator like Cygwin before the installing NS-2. The issue with windows operating system is that of stability of software. Most of the softwares offered by third parties are not compatible with platform of the windows. Our simulation was conducted in NS-2 in Linux – Ubuntu 12.04 which was installed on Vmware machine.

A total of 8 GB hard disk was allocated to Vmware machine as to store files resulting from simulation of different scenarios. A Ram of 1 GB was also allocated to run the operating system.

Figure 14 Flow Chart of Proposed Methodology

Allocations were done by looking at the requirement of storage as simulation having 1000 times and having 50 nodes can produce a data of round about 2 GB. Trace files and NAM are included in the 2 GB. Therefore, running a lot of simulations require that much space to be saved. The space occupation can also be reduced by not producing the trace file and by using on screen results which give the required specifications with the help of a C++ script explained in the coming sections.

5.1.2. Network Simulator-2 (NS-2)

Simulator we used is Network Simulator-2 (NS-2) as mentioned earlier, which is a platform used to simulate different networks which include conventional networks like ethernet and also wireless networks can be simulated by using the NS-2. NS-2 is an object oriented simulator, the language used is C++, with an OTcl interpreter as a frontend. NS-2 has Otcl script for configuring the network, a traffic pattern to declare data transmission from source to destination and a mobility pattern to specify the movement of the nodes inside the grid. Mobility model needs to be traced and also type of traffic at different layers like at network, MAC and physical layer should be recorded in a file for analysis and further consideration. Information is stored in a trace file too for same purpose of analysis. For the sake of simplicity, the information from the simulation for our algorithm was stored in an output file from where the results were extracted. Also, the results on the terminal can also be seen and easily evaluated.

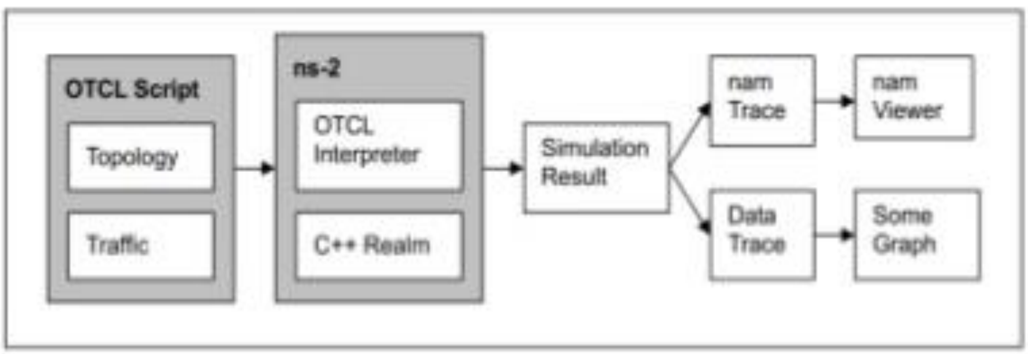


Figure 15. Working of Network Simulator (NS-2)

5.2 Implementation in MAC 802.11

The algorithm is implemented at the lower stack level to reduce complexity. For this purpose, modifications are made at the MAC layer by altering the pre-exisitng 802.11 mac file in NS2.35 setups (ns-allinone-2.35/ns2.35/tcl/ex/802.11/mac-802_11.cc). A tcl scripting file is linked to MAC which uses the following parameters for simulating an underground environment.

```
set val(chan)           Channel/WirelessChannel    ;#Channel Type
set val(prop)           Propagation/TwoRayGround   ;# radio-propagation model
set val(netif)          Phy/WirelessPhy            ;# network interface type
set val(mac)            Mac/802_11                 ;# MAC type
set val(ifq)            Queue/DropTail             ;# interface queue type
set val(ll)             LL                         ;# link layer type
set val(ant)            Antenna/OmniAntenna        ;# antenna model
set val(ifqlen)         50                         ;# max packet in ifq
set val(nn)             40                         ;# number of total nodes
set val(rp)             DumbAgent                  ;# routing protocol
set val(x)              5
set val(y)              100
set val(nam)            beacon.nam;
Mac/802_11 set dataRate_ 11Mb

Phy/WirelessPhy set CSThresh_ 10.00e-12
Phy/WirelessPhy set RXThresh_ 10.00e-12

Phy/WirelessPhy set Pt_ 0.008
```

Figure 16. Parameters declared in .tcl file

Transmission power is set to be 0.008W. The calibration constant A as mentioned in equation (2) is set at -22.628 dBm which is an absolute value obtained when the nodes are set at exact 1m apart. Results are compared in two scenerios. First scenario includes the physical dimension of the outdoor environment is 100m x 100m. A maximum total of 40 reference nodes was scattered or randomly placed in the square test area. During the simulation, a user carrying an unknown node walks from a starting point with coordinate (10, 10) to an ending point with coordinate (50, 50). This movement is directed diagonally across the plane of the simulation. The speed of the movement is set at 3.5m/s.

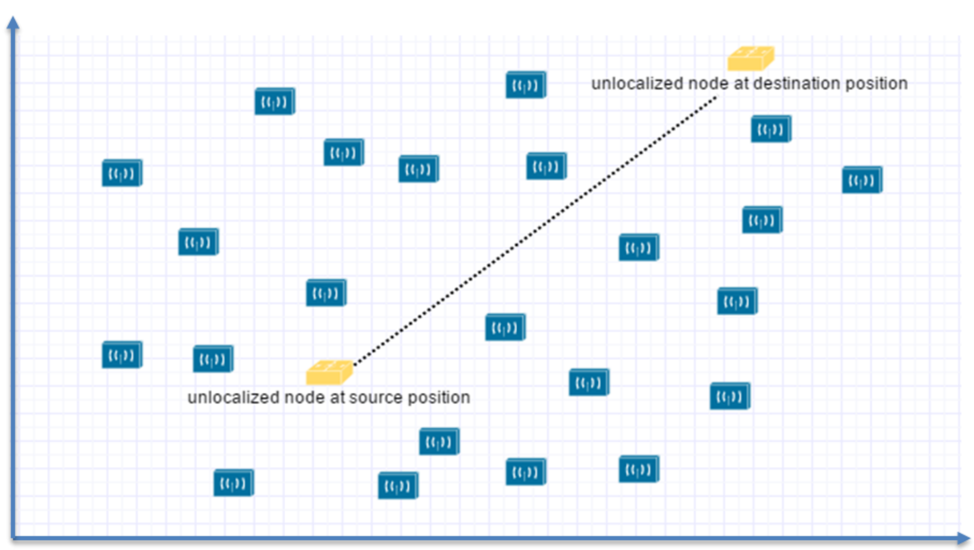


Figure 17 topology of 100mx100m rectangular area with 40 nodes randomly placed

The movement is tracked at every minute interval of the simulation. The accuracy of the proposed system is found by comparing the position estimated by this system with the calculated estimation by traditional methods of calculating weighted centroid localization.

Second scenario sets up the simulation area of 5m x 100m which is closest possible dimension of a mine tunnel. A total of 40 nodes are placed at equal distance of 5m apart around the walls of the tunnel. The coordinates of these nodes are fixed and known by the system. The unknown node would start moving from its source point (2, 10) to its destination point (2, 80). The movement is set at the speed of 3.5m/s and the unknown node is simulated to move straight in the tunnel.

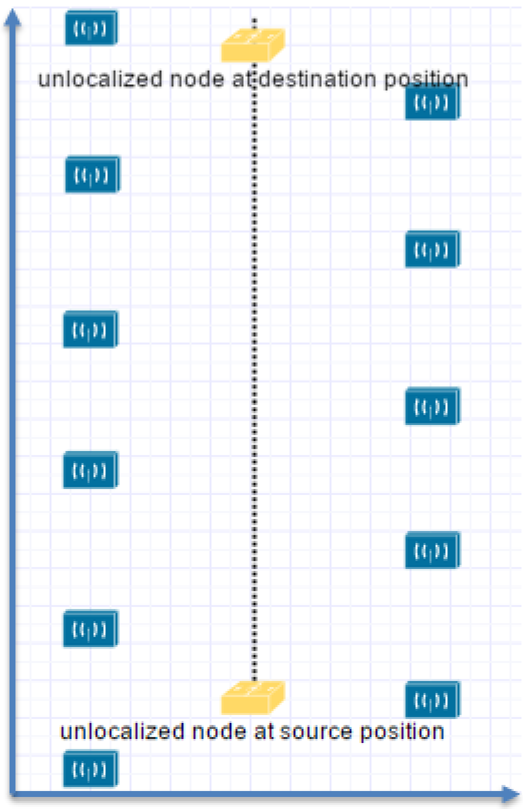


Figure 18 topology of 5mx100m mine tunnel where 40 nodes are placed alternately 5m apart

First, a round of traditional WCL algorithm is applied and then quad-based weighted centroid algorithm is applied to the simulation area and the results are calculated.

5.3 Performance Parameters

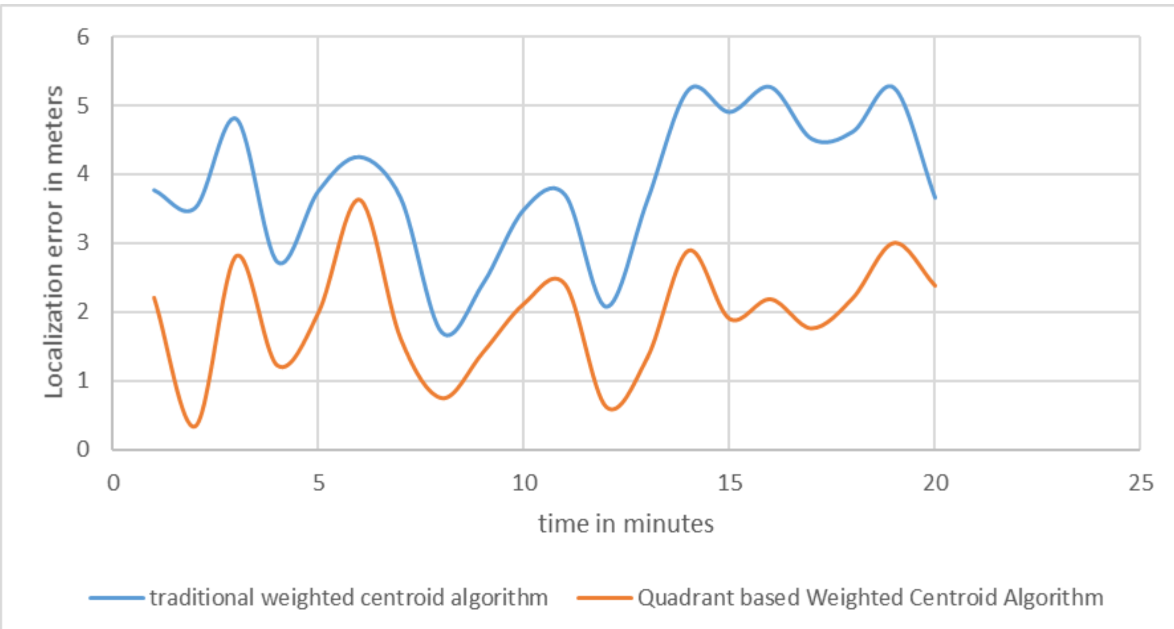
We have analyzed the localization error for our proposed scheme. We are analyzing our estimated position according to the node movement.

a. Localization error in an open rectangular area

b. Localization error in a mine tunnel

5.4 Results

Fig 19 shows the comparison of position estimation for both traditional weighted centroid algorithm and the quad-based weighted centroid algorithm with the predicted position for an open area. The error is recorded as soon as the simulation starts with the unknown node moving from its intial position of (5, 5) towards the destination of coordinates (50, 50) with a speed of 3.5m/s having a total of 40 nodes randomly placed in the surrounding area. The localization error observed over the time while the node moves across the area is shown as



follows.

Figure 19 Comparison of traditional weighted centroid algorithm with Quadrant-based weighted centroid localization error using in 100mx100m area

The localization error over the course of time as the node moves diagonally across the simulation area is observed to be better for the Quad-based weighted centroid algorithm with maximum error observed of 3.62m and minimum of 0.37m. Around 50% improvement in localization accuracy is observed as compared to the traditional weighted centroid algorithm. RSSI refinement through the use of pathloss factor improves the accuracy on tracking a mobile target.

Similarly, simulations were performed with a set up of 5mx100m which closely depicts a mine tunnel dimensions. The error is recorded as soon as the simulation starts with the unknown node moving from its intial position of (2, 10) towards the destination of coordinates (2, 80) with a speed of 3.5m/s having a total of 40 nodes equally placed at 5m apart each at alternate pattern. The movement of the node depicts a miner walking straight inside a mine tunnel. The localization error observed over the time while the node moves in the area is shown as follows.

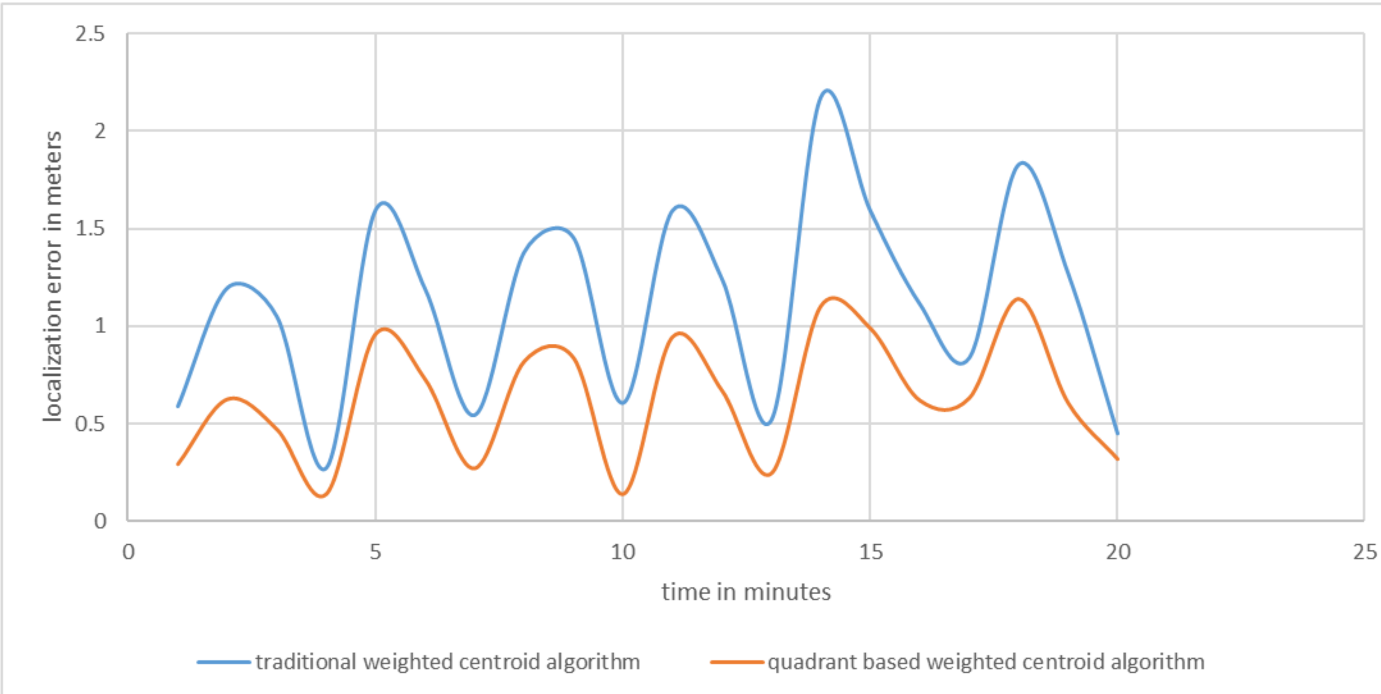


Figure 20 Comparison of localization error of traditional weighted centroid algorithm with Quadrant-based weighted centroid algorithm in a mine tunnel

As can be seen by figure 20, the quadrant-based weighted centroid algorithm outperforms the traditional weighted centroid and the localization error is much reduced now with around 1.14m to be the maximum and 0.10m to be the minimum error observed. Around 70% improvement in localization accuracy is observed as compared to the traditional weighted centroid algorithm. This is a significant improvement as the localization error has greatly reduced while keeping beacon nodes orientation and the estimated pathloss factor into account.

It can be seen that the results obtained in the mine tunnel are better than that of the open area which is due to the fact that the mine tunnels are narrow and close spaces and in a width of 5m, a miner would always be in close proximity with the nodes placed at the tunnel walls in an alternate pattern. The pathloss factor observed in a mine tunnel is less than 1.94 on average. On the other hand, in an open area where the nodes are randomly deployed, a miner would sometimes be surrounded by closely spaced nodes and in other instances he would have the beacon nodes placed far apart from him. This difference in the topology creates the differences in the RSSI values received. The pathloss estimation in an open area is observed to be around 1.85

on average however, the division of the area under consideration into quadrants still significantly improves the results.

In comparison with other RSSI-based location algorithms, our proposed system exhibits resemblance in terms of propagation constants calibration but the pathloss factor calculation is not suggested in other schemes. Using the pathloss and the quadrants division in our algorithm, makes it outperform other systems in terms of accuracy

Chapter 6

Conclusion & Future Directions

6.1 Conclusion

In this document, a different approach to localizing an unknown node in a mine tunnel is proposed that works better than the traditional methods of localization. The algorithm outperforms other proposed algorithms based on RSSI estimation as it provides an easy and enhanced solution to tracking user position in an underground environment. Overall average accuracy is improved through refining the estimation of path loss factor and by selection of 4 nodes located in different quadrants to obtain better localization results. The simulation results show the improvement provided by our proposed solution as compared to the simple centriod based localization algorithm.

It has been found that the results obtained by our proposed algorithm exceed in accuracy as compared to the results obtained by the simulation of the traditional weighted centroid algorithm and the accuracy was improved upto 50% in open space and 70% in underground tunnel. The results can be further improved by simulating the algorithm in the real underground environment or by inserting real time RSSI values in the simulation.

6.2 Future Direction

Simulation results from this research study indicate that better distance estimates can be achieved through improvement in estimation of pathloss factor that is prevalent in the environment. We have tried to improve the localization accuracy for mines. However, a number of extensions can be applied to the Quadrant-based Weighted Centroid Algorithm to further improve the localization accuracy. The study of the impact of using different propagation models can also be applied as well as more accuracy can be achieved if the real-time RSSI values of underground mines are used in the simulations. We plan to implement our proposed algorithm on real sensor network hardware and to ascertain its performance in real mine conditions to guage the performance of the proposed algorithm in real world scenarios.

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