Location-Based Indoor Mobile Advertising

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A dissertation submitted for the Degree of Master of Computer Science

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Declaration

The thesis is my original work and has not been submitted previously for a degree at this or any other university/institute.

To the best of my knowledge it does not contain any material published or written by another person, except as acknowledged in the text.

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Under my supervision. The thesis has been prepared according to the format stipulated and is of acceptable standard.

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Abstract

Smart phones and smart devices play a major role in people's lifestyle all over the world. Localization is one of the useful features available on those smart devices. Outdoor localization and indoor localization are the two main categories of localization.

The most common localization system on mobile phones is outdoor localization with GPS. However indoor positioning is generally not supported by GPS. This study mainly target on indoor localization or preciously track indoor location. A detailed discussion on most of the available techniques, methods and technologies for indoor localization is also included.

A discussion on Bluetooth Low Energy (BLE) along with trilateration based indoor localization methodology, effective use of smoothing RSSI signals using filters such as feedback filter and RSSI mean filter are key features of this study.

Prototype system showed an accuracy around ± 0.75 to ± 1 meter range. Bluetooth transmitting device quality, environment temperature, device temperature, impact of human body, reflections and interference from other communication signals are the main challenges faced with prototype. Accuracy of this system is significant for a successful implementation of for Location-Based Indoor Mobile Advertising. Since algorithms and techniques used for outdoor mobile advertising can be adopted for indoor as well, our main emphasis was to improve the accuracy of indoor localization.

Keywords: Indoor Localization, Bluetooth, Bluetooth Low Energy (BLE), Received Signal Strength Indicator (RSSI), Trilateration

Table of Contents

List of Figures

List of Tables

List of Abbreviations and Acronyms

GPS	Global Positioning System
TTFF	Time to First Fix
TTSF	Time to Subsequent Fix
NNOS	Non Line of Sight
WSN	Wireless and Sensor Networks
AOA	Angle of Arrival
TOA	Time of Arrival
TDOA	Time Difference of Arrival
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
APIT	Approximate Point in Triangulation
IMU	Inertial Measurement Unit
EMC	Electronic Magnetic Compass
QR Code	Quick Response Code
BLE	Bluetooth Low Energy
MAC Address	Media Access Control Address
LBS	Location-based advertising

Chapter 1 : Introduction

1.1 Background

Mobile phones play a major role in people's life these days. Hence precise mobile based advertising rather than just showing posters or banners, will be more effective. These kind of outdoor mobile advertising applications use GPS-Global Positioning System and map API such as Google map to find the geographical location of the customer.

Finding places and advertising can be done using the information provided by above technologies. When traveling, GPS technology is already used to deliver information and popup advertisements of the nearby places.

But when user enters to a shopping mall or a shopping complex, it is hard to use these technologies to track the exact location. Because there are hundreds of shops and several floors in a single shopping complex. To use location based mobile advertising in indoor situations are bit difficult. Most probably GPS won't work inside a building and no large gaps/separations between shops. Further there are multiple floors in a shopping mall, so track the location with the floor is not possible at the moment. Other than advertising finding places like shops or specific item in a large store may cause the same difficulties.

There are 3D GPS concepts but, those concepts still in research and developing stages. Tracking a customer's indoor location is the main problem for these kinds of applications. There are other issues such as identifying which end or which door the customer used to get into the building, which direction customer is walking, navigate customer to the relevant shop and most importantly user or customer privacy when using those applications.

Introducing these kinds of indoor location based information or advertising mobile application would be very effective to find sales, deals and products to customers. And easy to advertise product details, discounts and other relevant details from the shop owners.

1.2 Motivation

Mobile phones and mobile location tracking via GPS is used by a majority these days. To find outdoor location of any place people can use GPS via mobile phones, and most of the social media apps included those location tracking and tagging functionalities to their mobile applications. But finding indoor location is not popular or developed that much compared to GPS location or outdoor location tracking. Indoor localization is different when compared to outdoor localization, which is not work preciously as GPS. So the motive of this project is to discover and implement a system to find precise indoor location of mobile devices. Indoor localization can be used to find location in a huge shopping mall, find shops, and find items in supermarkets and advertising in shopping malls. Those are the main motivational factors to conduct the research to find best, accurate and low cost technology for indoor localization.

1.3 Aim and Objectives

- Study existing indoor location based mobile systems and gain knowledge about those studies
- Analyze and identify limitations of these type of systems and try find a way to overcome those limitations
- Main concerns are accurate or precious location, in which direction customer walking and some prior knowledge about customer
- Study different technologies to identify customer location accurately
- Identify customer privacy related issue while implementing those systems
- Design sample implementation or prototypes with identified indoor location tracking technologies. Test and evaluate those implemented prototypes and try to find most accurate and feasible indoor location technology for the proposed project (Ex-: GPS-Global Positioning System, Wi-Fi, BLE- Bluetooth Low Energy, BLE beacon)
- Evaluate implemented system using mobile devices in a simulated environment or sample environment. Changing variables of the environment can evaluate the accuracy of the system. Because main target of the project is to implement an accurate indoor location based system

1.4 Scope and Limitations

Scope of the project is to identify, analyze and implement a system to location based indoor mobile advertising application. First step, have to find related researches and projects in indoor localization. Study techniques and technologies that used on those projects, finding strength and weakness of those techniques and technologies. Then study about indoor location based technologies and select suitable technology or technologies for the project. There are other concerns such as identify closed shops, omit those shops when showing to the customers and privacy issues when customer get notifications or advertisement to their mobile phones. Accurate way to guide the customer to selected shop or relevant shop is another area to study in this project scope.

After background studies, identify and analyses those requirements, implement the prototype systems. Creating a simulated environment or a sample environment and using various kind of mobile devices should evaluate the prototype systems. Using prototypes evaluations can identify the most accurate and feasible technology to track indoor location of the customer.

Chapter 2 : Background/Literature Review

This chapter describes about main research work carried out starting localization from outdoor localization, indoor localization, methods, techniques and technologies used to track location. There are plenty of methods, technologies available for localization research area. This sections motive is to critically cover and evaluate the available research work related to indoor location based tracking technologies and methods.

2.1 Outdoor localization

Most popular localization which tracking outdoor location of devices using GPS. Satellite based Global positioning system (GPS) [1] [2] rapidly becoming a universal utility as the cost of integrating the technology into vehicles, machinery, computers, and mobile phones decreases. Following Figure 2-1 shows how GPS works tracking real time location.

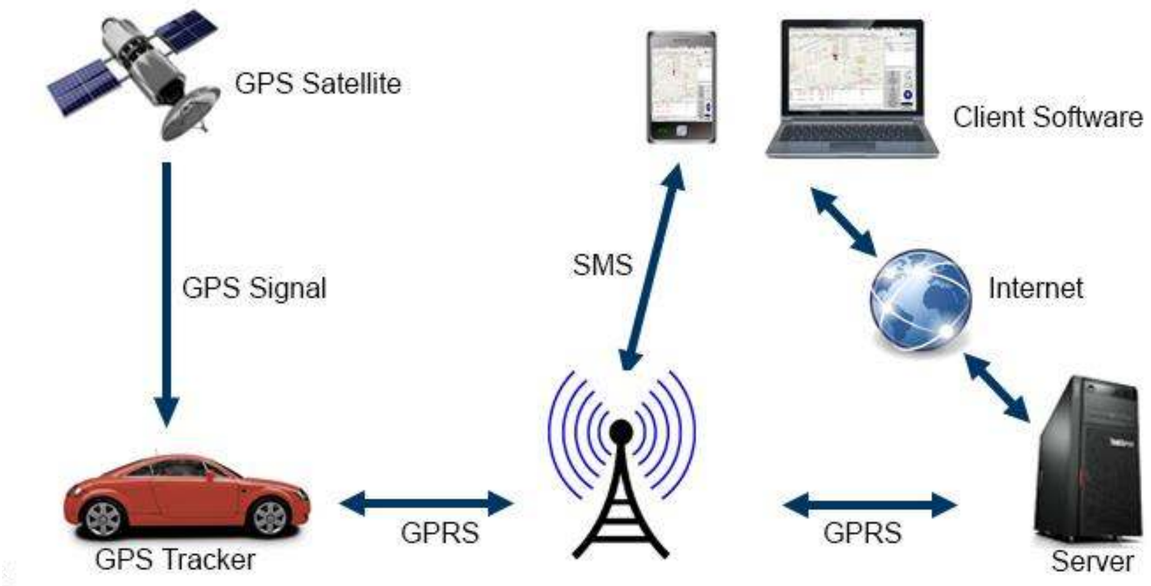

Figure 2-1: How GPS tracking works

GPS used network of 24 satellites in six different 12 hour orbital paths spaces so that every point of the globe covered by at least five satellites [2] [3]. As Figure 2-2 shows, the receiver can roughly determine the location with three satellites using trilateration technique. With more than three satellites the receiver can determine the user's latitude, longitude and altitude. Then using those collected data can calculate the information like speed, trip distance and distance to destination. Figure 2-2 shows the GPS trilateration works.

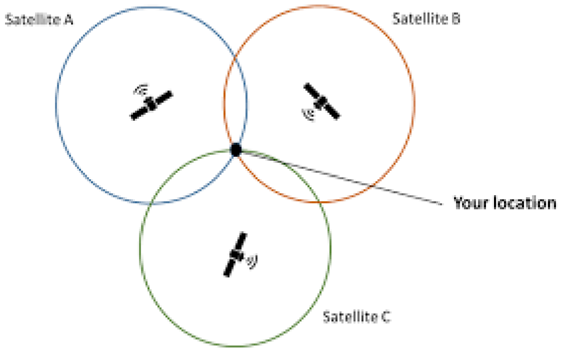

Figure 2-2: GPS trilateration

There are limitations in GPS with outdoor localization. A major problem occur radio signal speed constant only in vacuum. Water vapor and other particles slow down the radio signal speed in GPS [2]. Another limitation GPS only work in outdoor environment. Those signal cannot receive in indoor environments. Technologies like AGPS should use to track indoor location.

2.2 Indoor Localization

In this sections critically cover and evaluate the available research work related to indoor location based tracking technologies and methods. Indoor localization means estimating a location of the particular object in an indoor environment using wireless technologies. Basically indoor location tracking is a challenge since those location should be track using intangible wireless signals. There are many methods, techniques and technologies used to obtain accurate location in indoor localization. There are researches using single method and technology or using multiple methods and technologies to achieve high accuracy. Those multi methods and multi technology systems called hybrid localization systems. Main target is to achieve high accuracy, robustness, low complexity and scalability of the solution.

2.2.1 Classification of Indoor Localization

Global positioning system (GPS) [1] is the main technology used for outdoor positioning. It provides accurate user location information and is widely used for outdoor navigation, emergency services, location related advertisements and other location based services. However satellite-based navigation systems have limitations when comes to indoor environments. Signals get attenuated by objects like walls and roofs. The time to first fix (TTFF) and the time to subsequent fix (TTSF) become larger as satellite signals become non line of sight (NNOS) [4]. So, any other technologies which can be trusted to be giving precise user location information inside buildings or in underground spaces is a requirement. Figure 2-3 shows the approaches available for indoor positioning.

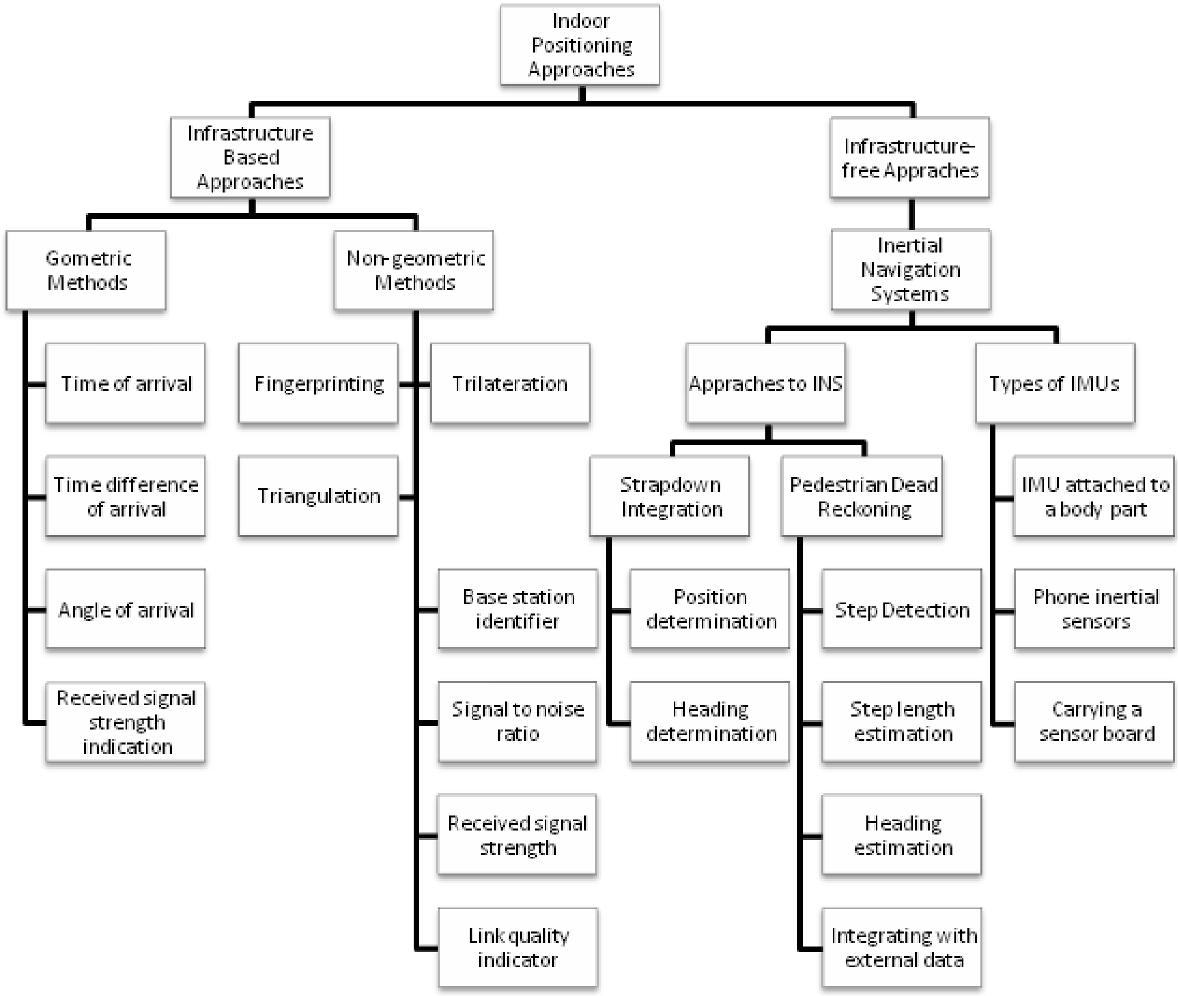

Figure 2-3: Indoor positioning related approaches

Indoor location tracking using received signal strength indicator is one technology that have been implemented to track indoor location. The development pace of location tracking research is highly tied up with advancement of wireless sensor network (WSN) [5] and wireless technologies. Sensor node in WSN became smaller and more powerful, processing information and track location became more intelligent. In those technologies basic concept to tag the location is just detected by two or more sensor nodes along movement path of the target object. Using three or more sensor nodes can be used detect distance between the target object and the sensor node. Determination of distance between two entities is called "ranging". So use this technology exact location coordinates of the target can be computed. Angulation or lateration techniques used to compute location coordinates using those sensor nodes. Figure 2-4 shows the classification of location tracking mention above.

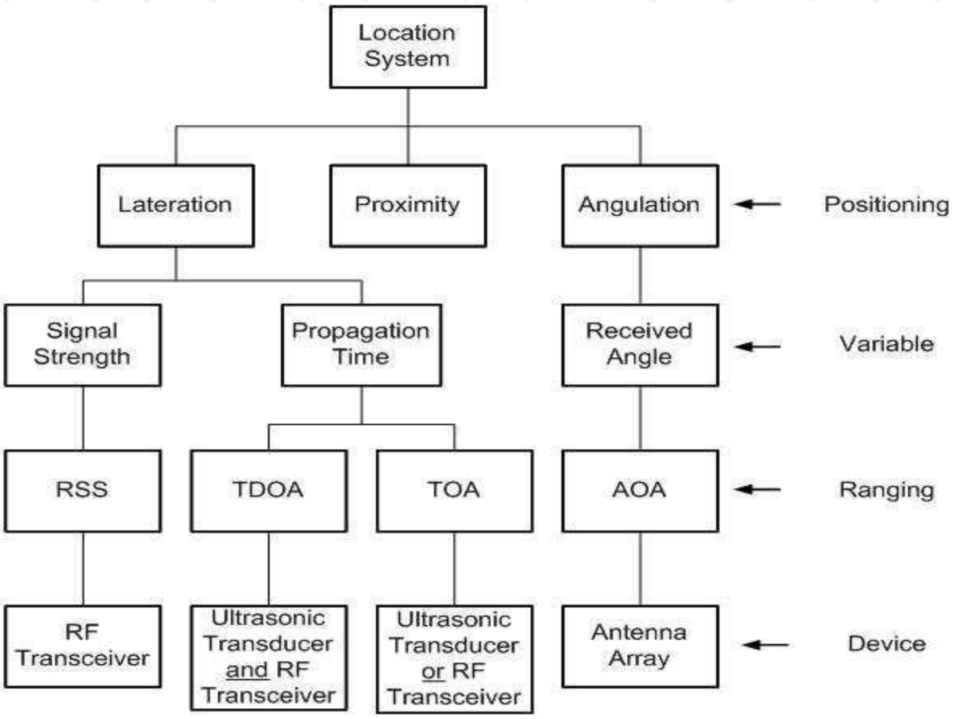

Figure 2-4: Classification of location tracking systems

The sections requirement of location systems can be more specific to suit different needs and environments such as accuracy, indoor environment, positioning techniques, tanging methods, security and privacy, device available, WSN deployment restriction, network scale, implementation cost, healthy consideration and etc. So technology perspective classification of location systems can be categorized as below diagram.

Classification main aspects [6] positioning, variable, ranging, device are discuss below.

- Positioning aspect

  In positioning there are three kind of techniques can be used to identify the location coordinates, lateration, proximity and angulation. Proximity is range free or detection based technique that does not calculate exact location coordinates [7]. Lateration and angulation are range based techniques that can compute exact location coordinates. Angulation compute location coordinates using angle of the target object while lateration calculate it from distance between target object and the sensor node.

- Variable aspect

  Signal strength, propagation time and received angle are the variables that can be used to find location using sensor data. Propagation time is the time duration taken for a signal to travel from transmitter to receiver. Signal strength measured at receiver when it receive the signal from transmitter. Signal strength reduce or become weaker when distance go further. Combination of those variables use to find exact location.

- Ranging aspect

  Four types of ranging aspects are angle of arrival (AOA), time 0f arrival (TOA), time of difference of arrival (TDOA) and received signal strength (RSS).

- Device aspect

  There are three types of distance measurement tools, antenna array, RF transceiver, ultrasonic transducer. Antenna array is used to measure angle of received signal. RF transceiver and ultrasonic transducer can be used to measure the power or strength of the signal.

Above discuss the main classifications of an indoor location tracking system. But following list are positioning techniques [6] used to identify indoor location accurately. Positioning is the initial state of a location tracking system. Because it all depends on the way location compute, methods used to calculate the distance and device selection.

- Proximity estimation

  Used to localization the wireless sensor nodes in a network. There are many proximity estimation approaches such as centroid algorithm, DV-hop scheme, and area-based approximate point-in- triangulation test (APIT) algorithm [7].

- Triangulation estimation

  Trigonometric approach [8] [9] to determining an unknown location based on two angles and a distance between those two nodes.

- Trilateration estimation

  Used to find an unknown location from several reference locations. The difference between trilateration and triangulation [8] [9] is information provided into the process of estimation. Instead of measuring the angles among locations, trilateration uses the distances among the locations to estimate the coordinate of the unknown location.

Those are the main techniques and methods used in received signal strength indicator method to accurately calculate the exact indoor location.

There are various changes in location tracking in indoor and outdoor. Below comparison Table 2-1 show the overview of those two tracking technique.

	Outdoor	Indoor
Path loss model	Linear	Affected by multipath and shadowing
Accuracy	Easy to achieve but not necessary (wide space)	Difficult to achieve but important (small space)
Space	Wide and not limited	Small and mostly rectangular
Deployment	Random and ad hoc	Can be planned
Transmission power	Maximum to maintain LQI	Adjusted to avoid interference
Height of reference nodes	Ground	Ceiling
Map	Global	Local

Table 2-1: Comparison of Indoor and Outdoor Location Tracking

When tracking location basically use hand held devices like mobile phones. Because those devices are easy to use and convenient. But when it comes to mobile device application major issues is the power. It can be transmission power, processing power and battery power. So should consider about those power management while doing location tracking. Below diagram Figure 2-5 shows the minimum power requirement for communication when it comes to indoor and outdoor location tracking.

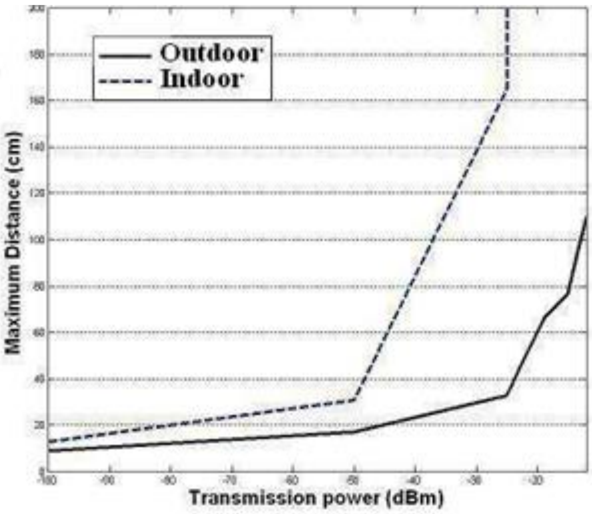

Figure 2-5: Minimum power required for communication

2.2.2 Techniques of Indoor Localization

When proposing a proper solution for indoor localization, should critically analyze the indoor localization techniques [7]. There are no 100% accurate technique available for indoor localization. Proximity estimation, triangulation, trilateration and scene analysis (location fingerprinting [10] [11]) techniques are popular in indoor location tracking.

2.2.2.1 Distance Estimation (Triangulation and Trilateration)

Distance estimation techniques are the main technique used in indoor localization. Triangulation and trilateration are the two basic approaches in distance estimation. Trigonometric approach to determining an unknown location based on two angles and a distance between those two nodes. In trilateration approach location determine by distance between at least three reference nodes and the device. To calculate the distance between reference node and the device uses methods Angle of Arrival (AOA), Time Difference of Arrival (TDOA), Time of Arrival (TOA), Received signal strength (RSS) and Received Signal Phase (RSP). AOA method used in triangulation approach and other methods used to calculate the distance [4] [8] [9].

- Received Signal Strength (RSS)

  Lateration approach which performs localization by using the distance between the target and at least three reference nodes. There are few practice and theoretical methods are implemented. As an example signal attenuation used to calculate the distance.

Attenuation consider as a function of the distance travel by the signal. Using those measurement of the attenuation the location of the target device can be identify [12].

- Time of Arrival (TOA)

  TOA also a lateration approach which calculate the distance between target nodes and the device. In TOA it measure the time signal gets to travel from one node to device. Synchronization between reference node and a timestamp should be implemented to measure distance accurately.

- Time Different of Arrival (TDOA)

  Lateration approach which need at least three reference nodes. In TDOA it calculate the time difference between start time of the emitted signal and received time of that signal to multiple reference points. Two TDOA measurement can be obtained by three fix located reference points. Then calculate the intercept and estimate the location of the target device. Line of sight required from this technique, so it is not feasible for indoor location. There can be multiple objects around the indoor location that can interfere the signal.

- Received Signal Phase (RSP)

  This technique used the transmission delay, expressed as a fraction of the wavelength of the transmitted signal. The localization of the object can be performed by using the phase dimension and phase different dimension. Line of sight needed so this could be a problem when doing indoor localization.

- Angle of Arrival (AOA)

  This technique used by triangulation approach. In this method location of the device calculated by intersection point of the two or more directional lines which starts from the two or more corresponding angle between reference nodes. Cost of the implementation is high and reflection surface may higher the error of the location are the main drawbacks with this technique.

2.2.2.2 Scene Analysis (Location Fingerprinting)

Location fingerprinting technique [10] [11] can be used indoor localization and outdoor localization. In this method find the location of the device using collected information about the environment and compare those information or data with current location. Scene analysis, RSS based location and position fingerprinting methods are the methods generally used. There are two modes which is online mode and offline mode. In online mode system collect information about environment and store those data. Then the offline mode those data used to identify the location of the device. Reflection, diffraction and scattering are the main challenges. To overcome those challenges following methods are used.

- Probabilistic method [13]
- K – nearest neighbor
- Neural Network
- Support Vector Machine
- Smallest M- vertex polygons

2.2.3 Technologies of Indoor Localization

There are multiple technologies that can be used in indoor localization such as GPS based, Cellular based, RFID, Bluetooth and Wi-Fi. Using above mentioned techniques can use along with this technologies to calculate or track the location of the device. Figure 2-6 shows the outline of above mentioned wireless technologies [14].

There are two approaches used by the researchers. Using an existing wireless network to track the location. This approach is good for cost effective and can reduce the implementation effort. This may occur multiple problem with existing system and functionalities and limitation with the existing system. The second approach is to develop or implement a wireless network to track the location. In this second approach it is easy to increase the accuracy by controlling, training and managing the network. However both of these approaches need some algorithms to measure and reduce the error to get high accuracy.

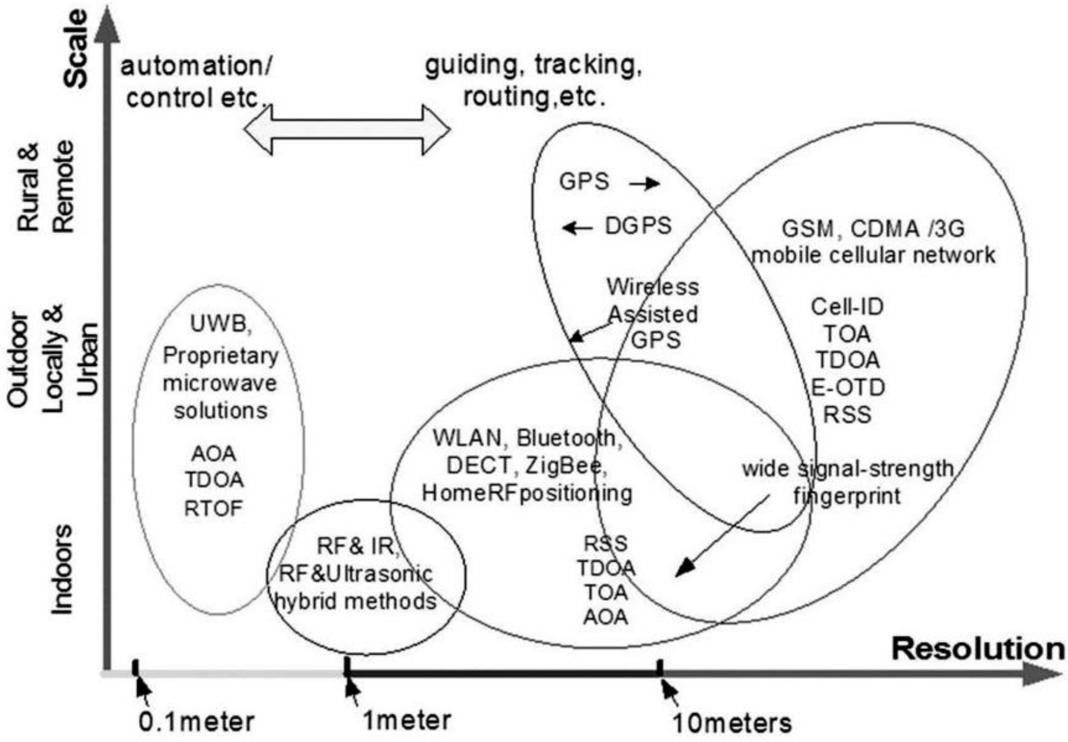

Figure 2-6: Outline of current wireless technologies

- GPS based

  Global Positioning System (GPS) is the most popular and mostly used outdoor localization or outdoor location tracking technology. GPS used satellite signals to estimate the location. However GPS unable track indoor location accurately. Satellite signals cannot cover the indoor environments. Therefore GPS cannot used to track indoor location.

- Cellular based

  Cellular based methods can track outdoor location of a cellular device using three or more transmitting towers. Indoor location can be determine by cellular based methods like Global System of Mobile (GSM) and Code Division Multiple Access (CDMA) cellular networks. But it is difficult to track when device move inside the indoor environment.

- RFID

  RFID technology can be used to detect indoor location [15]. There are more benefits than other technologies. RFID tags can be mapped into a database and according to those information can track RFID device. Main problem with this technology, there should be a RFID receiver as the device to track the location. It is difficult to use with mobile devices.

- Wi-Fi

  Popular technology among indoor location tracking [16]. Can use along with trilateration or triangulation methods. Wi-Fi has high data rate up to 108mbps and signal can travel between 50 to 100 meters. Can be used with already implemented networks. Power consumption and localization delay are the main problems with Wi-Fi.

- Bluetooth

  One of the popular and highly used localization technology for indoor location tracking. Data rate and the distance signal travel are lower than Wi-Fi technology. Power consumption is lower than Wi-Fi. Most of the smart phone available Wi-Fi and Bluetooth so no need a specific receiver to track the signal and location [17] [18] [19].

Above different technologies and methods used to track indoor location in similar location tracking systems. Calculate precious indoor location is the problem with those already implemented systems. Using single technology, method or technique is the major concern with those above mention studies.

2.3 Mobile Advertising

Location-based advertising (LBS) through mobile phones aims to remove geographical and information barriers between consumers and marketplace offerings by reaching shoppers when they are proximate to advertisers' locations. Though such contextual advertising seems convenient, it may also be perceived as intrusive. The results suggest that this location dimension and what the recipients are doing (context) affect their perceptions of usefulness of the ad, store evaluations, and willingness to respond to the offer.

Location based advertising strategy is not new. When radio listening moved out of the home, as consumers increasingly tuned in to radios in their cars or work places, the content of radio advertising did not change much. Many roadside billboards carry advertisements which are specific to the location of the product/service they advertise. Today, however, due to technological advances, location has become dynamic and traceable to a specific user. Therefore, location based advertising (LBS) strategy, though not new to marketing, has taken on new meaning. Because it is specific to the location of the user as well as the service provider/product, LBS advertising essentially refers to marketer-controlled information customized to the location where users access advertising media [20].

In this study there are independent variables that handle Location-based advertising. All treatments were manipulated using scenarios of real life situations.

- Advertising Strategy: The strategies were location independent and location based.
  - The LIS advertised the promotion as available from a “known store”, 13
  - The LBS advertised the promotion from a “known store near you (less than 0.1 mile away)”.
- Type of Location: Types of location were public and private. Privacy was manipulated as
  - (low) by coding the location as “mall”, “bus stand” and “library”, and
  - (High) by coding the location as “home”, “private office chamber” and “friend’s place”
- Situational (In) congruity: Situations were manipulated as congruent (leisure), and incongruent to consumption related tasks (work-related). Situational congruity was coded as
  - (incongruent) by work-related activities “executive meeting”, “intensely engaged in research”,
  - (Congruent) by leisure related activities “waiting for a bus”, “informal chat”, “shopping” and “watching TV”

Indoor location based advertising or Advertising on mobile devices has large potential due to the very personal and intimate nature of the devices and high targeting possibilities. Following are the studies that already done for indoor mobile advertising.

Kaasinen [21] analysed user needs for mobile location-aware services. In this study most users did not mind being pushed Information or notification, as long as they really needed the information. Thus, location itself is not enough to trigger pushed advertisements, but it has to be complemented with personalization. This need for personalization is recognized in a number of other studies as well. Advertising server with already registered users handle the personalization advertisement in this study.

A number of location-aware service studies list the mobile advertising as one of the future possibilities in the application area. Barnes [22] introduced the concept of tempting nearby users into the stores and delivering geographic messaging related areas.

Varshney and Vetter [23] suggested mobile advertising to be a very important class of mobile commerce. They augmented location information with the personalization of the delivery by obtaining the history of the user's purchases or consulting the user at an earlier stage. In addition, the users might be able to either receive push advertisements or actively pull the messages.

Ranganathan et al. [24] discussed mobile advertising in the context of pervasive computing environments. Presented a list of challenges and possibilities as well, some ideas of solutions for advertising in pervasive environments. The challenges include: reaching the people with the right ads, delivering ads at the right time, serendipitous advertising, means for users to follow up on the ad, and how to collect revenue for ads.

Randell and Muller [25] presented the Shopping Jacket infrastructure, which used GPS and local in stores for positioning. Wearers were alerted when passing an interesting shop. The system could also be used to guide the user around a shopping mall. GPS and GSM are the main technologies used to this study and accurate location is main bottleneck for this system as well.

Bluetooth and WAP Push Based Location-Aware Mobile Advertising System [26] introduce a novel B-MAD system for delivering permission-based location-aware mobile advertisements to mobile phones using Bluetooth positioning and Wireless Application Protocol (WAP) Push. This present a thorough quantitative evaluation of the system in a laboratory environment and qualitative user evaluation in form of a field trial in the real environment of use. Experimental results show that the system provides a viable solution for realizing permission-based mobile Advertising. Ad server collect information from wireless sensors and according to user account push advertisements. Positioning accuracy of the systems is roughly estimates within 50m to 100m.

When analysing existing systems or studies, already done the remote advertising potion. But accuracy of the location is very low. So in this research target to calculate precious indoor location rather concern about advertising. Because advertising scenarios are already implemented successfully.

Chapter 3 : Analysis and Design

The aim of the system is to identify user or customer location or current position. Location or the position of the target may change rapidly. So the system must monitor the location changes constantly. The system use smart phone's wireless technologies to identify the target user location along with wireless receiver which place in the premises. And use inertial sensors as the inertial measurement unit (IMU) to identify the movement of the users. System receives continuous sensor data from the sensors, so the changes of the user's motion such as periodic motion in walking and body turning can be detected. Using all those data propose system identify the most accurate location or position of the target user.

Identify location using wireless technologies and wireless sensor networks help of the received signal strength (RSS). There are three methods can use to identify location; Proximity, Triangulation, and Trilateration. From those technologies proximity gives used localization of the sensor nodes. It provide surrounding of the target node, not the exact coordinate of the target node. Proximity gives area of the target node location, so it can be used to identify range or which area target node is located.

Triangulation estimation [6] [27] [11] [9] is a trigonometric approach (Figure 3-1) of finding the location of target node based on two angle and distance between those two nodes. In this method it is required to have two reference nodes to be located on vertical baseline for 'x' axis, two reference nodes to be located on horizontal baseline for 'y' axis and distance between each reference nodes. Then should calculate or estimate the angles between baseline and the target node.

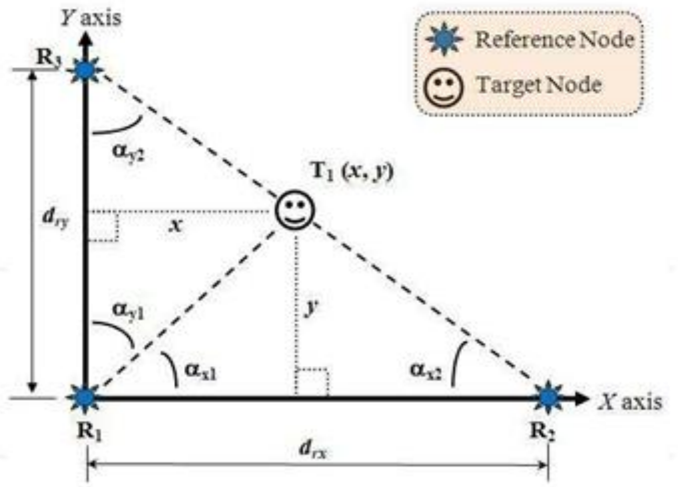

Figure 3-1: Trigonometric approach

Using inertial sensors [28] of the target node triangulation computation also can be done inside the target node by identify the angles from target nodes to reference nodes. This process can be conduct using electronic magnetic compass (EMC) module attached to the target node. Above design details are about basic triangulation estimation. Starting from basic solution to more complicates triangulation methods like dynamic triangulation algorithm to find accurate location solution.

Trilateration estimation [28] [29] is the third methods which can compute location using received signal strength (RSS) methodology. Like triangulation estimation (Figure 3-2), trilateration estimation use several reference node to track the location. Trilateration uses the distance between reference nodes and the target node to identify the location of the target location.

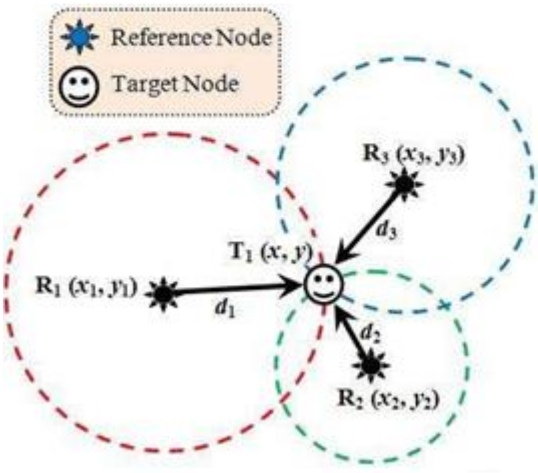

Figure 3-2: Trilateration estimation

As above Figure 3-2 using intersection of reference nodes distance and using three or more nodes find location of the target node. Distance for the reference nodes and target node gets from ranging technique. To use lateration methods at least three reference nodes are required.

Implement sample system or prototype for trilateration technique and collect data set to analyze. Using reference nodes, target node, target node sensors to identify the target node location and movement accurately.

3.1 Methodology

In this section motivation is to define the techniques, technologies and other methods used in indoor localization system which implement and evaluate. According to analyze of the past research work and fulfill research problem out of three above techniques, trilateration localization technique [30] selected to implement the porotype system. Trilateration core is to get the distance with reference nodes and target device. Received signal strength (RSS) approach used to collect distance aspect of the nodes.

Bluetooth as the technology to get signal strength for the system. Specifically Bluetooth Low Energy technology [31] to fulfill both requirement and design goals of the implementation. Since BLE used for indoor localization bandwidth, signal strength and power consumption are the key constraint. For indoor premises signal travel distance 7 to 10 meters more efficient than Wi-Fi signal travel distance more than 50 meters. Signal strength get more error when traveling large distance. Low power consumption and only need Bluetooth notify signal to get received signal strength. Not passing data through reference nodes, so low bandwidth not a big issue. Table 3-1 shows basic comparison between Bluetooth and Wi-Fi technologies.

	Bluetooth	Wi-Fi
Radio	Frequency Hopping Spread Spectrum (FHSS)	Direct Sequence Spread Spectrum (DSSS)
Data rate	1 Mbps	11 Mbps
Node per master	7	32
Slave enumeration latency	Up to 10s	Up to 3s
Data types	audio , graphics , Pictures , Files	Video , audio , graphics , Pictures , Files
Range(m)	10	100
Extendibility	No	Roaming possible
Complexity	Complex	Very complex
Positioning Technology	CoO, trilateration	CoO, trilateration, fingerprinting

Table 3-1: Bluetooth Wi-Fi Comparison

Most of the smart mobile phones available and embedded with Bluetooth technology. There is no additional technology part needed by the end user other than smart mobile phone and the mobile application. In trilateration need at least three reference node to transmit BLE signals in order to identify the location. Any Bluetooth transmit device which transmit Bluetooth low energy signals can be used as reference nodes for the system. Those transmit device should be low power consumption and cost effective. For this research implementation used device ESP32 which available both Bluetooth and Wi-Fi. Main reason to select this specific device because ESP32 fulfil the basic requirement of the methodology used in the research and the implementation. And ESP32 easy to connect with computers for programming purpose and easy supply power for the testing purposes. Those devices are just for testing purposes, not for commercial use. Because durability aspect of those devices are not in outstanding conditions. Figure 3-3 and Figure 3-4 shows the ESP32 device and sample overview.

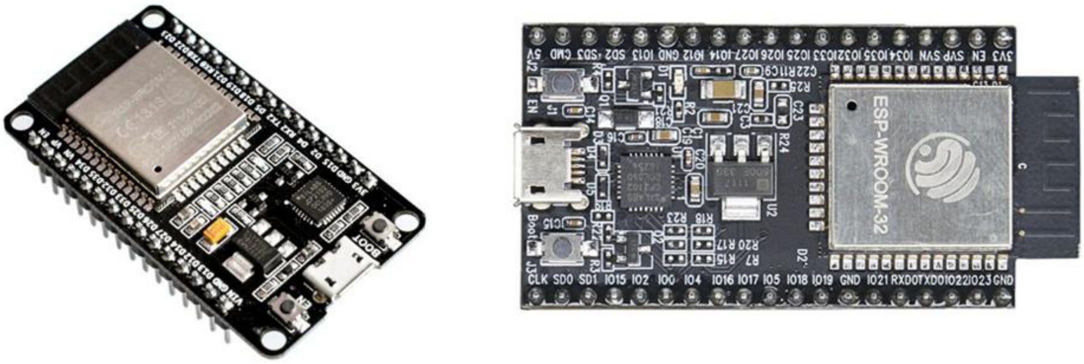

Figure 3-3: ESP32 device

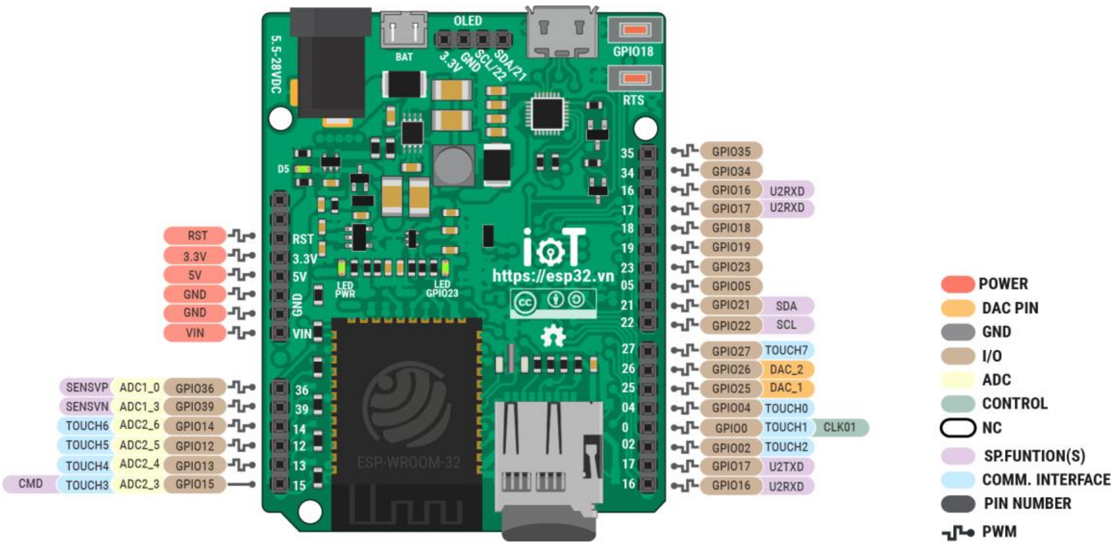

Figure 3-4: ESP32 overview

3.1.1 RSSI Data collection

Received Signal Strength (RSS) approach used to collect data between target device and reference nodes. Receiving Signal strength indicator of Bluetooth receiver used to get the decibel value of the received signal. Using smart phone or the device decibel value of the received signal converted to estimated distance. As an example using android devices, android operating system can identify the decibel value of the received signal strength and convert it into distance.

Receiving Signal strength vary due to obstacles and other material of the environment. So RSS smoothing filter used to smooth the received signal and minimize the variation of the received signal [32].

RSSI smoothing (feedback filter) [33] used to eliminate noise in different environment when using localization algorithms. This filter estimate approximate value so α weight value added to the equation. Although α value is vary between 0-1. In following equation $RSSI_n$ represent the most recent RSSI measurement and $RSSI_{n-1}$ represent the previous average RSSI value. This filtering approach ensure to minimize large different or error in RSSI value.

$$RSSI_{smooth} = \alpha * RSSI_n + (1 - \alpha) * RSSI_{n-1}$$

This represent the average RSSI value corresponding to the signal previous average value and the most recent value.

Using above calculated RSSI value following equation used to calculate the distance between device and the specific reference node [31].

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

$$d = 10^{(A - RSSI / 10 * n)}$$

Where, RSSI is the value collected in decibel, n is the path-loss exponent is the distance which need to calibrate according to the environment and A is the RSSI value one meter distance from reference node which need to calibrate according to reference devices used.

3.1.2 Trilateration algorithm

Trilateration algorithm used after collect received signal strength and calculate the distance between device and reference nodes. Reference nodes location should be known locations and distance between those locations calculate from above approaches.

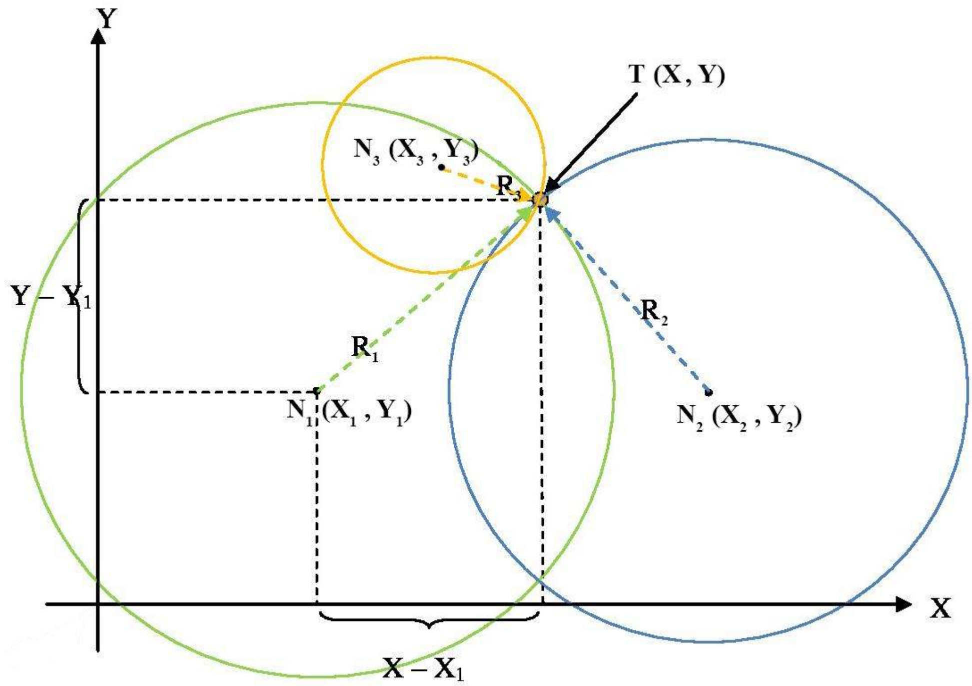

Figure 3-5: Trilateration algorithm

Figure 3-5 shows basic diagram of the trilateration algorithm works. N_1, N_2, N_3 are the points of the reference nodes which locations are known.

$N_1(X_1, Y_1)$, $N_2(X_2, Y_2)$, $N_3(X_3, Y_3)$ coordinates of the reference nodes or transmitting devices.

R_1 is the distance between N_1 and T, R_2 is the distance between N_2 and T and R_3 is the distance between N_3 and T. These values R_1, R_2, R_3 calculate using RSSI approach in the receiving device.

T(X, Y) coordinate of the devices need to calculate using the trilateration algorithm.

$$R_1 = (X - X_1)^2 + (Y - Y_1)^2$$

$$R_2 = (X - X_2)^2 + (Y - Y_2)^2$$

$$R_3 = (X - X_3)^2 + (Y - Y_3)^2$$

Using above three equations can determine the X and Y coordinates. Need three equations that is why this approach need at least three reference node which give three R values.

All known reference nodes coordinates are stored in database with relevant MAC addresses to identify uniquely. Estimation done using RSSI signal then distance collected from at least three nodes and calculate the estimate location of the unknown device or the mobile device. According to location coordinates push advertisement which store in the advertisement server in to the mobile interface through internet. This is the main methodology (Figure 3-6) is used to address the research question of this research.

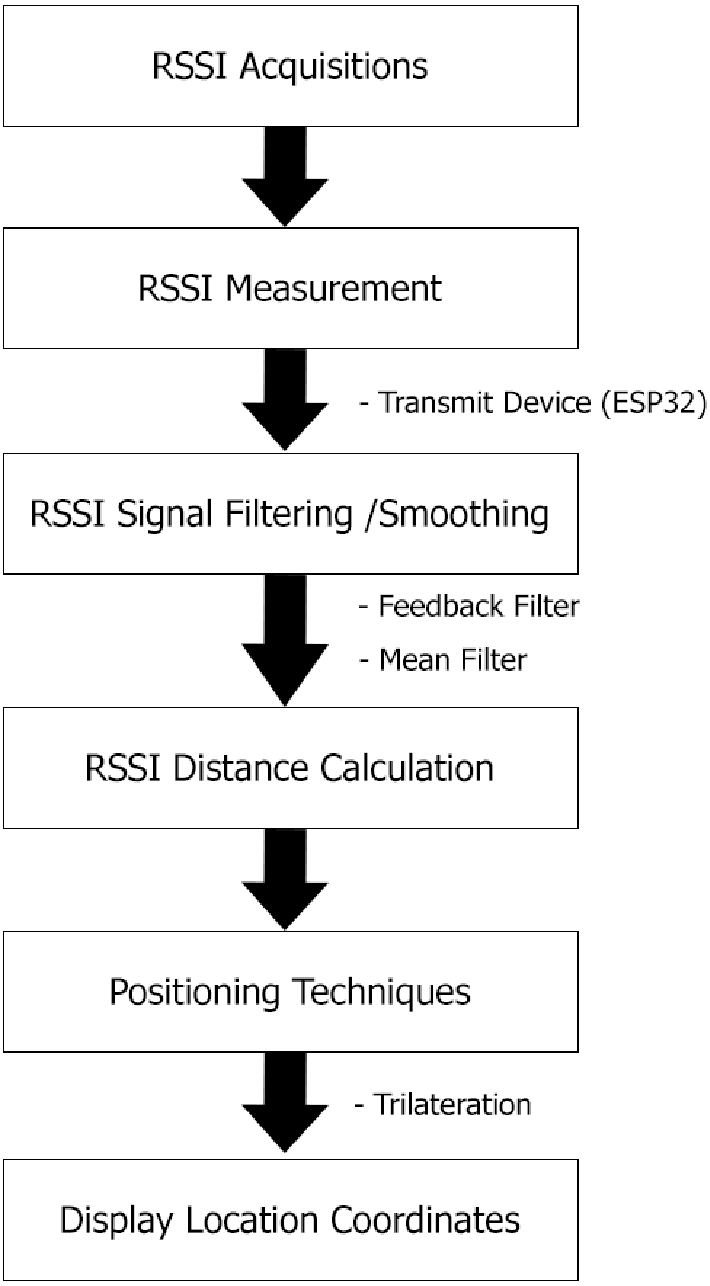

Figure 3-6: Research methodology

3.2 Design Goals

There are many indoor location tracking systems proposed, but most of those systems unable to achieve some constraints in real world deployment. Research goal to design a widely deployable location tracking system. Following criteria or constraints [34] are consider when design such systems.

- Acceptability – Ability to integrate with existing systems or infrastructure.
- Low power consumption – Power consumption of smart phone is critical limitation. So widely deployable mobile-base indoor tracking should not consume much energy from the battery powered devices.
- Cost – Infrastructure technology and equipment for indoor location system should not be too expensive. Initial cost may be high, but those amount should be acceptable.
- Maintainability – System and infrastructure should be maintain easily and cost effective way.
- Scalability – System should scale to larger area or multiple story building/location.

Design and implement an indoor location tracking system which achieve above constraints are the main design goal.

3.2 Design Assumptions

Smart phone is used to gather data and process to identify the indoor location. Wireless transmitter and receiver should work properly in the device. Bluetooth technology to identify signal strength from reference nodes and transfer data to the main system. Assume that wireless reference nodes are running and working normal to provide accurate location.

Other than wireless components basic sensors should available and working to identify motion of the user. In order to measurement user motion there should be no any relative motion between the user and the phone. So assume that user always carry phone attach to the body like in hand or in the pocket. Device sensors use to identify user movement and provide accurate location of the user or the device.

When advertising using the location, administrator of the system decide the floor plan and the advertising areas of their organization. System provide accurate location of the system and push prefixed advertisement to the device.

3.3 System Architecture

Find accurate location of the device user and push relevant advertisement details into the application is the basic idea of the proposed system. But finding accurate indoor location is the main purpose or the objective of the system.

Collect raw data from Received Signal Strength (RSS) method using wireless technology, Bluetooth details of the user's device. Process those raw data and find the accurate indoor location of the user or device. Then according to the location push advertisement in to the mobile application. The main outcome of the system is show location of the user in a floor map and show popup advertisements on the same application.

Collect data using above techniques and processing of the location done in another server to achieve design goal of the system. Location identification server basically process and respond with relevant location of the given user or device. Figure 3-7 shows the high level system architecture of the proposed system.

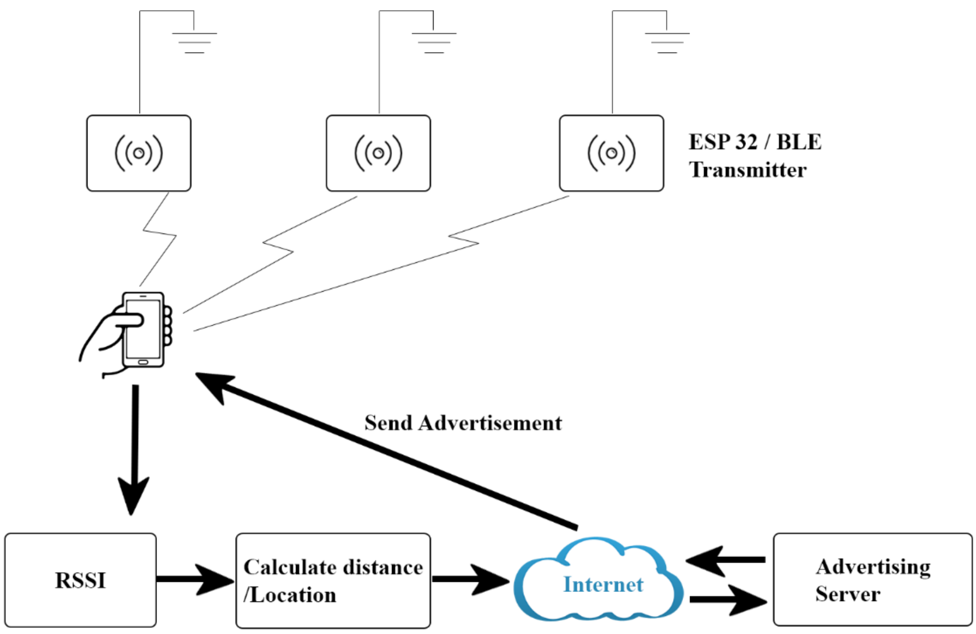

Figure 3-7: High level system architecture

3.4 Functional Overview

Main functionality of the system is to accurately identify the indoor location of the user or the device. Then advertising management and push advertisement to the mobile application. Main focus is to find the indoor location accurately.

Collect data from mobile device and reference nodes. Use received signal strength indicator (RSSI) technique to collect data about signal strength and calculate the location using already known location coordinates of the reference nodes. And using above methods, data and process those data to find information about proper indoor location. Then manage advertisement, track items or shops using given information in indoor location. Those are the main functional overview of the system.

3.4.1 Functionalities of the proposed system

- Method to identify user or the customer, using QR code
- Get the application and load floor plans to the device according to relevant floor
- Identify the user location from implemented technology
- Track user movement to help to identify user location accurately
- Send advertisement to the user according to his/her location
- Administration functionalities to manage advertisements and set them in proper location
- Administration functionality to map the floor of the area to manage advertisements

3.4.2 Evaluation Criteria

- Design and implement prototype systems using trilateration techniques and Bluetooth technology
- Create a simulated environment or sample environment to test the prototype systems
- Test the system using different kind of mobile devices
- Change environment variables to test the accuracy of the system such as test with different people, different walking patterns, test in crowded time and etc.
- Find the most accurate method with drawbacks and limitations of those systems

- When the system implemented administrator of the system can change the radius of the location which can send advertisements. Minimum radius of the system may depend on the strength of the devices.

  As an example if minimum radius is 2 meters, it means that user location can be identify with 2 meters accuracy. According to the environment and administrator requirement location radius can be maximize. Minimum location radius of the user may change according to devices, distance among devices and number of devices implemented in the premises.

Chapter 4 : Implementation & Testing

This chapter discuss about how to fulfill evaluation criteria with help of methods, techniques and a system. Tracking indoor location using Bluetooth is the main implementation technology. Trilateration technique used to calculate the indoor location using above mention methodology.

4.1 Tools and Techniques

Used several tools and technique to build the prototype, collect data to process and using those information to deliver a better indoor location.

Mainly mobile phone which run on android and other operating systems transmit and received Bluetooth signals used to build the prototype [35]. Bluetooth as a technology used as the main source of identify indoor location.

For the prototype and evaluation process used mobile phone which run on android OS with available of Bluetooth. To run the application those smart phone should contain at least API level 25. For the transmit Bluetooth signals used ESP32 device which can programmable to transmit Bluetooth signal in BLE scenario. Using 5v DC current can power up the device. Three to four devices should use to demonstrate the application.

According to the methodology trilateration method used to calculate the received signal strength (RSS), distance and then the location. RSSI smoothing techniques, filters use to filter and reduce the noise of the RSSI signals.

4.2 Test Implementation

Sample or prototype implementation to collect data and fine tune the prototype to get more accurate indoor location. Analyzing those test results can identify the better and accurate methods and technologies can apply.

4.2.1 Reference Nodes Configuration

Bluetooth transmit device (ESP32) setup using Arduino IDE to transmit low energy Bluetooth signals. Those signal can received by mobile device. Using strength of those signal strength distance calculated between receiver and transmitter.

Use Arduino to program ESP32 device. Arduino is open source software platform which provide opportunity to program microcontrollers easily. Arduino licensed under General Public License (GNU) permit various manufactures to develop devices based on Arduino. To transmit basic BLE signal used following Bluetooth notify program.

```
SimpleBLE ble;

void onButton(){
  String out = "BLE32 name: ";
  out += String(millis() / 1000);
  Serial.println(out);
  ble.begin(out);
}

void setup() {
  Serial.begin(115200);
  Serial.setDebugOutput(true);
  pinMode(0, INPUT_PULLUP);
  Serial.print("ESP32 SDK: ");
  Serial.println(ESP.getSdkVersion());
  ble.begin("ESP32 SimpleBLE");
  Serial.println("Press the button to change the device's name");
}

void loop() {
  static uint8_t lastPinState = 1;
  uint8_t pinState = digitalRead(0);
  if(!pinState && lastPinState){
    onButton();
  }
  lastPinState = pinState;
  while(Serial.available()) Serial.write(Serial.read());
}
```

Power supplied to the device ESP32, it run code and loop until power supply remove. And above loop sending device details such as name, MAC address and Bluetooth signal. Those details received by the mobile device or the receiving device.

4.2.2 Application Development and Configuration

After configure transmitting devices, next to develop the mobile application to receive those signals and estimate the location of the mobile device. For the prototype application develop only a basic android application which get location and represent in the screen according to the known reference nodes. Figure 4-1 shows the sample interface of the adding known reference nodes.

Figure 4-1: Interface to add known reference nodes

Get know devices coordinates and store in the application, this should extend to store those data in a database. Next step to get Bluetooth signal or BLE signal.

First of all in mobile application should get permission to access Bluetooth, fine location and coarse location. These permission allow mobile application to access Bluetooth receiver, access approximate location and access precise location of the device.

<uses-permission android:name="android.permission.BLUETOOTH"/>
<uses-permission android:name="android.permission.BLUETOOTH_ADMIN"/>
<uses-permission android:name="android.permission.ACCESS_FINE_LOCATION"/>
<uses-permission android:name="android.permission.ACCESS_COARSE_LOCATION"/>

Next using BluetoothAdapter, BluetoothDevice, BluetoothManager classes access the Bluetooth adapter and get data collected by the adapter. Data contain with RSSI value, device name, and device MAC address. Using previously entered known locations of the reference devices can identify the exact RSSI signal.

RSSI smoothing techniques can roughly get exact distance between transmitter and receiver. Then applying trilateration method can identify the location of the device. To get the location need at least three Bluetooth low energy transmitters.

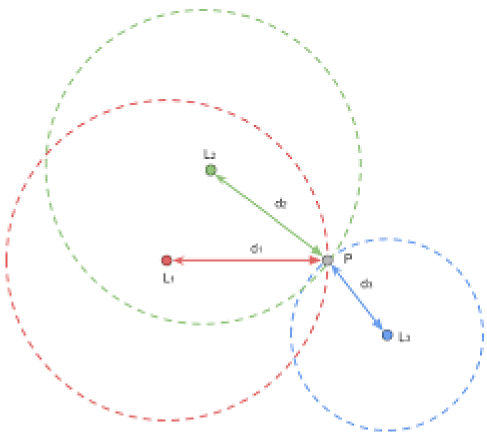

Figure 4-2: Trilateration method

Trilateration algorithm (Figure 4-2) estimate the location using input RSSI values and already available reference node coordinates. Figure 4-3 shows sample interface of know device coordinates and mobile device estimated coordinates. In next chapter evaluate data collected using above prototype system.

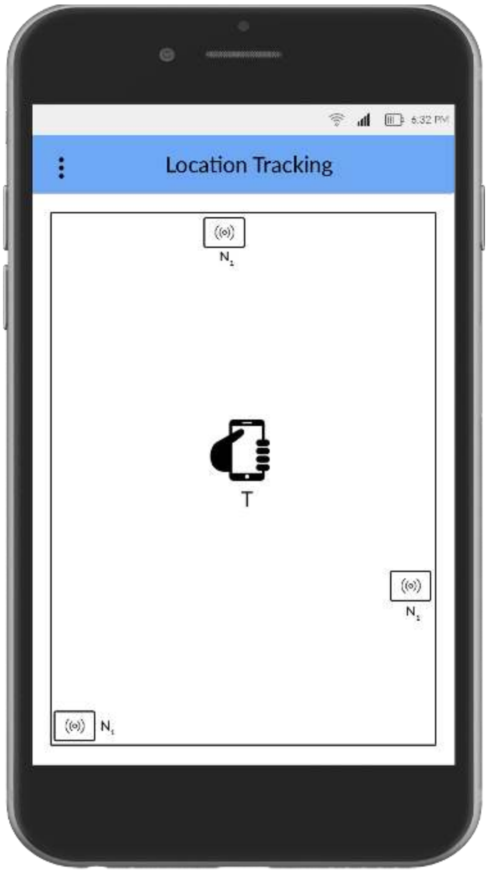

Figure 4-3: Location estimation or tracking interface

4.3 Testing

In this section provide details about testing the implemented system from the beginning. Before calculate location or distance should get precious values for RSSI values. First get RSSI values directly which transmit from Bluetooth device (ESP32) and received from the mobile device. Those values are raw RSSI values without any filtering or RSSI smoothing techniques.

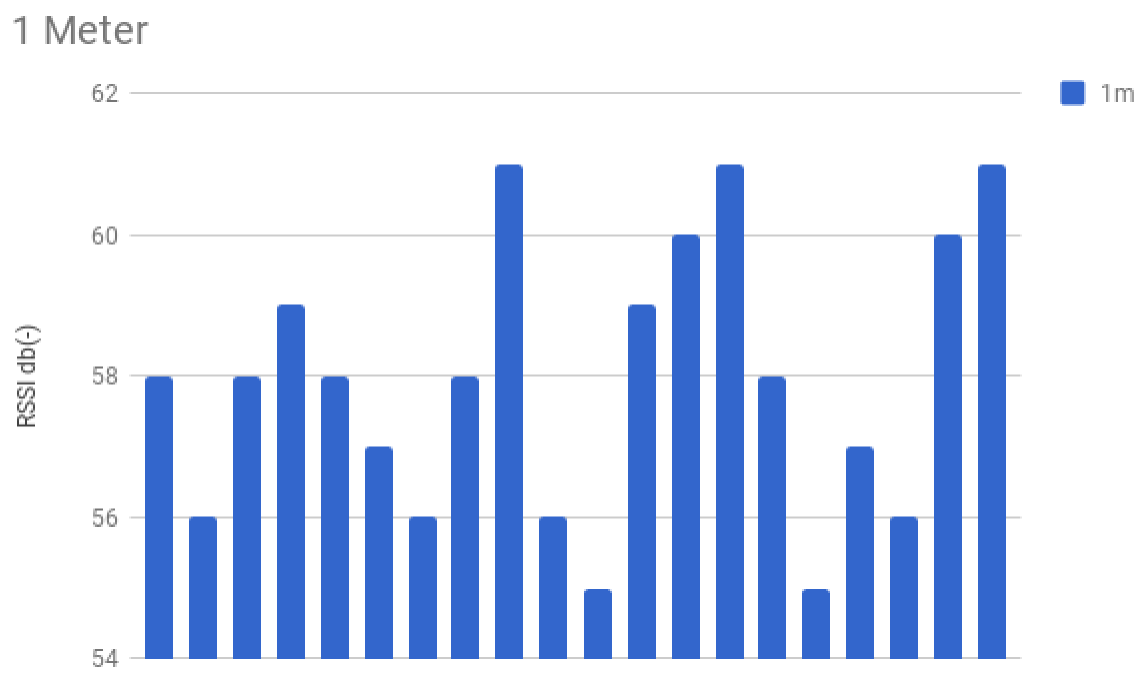

Figure 4-4: RSSI values without filtering for 1m

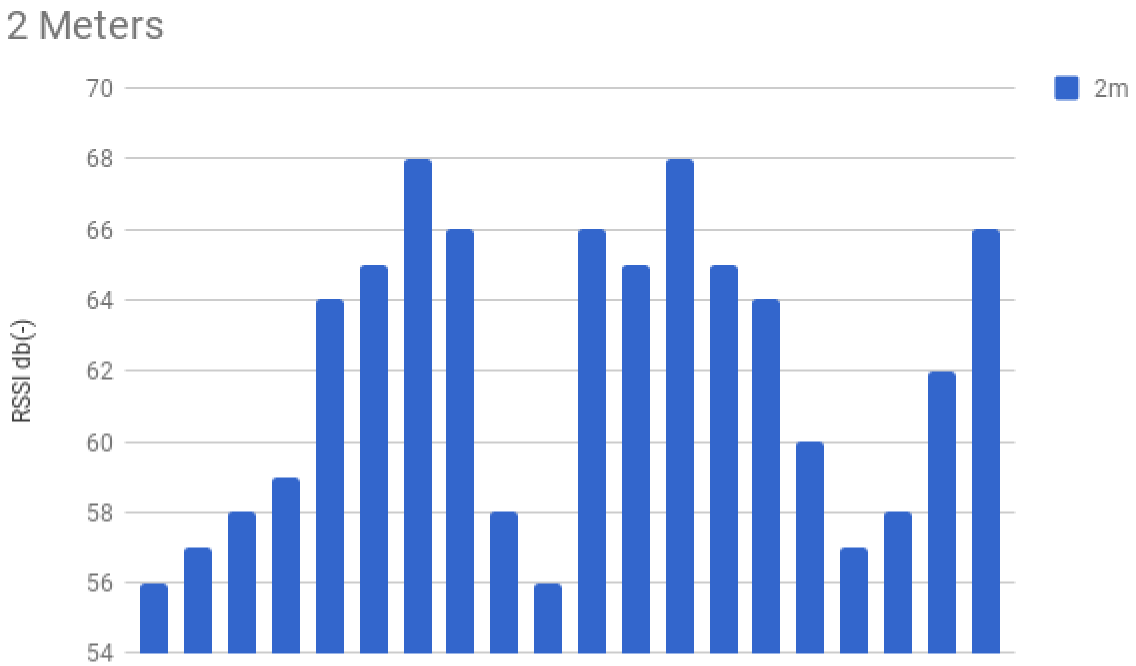

Figure 4-5: RSSI values without filtering for 2m

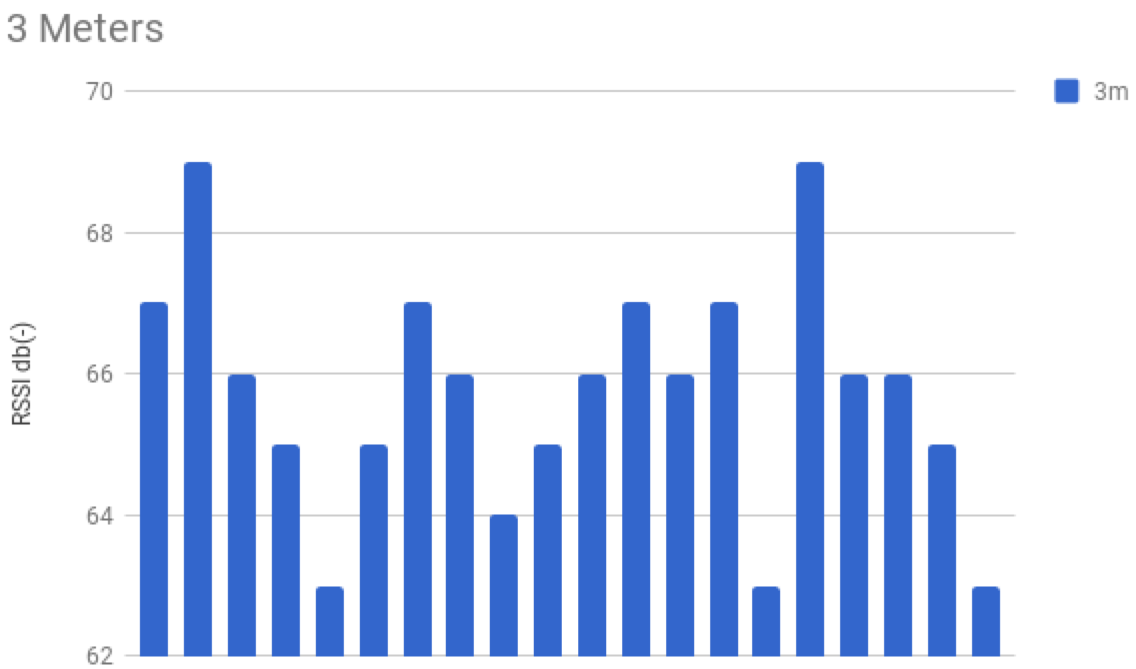

Figure 4-6: RSSI values without filtering for 3m

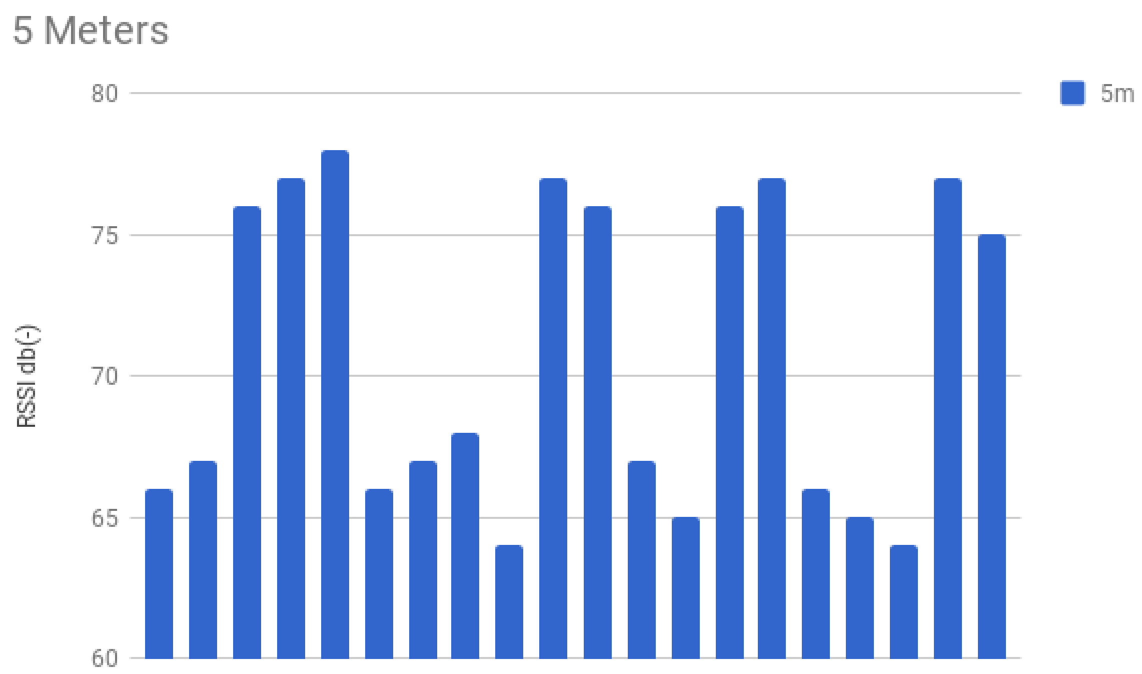

Figure 4-7: RSSI values without filtering for 5m

Above figures are display the variation of RSSI values according to the distance 1 meter (Figure 4-4), 2 meter (Figure 4-5), 3 meter (Figure 4-6) and 5 meter (Figure 4-7) distance between transmitter and the device. Table A-1 shows the actual test results in decibel.

Next step added RSSI smoothing technique, feedback filtering technique to the mobile application to smooth the RSSI values. In this technique most recent RSSI measurement, the previous average RSSI values and α weight value used to smooth the RSSI signal. Feedback filtering technique ensure to minimize large different or error in RSSI value. Basically this filtering technique try to remove the outliers of RSSI feed. Figure 4-8, Figure 4-9, Figure 4-10, Figure 4-11 shows the RSSI values with feedback filter over time. Table A-2 shows the actual test results in decibel.

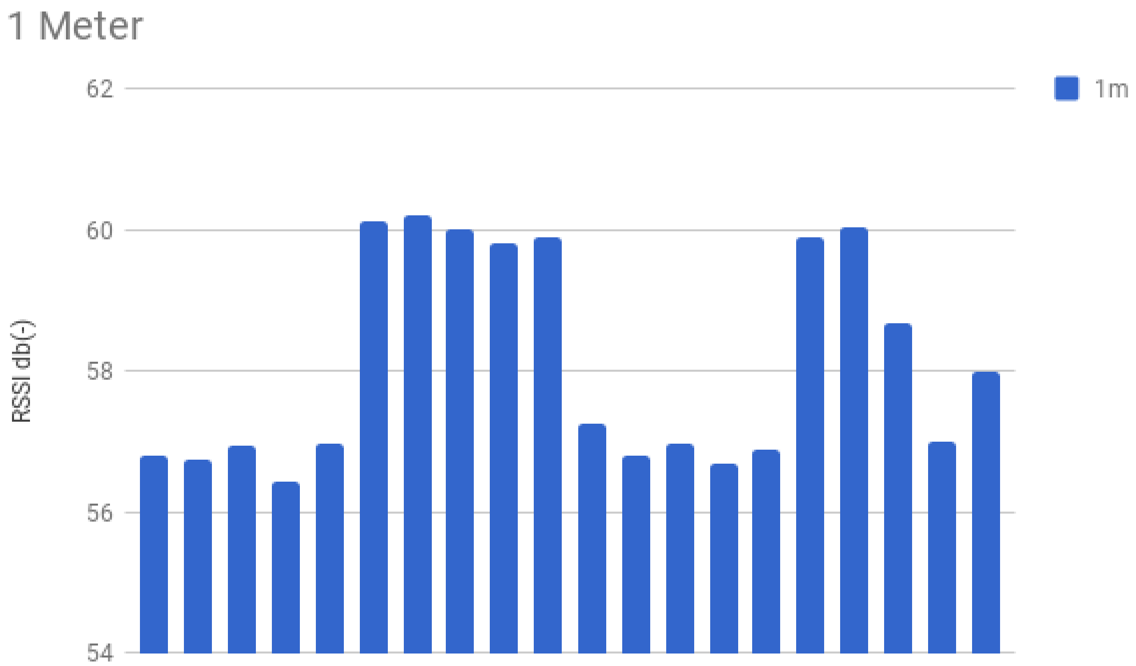

Figure 4-8: RSSI values with feedback filter for 1m

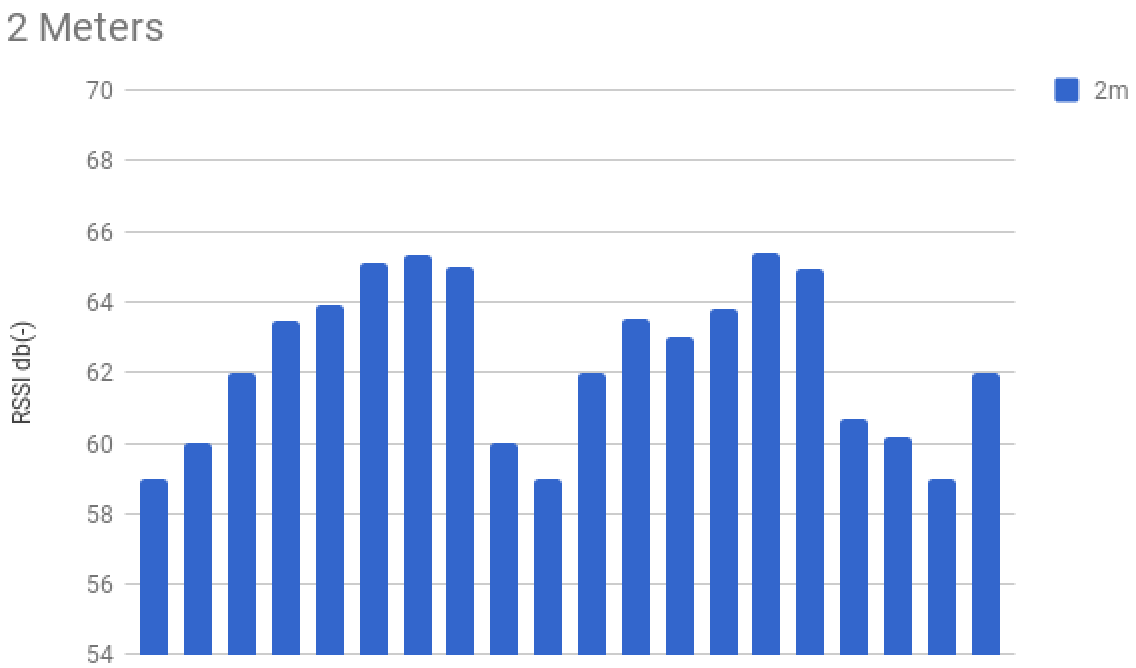

Figure 4-9: RSSI values with feedback filter for 2m

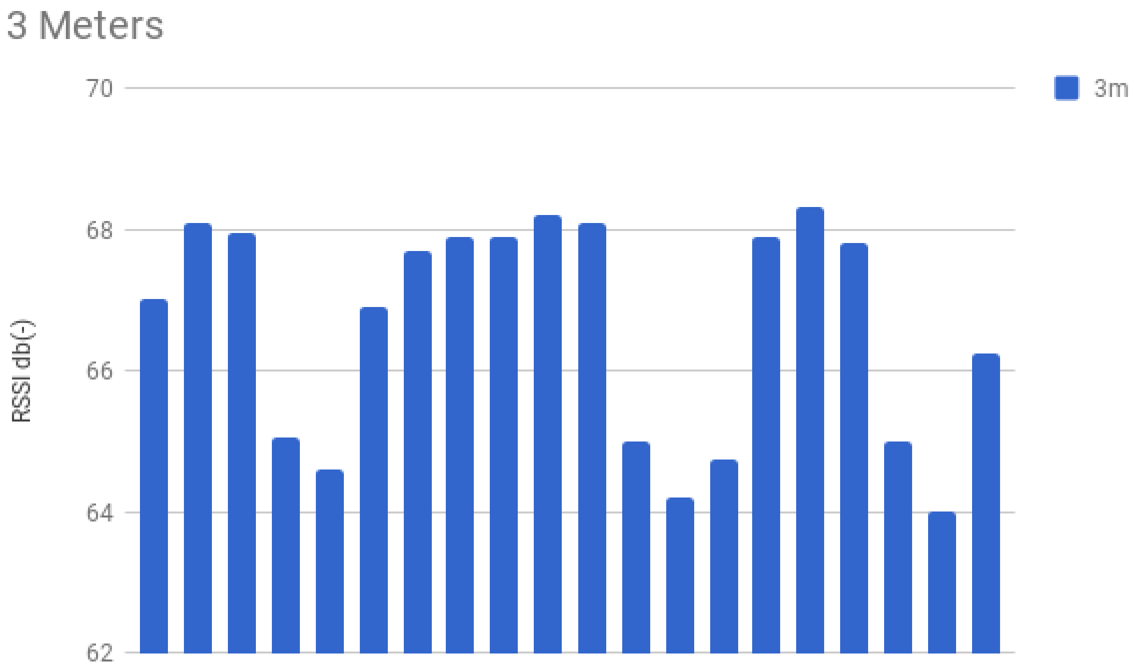

Figure 4-10: RSSI values with feedback filter for 3m

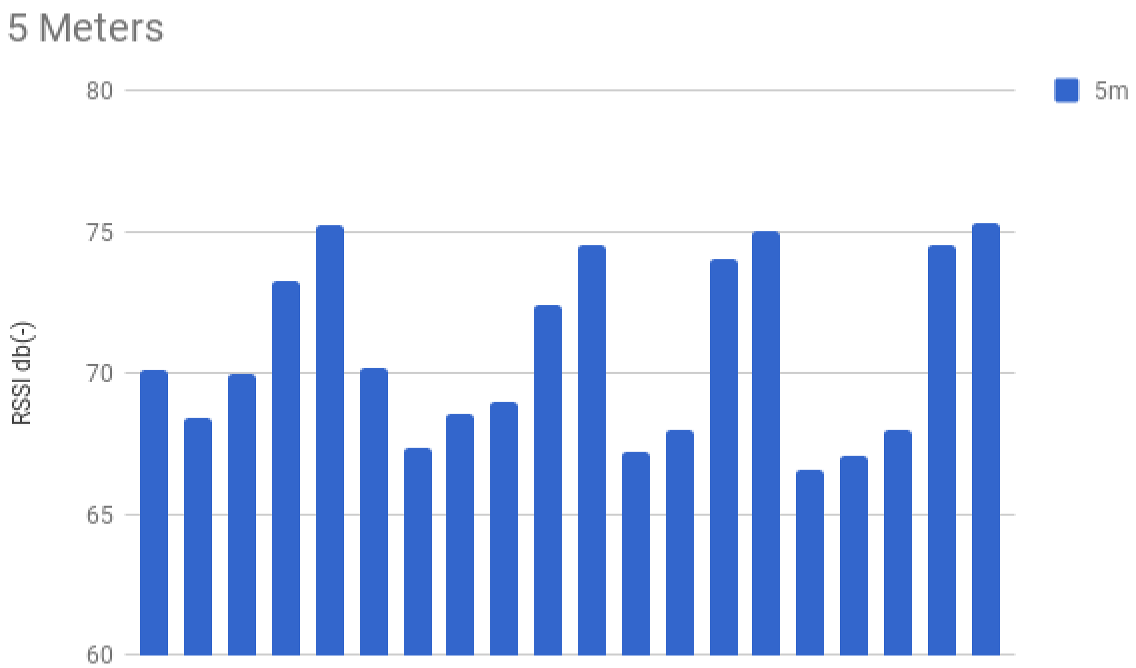

Figure 4-11: RSSI values with feedback filter for 5m

Then for further reduction of the RSSI outlier used mean filter or shifting technique. In this technique used mean value of some number of RSSI values and get that mean value as the RSSI value for distance calculation. For the testing got twenty values and get the mean value of them. This technique called moving values calculation, which help to update mean value while changing the RSSI value rapidly. Basically this test implementation for location tracking, so location always can be changed. Following figures (Figure 4-12, Figure 4-13, Figure 4-14, Figure 4-15) display RSSI variation along with feedback filtering and mean filter applied at once to smooth the RSSI value. Table A-3 shows the actual test results in decibel.

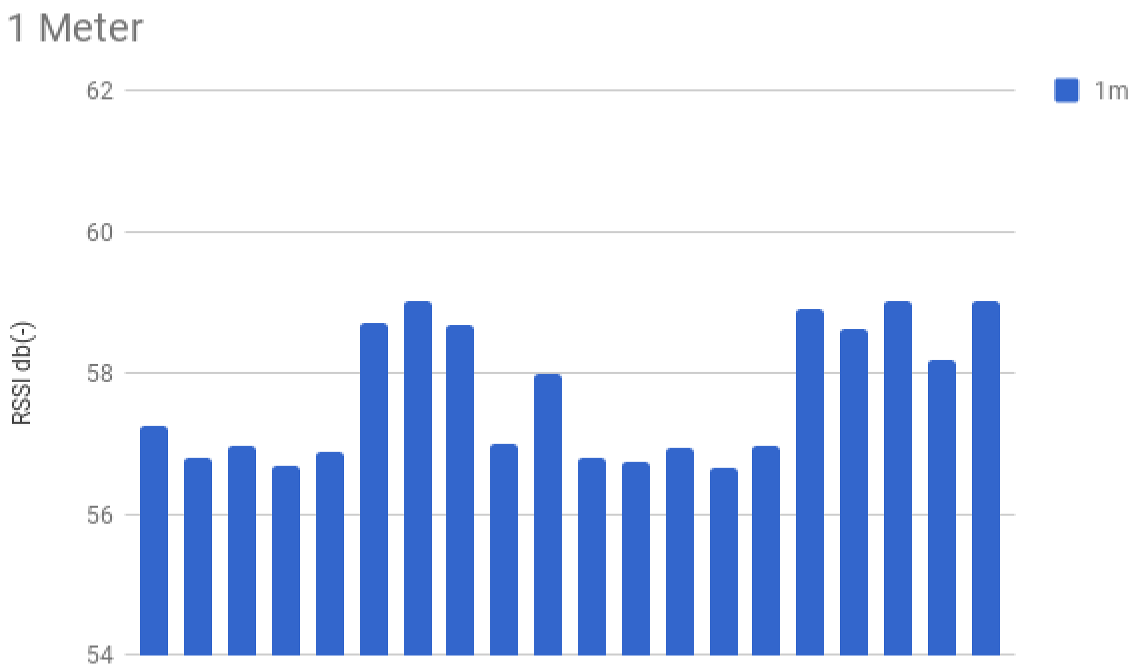

Figure 4-12: RSSI values with mean filter for 1m

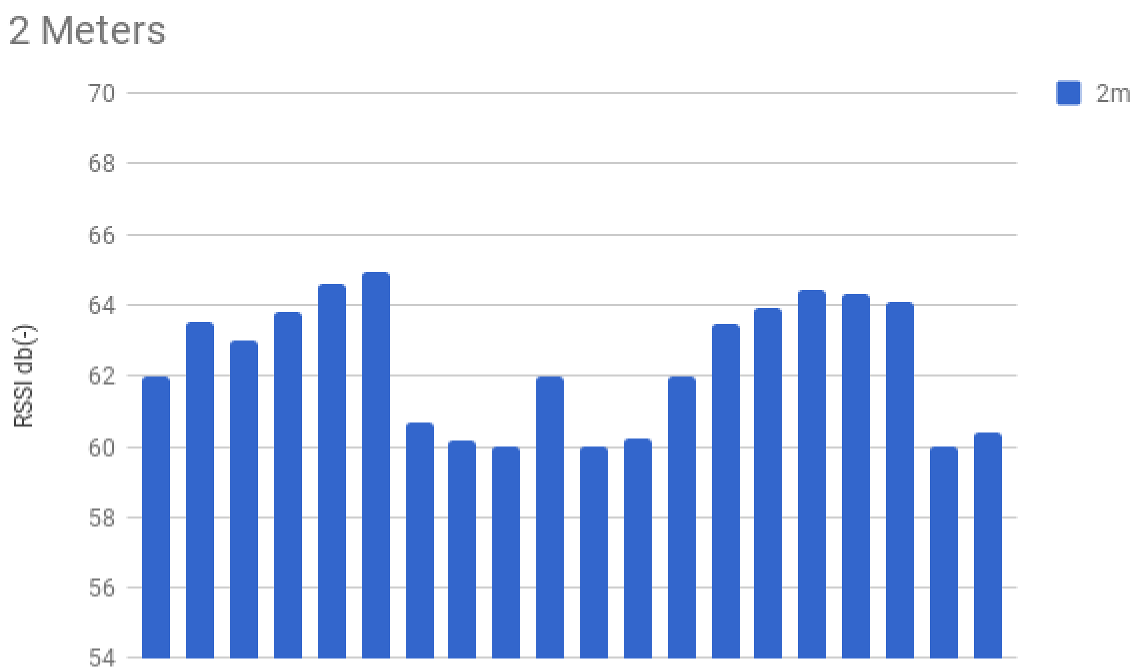

Figure 4-13: RSSI values with mean filter for 2m

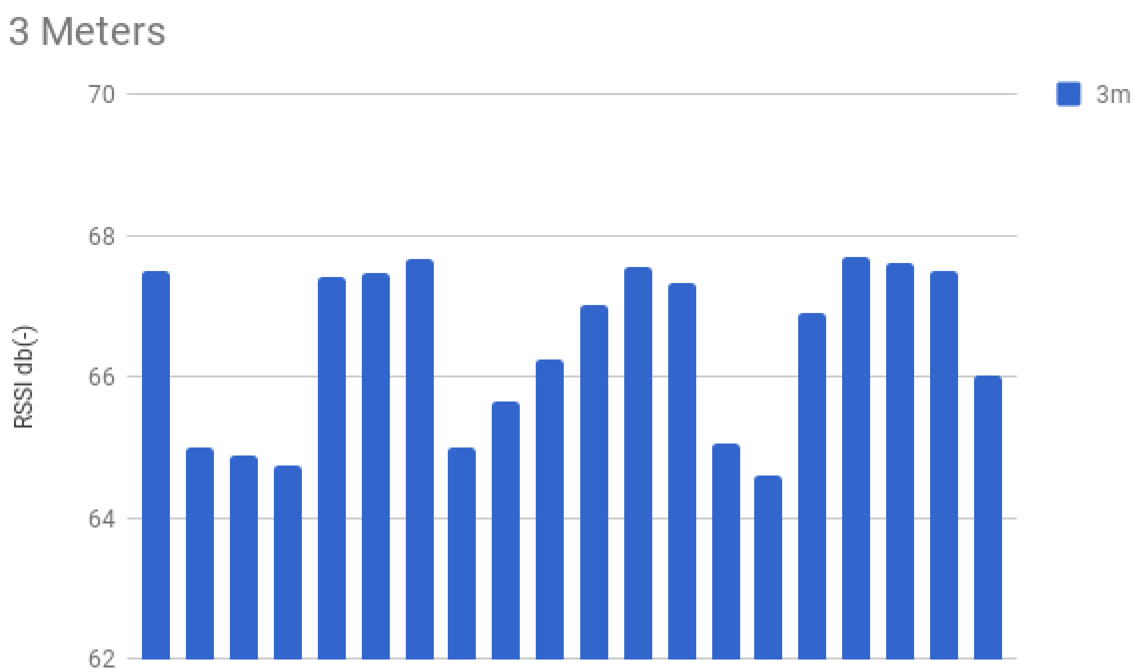

Figure 4-14: RSSI values with mean filter for 3m

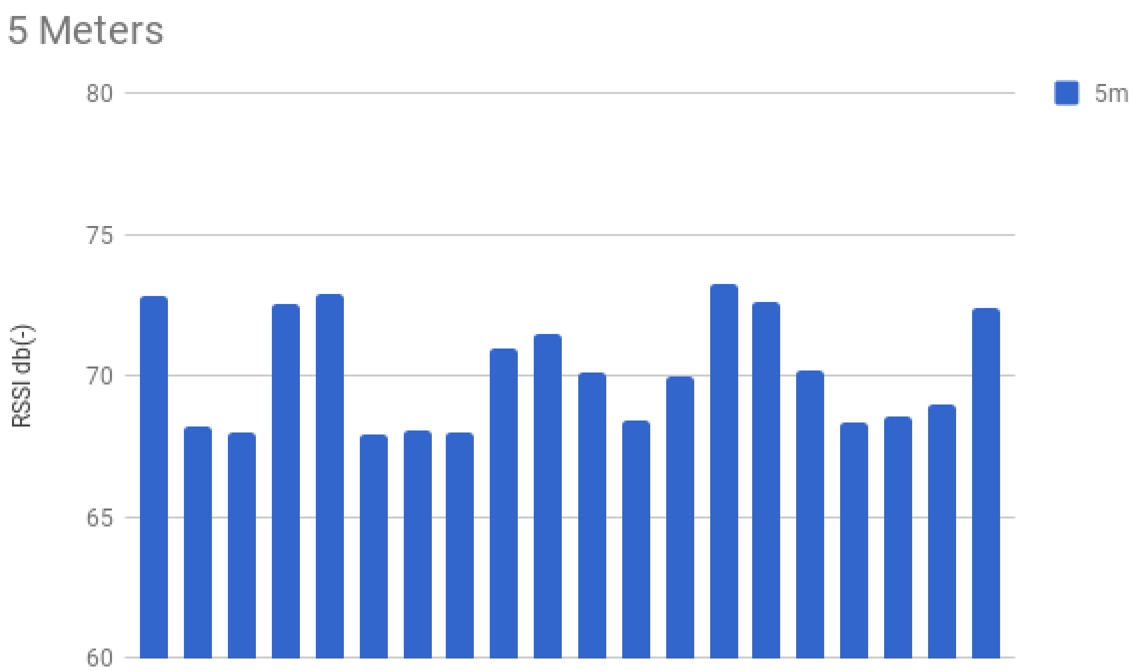

Figure 4-15: RSSI values with mean filter for 5m

Above figures display the variation of the RSSI values and techniques to smooth those RSSI values for 1m, 2m 3m and 5m distances.

Scenario 01

First scenario, testing variation of the location for single location coordinate over time. Figure 4-16 shows the visualization map of the reference node and device location coordinates. Average value of one meter RSSI value take as input to distance calculation equation.

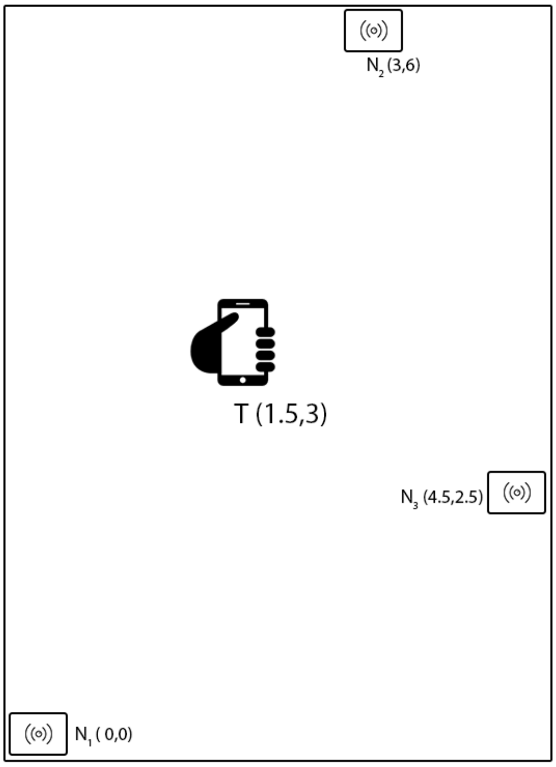

Figure 4-16: Sample map of the floor

Then Figure 4-17 and Figure 4-18 display the location variation overtime. Bluetooth signal is not static always, so it vary over time. So the RSSI value calculated by the system or the application display some variation over time. Calculate exact location to pin point is difficult. Radius of the location can be determine from this although the mobile device not moving. In this scenario system check with Wi-Fi enabled environment and Wi-Fi disabled environment for same set of results. Purpose to test with other radio signal interference.

Table A-4 shows the actual coordinates over time and Table A-5 shows estimated coordinates over time.

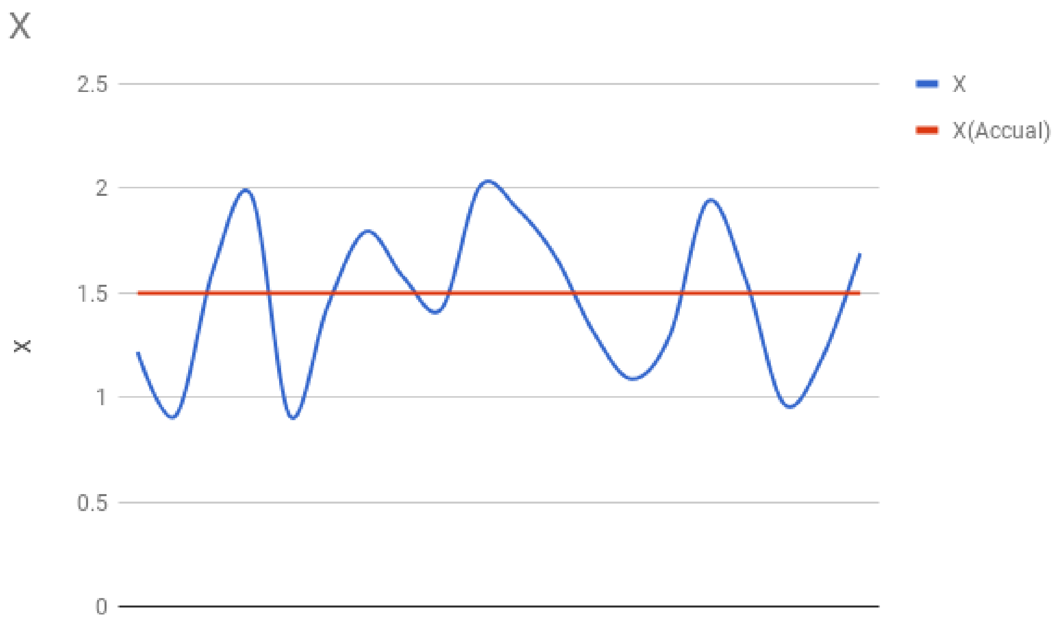

Figure 4-17: X coordinates Scenario 01

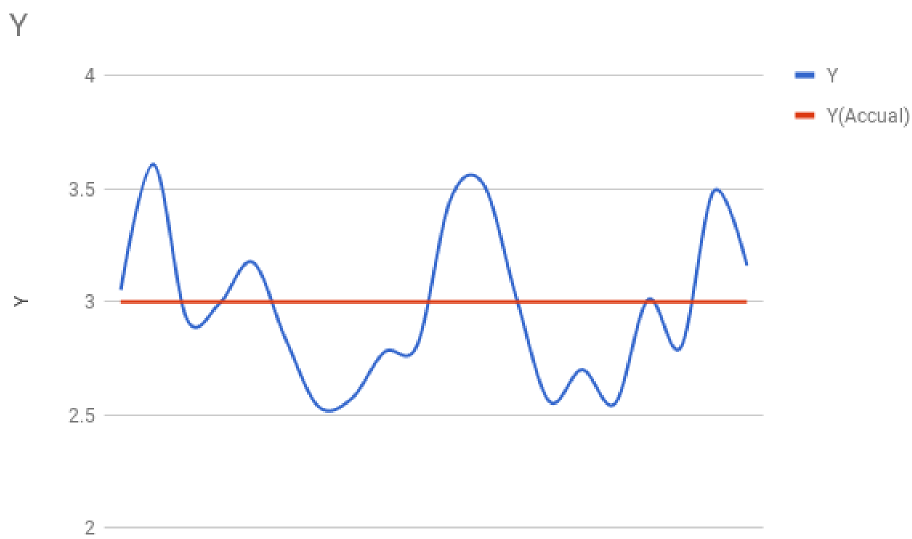

Figure 4-18: Y coordinates Scenario 01

Scenario 02

Testing with multiple location or moving location coordinates. Figure 4-19 display the visualization of the floor map with reference nodes and mobile device multiple location coordinates.

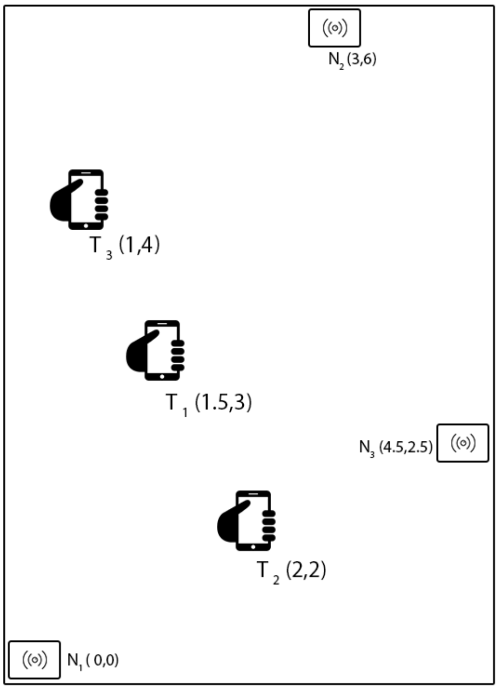

Figure 4-19: Sample map of the floor for scenario 02

Figure 4-20 and Figure 4-21 display multiple location testing environment to test the prototype system. This scenario gave proper idea about the distance variation over multiple location coordinates. Feedback filter and mean filter reduce the RSSI variation getting multiple RSSI values and smooth according to moving object.

Table A-6 shows the actual coordinates over time and Table A-7 shows estimated coordinates results over time.

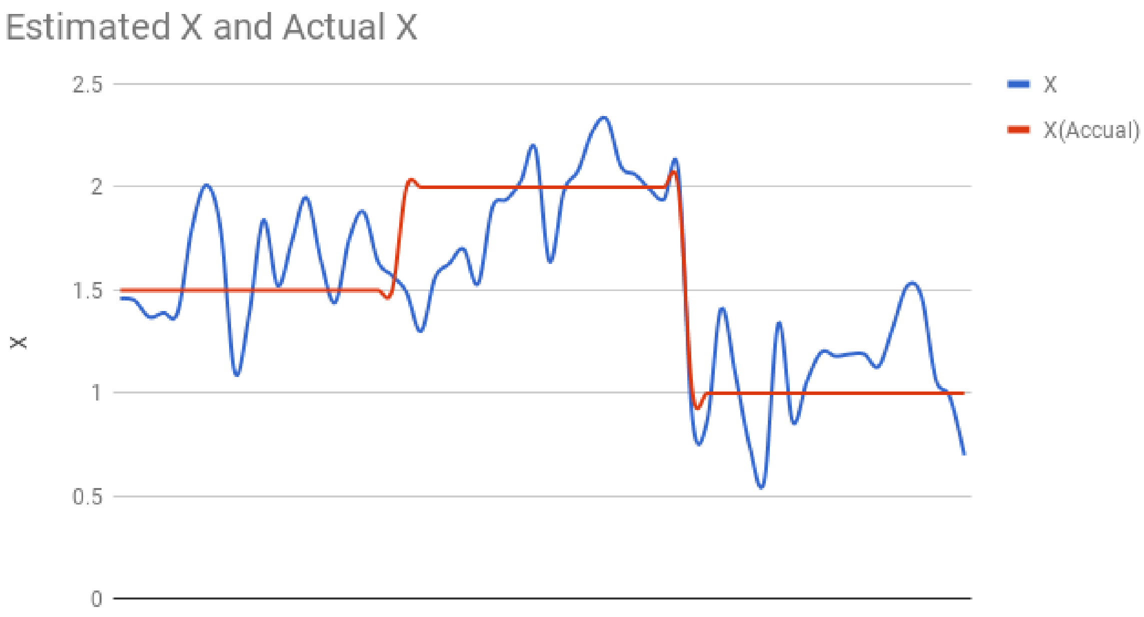

Figure 4-20: X coordinates Scenario 02

Figure 4-21: Y coordinates Scenario 02

Scenario 03

Testing with line of site issue. Testing with transmitting device not in line of site of the receiver or the mobile device. Wall or an obstacle blocking one transmitter and test for location coordinates. Same floor map and test location coordinates as scenario two. According to Figure 4-22 and Figure 4-23 display line of site is a major issue. At least three reference nodes should within the range for the unknown mobile device. If one reference node is out of site system gives huge error which difficult to handle.

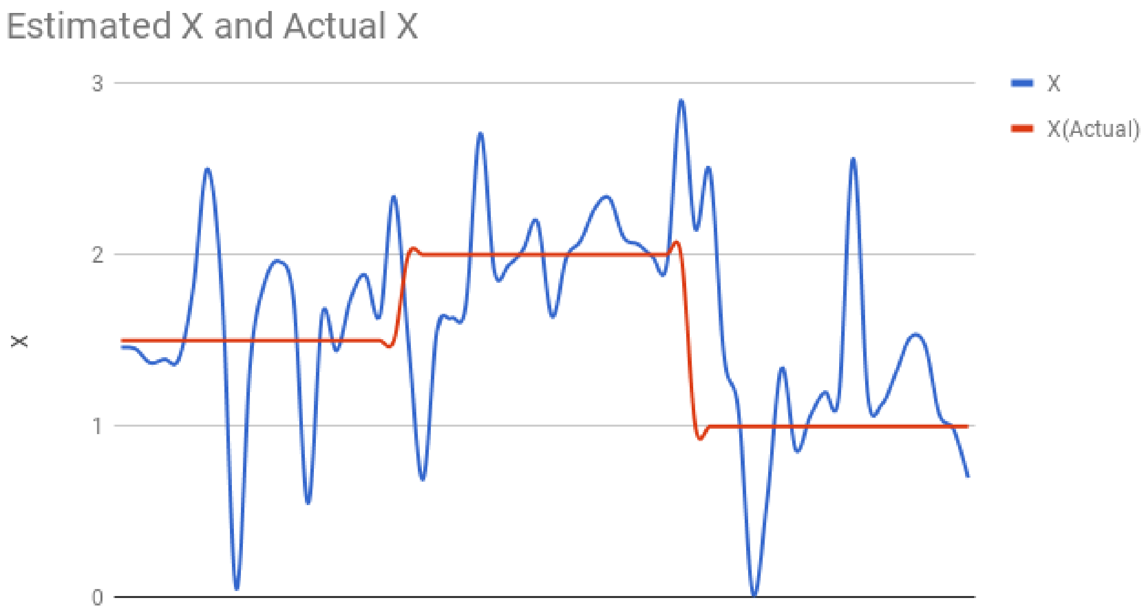

Figure 4-22: X coordinates Scenario 03

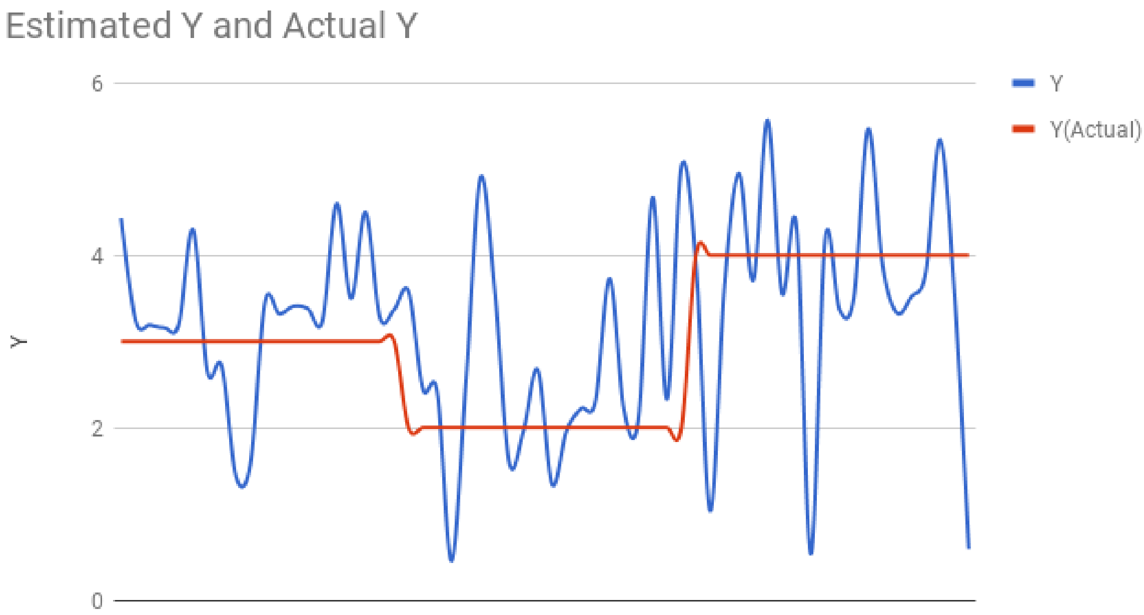

Figure 4-23: Y coordinates Scenario 03

Scenario 04

Testing with number of people at testing environment. Propagation loss caused by human body shielding. Tested with four people in the prototype environment. Which slight deviation from the scenario two. Figure 4-24 and Figure 4-25 shows the distance variation for sample propagation environment. Table A-8 shows the actual coordinates over time and Table A-9 shows estimated coordinates results over time.

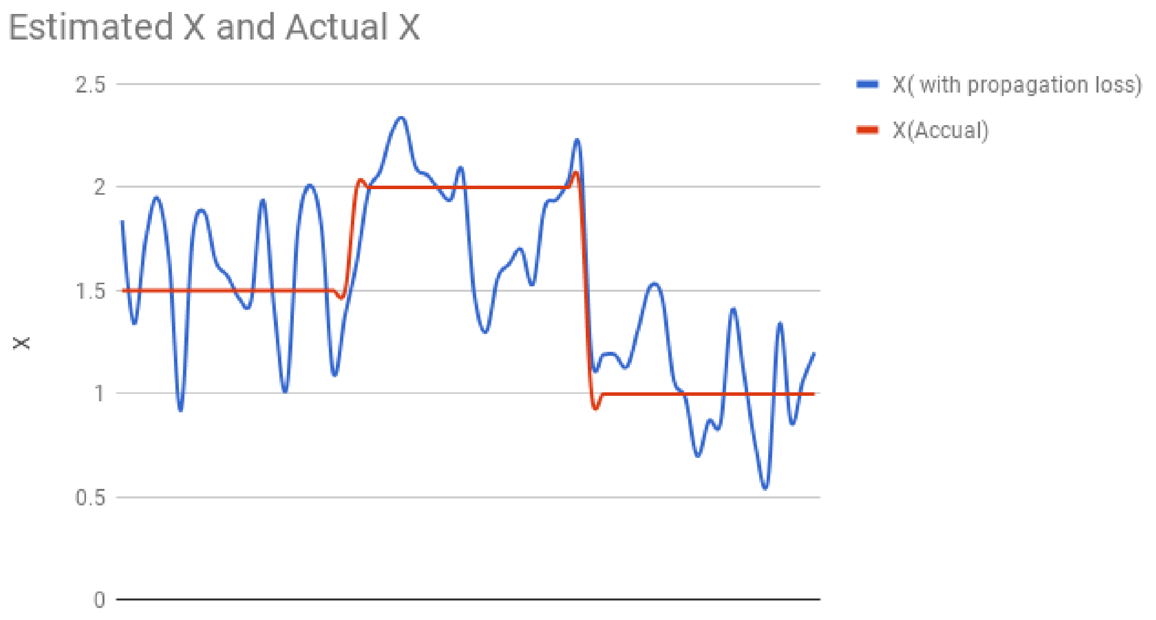

Figure 4-25: X coordinates Scenario 04

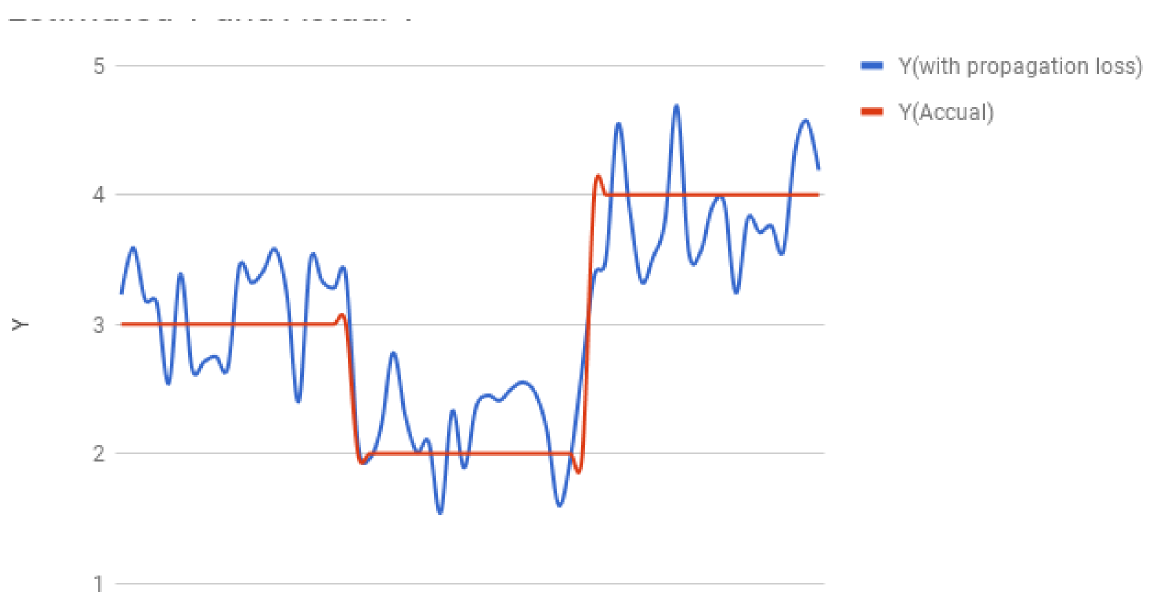

Figure 4-24: Y coordinates Scenario 04

Chapter 5 : Results & Evaluation

5.1 Overview

This chapter provide details about evaluation of the data which collected from implementation and testing chapter. In testing section of the above chapter used to display the all testing work from the beginning to end of the prototype system. Including with collecting RSSI values without using any filter which just transmitted from the Bluetooth transmitter and captured from the device, adding multiple filters and changing environment constant values.

First step was to smooth the RSSI signal strength. RSSI value always change over time. Collect data for 1m, 2m, 3m and 5m to identify the variation of the signal strength. Then added feedback filter to smooth RSSI value to reduce error of the RSSI value. In feedback filter always take immediate previous RSSI value and calculate the average value of those two values as new RSSI value. Testing environment α value take as 0.75 which is weight value for feedback filtering method.

Next step added mean filtering technique along with feedback filtering technique. This reduce the error further more according to the test result. In mean filtering rather than get direct RSSI value, collected twenty latest RSSI values and get the mean of that value. This filter work as a queue, first in last out method which newest value take in and oldest value remove from the value array used to calculate the mean RSSI. This technique used to reduce the variation when objects are moving. One of main objective in indoor localization is to reduce the error variation in RSSI values.

Calculate the distance between reference nodes and the unknown device was the next step. Distance calculation equation used to calculate the distance with relevant RSSI values. Those reference node (ESP32) or transmitting devices send MAC address to identify the node uniquely. For the equation ‘A’ is average RSSI value for 1meter distance and ‘n’ is path-loss exponent which is define when calibrate the system according to the environment of the system.

The final step was to use trilateration algorithm to calculate coordinates of the unknown device. Reference nodes coordinates were already in the system or known when calculate using trilateration algorithm. Then the system tested for multiple scenarios to identify accuracy and challenges while using prototype system.

5.2 Cost

Prototype system build with low cost devices and Bluetooth Low Energy (BLE) to reduce the cost of the system. There are various cost effective Bluetooth transmitting devices. ESP32 which used for the prototype environment also low cost easy to setup device. When using BLE it only transmit notify signal with some details about the device, so power consumption is very low. There are drawbacks like devices quality is very low in local market. Vary transmit output due to temperature of the transmit device.

5.3 System Scalability

Fulfill trilateration algorithm at least three reference nodes must in sight. From the evaluation Bluetooth transmitting devices signal strength not accurate after seven meters. When one reference node distance came to near those edge system switch reference node to nearest in sight node. System scalable from this method. If system works for more than one story building MAC address of each device known along with its position coordinate and other relevant details. System can identify floor which user current located in using those saved details.

5.4 System Accuracy

Prototype system test for RSSI smoothing and multiple scenarios to measure accuracy. According to scenario 01, scenario 02 and scenario 04 location can be track within the range of ± 0.75 to ± 1 meter. Bluetooth standard range is 10 meters, in this experiment used BLE (Bluetooth Low Energy) maximum range for this prototype is 7 meters due to low energy usage and quality of the used reference devices.

5.5 Challenges

- RSSI value variation was the main challenge get precious indoor location
- Line of sight issue, at least three reference nodes should be in line of sight of the unknown mobile device
- Cheap devices transmitting signal may vary according to the environment and the temperature of the device

Chapter 6 : Conclusion & Future Work

6.1 Conclusion

This section of the chapter discuss summary of the work has been done during this research and limitations indoor localization. Even though the research about indoor mobile advertising, the main aim is to develop a methodology and test it for indoor localization. Throughout the research discussed about various techniques, methods and technologies to get precious indoor location.

Develop a prototype system and environment to test and increase the accuracy of the given solution. Selected Bluetooth Low Energy (BLE) as the technology and trilateration technique to calculate location coordinates. For BLE transmission used device ESP32 which can transmit Bluetooth signals. Developed a sample mobile application to install in the unknown mobile device which need to locate. Bluetooth RSSI used to calculate the distance, before that smooth the RSSI signals. Bluetooth RSSI signals vary over time. To reduce the variation used filters like feedback filter and mean filter. Calculate the distance between reference nodes and unknown mobile device, needed at least three reference node distance to apply the algorithm. Applied trilateration algorithm to find the precious location of the unknown device. Location is not pinpoint, it is range of location. According to the location range push advertisement to the mobile device. Other than advertising this concept can used to find items, find shops or find indoor locations.

Test the system multiple time while using RSSI smoothing techniques, for single position over time and multiple positions over time. Then test for line of site issue, with people or propagation loss, scalability and the limitation of the system. Prototype system give location in range of ± 0.75 to ± 1 meter. Which is in the range of evaluation criteria for the indoor location advertising. There are various limitation for the indoor localization environments. Following are the major limitation found in this research.

- Variation of the RSSI signal strength over time
- At least three reference nodes need in site to calculate location coordinates
- Reference nodes location coordinates should be known
- Quality of the sample transmission devices, those devices act differently after several time period. Due to temperature and other environment situations.

Finally due to those limitations indoor location cannot be calculate the pin point. It is clear now that indoor positioning is a difficult task. Topology constraints in indoor environments are much more complex than those in outdoor environments. Accuracy of this system is a very significant and successful achievement for Location-Based Indoor Mobile Advertising.

6.2 Future Work

Proposed solution gave a proper outcome based on the scope of the research study which can be extend in several ways. Indoor localization using one method or technology is difficult according to above research and experiment. Combining multiple technologies to work with simultaneously may give some more accuracy than using only Bluetooth or only Wi-Fi. This methods not suitable with low cost, low energy model. Targeting on gather accurate indoor location will be achieved.

In this research used one technique which is trilateration. As future work using triangulation method, fingerprint method or combining any two or three methods will be effective to indoor localization.

When apply for shopping mall a place available multiple shops, there is a future work that checking the possibility and feasibility of use Bluetooth reference device as shop owners mobile phone. So no need to setup a special environment to manage indoor localization. This concept can be used only with mobile advertising. Difficult to manage other localization aspect location tracking and navigation.

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Appendix

Sample Code Segments

Mean filter Code Segment

```
public static double calMean(Double num) {
        if(numList.size()<=20) {
        numList.add(num);
        }else {
                numList.set(0, num);
        }
        Double avg = calculateAverage(numList);
        return avg;
}

private static double calculateAverage(ArrayList<Double> numList) {
         Double sum = 0.0;
         if(!numList.isEmpty()) {
           for (Double mark : numList) {
               sum += mark;
           }
           return sum.doubleValue() / numList.size();
         }
         return sum;
}
```

Test Results

RSSI values in decibel for 1m, 2m, 3m and 5m without any filters.

1m	2m	3m	5m
58	56	67	66
56	57	69	67
58	58	66	76
59	59	65	77
58	64	63	78
57	65	65	66
56	68	67	67
58	66	66	68
61	58	64	64
56	56	65	77
55	66	66	76
59	65	67	67
60	68	66	65
61	65	67	76
58	64	63	77
55	60	69	66
57	57	66	65
56	58	66	64
60	62	65	77
61	66	63	75

Table A-1: RSSI values without any filters in db.

RSSI values in decibel for 1m, 2m, 3m and 5m with feedback filter.

1m	2m	3m	5m
56.8	59	67	70.12
56.75	59.98	68.1	68.43
56.93	62.01	67.94	70
56.44	63.44	65.05	73.2
56.98	63.91	64.59	75.22
60.11	65.1	66.9	70.2
60.2	65.3	67.7	67.36
60	65	67.9	68.59
59.8	60	67.9	69.01
59.9	59	68.2	72.4
57.26	62	68.1	74.5
56.79	63.5	65	67.2
56.98	63	64.2	68.03
56.7	63.79	64.75	74
56.9	65.4	67.9	75
59.9	64.9	68.3	66.6
60.02	60.7	67.8	67.1
58.68	60.17	65	68
57	59	64	74.5
58	62	66.25	75.3

Table A-2: RSSI values with feedback filter in db.

RSSI values in decibel for 1m, 2m, 3m and 5m with feedback filter and mean filter.

1m	2m	3m	5m
57.26	62	67.5	72.82
56.79	63.5	65	68.2
56.98	63	64.9	68.03
56.7	63.79	64.75	72.55
56.9	64.6	67.4	72.9
58.7	64.9	67.45	67.9
59	60.7	67.65	68.1
58.68	60.17	65	68
57	60	65.64	71
58	62	66.25	71.46
56.8	60.02	67	70.12
56.75	60.2	67.54	68.43
56.93	62.01	67.32	70
56.66	63.44	65.05	73.2
56.98	63.91	64.59	72.59
58.9	64.4	66.9	70.2
58.6	64.3	67.7	68.36
59	64.05	67.6	68.59
58.2	60	67.5	69.01
59	60.4	66.03	72.4

Table A-3: RSSI values with feedback filter and mean filter in db

Scenario 01

X(Actual)	Y(Actual)
1.5	3

Table A-4: Actual (x,y) coordinates for scenario 01

X	Y
1.22	3.053
0.914	3.606
1.62	2.925
1.964	2.993
0.914	3.175
1.439	2.836
1.794	2.537
1.574	2.572
1.427	2.778
2.01	2.81
1.9	3.45
1.67	3.52
1.31	3.02
1.09	2.56
1.3	2.7
1.94	2.55
1.56	3.01
0.97	2.8
1.19	3.49
1.69	3.16

Table A-5: Estimated (x,y) coordinates for scenario 01

Scenario 02

X(Actual)	Y(Actual)
1.5	3
2	2
1	4

Table A-6: Actual (x,y) coordinates for scenario 02

X	Y	X	Y	X	Y
1.46	3.23	1.49	2.36	0.87	3.91
1.45	3.24	1.3	2.45	0.86	3.94
1.37	3.19	1.56	2.41	1.41	3.66
1.39	3.16	1.63	2.5	1.09	3.82
1.39	3.19	1.7	2.55	0.74	3.71
1.8	3.39	1.53	2.47	0.57	3.76
2.01	2.65	1.9	2.18	1.34	3.56
1.8	2.71	1.94	1.6	0.86	4.34
1.1	2.75	2.03	1.96	1.06	4.57
1.38	2.66	2.19	2.67	1.2	4.19
1.84	3.45	1.64	2.08	1.18	3.37
1.52	3.32	1.98	1.96	1.19	3.51
1.74	3.41	2.08	2.22	1.19	4.39
1.95	3.38	2.27	2.3	1.13	3.89
1.65	3.23	2.33	2.3	1.32	3.33
1.44	3.19	2.1	2.2	1.52	3.52
1.75	3.5	2.06	2.09	1.47	3.8
1.88	3.33	1.99	2.06	1.07	4.2
1.64	3.28	1.94	2.33	0.98	3.56
1.57	3.37	2.08	1.89	0.7	3.56

Table A-7: Estimated (x,y) coordinates for scenario 02

Scenario 04

X(Actual)	Y(Actual)
1.5	3
2	2
1	4

Table A-8: Actual (x,y) coordinates for scenario 04

X	Y	X	Y	X	Y
1.84	3.23	1.64	2.08	1.18	3.37
1.34	3.59	1.98	1.96	1.19	3.51
1.74	3.19	2.08	2.22	1.19	4.55
1.95	3.16	2.27	2.78	1.13	3.89
1.65	2.54	2.33	2.3	1.32	3.33
0.92	3.39	2.1	2.01	1.52	3.52
1.75	2.65	2.06	2.09	1.47	3.8
1.88	2.71	1.99	1.54	1.07	4.69
1.64	2.75	1.94	2.33	0.98	3.56
1.57	2.66	2.08	1.89	0.7	3.56
1.46	3.45	1.49	2.36	0.87	3.91
1.45	3.32	1.3	2.45	0.86	3.94
1.94	3.41	1.56	2.41	1.41	3.24
1.39	3.58	1.63	2.5	1.09	3.82
1.02	3.23	1.7	2.55	0.74	3.71
1.8	2.4	1.53	2.47	0.57	3.76
2.01	3.5	1.9	2.18	1.34	3.56
1.8	3.33	1.94	1.6	0.86	4.34
1.1	3.28	2.03	1.96	1.06	4.57
1.38	3.37	2.19	2.67	1.2	4.19

Table A-9: Estimated (x,y) coordinates for scenario04