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Indoor Location Estimation by Using Maximum Likelihood
Estimation Based Algorithm on Small Cell Networks

M. Sc. Thesis

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Indoor Location Estimation by Using MLE Based Algorithm on Small Cell Networks

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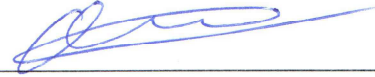
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Muhammad Ilyas

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ABSTRACT

Indoor Location Estimation by Using MLE Based Algorithm on Small Cell Networks

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This thesis presents a new framework for indoor localization using Third Generation(3G) Universal Mobile Telephone System (UMTS) Femtocell. The fingerprinting technique is applied to collect the Received Signal Strength Indication(RSSI) values through an Android User Equipment(UE) and data is processed in real time using MQTT server. To achieve better Radio Frequency (RF) planning and optimization for the placement of Femto Access Point(FAP), statistical analysis is performed by normalizing and calculating the Mean Squared Error(MSE) of the acquired data. To maximize the success rate in finding the location of the person, Maximum likelihood Estimation(MLE) based algorithm is used for tracking. Simulation was carried out both for 1 million samples and real life test using 100 samples. To make it more accurate and efficient, MLE based algorithm is developed and simulated in MATLAB. Both simulation approaches resulted in good success rates.

A case study is also part of this thesis, case study discuss about the real life project and deployment setup for indoor positioning estimation and localization techniques using multiple FAP's.

Keywords: Indoor Localization, Indoor Positioning, Location Estimation, Femtocells, Maximum Likelihood Estimation, MQTT, Normalization, Mean Squared Error, FingerPrinting, Small cells.

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LIST OF ABBREVIATIONS

3G	Third Generation
GPS	Global Positioning System
TDOA	Time Difference of Arrival
AOA	Angle of Arrival
UMTS	Universal Mobile Telephone System
RSSI	Received Signal Strength Indication
LBS	Location-Based Services
LOS	Line of Sight
RF	Radio Frequency
FAP	Femto Access Point
OS	Operation System
MSE	Mean Squared Error
MLE	Maximum Likelihood Estimation
MATLAB	Matrix Laboratory

ToA	Time of Arrival
AP	Access Point
ADSL	Asymmetric Digital Subscriber Line
MQTT	Message Queue Telemetry Transport
PDF	Probability Density Function
BS	Base Station
WAF	Wall Attenuation Factor
FAF	Floor Attenuation Factor
NLoS	Non Line of Sight
ToF	Time of Arrival
DL	Down Link
UE	User Equipment
GUI	Graphical User Interface
ID	Identification
BT	Bayt Technology
IMSI	International Mobile Subscriber Identity

1. INTRODUCTION

With the wide deployment of mobile wireless systems and small cell Networks, The location base services (LBS's) are getting popular and are realized with wireless devices specially smart phones. The LBS at outdoor locations normally use Global Positioning System (GPS) services to track the person because of clear line of sight and its simplicity [19]-[21]. However these techniques cannot be used directly in indoor environments lacking clear line of sight scenario. Also most of the time GPS signals either cannot be received in indoor locations or signals are too weak to identify or estimate the location.

There are number of well-known techniques used in the area of indoor localization. Among them Time of Arrival (ToA) and Time Difference of Arrival (TDoA) are the two most popular techniques for position estimation. These techniques need extra setup and configuration to provide valid measurements. Thus Received signal Strength Indication(RSSI) based localization is the most reliable technique use for indoor localization. In this technique the RSSI readings can be collected from any Access Point (AP). These techniques will be discussed in chapter 2 in detail.

Femtocells are indoor low power base stations which provide coverage through an ADSL (Asymmetric Digital Subscriber Line) line. It helps the service providers to improve their coverage inside structures [1]. Locating a person in an indoor environment is always a difficult task, mainly due to the phenomenon of reflection, diffraction and refraction of radio waves. Research is going on to use Femto Access Points (FAP's) for location based services [4]. In this study an experimental setup i.e. ground floor of a structure is selected and floor is divided into three zones. The objective here is to locate the person in these zones. All the three zones are completely covered by a grid [2]. The grid is further dividing the zones in different small clusters. Fingerprinting [2] - [6] which is simple and a popular technique for indoor localization is used for the creation of database of RSSI values. Although calibration phase for creating database for every cluster is a time consuming job. Finally a radio map [12] was also created by applying the statistical analysis on the measured RSSI values.

To get real time RSSI values continuously, a Message Queue Telemetry Transport (MQTT) protocol is configured on a server. For MQTT client I installed a piece of software on an android phone. This setup is capable of sending real time RSSI values from Android User Equipment (UE) to any remote destination in any part of the world through internet.

Considering that normal distribution [7] [8] [10] [11] is the best statistical technique to get the probabilities of continuous values between any two real numbers. I normalized [13] my data to compare it with the standard Probability Density Function (PDF) of Normal distribution. The simulation is performed in MATLAB to get the MSE [14] [15]. To find the location of a person in a specific zone I used MLE [8] [9] [12] [16] [17]. Simulation was carried out in Matrix Laboratory (MATLAB) and two tests were performed. In the first test the simulation generates random samples as an input and the results were automatically compared to our database. The second test was performed for a real scenario by movement of a person in all the three zones at random generating a total of 100 samples.

The results were reasonable but still not as per the desire. In this context a new technique was proposed and implemented called MLE based algorithm, the person was tracked in real time by using his footprints which leads the work to the desired results.

1.1 PURPOSE AND PRACTICAL APPLICATIONS

With the rapid advancements of the building construction technologies in the world, people switch from single story buildings to new sky scrapers, shops are converted to huge malls, instead of playing in home children are accessing the huge play grounds, doctor's clinics are converted in giant hospitals and population and demand is still increasing day by day. Accessing and finding people in these gigantic places is becoming impossible for us. Generally most of the people spend time in indoor locations. In order to locate people, we need a device which is used commonly by all the people in their daily life activities and the only device fulfilling the criteria is a cell phone. Hence, we can use their cell phones to track their locations.

In the last few years, in the field of communication, new Base Stations (BS) known as small cells were developed and are being used by people nowadays. There are different types of small cells

but in this Thesis we will focus on small cells known as the femtocells. These are the indoor base stations and their network can also be deployed in any indoor structure. The main purpose is to deploy the network of femtocells, so that it can serve us in two different ways. The most important reason behind the deployments of these networks is traffic offloading from macro base stations. Another purpose is to use them for tracking or identifying the location of people.

There can be many practical applications of these indoor networks; we can easily track the missing people and children in big malls. We can track the location of the doctors in big hospitals in any emergency situation. We can also track the location of patients who have mental disorders. These indoor networks can be lifesaving deployments, depending on the situation and location we are placing them.

1.2 PROBLEM STATEMENT AND OBJECTIVE

This thesis focuses on the location tracking using femtocell. The person will move randomly at different locations on the floor and the task is to track the location. While the person starts moving in the coverage area the RSSI values will be automatically sent to Laptop or PC and the setup will start tracking the person.

The goal of this thesis is to provide real time tracking and accurate location estimation of the required UE or person moving in that plan. The setup is developed in a way that it is applicable on any Android device and people can use it to track their loved ones. Normally the RSSI readings depend on the device by which it is collected and in that case the fingerprinting database may not support other phone to track it correctly. That's why a small application is used to get the RSSI values for the database and the database can work accurately with any device having that piece of software. On the other hand minimizing the errors, while estimating the location of the person, is also one of the main objectives to be achieved.

1.3 TECHNICAL CHALLENGES

The first challenge is the unpredictable nature of the RSSI values. There are different reasons for that, in indoor locations we have a serious issue with the line of sight (LoS) each and every thing

present in the way of the coverage signals is consider as a hurdle and results in reflection and diffraction of the signals. The FAP signals experience severe multi path and fading.

There are some other challenges too; the frequency at which the FAP is operating is the same as macro base stations. For which interference mitigation is required. Also, deploying the network of FAP's in an indoor structure results in severe interference in the coverage. Hence, the power of FAP must be adjusted in a way that it should not interfere much with the neighbors FAP's coverage area and macro base stations.

1.4 SCOPE

This thesis describes different techniques and algorithms which can be used for indoor localization. The two main algorithms used are MLE and new MLE based algorithm. The thesis is organized as follow.

Chapter 2 discussed the background study and related work of indoor localization. It also describes different techniques and algorithms in detail. The techniques and algorithms are previously used in different indoor localization setups. Those setups were developed using WLAN's, Femtocells, Zig bee Nodes and some beacon techniques.

For better results and better performance the propagation of the FAP antenna must be study and understand. Chapter 3 discussed the propagation of FAP antenna and the results of some tests performed with FAP. This chapter also explains the floor layout, gridding and some of the challenges faced in the initial deployment.

Next chapter 4, explain the MQTT server client scenario and the application installed in Android phone to RSSI values. Fingerprinting technique and both its offline and online phases are also explained in detail.

Chapter 5 is showing the simulations and their results, it includes the histograms developed for the zones. The PDF curves for all the three zones and then both of them are merged together to get the normalized graphs for all the three zones and the MSE is calculated. Furthermore MLE

simulation is explained and shows how it improves the success rate. MLE based algorithm the new technique is also explained in that chapter which leads this thesis to the desired stage.

A case study is also included in this thesis as chapter 6. This chapter demonstrates practical experience with implementation of the indoor localization deployment using small cells. The RF and re-selection maps are part of this chapter. It also explains how the re-selection points are optimized to get better results.

Finally chapter 7 adds the concluding remarks and the possible future advancements for indoor localization are discussed.

2. BACKGROUND AND RELATED WORKS

This section discusses about the different techniques so far used for Location Positioning and indoor localization. It will focus on the techniques used specifically for indoor localization. There are bunch of different techniques and algorithms used by different people, a person can easily find in literature but most of them are related by using WLAN ZigBee nodes etc. And some of them are related to femtocells or by using small cells but as the main task is to find the location of a person in an indoor location, So all the Algorithms discussed below are applicable for positioning using femtocells too.

Here the focus is on most commonly used algorithms, techniques and Estimations. Figure 1 presents the flow chart of the techniques and models used by different people; all the techniques and algorithms are discussed briefly.

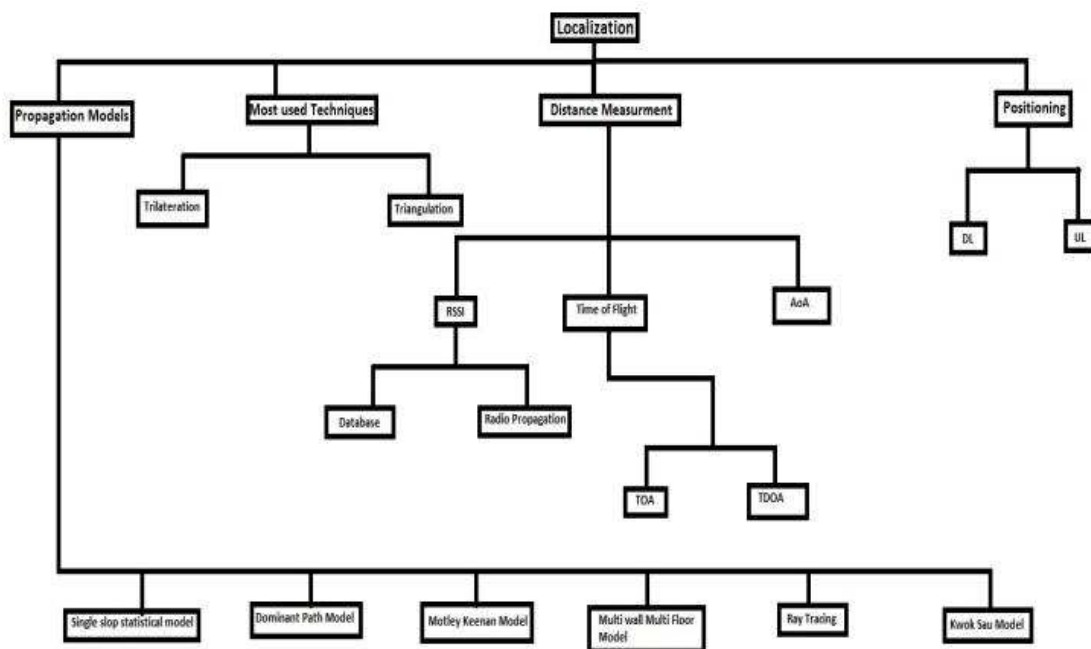


Figure 1 Localization Techniques and Algorithms Flow Chart

2.1 INDOOR LOCALIZATION

Finding a person in an indoor location has always been a challenge for engineers. Many techniques and algorithms have been developed for that purpose and still many of them are in

the development phase. Locating a person is important because a normal person live most of his life in an indoor location, on average people spent 80% to 90 %of their time in different indoor locations.

2.1.1 PROPAGATION MODELS

Propagation models are the type of models used to study the characteristics of radio waves in terms of frequency distance and other conditions depending on the environment. Such models are normally used for the prediction of path loss or the effective coverage area of a transmitter.

The One Slope Model is very fast, because it depends only on the distance between transmitter and receiver. The only parameter which is considered is therefore the path loss exponent. With the path loss exponent, the model is calibrated for each scenario. Walls and other elements in the building database are not considered in the One Slope Model.

In most cases propagation path contributes more than 90% of the total energy. DPS determines the dominant path between the transmitter and each pixel of receiver. DPS determines exactly the impulse response of a channel [18].

This model is a free space propagation model with attenuation added for each wall, floor or obstruction encountered along the route [22].

Mathematically we can write the LO path loss as (2.1):

$$LO = PO + 20 \log(d) + p \times WAF + k \times FAF \quad (2.1)$$

Where:

$$Po = 20\text{Log} [4\pi f/C]$$

d = distance between transmitter and receiver

p = number of walls between transmitter and receiver

WAF = wall attenuation factor

K = number of floors between transmitter and receiver

FAF = floor attenuation factor

Multi wall Multi floor model is basically derived from “Ray Tracing Model”. A path loss model which take into account multi penetrated walls and floors. The penetration losses due to walls and floors between transmitter and receiver have a significant impact on path loss [23].

Ray tracing model is the process of following the rays until they hit any object in his path, where the reflection ray is generated and that transmitted ray is measured by a Snellius law. The effect of change occurred in the rays depends on the thickness of walls, floors and any other obstacles crossing its path [24].

This model introduces a double slop approximation. The parameters are Line of Sight (LoS) stretch constant propagation values, the Non Line of Sight (NLoS) Stretch constant propagation values and the obstacles losses [25].

2.1.2 MOST USED TECHNIQUES

2.1.2.1 TRILATERATION

It is the process of determining relative or absolute points by measuring the distances using circles, spheres and triangles. The practical application can be found in surveying and navigation systems such as Global positioning system (GPS).

In figure 2 bellow P1, P2 and P3 are the centers of the spheres, r1, r2 and r3 represents the radii of the spheres.

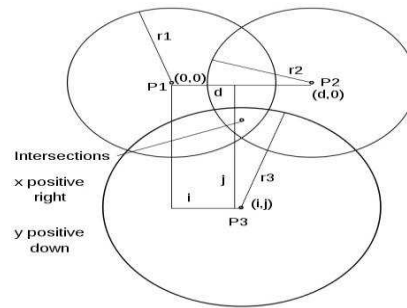


Figure 2 Trilateration

2.1.2.2 TRIANGULATION

Triangulation is the process of determining the location of the points by measuring its angle from a fixed baseline Figure 3, instead of measuring the distance which is trilateration.

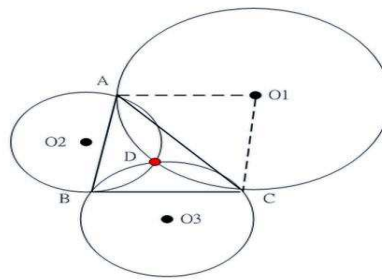


Figure 3 Triangulation

2.1.3 TECHNIQUES USED FOR DISTANCE MEASUREMENT

For distance measurements between FAP and UE the most use techniques are as follows.

2.1.3.1 RECEIVED SIGNAL STRENGTH INDICATION (RSSI)

RSSI are the values received from a FAP to UE we can continuously observed these values from our UE and can mark the points for different locations for different RSSI values. The RSSI values are normally measured in dBm. It is basically the strength of the signal received by the UE. The main two methods are as follows.

2.1.3.1.1 DATABASE

The method of collecting RSSI values at different points to track the location of the person. The accuracy depends on the number of points. The maximum number of tracking points leads to the accurate location.

2.1.3.1.2 RADIO PROPAGATION

This model is normally used in radar systems. The WAF (wall attenuation factor) for a radar system is (2.2):

$$P(d)[dBm] = P(d_o)[dBm] - 10n \log \left(\frac{d}{d_o} \right) - \begin{cases} nW * WAF & nW < C \\ C * WAF & nW \geq C \end{cases} \quad (2.2)$$

Where n indicates the rate at which the path loss decreases with distance, $P(d_o)$ signal power at some difference d_o , and d is the transmitter receiver distance. Moreover C is the maximum number of obstructions (walls), nW the number of obstructions between transmitter and receiver, and WAF is the wall attenuation factor.

2.1.2.2 TOF (TIME OF FLIGHT)

TOF (Time of Flight) is the measure of the time for an electromagnetic wave to travel a distance in a specific medium. The well-known ToF techniques are as follows.

2.1.2.2.1 TOA (TIME OF ARRIVAL)

It is the time taken by a wave from a single transmitter to a single receiver. TOA is the measure of absolute time of arrival to a base station.

2.1.2.2.2 TDOA (TIME DIFFERENCE OF ARRIVAL)

TDoA is an electronic technique used in direction finding and navigation. TDoA is a process in which a time of arrival of a specific signal from a transmitter to a physically separated receiver station is measured. The use of TDoA presents in [26].

2.1.2.3 AOA (ANGLE OF ARRIVAL)

Angle of arrival is the method of measuring the direction of propagation of a radio frequency wave's incident to an antenna array Figure 4. AOA determines the direction by measuring the TDOA at individual elements of the array. The application of AOA is a geo location for cell phones.

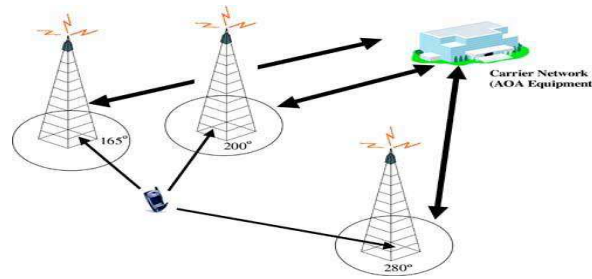


Figure 4 Angle of Arrival

2.1.4 POSITIONING

The position of the UE or cell phone can be found by two basic methods. In these methods the accurate position tracking depends on the number of FAP's whose downlink can be measured.

2.1.4.1 DL (DOWNLINK)

To measure the downlink the UE must be in connected mode instead of idle mode. When the position is required a dummy call can be generated from the UE side, But if the UE is a client and it is assumed that the UE is having some application layer protocol to communicate the measurement and obtain a map and position fix with a server [4].

2.1.4.2 UL (UPLINK)

Another way is to observe the uplink signal of mobile using all the visible Femtocells. The process is when the location is needed the positioning server instruct all the FAP's around the serving cell to make uplink measurement for the pilot of the mobile [4].

2.2 INTERFERENCE MITIGATION WITH MACRO CELLS

In general the term interference mitigation means to reduce the interference against other wireless AP's. In an indoor environment the interference mitigation can be reduced by disconnecting the WLAN's or any other AP's working on the same channels or sharing the frequency with your AP's.

In Femtocells although we are using it as an indoor AP and its coverage is limited to that specific indoor environment but still there is a serious interference issue which FAP is facing from Macro cell, because our Femtocells are using the same frequency channels as Macro cells. The strength of that interference depends on the location and distance of the Macro cell. The far it is the less will be the interference but if the macro cell is in a nearby location having some good power the FAP will be strongly affected by the Macro cell power. We can also assign a different channel to our FAP to avoid the Macro cells interference but that case is only possible in the less crowded areas. Most of the time in city centers and crowded areas operators power up all the channels for their user to provide good coverage. It is important for a FAP to set its own transmitting power approximately to mitigate the interference from Macro cells [27].

The interference for FAP's is not only because of Macro cells but another case can be if we are using more than one FAP in an indoor structure or we have a network of Femtocells in a structure. The interference is really high in those types of environments. First every FAP will have some interference to the coverage area of another FAP. Another issue is if there is FAP working with less power as compare to the nearby FAP's that FAP will be more affected as compare to the other FAP's. It is important to adjust the transmitting power of FAP's adaptively because a large number of FAP's are expected to be deployed [27].

As the FAP networks is an indoor network and the interference from different FAP's and BS's are NLOS (Non Line of Sight). So the two main scenarios to overcome the interference problem are TOA and NLOS solutions [28].

2.2.1 POWER LEVELS

The first and the most common used simple technique is to adjust the RF power levels for BS's. This adjustment depends on the location of the BS or FAP, because by reducing power levels may affect the throughput and performance. It will also affect the coverage of the BS or FAP.

2.2.2 AVOIDANCE OF LOCALLY USED FREQUENCIES

Several systems make use of technology that can enable the avoidance of certain frequencies and frequency bands by filtering notching etc. Another advance method of avoidance frequencies would be adaptive filtering. The main task is instead of fixed frequencies notching the system will dynamically change its frequency usage to avoid radio channels on which strong signals are detected.

2.2.3 DIFFERENTIAL MODE SIGNAL INJECTION

In this conceptual mode of signal, signal with same magnitude and opposite phase will be placed simultaneously on both wires, resulting in canceling of radiation in far fields.

2.3 FINGERPRINTING BASED POSITIONING

Fingerprinting based positioning is one of the most commonly used techniques in indoor localization. It is the process of collecting RSSI values from different Reference Points (RP's), after collecting all the required points, the database is developed. Another way is to come up with radio map [29]. Location of the UE is tracked by using the RP's and comparing them with previous database.

The fingerprinting approach is a cumbersome and requires an immense effort in the calibration stage. Creating a database is a tough job. It is necessary to take the readings correctly and efficiently because the results is completely dependent on the database. The efficient the database the more efficient can be the location tracking. Moreover, the accuracy of the estimated position increases with the number of collected measurements [30].

Before collecting readings for the database, a good approach is to divide your floor plan in small squares, rectangle or clusters. It is helpful to collect data from specific pre-defined spots and avoid the repetition in database for same locations. It also can be good approach to come up with a floor plan and put a grid on that floor plan but it is necessary to make sure that each and every cell present in the grid must be of equal size. The intelligent selection of the measured points can be used [29].

RSSI location fingerprinting technique is mostly used for indoor localization because they achieve good accuracy values [31]. Location fingerprinting techniques suggested for indoor positioning where GPS does not work well [30]

2.4 PROBABILITY DISTRIBUTIONS

Probability distribution is just a way to talk about organizing a list of probabilities [32]. Probability distributions are a fundamental concept in statistics [33]. It is a function or rule that assigns probabilities to each value of a random variable. These distributions are used both in theoretical level and practical level.

Some practical uses of probability distributions are:

- To calculate critical regions for hypothesis test and calculate confidence intervals for parameters.
- It is also useful to determine a reasonable distribution model for the data.
- Simulation studies with random numbers generated from using a specific probability distribution are often needed.

2.4.1 NORMAL DISTRIBUTION

The normal distribution refers to the family of continuous probability distribution described by the normal equation.

The normal distribution is described by the following (2.3) [34]:

$$Y = \left\{ \frac{1}{\sigma * \sqrt{2\pi}} \right\} * e^{-\frac{(x-\mu)^2}{2\pi^2}} \quad (2.3)$$

$$\mu = \frac{\sum x_i}{n} \quad (2.4)$$

$$\sigma^2 = \frac{\sum (x_i - \mu)^2}{1 - n} \quad (2.5)$$

$$\sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{1 - n}} \quad (2.6)$$

Where X is a normal random variable, μ is the mean, σ is the standard deviation, π is approximately 3.14, and e is approximately 2.718.

For a standard normal distribution Figure 5, the value of $\mu=0$ and $\sigma=1$.

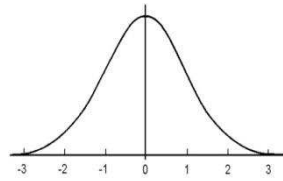


Figure 5 Standard Normal Distribution Curve

2.5 MSE

The error is calculated in the form of Mean Squared Error (MSE) using (2.7). In addition RMSE can also be calculated subtracting the bars from the curves followed by taking the square and finally summing them up.

$$MSE = \frac{1}{n} \sum_{i=1}^n (\hat{y}_i - y_i)^2 \quad (2.7)$$

Where Y represent the true values and $\hat{Y}$ represent the estimated values.

2.6 MLE

The maximum likelihood Estimation (2.8) is used to estimate the location of the person. The probabilities are calculated for all the cells according to the total number of cells present in that zone.

The maximum Likelihood Estimation X given for an observation $Y = y$ is [9].

$$\hat{x}_{ML}(y) = \arg \max_x f_{y|x}(y|x) \quad (2.8)$$

In terms of the continuum of hypothesis H_x and the experimental observation $y < Y \leq y + dy$, we observe that

$$f_{Y|x}(y|x)dy = P[y < Y \leq y + dy|H_x] \quad (2.9)$$

For example let's think about the population of a city, the idea there is like something 20 million individuals in the population, we only have a sample from that particular population, let's say we are interested in what is the probability that the individual was male. Let the probability distribution function be like (2.10)

Where P is the probability that the individual is male.

$$f(X_i|P) = P^{x_i}(1 - P)^{1-x_i} \quad (2.10)$$

$$X_i = \begin{cases} 1 & , \quad Male \\ 0 & , \quad Female \end{cases}$$

If an individual in our sample is male (2.11), if an individual in our samples is female (2.12). By substituting 1 and 0 in the equations bellow. Function f is telling us the probabilities, that the circumstance of only one observation, how about if we have N number of observations.

$$f(1|P) = P^1(1 - P)^{1-1} = P \quad (2.11)$$

$$f(0|P) = P^0(1 - P)^1 = 1 - P \quad (2.12)$$

For N number of observations our equation will become in the form

$$f(X_1, X_2, \dots, X_N|P) = P^{x_1} \cdot (1 - P)^{1-x_1} \cdot P^{x_2} (1 - P)^{1-x_2} \dots P^{x_N} (1 - P)^{1-x_N}$$

Writing the above equation using the product notation, by multiplying each of these individual in density functions what we actually going to obtain in the discrete case is, what is the probability that the random variable X_1 actually took on that value x_1 . This joint probability is the likelihood (2.13)

$$P(X_1 = x_1, X_2 = x_2, \dots, X_N = x_N) = \prod_{i=1}^N P^{x_i} (1 - P)^{1-x_i} = L$$

$$L = \prod_{i=1}^N P^{x_i} (1 - P)^{1-x_i} \quad (2.13)$$

The idea here is to maximize the likelihood, we can differentiate this likelihood function with respect to the parameter P. But the problem with differentiating this equation here is we have to apply chain rule or product rule to differentiate the equation.

$$\frac{dL}{dP} = 0 \Rightarrow \hat{P}_{ML}$$

In order to avoid the complication of differentiation we can simply take the log, the benefit of taking log is that we have a log rule that the log of a product is

$$\log ab = \log a + \log b$$

$$L = \log L = \log \prod_{i=1}^N P^{x_i} (1 - P)^{1-x_i}$$

After applying the log rule the equation becomes

$$= \sum_{i=1}^N \log[P^{x_i}(1-P)^{1-x_i}]$$

We have another log rule

$$\log a^b = b \log a$$

By applying the log rule our equation becomes

$$\begin{aligned} &= \sum_{i=1}^N [X_i \log P + (1 - X_i) \log(1 - P)] \\ &= \log P \sum_{i=1}^N X_i + \log(1 - P) \sum_{i=1}^N (1 - X_i) \end{aligned}$$

Now we have to differentiate the log likelihood equation, where $\hat{P}$ represents that we will going to maximize the log likelihood.

$$L = N\bar{X} \log \hat{P} + N(1 - \bar{X}) \log(1 - \hat{P}) \quad (2.14)$$

$$\frac{dL}{dP} = \frac{N\bar{X}}{\hat{P}} - \frac{N(1 - \bar{X})}{1 - \hat{P}} = 0$$

$$\frac{N\bar{X}}{\hat{P}} = \frac{N(1 - \bar{X})}{1 - \hat{P}}$$

$$\bar{X} - (1 - \hat{P}) = \hat{P}(1 - \bar{X})$$

$$\bar{X} - \hat{P}\bar{X} = \hat{P} - \hat{P}\bar{X}$$

So the final equation for MLE is (2.15), where X represent the sex of an individual. It means that the MLE for the population is just going to be the fraction of individuals.

$$\hat{p}_{ML} = \bar{X} = \frac{\sum_{i=1}^N X_i}{N} \quad (2.15)$$

2.7 MONTE CARLO SIMULATION

Monte Carlo simulation includes a group of methods for computational algorithms that rely on repeated random sampling to obtain a result. Typically a simulation must run many times over in order to get the distribution of a probabilistic entity. An overview of Monte Carlo method is shown in Figure 6

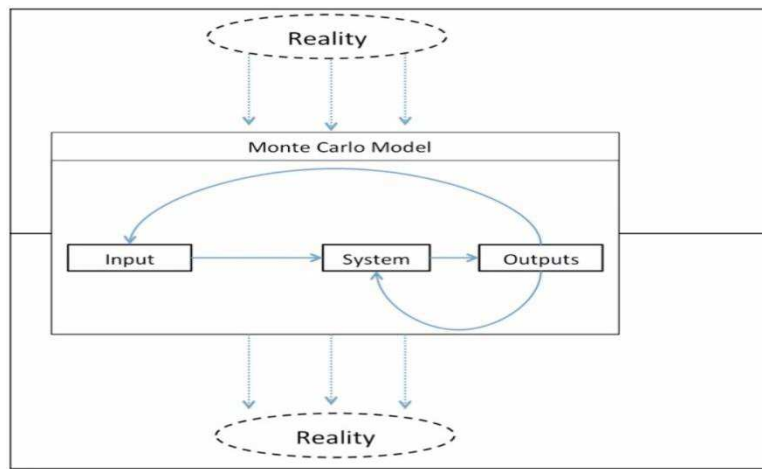


Figure 6 Monte Carlo Methods

3. FAP ANTENNA PROPAGATION

For position estimation in indoor environments the better approach can be first to study the FAP and the way it responds in different scenarios and places of structure. It is also necessary to get the knowledge of the antenna used by that FAP; in my case the antenna used by our FAP is **Antenova Calvus Penta-band SMD Antenna**. It offers near Omni directional characteristics and good resistance to de-tuning. The antenna patterns for 824 - 960 MHz are shown in Figure 7. And the antenna Patterns for 1710 - 2170 MHz are shown in Figure 8.

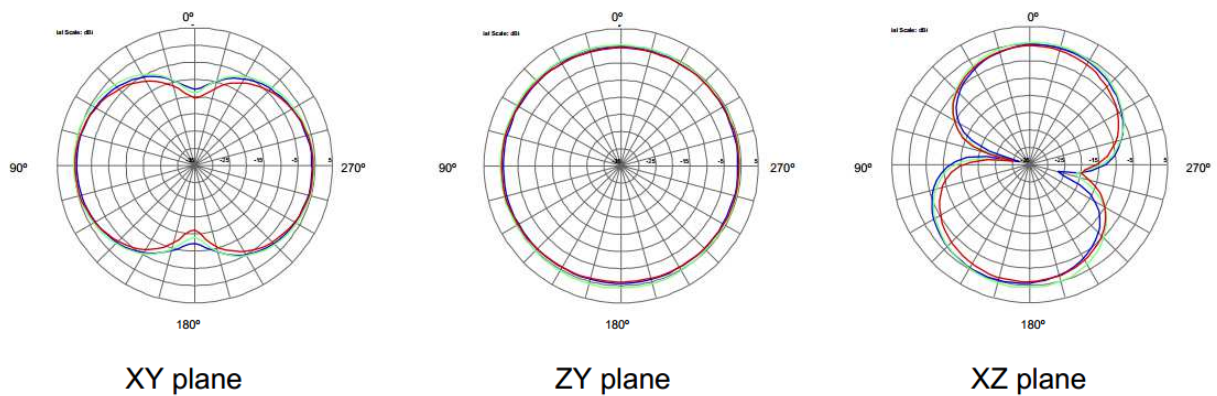


Figure 7 Antenna Patterns for 824-960 MHz

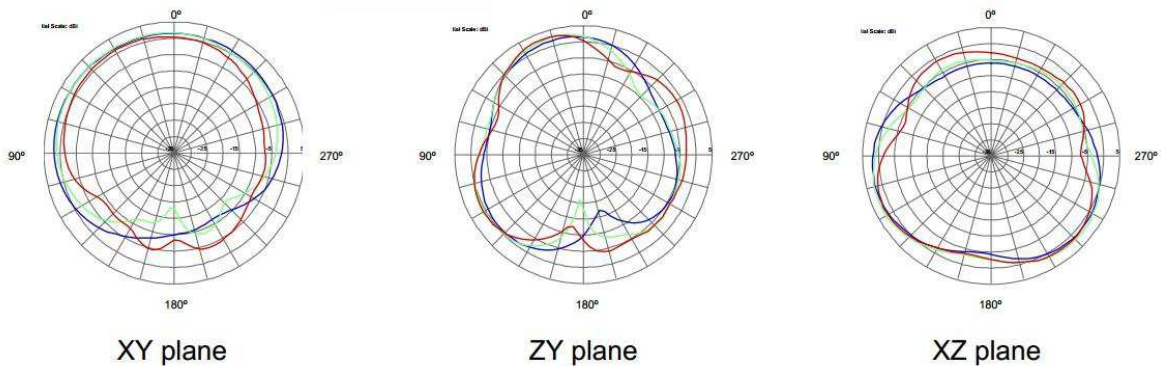


Figure 8 Antenna Patterns for 1710-2170 MHz

3.1 PRACTICAL TESTS TO STUDY ANTENNA PROPAGATION

There is always a slight difference between theoretical and practical work. The FAP in current case has an Omni directional antenna. To study the antenna propagation of FAP there are two ways to place the FAP, horizontally and vertically. Both of the tests are performed. Before performing the tests the FAP power and antenna gain levels are put at almost minimum to get the performance of FAP at those power levels and it is also easy to observe the FAP propagation at low powers and to get the coverage and the distances traveled by the propagation waves. The below Figures shows the FAP propagating the waves and the length it travels while the FAP is placed horizontally Figure 9 and Figure 10.

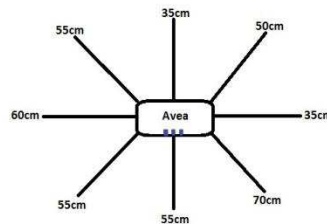


Figure 9 Getting into the FAP coverage Area

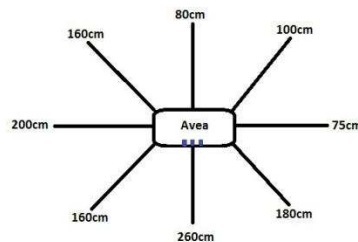


Figure 10 Getting out of the FAP Coverage Area

The FAP are placed vertically and in total eight readings are taken in eight different directions to get an idea of the wave's propagation. During tests it is noticed that there is a big difference when a person trying to get into the FAP area and while trying to get out of the FAP area. After studying it is clear that FAP's generally trying to give the coverage till the end boundaries while a UE is in the idle list of the FAP and the FAP is serving that UE which results in an area where the

FAP power can vary depending on whether the person is connected to FAP and trying to get out of the area or the person is not connecting to the FAP and trying to make a re-selection from some Macro Base station. We can observe those changes in the above and below Figure 11 and Figure 12. Another observation is by putting the FAP at minimum powers, the more the coverage will be affected from hurdles and by increasing the power of the FAP the propagation will be less affected by the hurdles.

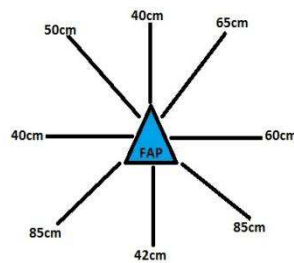


Figure 11 Getting in to the FAP Coverage Area

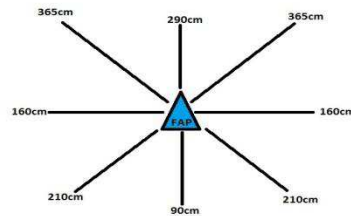


Figure 12 Getting out of the FAP Coverage Area

3.2 FLOOR PLAN AND ZONING

First of all for any indoor based location estimation you must have a floor plan representing the structure or the area where you want to estimate the location. The floor plan is shown in Figure 13. Here I divided my floor plan in three different zones and the experiments are done to find the location of a person in these three zones.

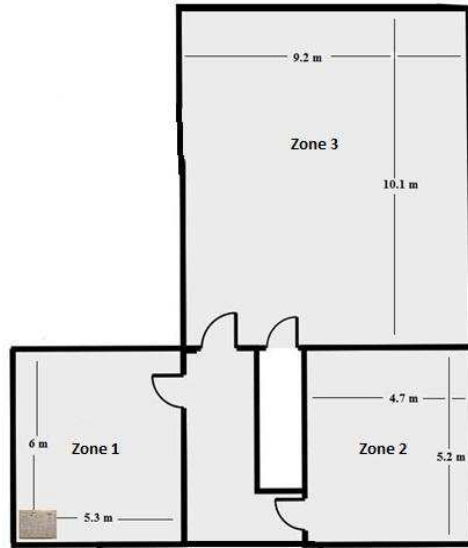


Figure 13 Floor Plan

The above Floor plan is BAYT Technology (BT) office ground floor all the tests are performed in that area. As the tests are performed just by using 1 FAP therefore the upper floors are not considered in these experiments, as because of the reflection, diffraction and interference issues where the FAP is not able to give enough coverage to cover the upper floors.

The plan is divided in three zones all the readings are taken in these three zones. The specification of every zone is in Table 1. From the table and figure it is clear that zone 1 and zone 2 is almost the same in size but zone three is the biggest zone and the maximum number of readings is also from zone three.

Zones	Length	Width
Zone 1	6m	5.3m
Zone 2	5.2m	4.7m
Zone 3	10.1m	9.2m

Table 1 Zones Specifications

3.3 GRIDDING

To get the RSSI readings in different spots of zones, the plan is sub divided into different clusters. Those clusters are the RP's. All the readings are taken according to the reference points. The number of readings depends on the number of reference points present in the cells the distribution of the reference points are shown in Table 2.

Zones	No of cells
Zone 1	33
Zone 2	34
Zone 3	90

Table 2 Reference Points

There is no specific scale or measurement of the cells in grid but one thing is sure that the size of the cells is equal in the whole plan. Zones 2 and 3 have almost the same number of cells but as zone 3 is almost the double size of zone 1 and zone 2 so we have the maximum number of cells in zone 3 as shown in Figure 14.

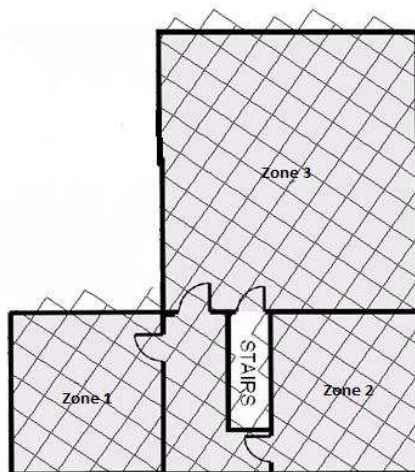


Figure 14 Gridding

3.4 CHALLENGES

Due to the unusual propagation of FAP antenna, interference from outside nearby macro cells, because those macro cells share the same frequency channels, used by FAP. Also in the office environment we have desk chairs some electronic equipment and some radio equipment too. All these things results in a path loss or a hurdle for the propagation of waves which affects the coverage. Once the wave hits anything in its way the direction of the wave is changed, which results into a new issue called NLoS (Non Line of Sight). In all the indoor location based tests there is no clear line of sight between the receiver and the transmitter and that is the main reason of not using GPS as the GPS works where we do not have any line of sight issues.

As far as hurdles are concerned in my case I have walls which separate the zones from each other. The walls can also be a good assumption for another technique of location estimation in which you can keep tracking of your previous values from a radio map or a fingerprinting database. The assumption can be that the person cannot cross through the wall and the only way to leave the zone is to cross through the door. By taking good enough readings can lead to follow the person continuously.

To overcome the problem of interference, path loss, reflection and diffraction of wave's different type of techniques can be used. This can help us in at least decreasing the interference issues. One of the solutions which can be used in this kind of situation is interference mitigation. Interference mitigation is the process in which the equipment's are adjusted in a way that they minimally affect the propagation of neighbor equipment. For interference mitigation as we normally do not have access to Macro cells or to change the power of the Macro cells or adjust them according to our needs the best way is to adjust the power of FAP.

3.4.1 POWER ADJUSTMENTS

For power adjustments of the FAP which really depends on the manufacturers of the FAP's. In general scenarios by changing the Power and Gain of the antenna are the easiest process to adjust your FAP output according to the surrounding environment. For these changes it is necessary to access the FAP configuration and Radio powers and try to learn the propagation at

different power levels that can be helpful in adjusting the FAP coverage according to the desired way.

3.5 RF PLANNING

For an indoor environment it is really necessary to select the best place for FAP, so that FAP is able to cover the maximum area of the plan. The placement of the FAP is simple when there is a clear LoS and no hurdle issues for the propagation, that kind of place can be a big hall or a convention center or any location where we want to cover a single room or place.

But if the FAP have to cover a complete floor or a structure or more than one floor having different rooms etc. than the detailed RF planning is required. In simple words RF planning means to specify the location of the FAP or to decide where to put the FAP, but placing the FAP in a location need planning and the best way is to come up with the RF map.

Initially three tests are performed by using 3 FAP's, 2 FAP's and 1 FAP. Figure 15 shows the RSSI values using 3 FAP's and Figure 16 shows the RSSI values using Two FAP's.

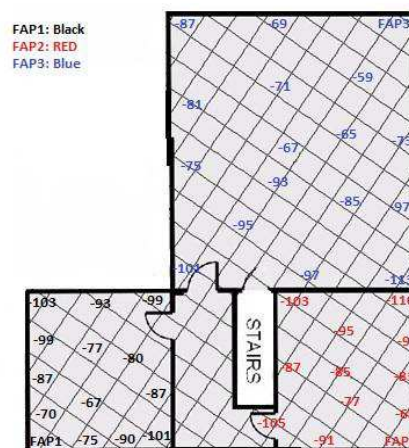


Figure 15 RSSI Readings using Three FAP's

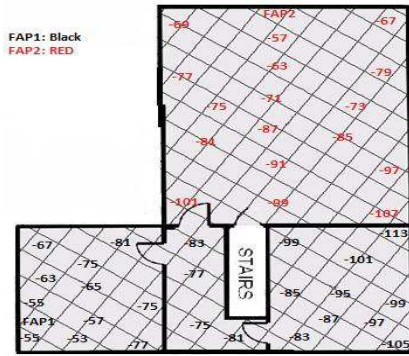


Figure 16 RSSI Readings Using two FAP's

Getting the RF Map is the process of taking RSSI readings at different location and try to come up with a map showing the readings the best way is to divide the readings in different section it can help in differentiating the areas and is easy to differentiate between the coverage and it is also helpful in estimating the location of the person. The RF map for our current floor plan is shown in Figure 17. Figure also shows the exact location where I put the FAP. It also shows that the FAP is covering all the area of the plan and I am having readings in almost every spot of the zones. For taking readings it is a better way to put a grid on floor plan and the divide the plan in different small cells the maximum number of reading results in maximum success rates.

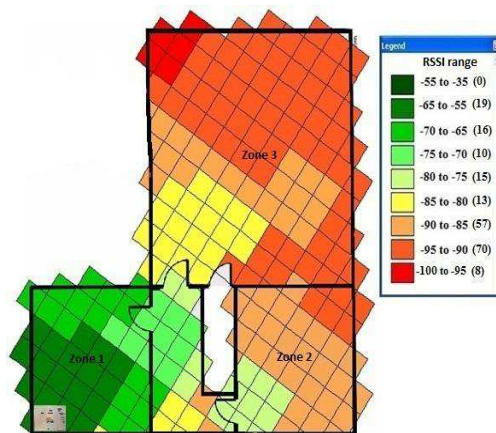


Figure 17 Radio MAP using one FAP

4. MQTT AND FINGERPRINTING

The nature of the RSSI values is completely unpredictable in indoor locations. Because of this unpredictable nature most of the indoor positioning systems used RSSI based location fingerprinting technique in order to compute a more accurate estimation of user's position. To make this project more valuable and make it ready for commercial use, MQTT protocol is one of the best protocols for message transferring.

4.1 MQTT PROTOCOL

MQTT (Message Queue telemetry Transport) was originally developed by IBM and its partners from different industries. Over the last couple of years the protocol has been moved into the open source community. MQTT has seen significant growths in popularity as mobile application have taken off. It is also in the process of moving in the hands of standard body.

The design and aim of MQTT is simple and it provides published and subscribes messaging and was successfully designed constrained devices and low bandwidth and high latency networks such as dialup lines and satellite links.

4.1.1 SERVER, CLIENT AND B-LOCATOR CLIENT APP

The setup is configured in a way that whenever there is a change in RSSI values, it will automatically update the server. A high end server needs to be configured in order to successfully transfer the messages through the network without any delay. The RSSI values will send to the remote server by using JMS (Java Messaging Service)/MQTT server. MQTT is an open source server configured on the server side. MQTT client server configuration can be used for messaging transfers. First an MQTT client is configured called publisher; it will published the received RSSI values. Than server side is configured in remote server which is called subscriber to get the incoming RSSI values in real time. To get access of this remote server put it on open access so that the server can be easily connected from any remote area through internet.

RSSI values are gathered through an application installed in an android phone. The RSSI values are collected through the Android Telephony service. The application can work with any android

phone with little configuration. In order to send RSSI values for phone to server a small process of authorization is done the MQTT is allowing his clients by user name and password to connect with MQTT and send data.

After configuration of the code in JAVA then .apk format file is developed which is an android format file and can be installed in any android phone. The app can start working by simply clicking the icon. In its initial configuration it shows the device Identification (ID) number, phone number if you allowed, software version and the operator in our case it must be AVEAINDOOR which represent our FAP Figure 18. The up gradation of the software is still in progress in order to get the maximum information out from both FAP and UE side.



Figure 18 B-Locator Client App

After finishing the entire configuration the setup is ready to test now. For testing process a dedicated PC is used. As the server is in open access, the PC can be configured in any location having internet access. A test is performed to check the reliability of the setup, application and server side. The figure is showing the real time RSSI values collected through MQTT server. The image shows that in some cases more than 1 RSSI values are collected in a second. Which shows the configuration is not set for any specific duration it is set for any change in RSSI values occurred must be reported.

4.2 LOCATION BASED FINGERPRINTING

An Android phone is used to get the RSSI values from different RP's. The main advantage is we can access that data anywhere through internet and track the location of the required target in that specific floor or structure depends on the deployment. The location fingerprinting is mainly divided into two phases. The first phase is called offline phase in which the RSSI values has been collected from all the reference points to create the database and the second phase is called the online phase in which the RSSI values are taken in real time to track the location.

4.2.1 OFFLINE PHASE

Offline is also known as the training phase in which the readings are taken to develop the database which will be used in the online phase to get the location. The training must be done where the setup is deployed in order to get the exact readings and avoid mistakes good calibration is required. It is better to take at least five readings at every RP and take the average if the RSSI values are not stable and changes with time. The time to make the database depends on the area of the plan, if the place of the FAP is fixed and will not be removed frequently a single database is enough, but if the FAP location and power levels are not certain it will be better to come up with the new databases every time in order to increase the success rate.

4.2.1.1 FINGERPRINT COLLECTION

Before fingerprinting the plan must be divided into small clusters or cells and these clusters represents our reference points. All the RSSI readings must be taken for each reference point. Android phone is used to collect the RSSI readings for every RP. The client is configured in an Android device with the help of a small piece of software showing RSSI values and some other basic information. There are many other message passing protocols available but MQTT is an open source and easy to use and the transfer rate is much better than the others.

To collect the RSSI readings for a reference points the setup is configured that with every change of RSSI values at the UE side will be transferred to the server and it will get back to the PC where

anyone can observe the readings in real time with almost no delay, whoever have the access by using “mosquito” tool.

As fingerprinting is a sensitive process and any movement within the coverage can affect the propagation. Therefore precautions must be taken, it is better to get at least two readings for every RP if the readings are not stable take at least 10 readings and then take the average in order to avoid errors. The readings can be collected in two different ways depends on the plan or the area where the readings will be taken. The first one can be while the person or mobile equipment are moving towards the FAP and the second one can be while the mobile equipment are moving away from the FAP.

The RSSI readings are collected through Samsung Galaxy S3. All readings are taken carefully in total five readings are taken for every reference point to avoid errors. Only one FAP is used in the whole process. The power is set in order to cover the entire plan. After creation of database the radio map is also created Figure 19.

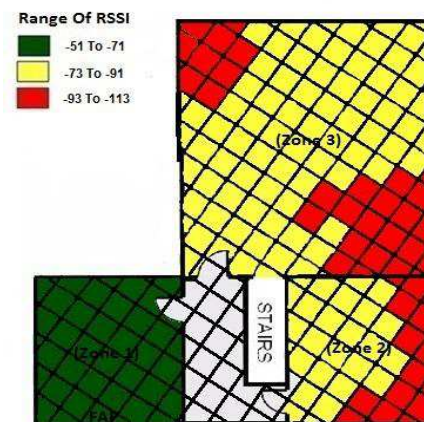


Figure 19 Radio MAP for Fingerprinting Database

After completing the database it is observed that the distribution of the RSSI values are in a way that we don't have any overlapping of RSSI Values in Zone 1 but I have overlapping region in Zone 2 and zone 3 Table 3. To overcome this problem a simulation is done to estimate the location of the person which is described in detail in the next chapter.

Zones	RSSI Range
Zone 1	-51dBm to -71dBm
Zone 2	-79dBm to -97dBm
Zone 3	-73dBm to -113dBm

Table 3 RSSI Ranges

4.2.2 ONLINE PHASE

The online phase is basically the test phase or it is the practical experiment made to get the results for the process and to identify or estimate the location. In normal scenario the number of readings necessary to get the result depends on the configuration, it depends on the person and the way he/she deploy the setup. In some cases more than one reading is needed to get the location estimation in my case only one reading is enough to get the estimation of the location.

Numbers of test were performed in the testing process to come up with effective results and every possibility of the location estimation. Two types of tests are mainly performed. Test 1 is a real scenario test in which the person moves randomly in all the three zones and a simulation is done to estimate the location of the person. In total, 100 tests are performed in the first case. The test 2 is completely a simulation based test by using the Montecarlo simulation. THE simulation is executed around 10^6 times.

5. SIMULATION AND RESULTS

To make the selection of the location automatically after receiving the RSSI values, automation is needed. After successfully completing the fingerprinting process, database is developed.

5.1 NORMALIZATION AND MSE

Initially Histograms and PDF curves are simulated. The simulation is done for the normalization of data to get the MSE.

5.1.1 HISTOGRAMS

The Histograms are made for all the three zones separately presented in Figure 20, Figure 21 and Figure 22. The x-axis represents the RSSI values in different ranges as our zones are divided into different ranges. On the y-axis we have the number of samples. Each bar height represents the number of samples for specific RSSI value.

After completing the histograms the data is simulated for the normal distribution.

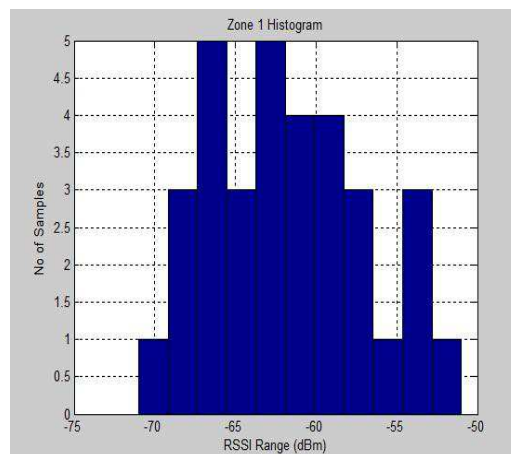


Figure 20 Zone 1 Histogram

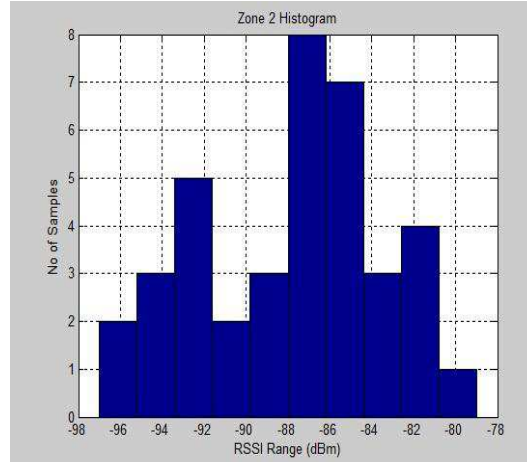


Figure 21 Zone 2 Histogram

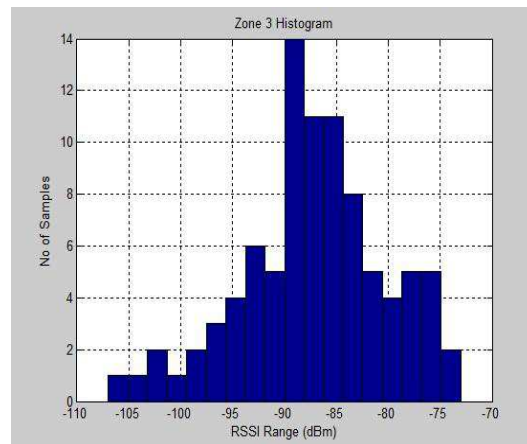


Figure 22 Zone 3 Histogram

5.1.2 NORMAL DISTRIBUTION

The Probability Density Function of Normal Distribution is simulated for the entire three zones Figure 23, Figure 24 and Figure 25. X-axis presents the ranges of RSSI values and the Y-axis represents the density.

The density must be in between 0 and 1 for the PDF of Normal Distribution. Now to get the MSE and for normalization of data the histograms and the PDF curves must be merged together.

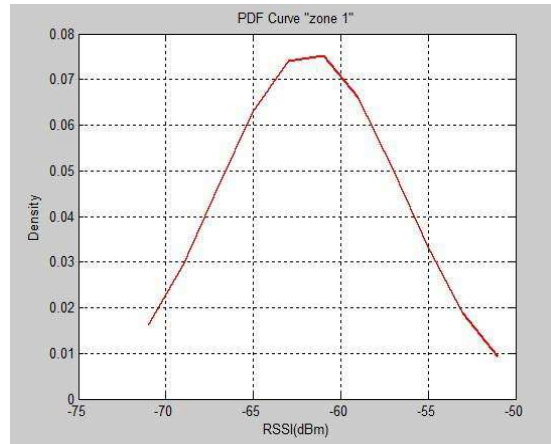


Figure 23 PDF Curve Zone 1

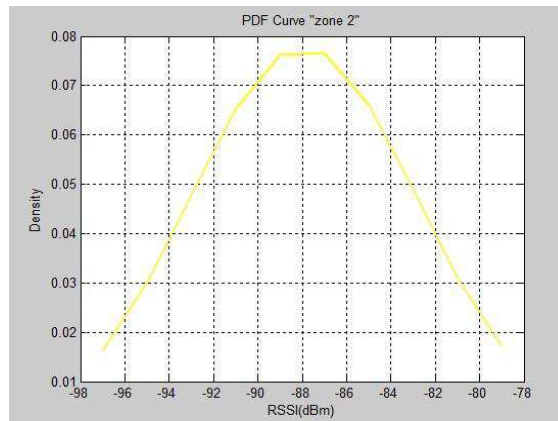


Figure 24 PDF Curve Zone 2

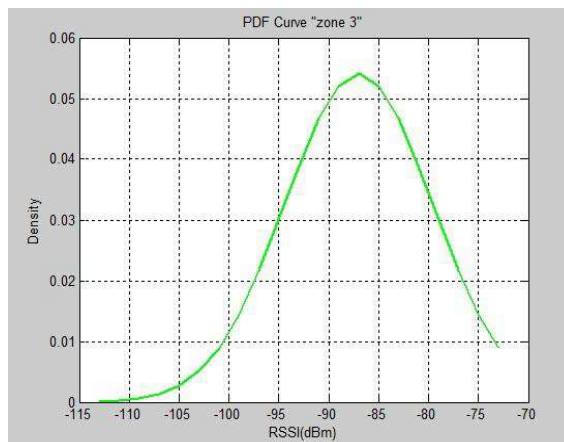


Figure 25 PDF Curve Zone 3

5.1.3 NORMALIZATION

Normalization is comparatively tricky process where the number of samples must be converted to the density and the peak of each bar must be subtracted from the curve to get the error between curve and bars Figure 26, Figure 27 and Figure 28.

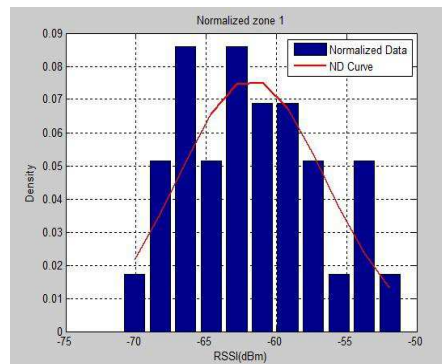


Figure 26 Normalized Zone 1

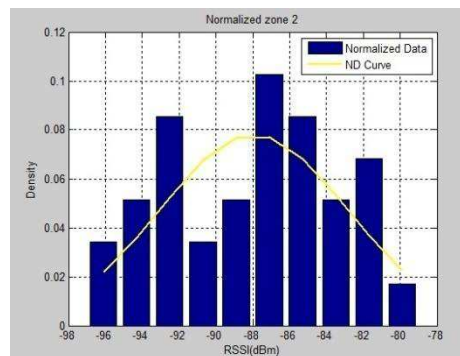


Figure 27 Normalized Zone 2

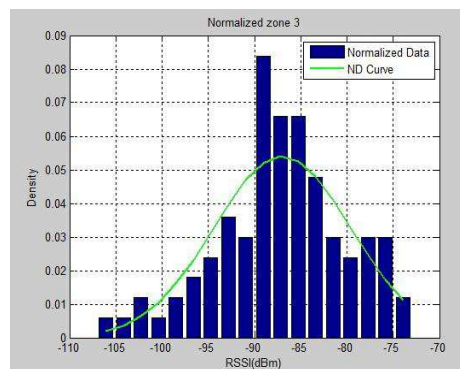


Figure 28 Normalized Zone 3

5.1.4 MEAN SQUARE ERROR (MSE)

The bars are subtracted from the PDF curve at every point. Simulation results for the MSE are shown in Table 4.

Zones	Mean(μ)	Standard Deviation(σ)	Mean Squared Error
Zone 1	-61.78 %	5.25	0.0556
Zone 2	-87.94%	5.122	0.0720
Zone 3	-87%	7.3805	0.0467

Table 4 Mean, Standard Deviation and Mean Squared Error

5.2 MAXIMUM LIKELIHOOD ESTIMATION (MLE)

Let x be the total number of cells, and y is the number of samples for a specific RSSI value in that zone, For example lets solve it for an RSSI value -51dBm. I only have 1 sample of -51dBm at Zone 1, while for Zone 2 and Zone 3 I don't have any sample for -51dBm.

For Zone 1, $Y/x = \text{Probability}$, $1/33 = 0.030$, For Zone 2, $0 / 34 = 0$, For Zone 3, $0 / 90 = 0$

So according to the probabilities the location of the person is spotted in zone 1. In simple words the simulation will estimate a zone for UE according to the maximum probability.

On the basis of Monte Carlo simulations, the simulation is run 10^6 times to get the success rate of the simulation. The result was about 84%. And the failure rate was about 16% Figure 29.

A real life test is performed on the basis of this simulation which ends up with the success rate of 80%, For 100 trails. The person randomly starts moving in these three zones having an Android phone. The RSSI values are collected through B-locator client application. In total 33 samples are collected from zone 1 and 33 samples are collected from zone 2 and 34 samples are collected from zone 3.

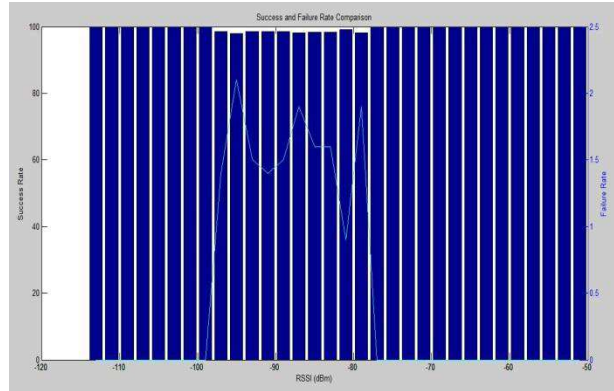


Figure 29 Success And Failure Rate Comparison for Basic MLE

5.3 MLE BASED ALGORITHM

In order to improve the success rate, a new simulation is developed in MATLAB. The new technique used is to track the UE in real time with the person footsteps. A numbers of sequences are developed to identify the footsteps.

The following assumptions were made for the algorithm. The person can move only in four directions for the points where he begins Figure 30. He can either move straight, backward, left or right.

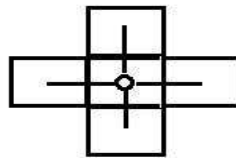


Figure 30 Movement From initial position

After putting the first step the person can now move in any of the three directions, the next assumption is that the person will less likely to return to his previous position. In that case he can only move in the following directions Figure 31. These movements can straight, left or right directions. This assumption also help us to avoid the repetition of the sequences, in which the UE may only move between forward and backward directions.

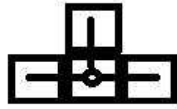


Figure 31 Movement After First Step

After those assumptions the shape which made for our real scenario is Figure 32. The figure bellow shows us all the possible direction from a specific cell having an RSSI value of -91dBm.

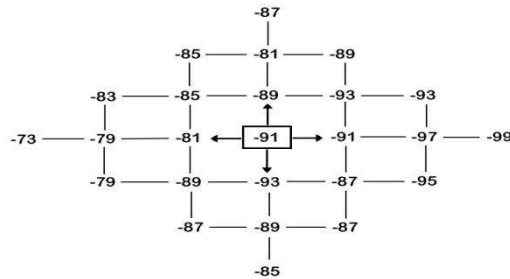


Figure 32 Possible Directions of Movement

To avoid the sequence overlapping in total four number of sequences are developed including the RSSI value from where the person start moving. The sample sequence is as follow.

$$-91 \rightarrow -91 - 97 - 99$$

The sequences are simulated in a way that if there is no sequence overlapping the code can decide the location by the first footprint, after two footprints and with three footprints. After three footprints if the sequences are still overlapping each other in any other zone, that overlapping is considered as an error.

After applying this sequence technique the success rate cross the 90% and the target is achieved Figure 33.

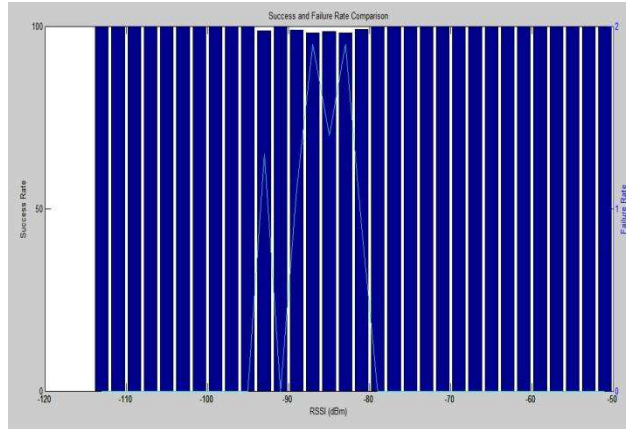


Figure 33 Success and Failure rate comparison for MLE based algorithm

5.4 RESULTS COMPARISONS

Table 5 presents the results comparison stepwise initially started from 33% till 90%. Initially it is assumed that for a dummy person to find the location of the person with in these three zones is 33%. After development of the Radio map a dummy person having radio map may identify the location of the person with a success rate of about 67%. After using the MLE based algorithm our success rate was 84%. By applying the new technique of footprints and tracking the person with his footsteps the success rate crosses the 90%.

Scenarios	Success Rates	Failure Rates
Blind Decision	33%	67%
RF MAP	67%	33%
MLE	84%	16%
MLE based Algorithm	90%	10%

Table 5 Results Comparison

5.5 CONFIDENCE INTERVAL

A confidence interval gives us an estimated range of values which is being

calculated from a given set of sample data. Confidence interval are usually calculated to ensure that the success percentage is 95%, however, one can set the confidence as 90%, 99%, 99.9% for the unknown parameter.

The equation (2.16) gives the mathematical expression to calculate confidence interval for number of samples (n) being less than 30 (i.e. $n < 30$).

$$CI = \bar{X} \pm t \frac{s}{\sqrt{n}} \quad (2.16)$$

Where s represents the sample standard deviation and n is the sample size. We can get the values of t from the t-table and $\bar{X}$ represent the sample mean.

According to our simulation the confidence interval we observed from the practical experiment is ± 1 . For theoretical analysis of our data results, for the 95% confidence interval the calculation results are as follows

Mean	91.04633
Standard Deviation	0.630636
No of Samples	15
Confidence Coff	1.96
Margin Error	0.31914
Upper Bound	91.36548
Lower Bound	90.7271

Table 6 Confidence Interval

6. CASE STUDY

This case study is regarding the deployment of small cell network at Rixos Antalya. The purpose is to find the location of the Children at their playground. Initially for demonstration purposes the network of 11 small cells are deployed in a convention center at Rixos.

6.1 CONVENTION CENTER LAYOUT AND SMALL CELLS LOCATION

The length of the hall is 52 meters and the width of the hall is 34 meters. The blue squares represent the area which is not included in the hall. In total 11 Small cells are deployed in the Convention center hall. To cover the hall area completely RF planning is done. Normally a single small cell can cover all the area of that hall if it is propagating on his maximum power, but to show the re-selection and for location estimation, task is to deploy the network of 11 small cells. To complete the task the power of the small cells are calibrated in a way that it should minimally affect the coverage of the neighbor small cells.

To overcome the interference problem the plan was design in a way that four small cells should deploy at each side of the hall length wise. And three small cells will be at the middle of the hall. The layout also shows the direction of the small cells. All the small cells are placed vertically. Although due to the Omni directional nature of the propagation the placement of the small cell doesn't really affect the coverage. But still the coverage is comparatively better to the front as compared to the back side of small cells.

The line of sight is almost clear between the UE and the small cells because we have no hurdles at that place. The only interference is because of the small cells to its neighbor cells and two macro indoor antennas placed inside Rixos were continuously affecting the range.

6.2 CHILD ACCESS TERMINAL

The project is to find the children by using the small cells. The problem is that the person can only be detected by the small cell if he has a phone or any device in which he/she uses the sim card, but children having a phone are not a viable option.

A child access terminal is used to track the location, for safety purposes the watches are sealed from outside. They are operating on Android 4.2.2 Operating System (OS).

6.3 RF MAP

An Android phone Samsung S3 is used to collect the RSSI values from entire plan. The small cells were operating on different power levels depending on the place of deployment. The RF map is mainly divided into three different ranges Figure 34. The Green clusters present the RSSI range from -40dBm to -80dBm. The yellow clusters present the range in between -81dBm to -100dBm. And the Red presents the rage from -101dBm till -120dBm.

It can be easily observed that most of the RF map is designed in a way that before crossing the -101dBm range it will make a re-selection. But in some places we still have red clusters which show us that the small cells operation in that area is operating on less power than their neighbor cells.

The plan is divided in a way that the distances between the two small cells are about 13 meters and the distance between the small cells placed at the corners are about 6.5 meters away from the walls.

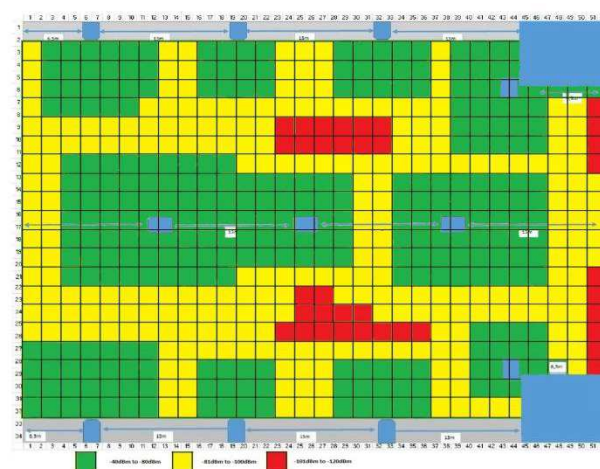


Figure 34 RF MAP using 11 FAP's

6.4 RE-SELECTION MAP

The bellow re-selection map is the expected re-selection borders for the small cells operating in that plan Figure 35. The circles represent the expected coverage area of the small cells. The colors of the circles represent the different power levels for those small cells. It can be easily observed that the cells operating on high power levels overlap the coverage area of neighbor cells. Another problem faced is, there is difference in the re-selection points, while getting into a small cell coverage area and while getting out of the coverage area. The small cells are by default operating in a way that if a UE is trying to get into the FAP coverage area suppose the re-selection point is -95dBm. The re-selection will occur from any other cell to small cell at -95dBm. Once it is connected to the small cell the re-selection criteria changes automatically the small cells try their best not to leave the UE's from their coverage area. And while getting out of the coverage area the re-selection point is between -115dBm to -120dBm. These values in real life occur in an error area which can be 5 meters or may be less or more than that depending on the small cell power levels and the area covered by the small cell.

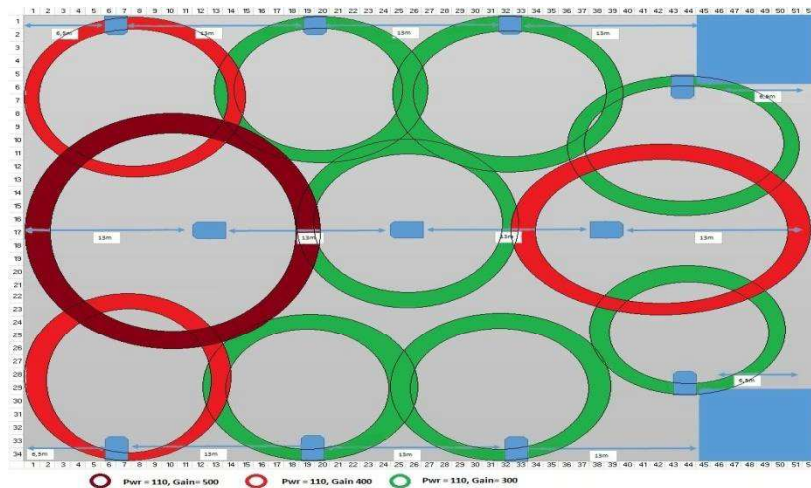


Figure 35 Re-selection MAP

6.5 RE-SELECTION OPTIMIZATION

To make the location estimation more reliable, re-selection optimization must be done. There are different parameters for the optimization with the help of which the re-selection points can be specified according to the needs.

In the current scenario we have to set the points in a way that the points for getting into the coverage area and getting out of the coverage area must be almost the same. That will help in interference mitigation. The points are set for -90dBm the re-selection process start working with minimum error. The error plan is decreased to about 1 meter. The points for getting in and getting out from the coverage of a small cell are almost the same.

Test is performed using three FAP's in a Hall at Bayt Technology and the re-selection points after optimization seems better.

The same configuration is used for the demonstration at RIXOS using six FAP's, The setup was tested by a referee and this time the setup was successfully demonstrated, the re-selection and Radio map in Figure 36 and Figure 37 show the re-selection points and RF map for six FAP's.

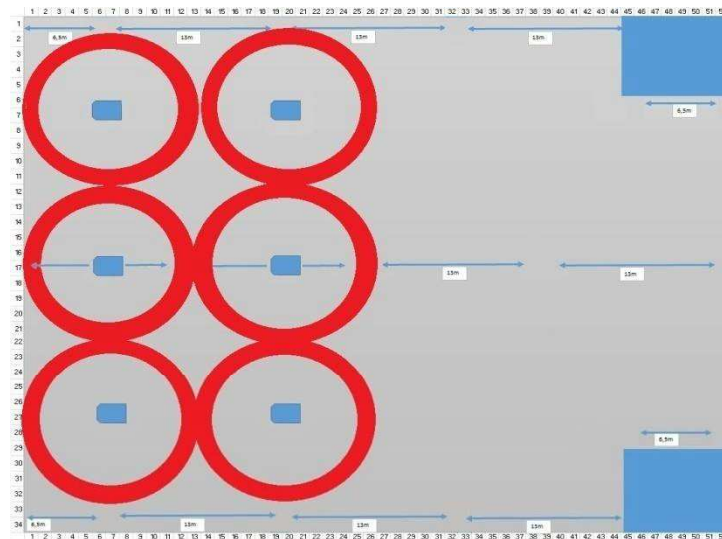
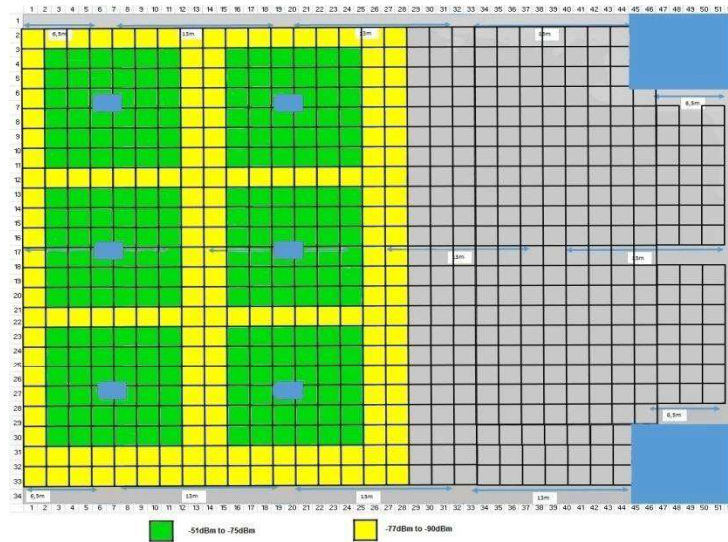


Figure 36 Re-selection MAP



6.6 SIMULATION AND RESULTS

To be more specific regarding the location of the person the code is developed in JAVA. The structure is that all the small cells coverage areas are mainly divided into three sections “near small cells”, “middle area” and “border area”. Or in simple words Zone 1 Zone 2 and Zone 3. The zones are divided on the basis of RSSI ranges. The complete RSSI range is divided in three sections. The first section is Zone 1 the second section is zone 2 and the third section zone 3

Figure 38.

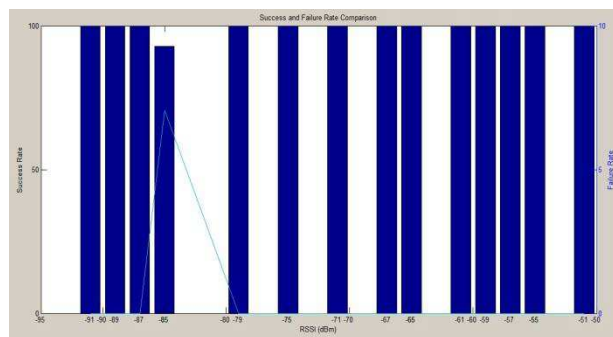


Figure 38 Success and Failure Rate Plot For Rixos Demonstration

7. CONCLUSION

In this thesis, an RSSI based fingerprinting database is developed and used with different algorithms to improve the performance and success rates. This framework can be used with any structure. This work presents the location estimation using fewer resources. The uniqueness of this work is that I use only one FAP and come up with reasonable success rates. The point of focus was to develop a framework which is not only applicable in labs or for experimental purposes but can be used in daily life scenario too, for an indoor environment. This framework can be extended / applicable for any structure and can detect the location of a person having an Android phone. The use of an available open source MQTT server for indoor localization was also proposed. In addition the location of the person can be observed from any remote area having an internet connection.

An Android phone is used as a UE. MQTT server and client are also used to access the RSSI values in real time and can be easily accessible from any remote location. The RSSI values are collected in a way that with any movement or any update in RSSI values it will automatically update the system and the values were collected.

Initially it is considered that the probability for a normal person to find the location within three zones is 33%. Fingerprinting database is developed which is divided in two phases offline phase to collect the values for database to be compared with the values from online phase for location estimation. It is assumed that by using my database for a normal person the possibility is almost 67% that he can correctly identify the location of the person.

To improve the success MLE based algorithm is used, which helps in improving the success rate to 84%. A real life scenario test is also performed in parallel to check the results in real life. The test ends up with the success rate of about 80%.

There are still some improvement needed and then a new MLE based algorithm were designed and used in simulation. This was tracking the person in real time with his footprints. Some assumptions are also made for that simulation. The success rate was increased up to 90%.

A case study is also part of this thesis by using more than 1 FAP a network of the FAP's are deployed. The nature of the FAP's are studied in details. The differences between the localization techniques using 1 FAP and by using more than 1 FAP's are cleared.

Both setups are deployed and tested in two different locations. The first location is Bayt office Ground Floor. One FAP was used for the position estimation. Another location was a Convention center in which two different configurations were used. In the first configuration 11 FAP's were used for location estimation. In the second configuration 6 FAP's were used for location estimation.

7.1 FUTURE WORK

There is still room for improved indoor location estimation. The success rate can still be improved by using same or different techniques and algorithms. This work presents the location estimation of the person with in three different zones. The next task can be to find the location of the person with in a plan or a structure without specifying any zones. The error will be in that case the distance measurement between the estimated location and the exact location of the UE.

The real time tracking or continuously following the footprints of the person is a good technique and it can be further enhanced to track the location of the person more accurately by further calibrating the fingerprinting database.

The RF planning is another side to improve the location estimation. In the same scenario if the number of overlapping RSSI values were decreased it will result in a reasonable success rate.

By using the pilot/beacon FAP's can also result in some better tracking. The beacon can be activated by a dummy call to check the distance of UE from the AP. In that case more than 1 FAP will be needed and the ideal condition will be to use at least three FAP's. All the three FAP's were initiate a dummy call in a sequence to get the distance from the UE and then by using well known trilateration or triangulation techniques we can estimate the location of the person.

To get the location of the person with fewer errors or to get the exact location by merging the beacon and RSSI technique together at a single platform can be a best idea.

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APPENDIX A

SAMPLE LOGS

Below are the sample RSSI logs showing three different locations within the FAP coverage.

```
2014-08-21 16:29:35 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:29:39 EEST
2014","IMSI":"286034070385186","RSSI":-71}
2014-08-21 16:29:35 INFO MQTTSubscriber:200 -
{"distance":"close","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:29:37 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:29:41 EEST
2014","IMSI":"286034070385186","RSSI":-71}
2014-08-21 16:29:37 INFO MQTTSubscriber:200 -
{"distance":"close","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:29:39 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:29:43 EEST
2014","IMSI":"286034070385186","RSSI":-71}
2014-08-21 16:29:39 INFO MQTTSubscriber:200 -
{"distance":"close","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:29:41 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:29:45 EEST
2014","IMSI":"286034070385186","RSSI":-71}
2014-08-21 16:29:41 INFO MQTTSubscriber:200 -
{"distance":"close","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:29:43 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:29:47 EEST
2014","IMSI":"286034070385186","RSSI":-71}
2014-08-21 16:29:43 INFO MQTTSubscriber:200 -
{"distance":"close","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:29:45 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:29:49 EEST
2014","IMSI":"286034070385186","RSSI":-71}
2014-08-21 16:29:45 INFO MQTTSubscriber:200 -
{"distance":"close","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:29:47 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:29:51 EEST
2014","IMSI":"286034070385186","RSSI":-71}
2014-08-21 16:29:47 INFO MQTTSubscriber:200 -
{"distance":"close","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:29:49 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:29:53 EEST
2014","IMSI":"286034070385186","RSSI":-71}
2014-08-21 16:29:49 INFO MQTTSubscriber:200 -
{"distance":"close","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:29:51 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:29:55 EEST
2014","IMSI":"286034070385186","RSSI":-71}
2014-08-21 16:29:51 INFO MQTTSubscriber:200 -
{"distance":"close","imsi":"286034070385186","fapId":"26849126200390"}
```

2014-08-21 16:29:53 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:29:57 EEST 2014","IMSI":"286034070385186","RSSI":-71}
2014-08-21 16:29:53 INFO MQTTSubscriber:200 - {"distance":"close","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:29:55 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:29:59 EEST 2014","IMSI":"286034070385186","RSSI":-71}
2014-08-21 16:29:55 INFO MQTTSubscriber:200 - {"distance":"close","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:30:06 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:30:01 EEST 2014","IMSI":"286034070385186","RSSI":-71}
2014-08-21 16:30:06 INFO MQTTSubscriber:200 - {"distance":"close","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:30:09 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:30:03 EEST 2014","IMSI":"286034070385186","RSSI":-71}
2014-08-21 16:30:09 INFO MQTTSubscriber:200 - {"distance":"close","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:30:09 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:30:05 EEST 2014","IMSI":"286034070385186","RSSI":-75}
2014-08-21 16:30:09 INFO MQTTSubscriber:200 - {"distance":"middle","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:30:09 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:30:07 EEST 2014","IMSI":"286034070385186","RSSI":-75}
2014-08-21 16:30:09 INFO MQTTSubscriber:200 - {"distance":"middle","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:30:09 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:30:09 EEST 2014","IMSI":"286034070385186","RSSI":-75}
2014-08-21 16:30:09 INFO MQTTSubscriber:200 - {"distance":"middle","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:30:10 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:30:11 EEST 2014","IMSI":"286034070385186","RSSI":-79}
2014-08-21 16:30:10 INFO MQTTSubscriber:200 - {"distance":"middle","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:30:11 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:30:13 EEST 2014","IMSI":"286034070385186","RSSI":-81}
2014-08-21 16:30:11 INFO MQTTSubscriber:200 - {"distance":"middle","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:30:11 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:30:15 EEST 2014","IMSI":"286034070385186","RSSI":-83}
2014-08-21 16:30:11 INFO MQTTSubscriber:200 - {"distance":"middle","imsi":"286034070385186","fapId":"26849126200390"}
2014-08-21 16:30:13 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:30:17 EEST 2014","IMSI":"286034070385186","RSSI":-81}
2014-08-21 16:30:13 INFO MQTTSubscriber:200 - {"distance":"middle","imsi":"286034070385186","fapId":"26849126200390"}

2014-08-21 16:30:16 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:30:19 EEST
 2014","IMSI":"286034070385186","RSSI":-83}
 2014-08-21 16:30:16 INFO MQTTSubscriber:200 -
 {"distance":"middle","imsi":"286034070385186","fapId":"26849126200390"}
 2014-08-21 16:30:43 INFO MQTTSubscriber:164 -
 {"fapMode":"NONE","imsi":"286034030108297","date":"Thu Aug 21 16:30:42 EEST
 2014","fapId":"26943818200082"}
 2014-08-21 16:32:20 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:32:17 EEST
 2014","IMSI":"286034070385186","RSSI":-97}
 2014-08-21 16:32:20 INFO MQTTSubscriber:200 -
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 2014-08-21 16:32:20 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:32:19 EEST
 2014","IMSI":"286034070385186","RSSI":-87}
 2014-08-21 16:32:20 INFO MQTTSubscriber:200 -
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 2014-08-21 16:32:20 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:32:21 EEST
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 2014-08-21 16:32:20 INFO MQTTSubscriber:200 -
 {"distance":"middle","imsi":"286034070385186","fapId":"26849126200390"}
 2014-08-21 16:32:20 INFO MQTTSubscriber:164 - {"DATE":"Thu Aug 21 16:32:23 EEST
 2014","IMSI":"286034070385186","RSSI":-79}
 2014-08-21 16:32:20 INFO MQTTSubscriber:200 -
 {"distance":"middle","imsi":"286034070385186","fapId":"26849126200390"}
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 2014-08-21 16:32:21 INFO MQTTSubscriber:200 -
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 2014-08-21 16:32:23 INFO MQTTSubscriber:200 -
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 2014-08-21 16:32:31 INFO MQTTSubscriber:164 -
 {"fapMode":"NONE","imsi":"286039000164330","date":"Thu Aug 21 16:32:29 EEST
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 2014-08-21 16:32:39 INFO BorderListener:57 -
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 2014-08-21 16:32:41 INFO BorderListener:57 -
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2014-08-21 16:32:42 INFO MQTTSubscriber:164 -
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2014-08-21 16:32:46 INFO BorderListener:57 -
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2014-08-21 16:32:48 INFO BorderListener:57 -
{"distance":"border","imsi":"286039000164330","fapId":"26849126200390"}
2014-08-21 16:32:49 INFO MQTTSubscriber:164 -
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2014","fapId":"26943818200082"}
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2014-08-21 16:33:05 INFO BorderListener:57 -
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{ "distance": "border", "imsi": "286039000164330", "fapId": "26943818200082" }
2014-08-21 16:33:09 INFO BorderListener:57 -
{ "distance": "border", "imsi": "286034070385186", "fapId": "26943818200082" }
2014-08-21 16:33:10 INFO BorderListener:57 -
{ "distance": "border", "imsi": "286039000164330", "fapId": "26943818200082" }
2014-08-21 16:38:21 INFO MQTTSubscriber:164 -
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2014", "fapId": "26849126200390" }
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2014-08-21 16:38:25 INFO BorderListener:57 -
{ "distance": "border", "imsi": "286039000164330", "fapId": "26849126200390" }
2014-08-21 16:38:27 INFO BorderListener:57 -
{ "distance": "border", "imsi": "286039000164330", "fapId": "26849126200390" }
2014-08-21 16:38:29 INFO BorderListener:57 -
{ "distance": "border", "imsi": "286039000164330", "fapId": "26849126200390" }
2014-08-21 16:38:31 INFO BorderListener:57 -
{ "distance": "border", "imsi": "286039000164330", "fapId": "26849126200390" }
2014-08-21 16:38:33 INFO BorderListener:57 -
{ "distance": "border", "imsi": "286039000164330", "fapId": "26849126200390" }
2014-08-21 16:38:35 INFO BorderListener:57 -
{ "distance": "border", "imsi": "286039000164330", "fapId": "26849126200390" }
2014-08-21 16:38:37 INFO BorderListener:57 -
{ "distance": "border", "imsi": "286039000164330", "fapId": "26849126200390" }
2014-08-21 16:38:39 INFO BorderListener:57 -
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2014-08-21 16:38:41 INFO BorderListener:57 -
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2014-08-21 16:39:35 INFO BorderListener:57 -
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2014-08-21 16:39:39 INFO BorderListener:57 -
 {"distance":"border","imsi":"286034070385186","fapId":"26849126200390"}
 2014-08-21 16:39:41 INFO BorderListener:57 -
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 2014-08-21 16:39:43 INFO BorderListener:57 -
 {"distance":"border","imsi":"286034070385186","fapId":"26849126200390"}
 2014-08-21 16:39:45 INFO BorderListener:57 -
 {"distance":"border","imsi":"286034070385186","fapId":"26849126200390"}
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 {"distance":"border","imsi":"286034070385186","fapId":"26849126200373"}
 2014-08-21 16:41:53 INFO BorderListener:57 -
 {"distance":"border","imsi":"286034070385186","fapId":"26849126200373"}
 2014-08-21 16:42:15 INFO MQTTSubscriber:164 -
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 {"distance":"border","imsi":"286034070385186","fapId":"26849126200119"}

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2014-08-21 16:42:23 INFO BorderListener:57 -
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2014-08-21 16:42:25 INFO MQTTSubscriber:164 -
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{ "distance": "border", "imsi": "286034070385186", "fapId": "26849126200373" }
2014-08-21 16:42:29 INFO BorderListener:57 -
{ "distance": "border", "imsi": "286034070385186", "fapId": "26849126200373" }
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2014-08-21 16:42:41 INFO BorderListener:57 -
{ "distance": "border", "imsi": "286034070385186", "fapId": "26849126200373" }
2014-08-21 16:42:43 INFO BorderListener:57 -
{ "distance": "border", "imsi": "286034070385186", "fapId": "26849126200373" }
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