# AN INDOOR POSITIONING SYSTEM MODEL USING Wi-Fi NETWORK

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# Declaration

We, hereby declare that this thesis is based on results we have found ourselves. Materials of work from researchers conducted by others are mentioned in references.

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# ABSTRACT

Traditional outdoor positioning systems such as GPS, fails to locate indoor places and thus Indoor Positioning Systems (IPS) have a lot of importance. These systems are integral in providing Location Based Services (LBS) which can ease the daily life with useful information about one's current surroundings. Local network infrastructure such as Wi-Fi which is already available in places such as hospitals, shopping malls and educational institutions, can be used to locate a place in the indoor environment using the properties of the Wi-Fi signal. Hence we propose a model for indoor positioning system which implements a trilateration method using the amount of signal loss of at least three Access Points (AP) to find the position of a target. Also, we use techniques to stabilize the signal collection and compare the data with historical data to provide considerably accurate positional information. This system consists of very few components and the deployment criteria are comparatively simpler, so it can be easily deployed. Also, the use of low cost equipment such as Wi-Fi routers makes sure that the system is economically feasible.

# Acknowledgement

We would like to express our gratitude to the Almighty who gave us the opportunity, determination, strength and intelligence to complete our work.

A very big and humble thank you goes to our supervisor Dr. Amitabha Chakrabarty who has constantly believed in us and has been there for us through thick and thin of the thesis and continuously pushed us to complete our work in time. We are fortunate and grateful to be able to work under his supervision.

Lastly, our gratitude goes to the faculty members of the Department of Computer Science and Engineering, BRAC University from whom we gained the knowledge, appreciation and help for the completion of our thesis work.

# Table of Contents

# List of Figures

# Chapter 1: INTRODUCTION

In introduction we will discuss about the indoor positioning system and the various possibilities for it to be used in different location based applications. We also talked about the infrastructures available and gave an overview of what features we have in our proposed system. In later parts we have described about our implementation in a broader way.

## 1.1 Introduction

In the last few years, the world has seen surge in location based services. With this surge, the need for efficient positioning applications have increased substantially[1][2][3]. The industry as well as the academicians are continuously striving to develop systems that can address the growing demand. Even though there has been numerous approaches towards solving the indoor positioning problem, there is currently no solution available which can meet the desired accuracy level while keeping the system under required cost [1]. Indoor positioning systems that run on mobile devices are critical in providing context aware services which include providing service availability information to customers in shopping malls, monitoring people inside assisted living facilities, tracking assets in warehouses etc. [2, 3].The technologies that are being used to develop these solutions also vary in their characteristics such as mobility, ability to be modified and accuracy. They can also be classified based on their trade off for accuracy with economy. Among the technologies that are being used for indoor positioning are RFID, Wi-Fi networks, Bluetooth, Ultrasonic rays etc. Also, they differ in positioning and ranging techniques such as Time of Arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AOA), Received

[1] http://www.businessinsider.com/social-media-boost-location-based-data-2013-9
[2] https://rashidfaridi.com/2010/12/29/boom-for-location-based-service-in-china/
[3] http://www.brainstormmag.co.za/trends/10837-lbs-market-set-to-boom

Signal Strength Indicator (RSSI) and Triangulation, Trilateration, Scene Analysis [9, 10, and 8].

There has been several comparative analysis of existing systems and frameworks for indoor positioning solutions. They consider the efficiency, accuracy, economy user friendliness and scalability of these solutions [3]. While TOA, TDOA and AOA techniques suffer from path reflection and excessive use of processing resources, they are quite good in pinpointing locations when the target area is not overstretched. RSS based technique can be accurate to a certain extent but the signal loss and deflection can make positioning tough to achieve. If this system is implemented using a combinatory approach of RSS based technique with some help from the scene analysis technique, it can reach the accuracy level that would be sufficient to support numerous applications using indoor positioning [2].

This system proposes to use Wi-Fi network properties due to the fact that wireless local networks are easier to establish in public places and are becoming less and less costly. Also, the network can handle traffic for data as well as function as base stations for the system. However, they do have some drawbacks such as the band frequency of common routers is 2.4 GHz, which is similar to the frequency used by different home and office appliances. This causes noise in the propagating signal and contaminates the collected data.

## 1.2 Objective

Creating an indoor positioning system through a minimalistic approach. Prepare a system which is easier to deploy and can be integrated with already available infrastructure. Indoor positioning systems need to be light and dynamic enough to run using minimum infrastructure while maintaining accuracy.

Laying the ground works for indoor location based service providing applications with the model. IPS can help make it easier for customers and service users to roam in unknown environments.

Bringing down the overall cost of an indoor positioning system. An affordable IPS can be set up by organizations to help boost their productivity and increase their business.

Minimize the number of Wi-Fi access points at any given indoor area and integrate the existing ones in the system. Fewer Access points mean less cost in establishing the whole system.

Implement the solution in such a way that every other business can integrate and adopt with the system. Integration with older infrastructure can lessen the burden on organizations and maximize the chances of them actually being interested in deploying this system.

## 1.3 Motivation

Our main motivation throughout this thesis was to have a contribution in the sector of localization, precisely indoor localization based on network infrastructure. We wanted to implement a solution which can integrate the already available and popular infrastructure such as Wi-Fi access points and its network capabilities that can be reliable enough to provide location related data. The fast paced world of technology has seen a good amount of advancement in this sector and there are yet necessities for easily deployable and integration ready solutions that can function reliably. Our main objective was prepare the best solution with least resources available and design a solution that can stand ample amount of constraints. The possibilities of further uses of this kind of a system can be numerous. This is why we were motivated to undertake this topic for our thesis research.

## 1.4 Thesis Outline

*Chapter 1* is the introduction of thesis. We have discussed our motivation and objectives.

*Chapter 2* is the background study that covers the literature review and all the research work we have done and projected the basic indoor positioning techniques and technologies that are currently being used.

*Chapter 3* is the implementation section where we described components, equations and algorithms that have been used to create the proposed system.

*Chapter 4* is the results of our algorithms projected through graphs and result comparison regarding our indoor positioning system.

*Chapter 5* contains conclusion and discussion about the future aspects of our thesis and research.

# Chapter 2: LITERATURE REVIEW

There has been numerous efforts to address the indoor localization problem. The approaches vary in the techniques, technologies as well as the evaluation procedures. However, the prominent works on this issues have stuck with very basic ideas and technologies in their effort to solve this problem. This has been done so that the system or solution they design can be deployed easily and can be integrated with existing technologies.

## 2.1 Positioning Techniques

There are three techniques which are popular in implementing indoor localization systems. They are discussed below:

### 2.1.1 *Triangulation*

Triangulation uses the geometric properties of a triangle to estimate a location. It has two parts which are lateration and angulation. Lateration refers to the estimation of a location based on calculating distances of a point from multiple reference points. Angulation locates an object by computing angles relative to multiple reference points [3]. This technique uses the angle of arrival of at least two reference points and their corresponding lines to find the intersection point which defines the estimated position of the object/person. [4, 5]

### 2.1.2 *Trilateration*

In trilateration, the position of an object is estimated by evaluating its distance from at least three reference points. [2] Trilateration based positioning method is a well-studied method which estimates an object's position without considering the angle like triangulation instead it calculates RSSI values from at least three Wi-Fi APs station with known set up co-ordinates. The more

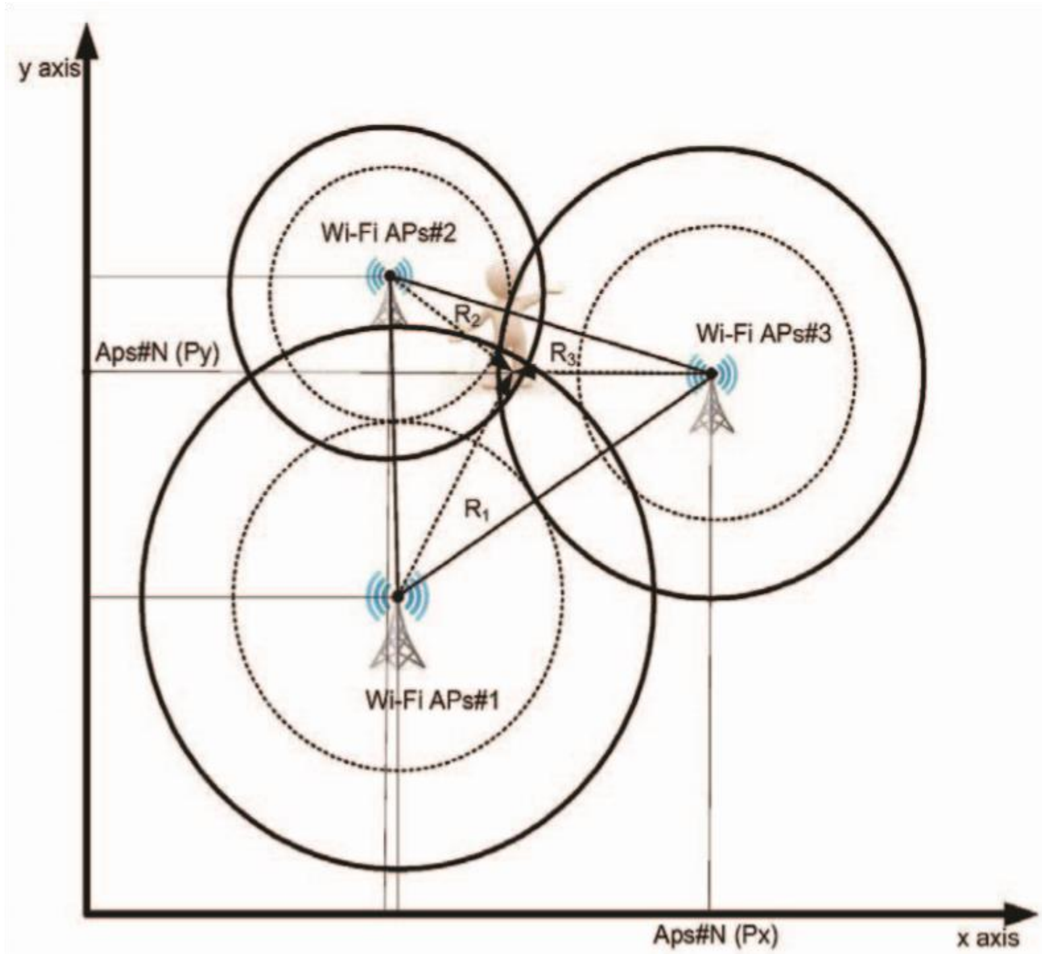


Figure 1: The Wi-Fi trilateration Technique

access point increases the accuracy more. The signal strength and distance are given by ability to approximate the radian, after that a circle with the radian can be drawn around each Wi-Fi transmitter. A minimum of n+1 Wi-Fi APs stations are needed to provide a position in n-number of dimensions.

### 2.1.3 *Scene Analysis*

This positioning technique uses the system of analyzing an observed scene. The scene can vary based on the use of it in certain contexts. For example, it can be any type of signal, from a sensor or from the environment itself which can be used to differentiate among locations. While using this approach, the position of the device can be determined from the similarity between scenes [5]. Scene analysis is a principle where fingerprinting is effectively used. Fingerprint is the unique characteristic or collection of characteristics of a scene. It implements comparing the collected characteristic with the already stored characteristics in the database. This technique has two phases. They are:

- Training Phase (Offline Phase)
- Tracking Phase (Online Phase)

In the training phase, signal strength from Aps are collected at pre-identified locations, which are called Reference points (RPs). This operation builds the fingerprint database which will be used in the tracking phase. Since the mobile user's position will be determined from these RPs in database, they should be evenly and homogenously distributed.

In the tracking phase, mobile user's real time RSS data for surrounding APs are compared with RPs dataset using probabilistic and deterministic algorithms to find a match for location [4].

### 2.1.4 Proximity

The proximity principle is mostly used in models which are heavily based on radio frequency. In this principle, a grid of antenna based in fixed locations are used. When a person carrying a device (mobile station) is recognized, the antenna which is closest to the device is considered to be calculating the person's location. If more that on antenna detects the mobile station, the antenna which receives the strongest signal is considered to be calculating the mobile station's location [4, 26].

## 2.2 Range Measurement Techniques

There are a few range measurement techniques that are used to evaluate the distance of an object or point in a plane. Some of the more popular methods are discussed briefly below:

### 2.2.1 *TOA (Time of Arrival)*

The propagation time of the signal from the target to the reference point is proportionate to the distance between them [4]. To use TOA technique, one needs to have at least three reference points to triangulate and find a point in 2D plane. The drawbacks of the system is that the transmitters needs to be synchronized [2,4,5] and a timestamp [3] has to be labeled in transmitting signal in order to how much distance it has travel.

### 2.2.2 *TDOA (Time Difference of Arrival)*

TDOA determines the relative location of a transmitter by using the difference in time the signal reaches multiple receivers. Three receiving units give two TDOAs and the intersection point defines the location of the target [4]. This ranging technique also suffers the multipath problem [4, 5].

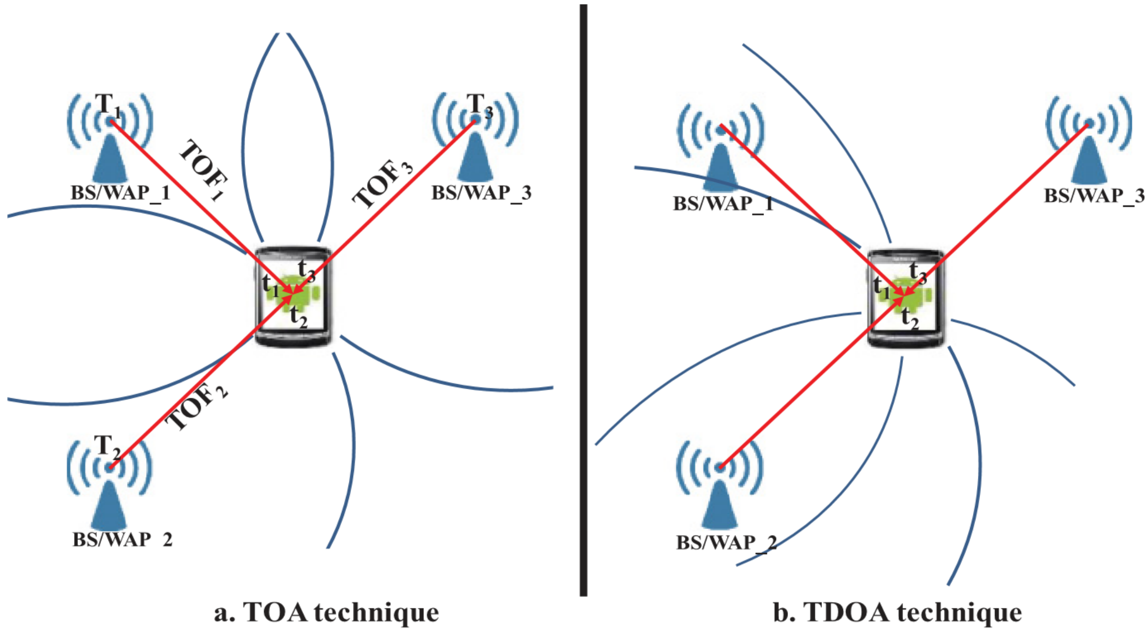


Figure 2: Comparison between TOA and TDOA Technique [22]

### 2.2.3 *AOA (Angle of Arrival)*

AOA uses the intersection of several pairs of angle direction lines formed by the circular radius of base station towards target to locate the desired point in the plane [3]. The location of a target can be calculated when the AOAs of the received signals from the smartphone by two or more Base station/ AP are defined and the distance between two BS/AP is known [6]. However, AOA suffers from shadowing and multipath reflection problems and needs expensive and complex equipment [4].

### 2.2.4 *RSS-Based Method*

The Received Signal Strength Indicator (RSSI) which is characterized by its attenuation during propagation has been used in a number of indoor localization systems. Although RSSI can provide meter-level localization accuracy in simple environments, it suffers from sudden performance degradation in comparatively challenging and complex situations due to multipath fading and temporal dynamics. A large portion of the present reliable

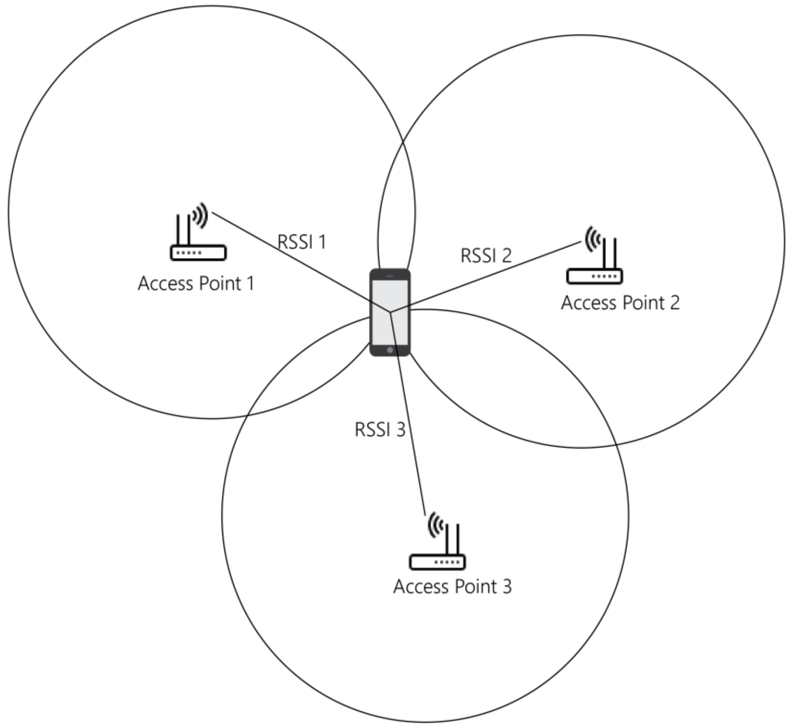


Figure 3: RSSI Based Model

RSSI-based positioning systems still stay at room-level accuracy [7]. The Received Signal Strength or RSS based method uses two different techniques to estimate the range of the target. One of them is pseudo-range measurement which is based on known radio propagation analytic relationship. It uses trilateration to find smartphone locations from the estimated pseudo-ranges between smartphones and multiple base station or access points. The second method is RSS-Fingerprinting which is based on pre-stored RSS values of base stations in a database. Here, offline and online methods are performed to estimate the location of a target. In the offline stage, a radio map is created which is compared with the current data in online stage to determine position [6, 4].

# Chapter 3: PROPOSED SYSTEM AND IMPLEMENTATION

In the following sections we discuss about the proposed system and the implementation process. The section is further divided in equations, system components which have been discussed and explained step by step. These discussion are accompanied with the diagrams which represent the system and its implementation procedure.

## 3.1 Equations used in System

Our system is largely based on two basic equations with regard to the range measurement. They are

- Free Space Path Loss equation [$i$]
- Euclidean equations of intersecting circles [$ii$] which can be solved to find the intersection point of at least three circle and find the coordinates of the target's position.

### *3.1.1 FSPL Equation*

Free Space Path Loss (FSPL) equation is one of the core equations that have been used to implement this system. The usual value which is derived from this equation is that of the amount of signal loss for a signal propagating through a medium which is traditionally air. This equation can me modified to fit our purpose of gaining the distance of the receiver and the transmitter through using the known loss of signal and other known values. They include constants such as the speed of light (C), Pi ($\pi$), known frequency value of the transmitter (f).

$$FSPL = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}(\frac{4\pi}{c}) \ \ldots\ldots\ldots (i)$$

If we consider the distance (d) in meters, frequency (f) in MHz and signal loss (FSPL) in dB, we can derive the following equation with a constant in it:

$$FSPL = 20\log_{10}(d) + 20\log_{10}(f) - 27.55$$

The above equation can be used to calculate the distance (d) from a transmitting device to receiver based on the propagation loss of the signal. The distance (d) is then used as the radius (r) of the following equations [2] for different AP's.

### *3.1.2 Euclidean Equation*

$$\begin{Bmatrix} (x_1 - x_0)^2 + (y_1 - y_0)^2 = {r_1}^2 \\ (x_2 - x_0)^2 + (y_2 - y_0)^2 = {r_2}^2 \\ (x_3 - x_0)^2 + (y_3 - y_0)^2 = {r_3}^2 \end{Bmatrix} \ldots\ldots\ldots (ii)$$

The above equations represent three circles which are created by the three APs and their radius is also known. When we solve these equations for known values which are the centers of the circle and the radius, we can find the coordinate of the target which is $(x_0 , y_o)$ which is the intersection point on all three circles' circumference

## 3.2 System Components

This system works with 3 key components as mentioned earlier. According to that the system works with 3 major area. The components are discussed in the below sections.

### *3.2.1 Server End*

Whole system needs to have a server to stack up all the necessary data. It includes the floor map, Router/ Access Points coordinates, coordinates of the lifts and stairs, and a database of RSSI vs. distance table. In the Floor map the routers coordinates must be pin pointed with their labels. For any kind of modification or update for the map and router a system administrator has to be there to make the change. System administrator can also has the access to add new router location or remove existing location if situation arises. All the modification will be updated to the database and ready for use as soon as the admin approves the update. Depending on the floor plan administrator can also update the access status of lifts or stairs.

### *3.2.2 Access Point /Router End*

All the routers will have their very own unique ID / Name. It will also contain the floor number and the sector name in which it resides. AP should be placed in such a way that the mobile device will always be receiving sufficient RSSI from at least 3 routers. All AP will be connected with the same network so that it can work as a seamless RSSI filled area.

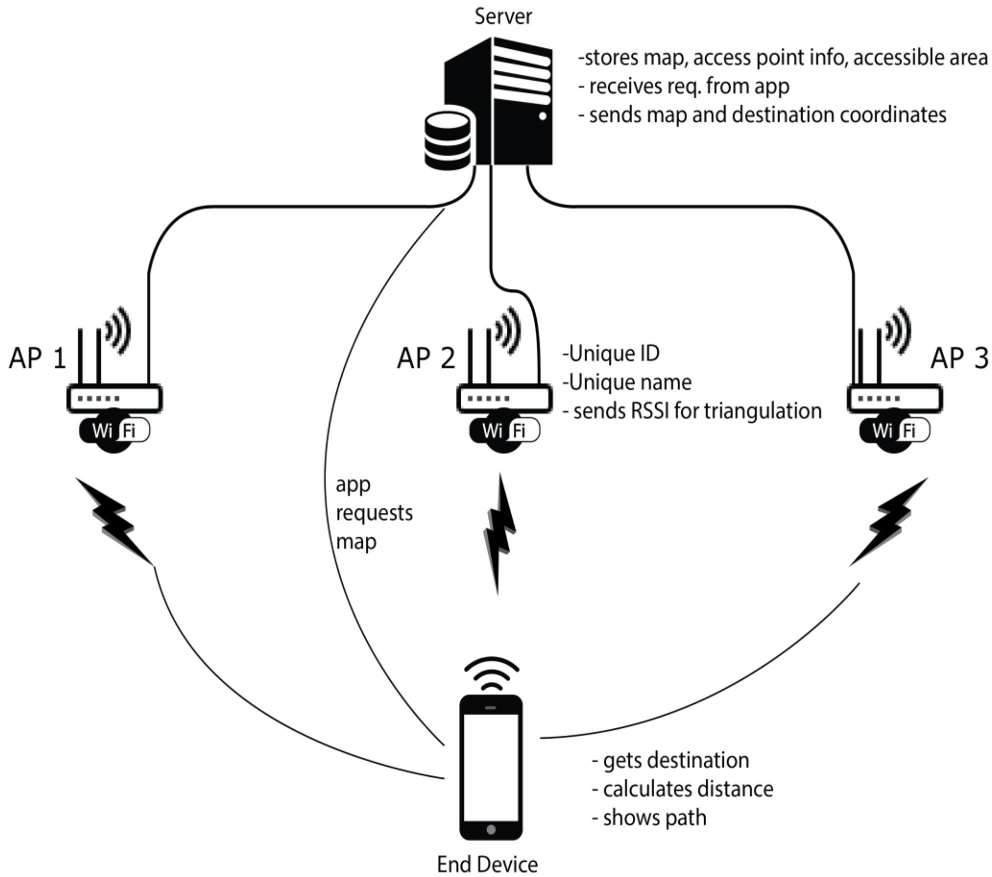


Figure 4: System Diagram

### *3.2.3 Client End*

Client need to use a specific application in their mobile. The app will be available for all in the mobile app market. When a user comes into the place, where the system is implemented, he will get a popup in the app to get connected with the systems network. To use the Indoor Positioning System in his app user must connect with the network. If connected, the app will send a request for the floor map corresponding to the AP. Due to the unique naming format of the APs server will easily be able to determine the which floor map needs to be pushed to the app. In the app, after getting the map from the server, user's location will be shown on the map. This location will be calculated via trilateration method using the RSSI values of nearest AP (at least three). Server will also send a list of floor and some details of each with it. User will then be able to choose his destination. If the destination is in the same floor user will be able to put a marker and get the shortest path instantly. If not in the same floor app will direct the user to the closest lift/stairs/escalators/or any other means available to change the user's current position to the destined floor. The map will be instantly updated when user reaches the destined floor. Both destination coordinates and current coordinates will be stored in the devices database for faster and more reliable distance and position measurement. App will also show the distance covered in numeric form as user approaches destination. A notification will be given to the user while destination is reached.

## 3.2.4 Workflow Diagram

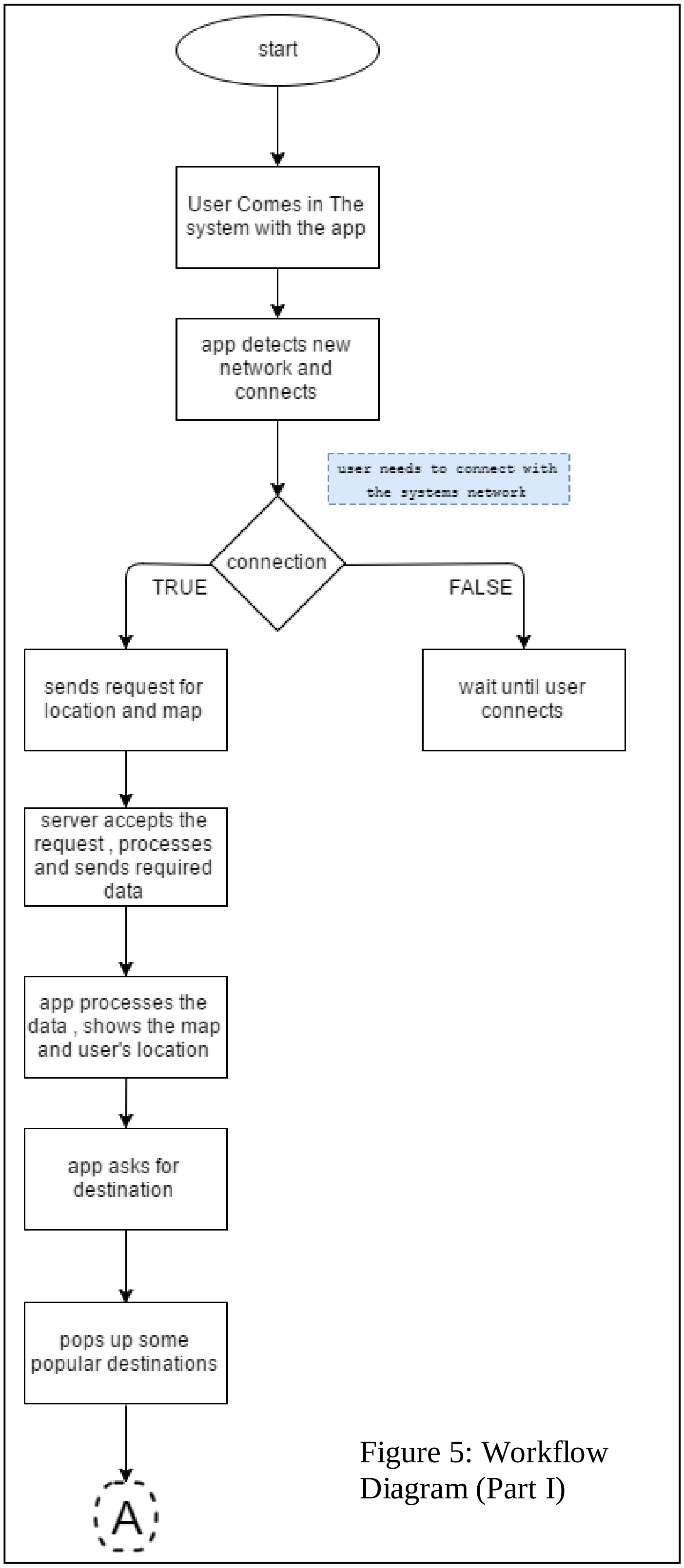


Figure 5: Workflow Diagram (Part I)

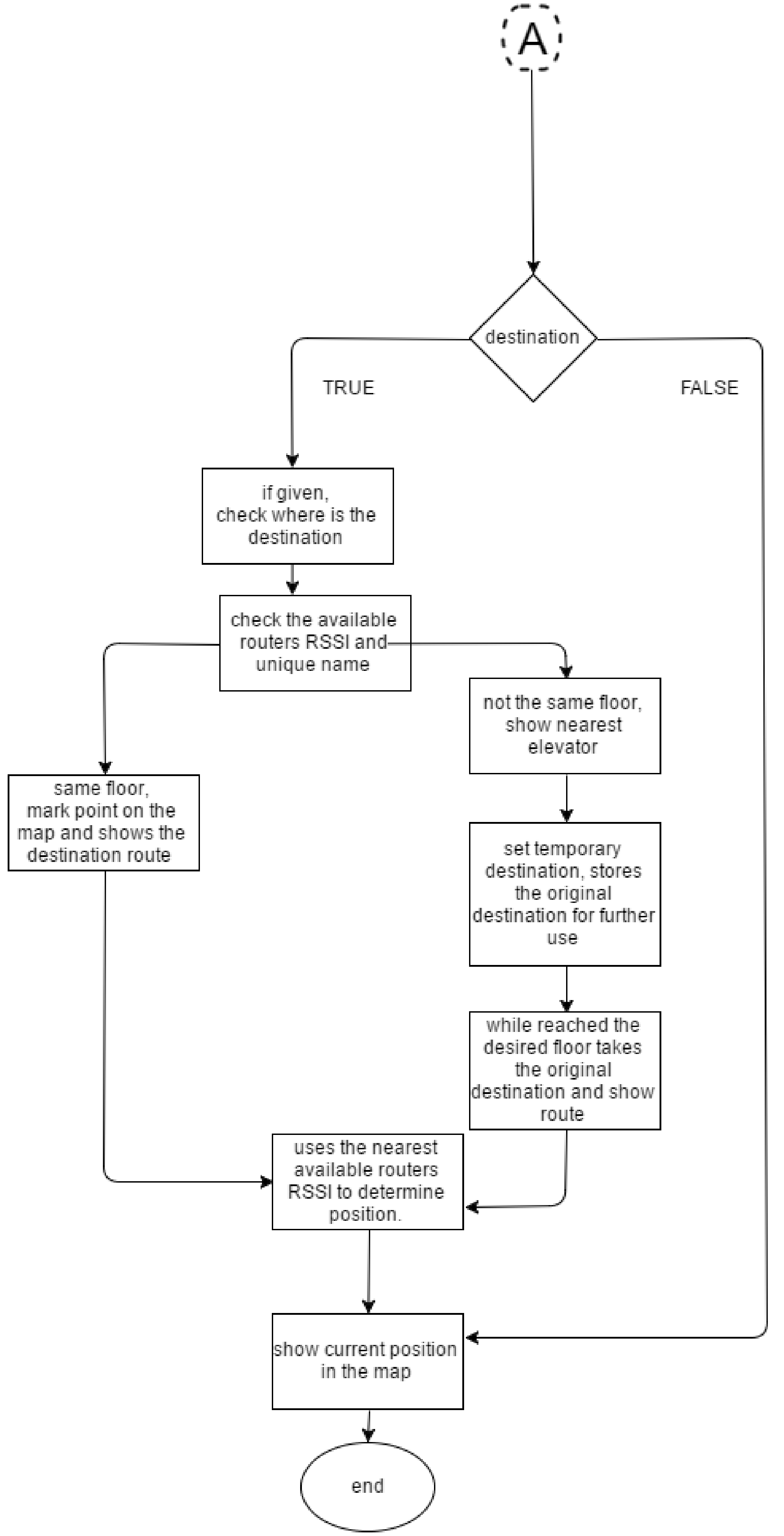


Figure 5: Workflow Diagram (Part II)

# Chapter 4: RESULT ANALYSIS

## 4.1 Experimental Setup

While the system was still in analysis phase, an experimental setup the range measurement technique was performed. In this experiment, three routers were placed in a rectangular area and the area was divided in grids of squares which had edges of 0.5m. The intersecting points were marked and the RSSI was collected on those points. After that the distances of those marked points from all the routers were calculated and tabulated with their corresponding RSSI values that was collected. The path loss was calculated for each point and then it was plotted on the graph against the distance. Hence it provided the distance vs. path loss graph.

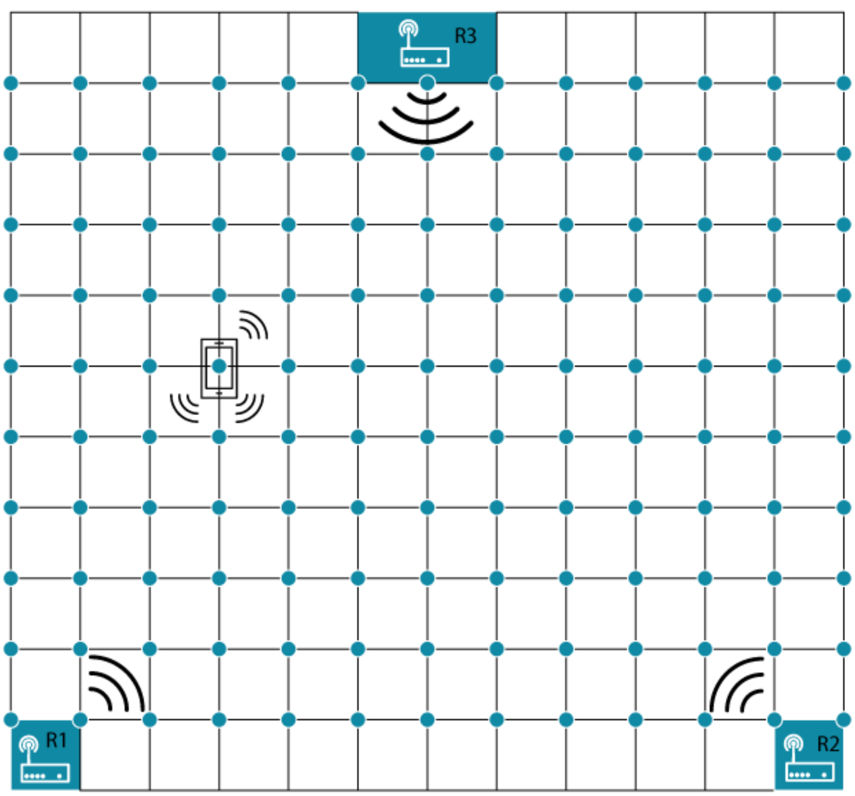


Figure 6 : Experimental Grid Setup

### *4.1.1 Experiment Grid*

When the graph was analyzed, it was evident that the path loss values corresponding to the distances were not the same as the ideal values. However, the pattern of both the lines were quite similar. So, it assured the viability of this ranging technique. The reasons as to why the faulty values occurred is that the collected RSSI values were corrupted due to fluctuation in signal and the barrier of human body.

### *4.1.2 Graphs: Derived from Grid*

*<u>Result for Windows device:</u>*

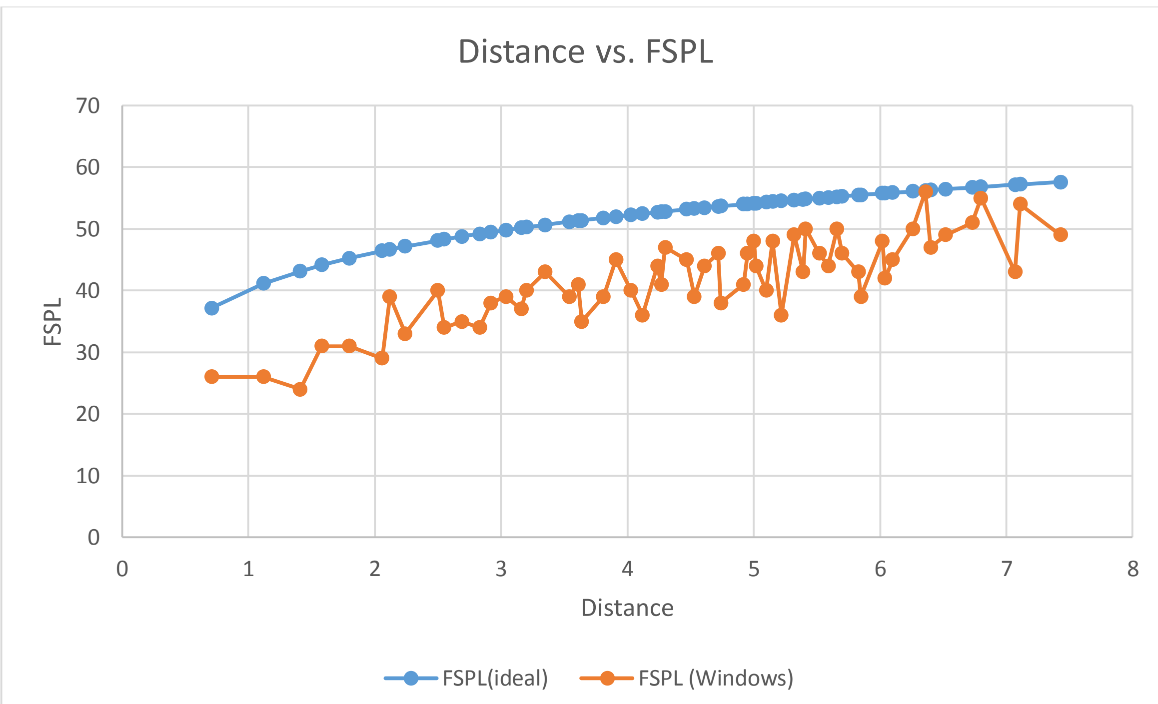


Figure 7: Distance vs. FSPL (Windows)

The graph above (Figure 4) represents the relationship between the amount of signal loss while propagating through a medium and the distance covered by the signal for a windows OS based Laptop device.

*<u>Result for Android device:</u>*

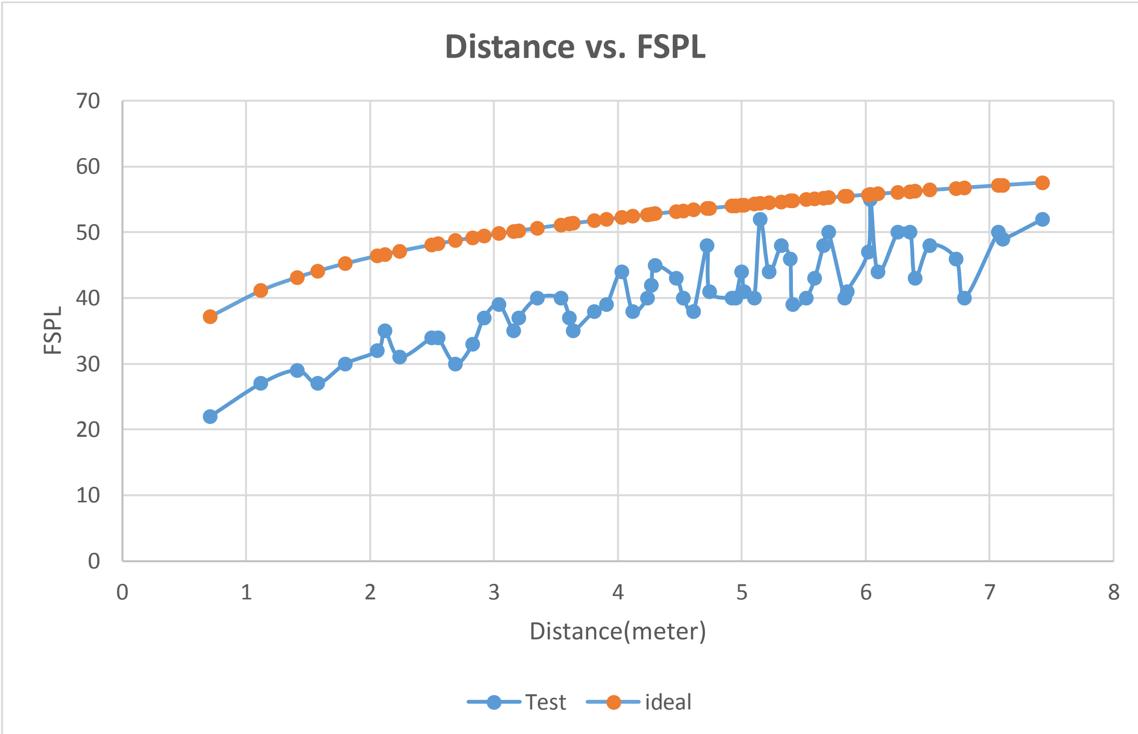


Figure 8: Distance vs. FSPL (Mobile)

This graph represents the relationship between the amount of signal loss while propagating through a medium and the distance covered by the signal for an Android OS based mobile device.

What is noticeable in both the graph is that they produce a similar pattern though the Wi-Fi module they use are quite different and processed in two unique ways. For a better observation two graph are superimposed onto one another.

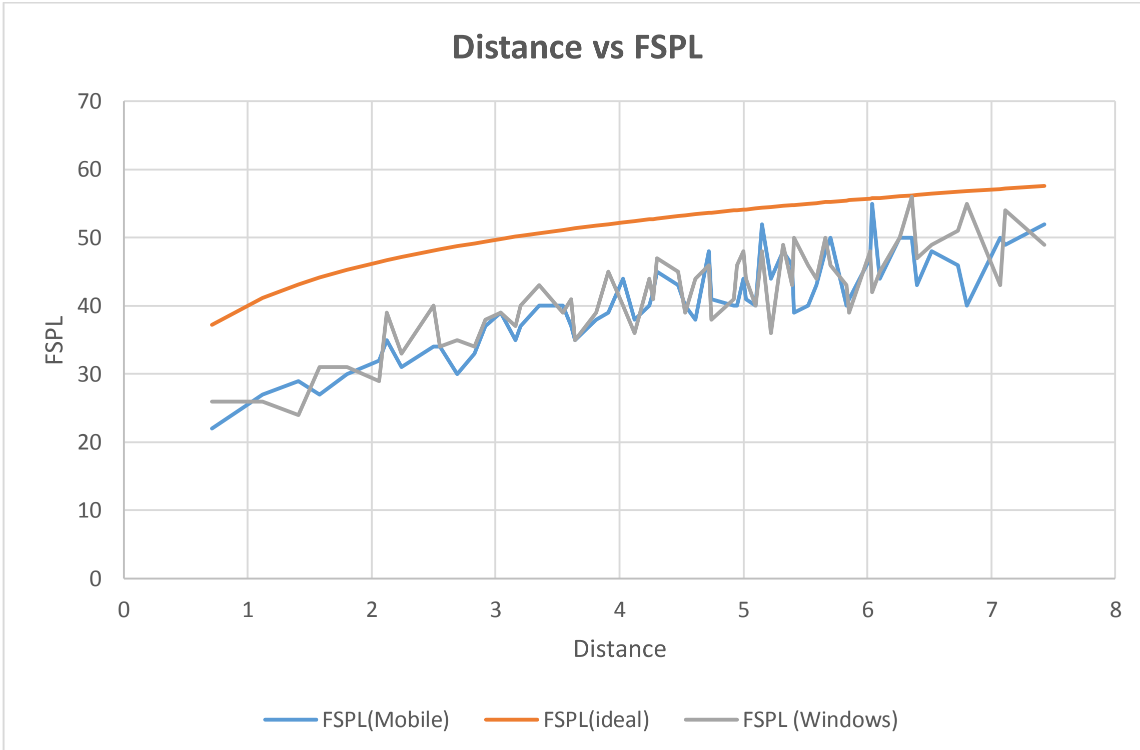


Figure 9: Distance vs. FSPL Graph (Combined)

To reduce this error due to the apparent volatile nature of signals, we propose to use successive approximation and other techniques which can significant increase the reliability of signal and in turn provide quite accurate positioning estimates. Also, implementing a range based survey techniques of recent values to predict possible false/ corrupt signals can decrease the chances of miscalculation and make the system even better.

At every nearest router the app will get necessary updates regarding the user's position and shortest path. It will help the app to calculate estimated time and distance to the destination with less calculation and thus consuming lesser energy for signal processing.

RSSI values can vary based on the barriers on the path and also the orientation of the user's device. To minimize erroneous RSSI values, Successive Approximation will be implemented. In this approach the end device will collect after a certain amount of interval. This will make sure that the RSSI values are stable and more reliable for calculation.

As the end device possibly will be on the move all the time it is really important to keep the map updated as the device moves. By varying the refresh rate of the signal processing in the app we can reduce the chance of miscalculating user's actual position and distance from the destination. To reduce the energy consumption of the device, processing rate of the RSSI values would need to be at an optimum level. At this rate the device will be able to maintain a seamless pathway of exploration without the users having to stop for updating the map.

## 4.2 System Application

The following section represents the application that was developed to implement the system. The section contains screenshot of the application, the graphs derived to show the percentage of error and the important code snippets that was written to create the application.

### 4.2.1 Application Screenshots

The following screenshots represent several phases of the application in use. The image in Figure10 (a) shows the homepage of the application when a user initiates the application. This shows the Wi-Fi access points avail available and also has a button that can fetch the floor map when pushed. The image in Figure 10(b) represents the positioning on the map for a user. The map consists of the places where a user might want to go and also the obstacles. The red dot on the map represents the destination that user can choose and the grey dot represents the user himself.

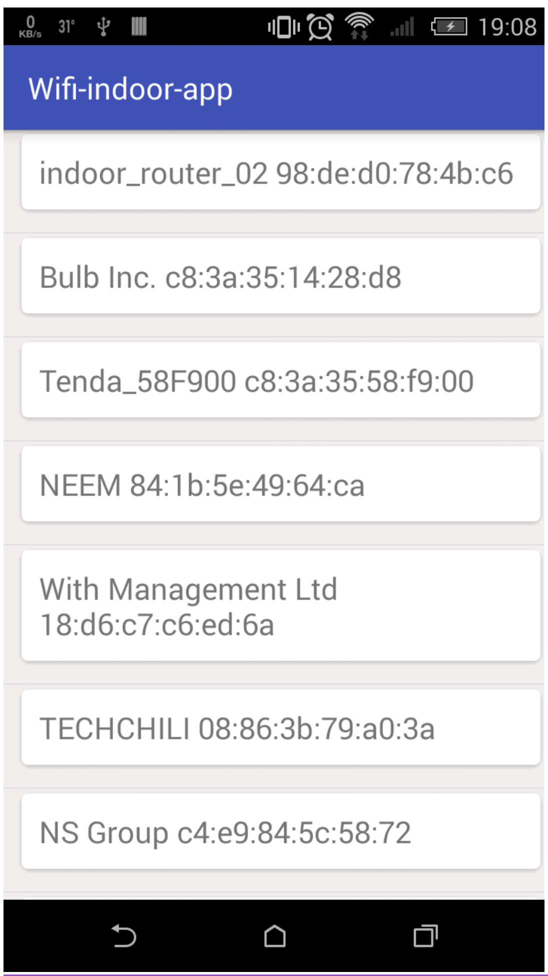


Figure 10(a): Application Home Page

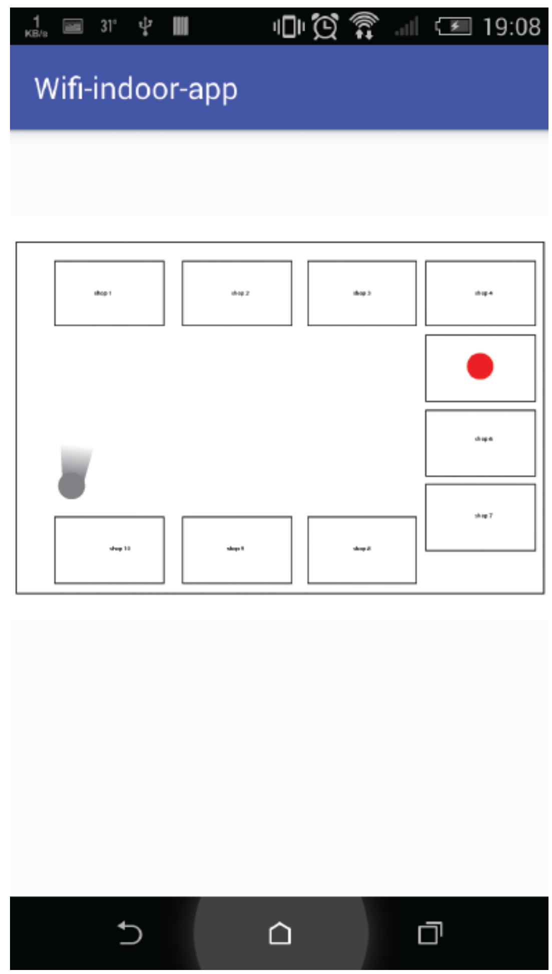


Figure 10(b): Fetched Map and Positioning in action

## 4.2.2 Code Snippet of map receiver and map fetching via an open network

```
wifi = (WifiManager)  getApplicationContext().getSystemService(Con-
text.WIFI_SERVICE);
        map = (ImageView) findViewById(R.id.map);

        ncreceiver = new NetworkChangeReceiver(); // Create the receiver
        registerReceiver(ncreceiver, new IntentFilter("android.net.conn.CON-
NECTIVITY_CHANGE")); // Register receiver
        myHandler = new Handler() {
            @Override
            public void handleMessage(Message msg) {...}

download(image_url, myHandler2);
```

Figure 11(a): Map downloader

```
List<WifiConfiguration> list = wifi.getConfiguredNetworks();
                for( WifiConfiguration i : list ) {
                    if(i.SSID != null && i.SSID.equals("\""
+ networkSSID + "\""))
                   {
                        wifi.disconnect();
                        wifi.enableNetwork(i.networkId, true);
                        wifi.reconnect();
                        break;
                    }
                }
```

Figure 11(b): Connection switching for Map

```
wifi.startScan();
        WifiScanReceiver wifiReciever = new WifiScanReceiver();
        registerReceiver(wifiReciever, new
IntentFilter(WifiManager.SCAN_RESULTS_AVAILABLE_ACTION));
        List <ScanResult> losr = wifi.getScanResults();

        wifi_result_adapter wra = new wifi_result_adapter( this
,R.layout.wifi_results_layout_unit);

        for (int i =0; i < losr.size(); i++){

            wra.add(losr.get(i));
        }
```

Figure 11(c): Available Wifi Connection

```
private String saveToInternalStorage(Bitmap bitmapImage, String fileName) {
        ContextWrapper cw = new ContextWrapper(getApplicationContext());
        // path to /data/data/yourapp/app_data/imageDir
        File directory = cw.getDir("imageDir", Context.MODE_PRIVATE);
        // Create imageDir
        File mypath = new File(directory, fileName);

        FileOutputStream fos = null;
        try {
            fos = new FileOutputStream(mypath);
            // Use the compress method on the BitMap object to write
image to the OutputStream
            bitmapImage.compress(Bitmap.CompressFormat.PNG, 100, fos);
        } catch (Exception e) {
            e.printStackTrace();
        } finally {
            try {
                fos.close();
            } catch (IOException e) {
                e.printStackTrace();
            }
        }
        return directory.getAbsolutePath();
    }
```

Figure 11(d): Destination and current position marker

### 4.2.3 Error Comparison Graphs

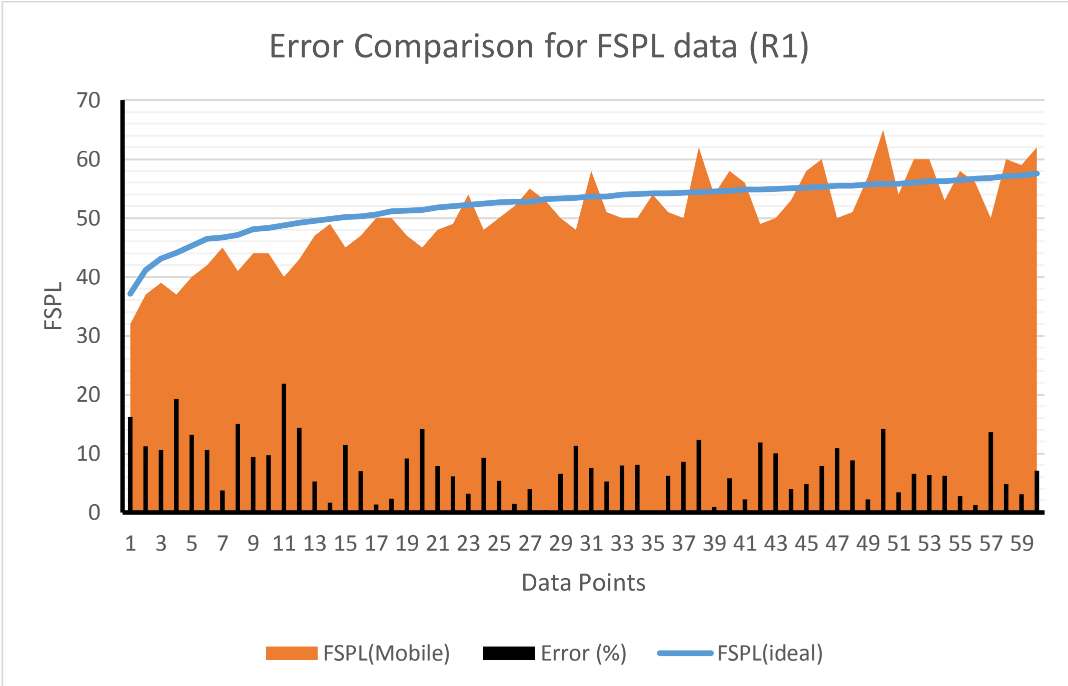


Figure 12(a): Error Comparison for FSPL Data (R1)

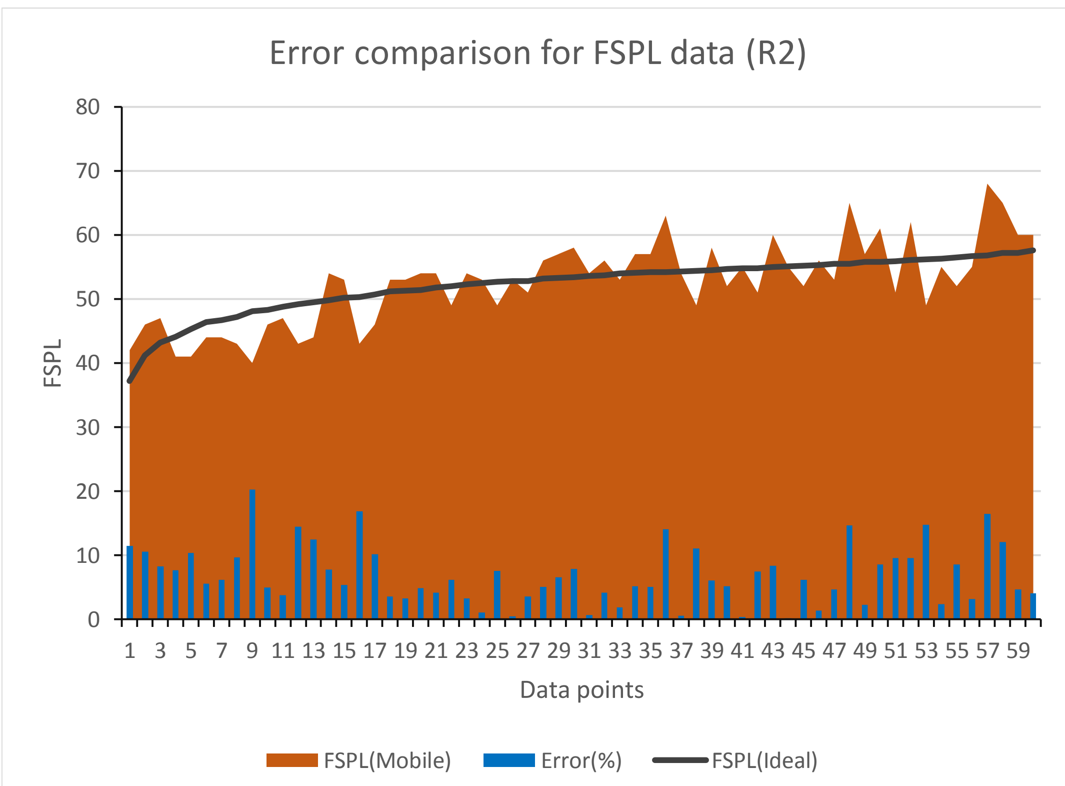


Figure 12(b): Error Comparison for FSPL Data (R2)

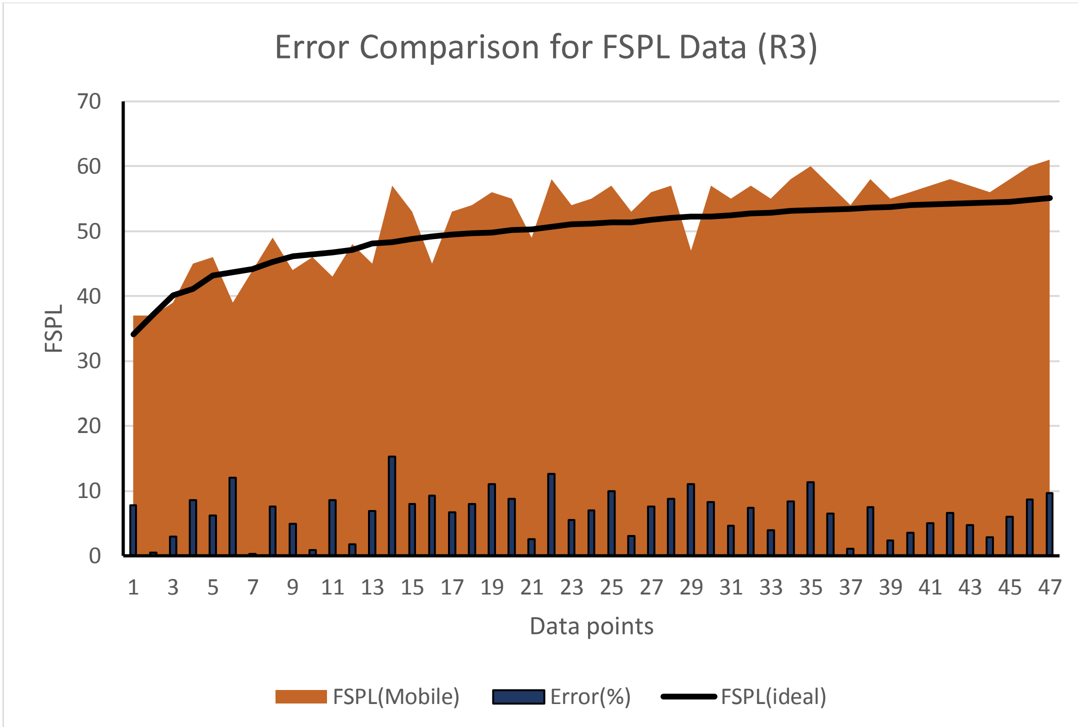


Figure 12(c): Error Comparison for FSPL Data (R3)

The above graphs represent the amount of error that was specifically calculated for each data point. The smooth curve represents the ideal values and the rather jagged curve represents the values that were found through using the proposed system. As one can see, at some points, the smooth curve and jagged curve have intersected. At these points the error ration is very low or almost non-existent. In other points, there are some level of error which is quite expected. If we analyze the pattern of error, we would see that the closer the data points were, meaning the less the distance of receiver from the transmitter, the error is somewhat low, since a small fluctuation or bad reading would mean larger ratios caused by low values to be divided with. But in further distances, the error ratio is rather small, but after a certain period, that also starts to become high.

# Chapter 5: CONCLUSION

## 5.1 Discussion

The proposed system can be used to implement a location based application which provides customized services based on your current location in an indoor environment. Places such as hospitals, airports, shopping malls, educational institutions, fairs and exhibitions can use this system to direct their users and visitors to their respective destinations and also attract potential customers. This proposed system here is not free of drawbacks. While the components are cheap and easily available they are prone to corrupt signals due to barriers and noise due to signals from other devices. However the primary goal of building a system which is easily deployable and considerably accurate within indoor environment has been achieved to a certain degree.

## 5.2 Future Challenges

The future iteration of this paper will include a more robust approach that would increase the precision and reliability of this system to a notable extent. Future challenges for this proposed model include the integration of a module which can alert the users of its application about the presence of nearby services or establishments whenever it is in the proximity of it. Also, building the application using this model on different platform (Windows, Apple) would be on the priority list as well. While there are simple techniques used to clear out noise and corruption of signal, there are more complex procedures available which might lessen the chances of bad data for the system. Integrating such procedures to increase the reliability of the system would also be a challenge.

# Reference


[1] Dimitrios Lymberopoulos, Jie Liu, Xue Yang, Romit Roy Choudhury, Vlado Handziski, and Souvik Sen. 2015. A realistic evaluation and comparison of indoor location technologies: experiences and lessons learned. In Proceedings of the 14th International Conference on Information Processing in Sensor Networks (IPSN '15). ACM, New York, NY, USA, 178-189.

[2] M. T. Rashid, M. S. S. Chowdhury and M. F. Nawal, "Composite indoor localization and positioning system based on Wi-Fi repeater technology," 2016 IEEE Region 10 Conference (TENCON), Singapore, 2016, pp. 2130-2133.

[3] H. Liu, H. Darabi, P. Banerjee and J. Liu, "Survey of Wireless Indoor Positioning Techniques and Systems," in IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), vol. 37, no. 6, pp. 1067-1080, Nov. 2007.

[4] Adalja Disha, M. A Comparative Analysis on Indoor Positioning Techniques and Systems. Int. J. Eng. Res.Appl. (IJERA) 2013, 3, 1790–1796

[5] O. Costilla-Reyes, "Dynamic Wi-Fi fingerprinting indoor positioning system," 2014 International Conference on Indoor Positioning and Indoor Navigation (IPIN), Busan, 2014, pp. 271-280.

[6] Halgurd S. Maghdid, Ihsan Alshahib Lami, Kayhan Zrar Ghafoor, and Jaime Lloret. 2016. Seamless Outdoors-Indoors Localization Solutions on Smartphones: Implementation and Challenges. ACM Comput. Surv. 48, 4, Article 53 (February 2016), 34 pages.

[7] Zheng Yang, Zimu Zhou, and Yunhao Liu. 2013. From RSSI to CSI: Indoor localization via channel response. ACM Comput. Surv. 46, 2, Article 25 (December 2013), 32 pages.

[8] Baniukevic, C. S. Jensen and H. Lu, "Hybrid Indoor Positioning with Wi-Fi and Bluetooth: Architecture and Performance," 2013 IEEE 14th International Conference on Mobile Data Management, Milan, 2013, pp. 207-216.

[9] Scott Bell, Ting Wei, Wook Rak Jung, and Alyssa Scott. 2011. A conceptual model of trust for indoor positioning systems. In Proceedings of the 3rd ACM SIGSPATIAL International Workshop on Indoor Spatial Awareness (ISA '11). ACM, New York, NY, USA, 7-14.

[10] K. Al Nuaimi and H. Kamel, "A survey of indoor positioning systems and algorithms," 2011 International Conference on Innovations in Information Technology, Abu Dhabi, 2011, pp. 185-190.

[11] P. Sriploy, P. Uthansakul and M. Uthansakul, "Effect of path loss on the distributed beamforming for Wireless Sensor Networks," 2013 10th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, Krabi, 2013, pp. 1-4.

[12] S. S. Saab and Z. S. Nakad, "A Standalone RFID Indoor Positioning System Using Passive Tags," in IEEE Transactions on Industrial Electronics, vol. 58, no. 5, pp. 1961-1970, May 2011.
doi: 10.1109/TIE.2010.2055774

[13] Hakan Koyuncu, Shuang Hua Yang, "A Survey of Indoor Positioning and Object Locating Systems" in IJCSNS International Journal of Computer Science and Network Security, vol. 10 No. 5, pp. 121-128, May 2010.

[14] Wook Rak Jung and Scott Bell. 2013. Quantitative comparison of indoor positioning on different densities of Wi-Fi arrays in a single environment. In Proceedings of the Fifth ACM SIGSPATIAL International Workshop on Indoor Spatial Awareness (ISA '13), Martin Tomko, Scott Bell, and Ki-Joune Li (Eds.). ACM, New York, NY, USA, 29-36.
DOI=http://dx.doi.org/10.1145/2533810.2533816

[15] Daisuke Taniuchi and Takuya Maekawa. 2015. Automatic Update of Indoor Location Fingerprints with Pedestrian Dead Reckoning. ACM Trans. Embed. Comput. Syst. 14, 2, Article 27 (February 2015), 23 pages. DOI=http://dx.doi.org/10.1145/2667226

[16] Ma R, Guo Q, Hu C, Xue J. An Improved WiFi Indoor Positioning Algorithm by Weighted Fusion. Khoshelham K, Zlatanova S, eds. Sensors (Basel, Switzerland). 2015; 15(9):21824-21843.
Doi : 10.3390/s150921824.

[17] C. Beder and M. Klepal, "Fingerprinting based localisation revisited: A rigorous approach for comparing RSSI measurements coping with missed access points and differing antenna attenuations," 2012 International Conference on Indoor Positioning and Indoor Navigation (IPIN), Sydney, NSW, 2012, pp. 1-7.
Doi: 10.1109/IPIN.2012.6418940

[18] He Wang, Souvik Sen, Ahmed Elgohary, Moustafa Farid, Moustafa Youssef, and Romit Roy Choudhury. 2012. No need to war-drive: unsupervised indoor localization. In Proceedings of the 10th international conference on Mobile systems, applications, and services (MobiSys '12). ACM, New York, NY, USA, 197-210.
DOI=http://dx.doi.org/10.1145/2307636.2307655

[19] H. Abdelnasser et al., "SemanticSLAM: Using Environment Landmarks for Unsupervised Indoor Localization," in IEEE Transactions on Mobile Computing, vol. 15, no. 7, pp. 1770-1782, July 1 2016.
Doi : 10.1109/TMC.2015.2478451

[20] Nam Tuan Nguyen, Rong Zheng, Jie Liu, and Zhu Han. 2015. GreenLocs: An Energy-Efficient Indoor Place Identification Framework. ACM Trans. Sen. Netw. 11, 3, Article 43 (February 2015), 21 pages. DOI=http://dx.doi.org/10.1145/2700271

[21] Andreas TEUBER, Bernd EISSFELLER. 2006. WLAN Indoor Positioning Based on Euclidean Distances and Fuzzy LogicWLAN Indoor Positioning Based on Euclidean Distances and Fuzzy Logic. IN PROCEEDINGS OF THE 3rd WORKSHOP ON POSITIONING, NAVIGATION AND COMMUNICATION (WPNC'06). IEEE, Hannover, Germany, 159-168.

[22] Mo Li, Pengfei Zhou, Yuanqing Zheng, Zhenjiang Li, and Guobin Shen. 2014. IODetector: A generic service for indoor/outdoor detection. ACM Trans. Sensor Netw. 11, 2, Article 28 (December 2014), 29 pages.
DOI: http://dx.doi.org/10.1145/2659466

[23] Zheng Yang, Chenshu Wu, Zimu Zhou, Xinglin Zhang, Xu Wang, and Yunhao Liu. 2015. Mobility Increases Localizability: A Survey on Wireless Indoor Localization using Inertial Sensors. ACM Comput. Surv. 47, 3, Article 54 (April 2015), 34 pages.
DOI=http://dx.doi.org/10.1145/2676430

[24] S. R. Doiphode, J. W. Bakal and M. Gedam, "A hybrid indoor positioning system based on Wi-Fi hotspot and Wi-Fi fixed nodes," 2016 IEEE International Conference on Engineering and Technology (ICETECH), Coimbatore, 2016, pp. 56-60.
Doi : 10.1109/ICETECH.2016.7569191

[25] X. Zhang, A. K. S. Wong and C. T. Lea, "Automatic Floor Plan Analysis for Adaptive Indoor Wi-Fi Positioning System," 2016 International Conference on Computational Science and Computational Intelligence (CSCI), Las Vegas, NV, 2016, pp. 869-874.
doi: 10.1109/CSCI.2016.0169

[26] C. di Flora, M. Ficco, S. Russo and V. Vecchio, "Indoor and outdoor location based services for portable wireless devices," 25th IEEE International Conference on Distributed Computing Systems Workshops, 2005, pp. 244-250.
doi: 10.1109/ICDCSW.2005.77

[27] A. Vasilateanu, N. Goga, L. Guta, M. N. Mihailescu and B. Pavaloiu, "Testing Wi-Fi and bluetooth low energy technologies for a hybrid indoor positioning system," 2016 IEEE International Symposium on Systems Engineering (ISSE), Edinburgh, 2016, pp. 1-5.
doi: 10.1109/SysEng.2016.7753121