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Wi-Fi- based Indoor Positioning System Using Smartphones

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Abstract

The demand for Indoor Location Based Services (LBS) is increasing over the past years as smartphone market expands. There's a growing interest in developing efficient and reliable indoor positioning systems for mobile devices. Smartphone users can get their fixed locations according to the function of the GPS receiver. This is the primary reason why there is a huge demand for real-time location information of mobile users. However, the GPS receiver is often not effective in indoor environments due to signal attenuation, even as the major positioning devices have a powerful accuracy for outdoor positioning.

Using Wi-Fi signal strength for fingerprint-based approaches attract more and more attention due to the wide deployment of Wi-Fi access points or routers. Indoor positioning problem using Wi-Fi signal fingerprints can be viewed as a machine-learning task to be solved mathematically. This whitepaper proposes an efficient and reliable Wi-Fi real-time indoor positioning system using fingerprinting algorithm. The proposed positioning system comprises of an Android App equipped with the same algorithms, which is tested and evaluated in multiple indoor scenarios. Simulation and testing results show that the proposed system is a feasible LBS solution.

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Introduction

With the rapid development of mobile communication and the pervasive computing technology, the requirement of obtaining location-aware services is rapidly increasing. Dramatic performance improvements in mobile communications standards have propelled mobile technology to become the fastest adopted technology of all times. Mobile network infrastructure costs have also fallen dramatically, while performance has soared.

Over the past decade, we have seen great improvements in downsizing of the computer hardware, arrival of various new technologies like wireless networks, battery capacities, high performance chips etc, which made mobile devices a smartphone. These technologies allowed the manufacturers to build mobile devices that can be carried around and have the same performance as traditional computers. The benefit of mobile devices can be leveraged by the so-called location-based services. Applications that act differently depending on the location or the context of the user or, even better, proactively offer location dependent information to the user are currently a hot topic in research and are considered a promising market.

Nowadays, the Global Positioning System (GPS) can provide accurate and reliable position information for location services. GPS cannot be used effectively under indoor environment since there is a signal degradation. Thus various positioning-enabled sensors such as GPS receivers, accelerometers, gyroscopes, digital compasses, cameras, Wi-Fi etc. have been built in smartphones for communication, entertainment and location-based services.

In this whitepaper, we will discuss about an indoor positioning system made using the Wi-Fi routers which are called Access Points (APs) and a Wi-Fi enabled android smartphone. But before moving further, what all technologies are available for indoor positioning? And why are we using Wi-Fi?

Indoor Positioning Systems

Indoor localization systems employ a wide range of different technologies; these systems could use any combination of the following:

- Ultra-wideband (UWB)
- Infrared
- Radio frequency identification (RFID)
- Inertial sensors, magnetic sensors etc.
- Sound (ultra-sound or audible sound)
- Wi-Fi
- Camera

The first five positioning systems in the above listing are able to localize users with high accuracies. However, these systems require the installation of additional hardware, which lead to high budget and labor cost, preventing them from having large-scale deployments.

The use of Wi-Fi to estimate location is a great approach, since Wi-Fi Access Points (AP) are readily available in large quantities in today's indoor environment and it is possible to use available mobile devices on the users' side.

This process of estimation involves capturing the strength of Wi-Fi signal received on the device's end and then using it to do analysis regarding the user's location. Let's explore the different techniques using which we can determine the location of a user.

Indoor Positioning Techniques

In Table 1 below, the accuracy, key characteristics, main advantages and disadvantages of the various positioning techniques used in mobile devices are compared. GPS with a high accuracy has emerged as the leading technique to provide location information. Assisted GPS (A-GPS) is a system allowing global positioning system (GPS) receivers to obtain information from network resources to assist in satellite location. An A-GPS system is especially useful when the receiver is in a location where it is difficult for the satellite signals to penetrate. Both GPS and A-GPS techniques need the signal from the satellite to propagate without obstruction to the receiver, which is the line of sight (LoS), to support high accuracy positioning.

Wi-Fi positioning and INS can provide medium accuracy without LoS, thus they are more suitable to be used in indoor environments. However, high cost for infrastructure and limited coverage is a major issue for Wi-Fi positioning. INS also has some issues since it is prone to rapid accumulative errors.

Table-1: Comparison of Indoor Positioning techniques based on their accuracy level, advantages and disadvantages.

Technique	Accuracy Level	Advantage/ Disadvantage
GPS	High (<10 m)	Good accuracy/ Line of Sight (LoS) is needed
A-GPS	High (10 m)	Assisted GPS/ Network interaction is required and only effectively used for locating a particular place in a small area
Wi-Fi positioning	Medium (10-100 m)	Good accuracy for indoor environments and no need LoS/ Medium cost for infrastructure and limited coverage
Inertial Navigation System (INS)	Medium (10 m)	Affordable/ Bias and drifting are a concern(accumulative error)
Cellular network positions	Low-medium(1 km)	No requirement for infrastructure/ Problematic in low signal conditions

Let’s explore more about Wi-Fi positioning techniques. There are few terms we need to understand before moving forward.

• **Access Points (APs):**
It is a networking device that allows a Wi-Fi enabled device to connect to a wired network. For e.g, Wi-Fi routers.

• **Received Signal Strength (RSS):**
It is a measurement of how well your device can hear a signal from an access point or router. It is a value that is useful to determine if you have enough signal to get a good wireless connection.

Note: Because a RSS value is pulled from the mobile device’s Wi-Fi card (hence “received” signal strength), it is not the same as transmit power from a router or AP.

• **Wireless local area network (WLAN):**
It is a wireless computer network that links two or more devices using wireless communication within a limited area such as a home, school, computer laboratory, or office building.
802. IEEE 802.11 standards: It refers to the set of standards that define communication for wireless LANs (wireless local area networks, or WLANs). The technology behind 802.11 is branded to consumers as Wi-Fi. IEEE 802.11 is the set of technical guidelines for implementing Wi-Fi.

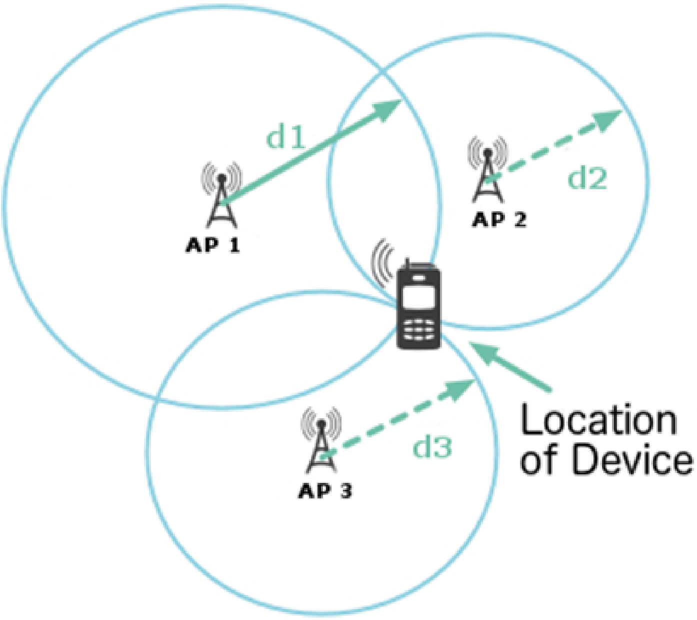
• Radio Signature: For a given location the signal strengths from all the APs create a unique set of information which can also be referred to as the radio signature for that location.

The two most frequently used methods for estimating the location of indoor mobile objects with Wi-Fi networks are:

Trilateration method:

This method is widely used in conventional surveying and GPS positioning. It uses the distances of an object from three or more known fixed points, to determine the position of an object. As shown in the below figure there are three APs to send signals which is received by the mobile device. Now the received signals (RSS values) are converted into spatial distances, which are used as the radii of circles i.e. d1, d2, d3 etc.

Figure-1: Simple design of Trilateration method for Indoor Positioning



Since the complexity of indoor space can have a great impact on the signal, when one converts the signal strength to a spatial distance, it can inevitably produce errors. To reduce the error, researchers have suggested a variety of methods to assist trilateration. If you want to explore more in this area of research, read here.

Fingerprinting method:

This method has been used for indoor positioning for several years. Its main advantage is that it can use existing WLAN infrastructures or other network environments. Compared to techniques like Trilateration, Fingerprinting technique is more suitable for indoor environments and is relatively simple to deploy. There are no specific hardware requirements, so any existing WLAN infrastructure can be used for positioning.

Exploring Fingerprinting method

The fingerprinting method is based on the relationship between a given location and its corresponding radio signature.

It's been observed that points with a certain minimum distance between them and spread over the area of interest possess a unique set of RSS readings from APs and this is referred to as the fingerprint for that location.

Let's try to understand more about this method. When used with Wi-Fi systems, the fingerprinting method can be typically divided into two phases, calibration phase and positioning phase.

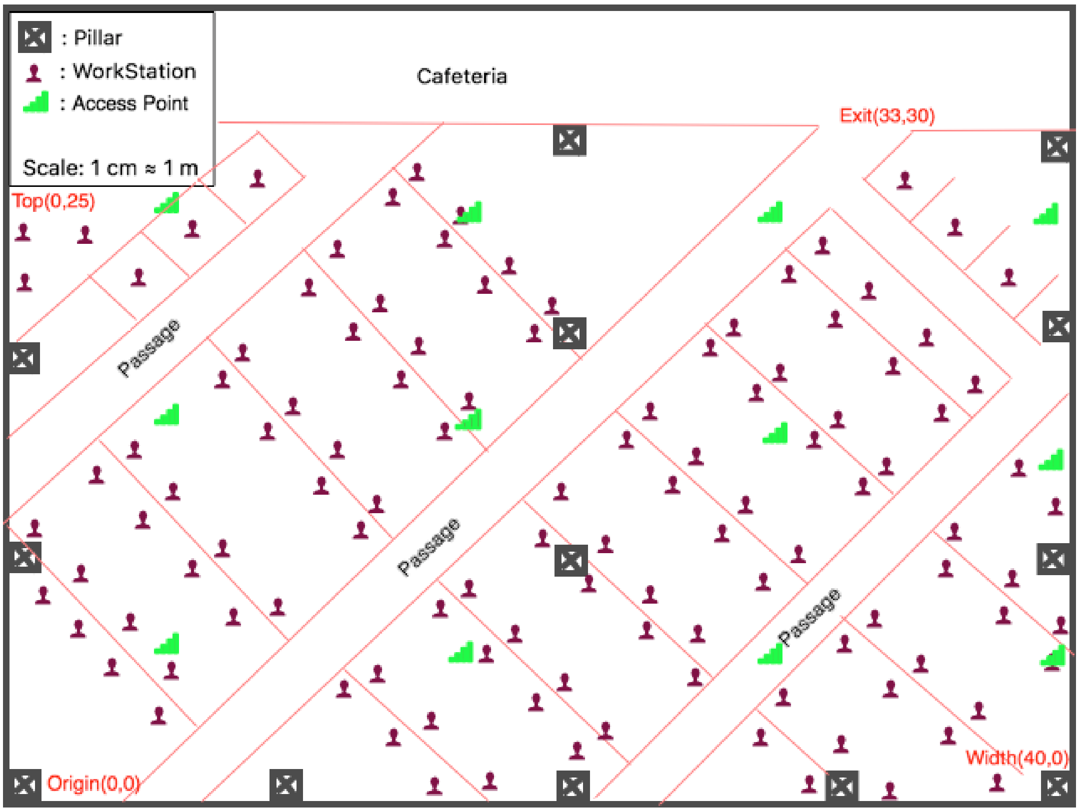
Calibration Phase:

As the name suggests, this is a phase in which we calibrate the area of interest based on some Reference points. To have a better understanding of this phase lets go through the process implemented to achieve the unknown location of a device.

Step-1: We can draw the indoor area where the WLAN system is setup on any type of canvaslike Drawing sheet, Paint Software etc. or we can go for any other software available online for this purpose. We should consider taking a scale before drawing which is equivalent to the real-time reading in the area.I have taken one cm on drawing sheet equivalent to one meter on the area of interest since it was suitable for me. Now after deciding the scale, measure the area's dimensions like width and height, convert it to your scale and draw it on the canvas taking any corner as origin (0,0). Next task would be to start locating access points on the canvas based on their position according to origin.

Please refer the following figure for better understanding; this is the layout of my organization where I conducted the experiment.

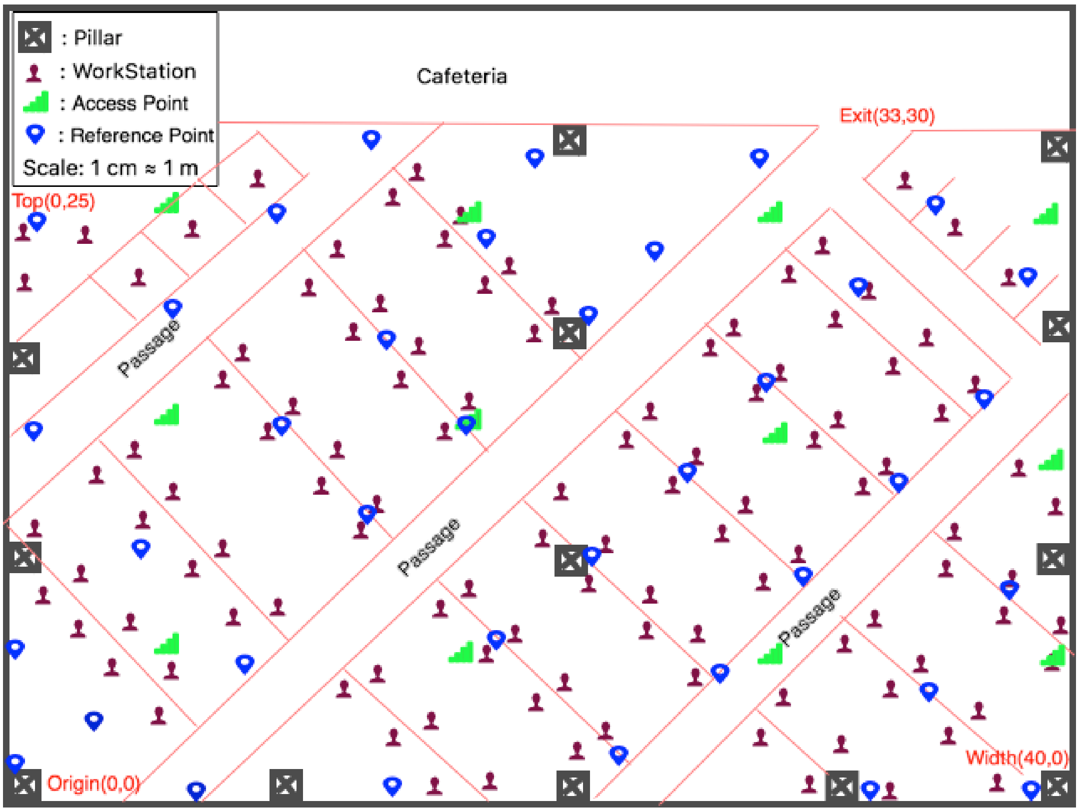
Figure-2: Floor plan showing location of APs



Step-2: Now we would select some points in the area of interest which are placed at a definite interval and spread all over the area of interest like a grid as show in the figure below and these points are called Reference points(RPs). Each reference point will have signal strength readings from APs in the area of interest. If a particular RP is closer to a particular AP, then the signal strength will be strong and vice-versa.

In case if a particular point is out of range of an AP then we can assume the least possible value of signal strength in that case, so that each RP will have a reading from all APs. Now looking at the information available to us, we see that each RP has a unique set of signal strength readings from the Aps. They also have a fixed location which makes it a unique point in the area of interest which can be referenced as a fingerprint for that location. So we are going to take readings from multiple reference points, store them in the local database.

Figure-3: Floor plan showing location of APs and RPs



Step-3: Again, we are taking RSS readings on each RP from all the APs assuming if AP is out of range, then we assign it the least value of RSS. Now for a fact, I want to let you know that RSS values fluctuate with time. So to fix this, I took multiple RSS values in a definite time interval (for e.g.10 values in an interval of 2 seconds) and took mean of them. Now let's say there are 4 RPs, then each RP will have 4 mean RSS readings. Apart from mean RSS values, we also know the location coordinates of RP and AP.

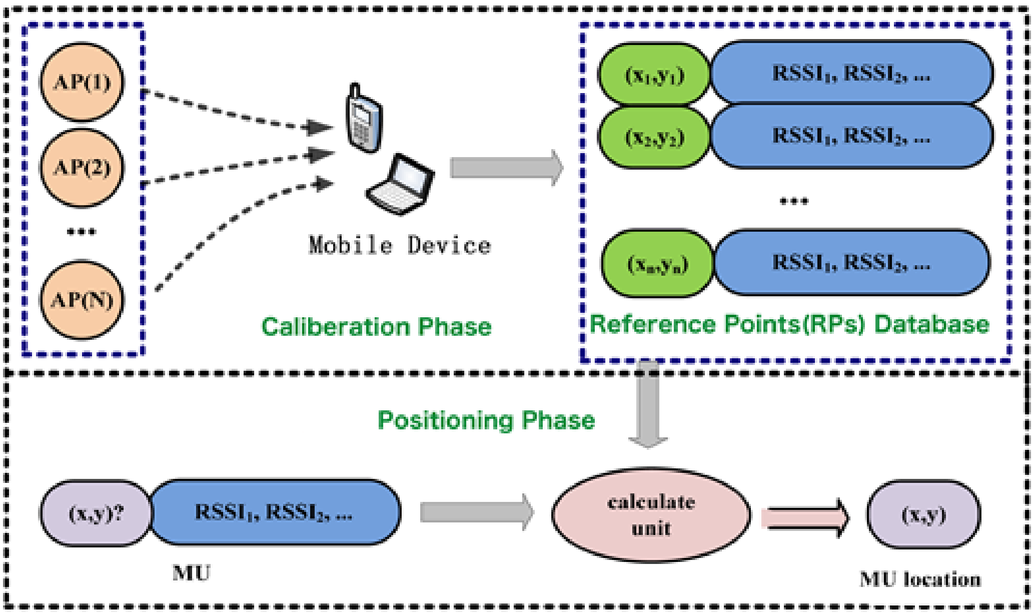
All this information is stored in the local database in which RSS readings of all the RPs which contains mean values from each AP and AP details like location, IP etc are saved. To make this database I have made an Android App which stores the details of AP and RP. Read here to explore it.

Positioning Phase:

We now have ample amount of information about the area of interest. We know near which RP the signal strength of which AP is strongest and weakest and we know the locations of that AP and RP. Let's say we want to locate the device which is at an unknown location. We first scan the area using Wi-Fi for the available APs on that point and we calculate their mean signal strength values.

Now we already have a dedicated database of points which are scattered all over the area (RPs). We must pick the points which are nearest to the unknown location matching their signal strengths. This evaluation can be done using Fingerprinting algorithms.

Figure-4: Simple design to explain the Fingerprinting method



Fingerprinting algorithms can be classified into two basic groups: deterministic and probabilistic algorithm.

Deterministic algorithm:

As the name suggests, this algorithm attempts to find the minimum distance between the unknown location and various calibration reference points location from database. This may or may not be equal to the minimum physical distance between the actual device's location and the recorded location of nearest RP from the calibration phase. The distance between the device's actual location and evaluated location from algorithm is generally regarded as the best raw location estimate contained in the calibration database.

Different types of deterministic algorithm:

- **Nearest Neighbor (NN) Algorithm:**

The nearest neighbour algorithm is easy to implement and executes quickly. We know we have stored RPs in database and each RP have RSS mean values from each AP. The idea of this algorithm is to calculate the Euclidean distance between the RSS values from all APs at an unknown location and the signal strength mean values of APs from each RP recorded in database, and later find the closest neighbor. The Euclidean distanceis defined as length of line segment which is connecting two given points.

So let's say there are n number of RPs in an area, then we get n number of Euclidean distance at an unknown location and the least Euclidean distance will be the nearest neighbour.

- **K-Nearest-Neighbor (KNN) Algorithm:**

The KNN algorithm is an extension of the NN algorithm introduced above. "K" is the number of the minimum Euclidean distance values. To elaborate, in the NN algorithm we considered only one nearest neighbor and here we take into account K number of nearest neighbors. If k=1 then KNN turns into NN. After getting K number of nearest neighbors we take mean of their location co-ordinates and the outcome is the estimated location of the device.

- **Weighted K-Nearest Neighbors Algorithm:**

This is again extension of KNN algorithm. The difference here is instead of taking mean of location co-ordinates we perform weighted mean.

Probabilistic algorithm:

In order to achieve more accurate results, probabilistic algorithms have been developed. These algorithms are also sometimes called randomized algorithms. A probabilistic algorithm is an algorithm where the result and/or the way the result is obtained depend on chance. Here instead of calculating the Euclidian distance we calculate the probability of the device's location near to an RP using a probability factor [c]. Please explore the android app which is made in this reference to have a better understanding. Also you will be able know about implementation of these algorithms at code level.

Fingerprint Positioning Vs. Trilateration:

Table-2: Comparison of Trilateration and Fingerprinting method

Method	Accuracy	Advantage	Disadvantage
Trilateration	Medium	Continuous positioning; no calibration phase required	poor positioning accuracy may occur, caused by environmental effects
Fingerprinting	High	Continuous positioning; environmental effects are considered in the calibration phase	Poor positioning accuracy in environment where surroundings change frequently

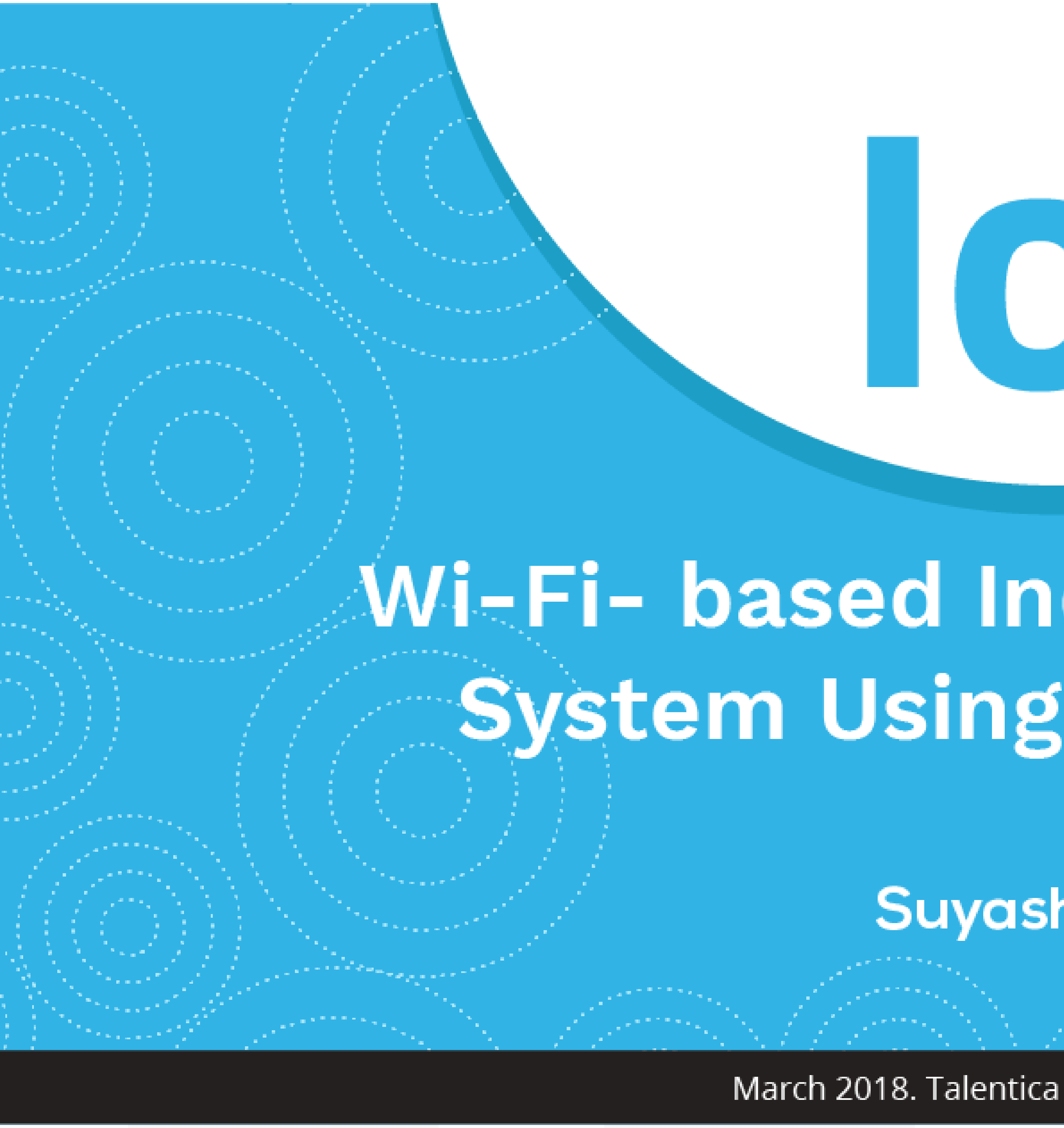
Technical Challenges in Wi-Fi based positioning:

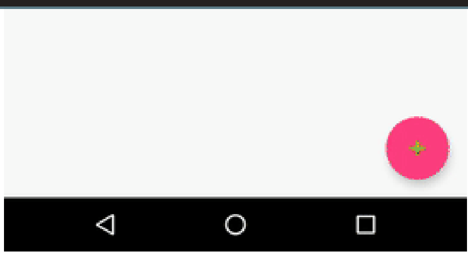
There are some technical challenges in designing and deploying signal strength based indoor positioning system using smartphones as a platform. The instability of RSS in indoor environments is the major challenge for RSS-based WLAN positioning systems.

• The first reason is the structure of the indoor environment and the presence of different obstacles, such as walls, doors and metal furniture etc.
The WLAN signals experience severe multipath and fading effects. Also the RSS value varies over time, even taken at the same location.

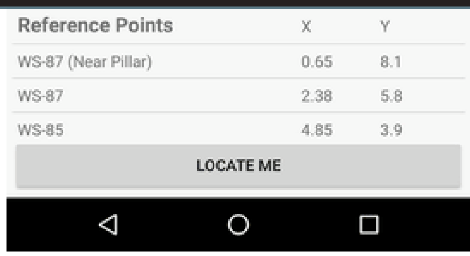
• Secondly, the IEEE 802.11 WLAN frequency range is in the 2.4 GHz public bands, which is shared with many other devices such as microwave ovens, smartphones, laptops and other wireless signal transmitters. In the calibration phase, which is used for collecting the RSS data and storing the corresponding location information in a database, these devices will likely lead to radio interference and make the wireless signal strength fluctuate.

• Furthermore, normal human body can also affect the WLAN signal strength since the 2.4 GHz Wi-Fi signal strength could be greatly attenuated through human bodies, which consists of 70% water and water can absorb the resonance frequency at the 2.4 GHz. Therefore, when signal strengths are collected using a smartphone, the RSS values on the straight line between the smartphone and an access point (AP) will be influenced by the body of the person. To overcome this, we can have time factor too in the experiment, which can change the mean values of RSS for an AP. In that case we need to take readings in calibration phase at multiple times in a day.





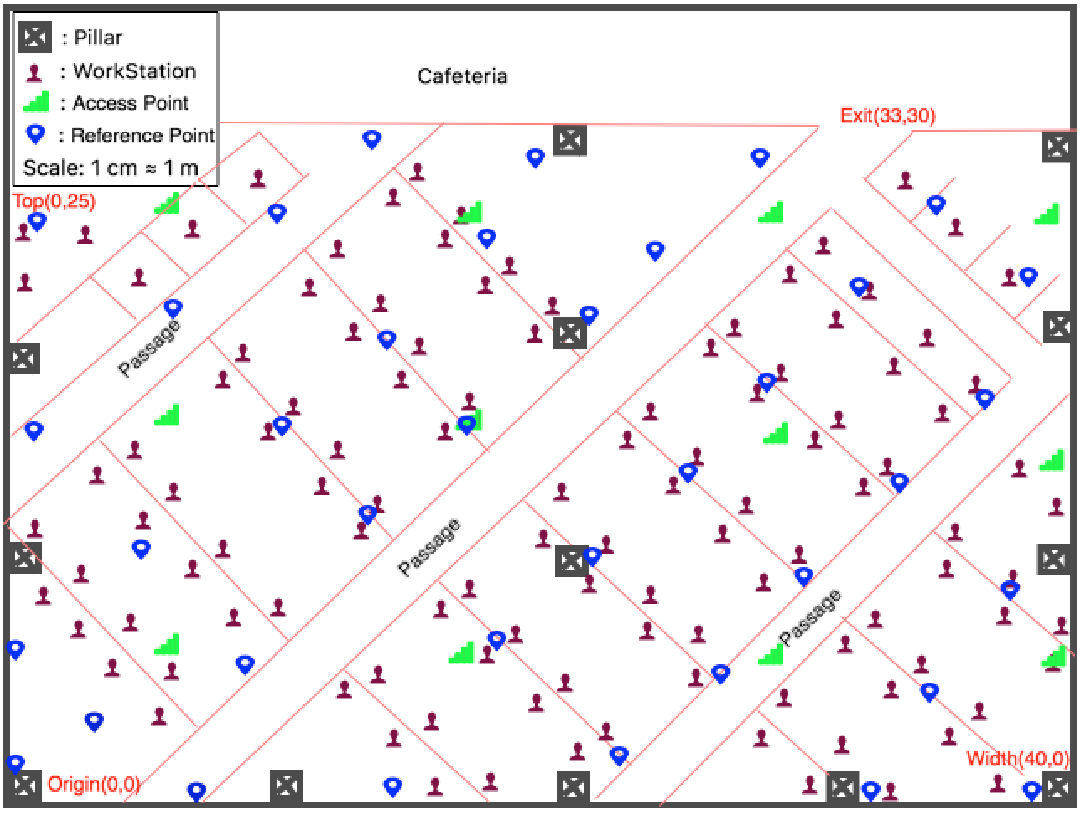
App home screen showing list of projects



Selecting a project shows its APs and RPs with their locations (x,y)

Next you need to plan for reference point's addition. Below is the figure of floor plan for 2m distance interval between RPs.

Figure-6: Floor Plan with 2m distance between RPs (blue)



As we can see above, we used 2m as the distance interval between RPs above. We could have used 1m or 1.5m, right? So let me tell you I tried with all 3 intervals and the results were not satisfactory for 1m and 1.5m interval.

Tests Results

The result of the three scenarios are mentioned below in tables. The Actual location stands for the location on which we are testing the App and the location returned by the App is under location evaluated from the App in positioning phase.

All the location values are approximated to the nearest integers. The acceptable column is judged by how much offset distance both the readings have. If it is greater than twice the interval, then it's not acceptable.

Table-3: Results for test scenario 1 (RP spacing: 2 m)

Test Point	Actual Location(m)		Location evaluated from App(m)		Acceptable?
	X	Y	X	Y	
1	06	14	05	15	Yes
2	06	20	05	22	Yes
3	06	30	05	29	Yes
4	13	14	10	14	Yes
5	13	26	11	24	Yes
6	22	02	23	04	Yes
7	22	22	23	24	Yes
8	31	14	33	19	Yes
9	34	02	35	03	Yes
10	35	16	35	18	Yes
Total matching Rate					90%

Table-4: Results for test scenario 2 (RP spacing: 1.5 m)

Test Point	Actual Location(m)		Location evaluated from App(m)		Acceptable?
	X	Y	X	Y	
1	06	14	05	14	Yes
2	06	20	05	23	No
3	06	30	04	26	No
4	13	14	10	17	No
5	13	26	12	25	Yes
6	22	02	24	05	No
7	22	22	22	24	Yes
8	31	14	33	19	No
9	34	02	35	03	Yes
10	35	16	34	17	Yes
Total matching Rate					50%

Table-5: Results for test scenario 3 (RP spacing: 1 m)

Test Point	Actual Location(m)		Location evaluated from App(m)		Acceptable?
	X	Y	X	Y	
1	06	14	08	05	No
2	06	20	07	13	No
3	06	30	08	26	No
4	13	14	10	17	No
5	13	26	12	28	No
6	22	02	14	05	No
7	22	22	14	24	No
8	31	14	34	19	No
9	34	02	34	01	Yes
10	35	16	39	22	No
Total matching Rate					10%

According to the results, scenario 1 has the best match rate of 90% while scenario 3 has the worst match rate of 10%. Scenario 2 gives the total match rate of 50%. For scenario 3 results, the reason for the failure rate of 10% is that the unknown point has similar distances to more than one nearby RPs. In this case the matching algorithm cannot successfully identify the real best matched one due to the limited grid resolution. Comparing the results among the three scenarios, we can conclude that the spacing of the RPs setup for scenario 1 is reliable for our location determination in testing indoor environment since the success rate reaches 90% with an accuracy roughly equal to 2m spacing.

The performance of a positioning system is mainly determined by both positioning algorithm and quality of observations.

Different mobile devices receive different qualities of observations due to different performance of their Wi-Fi adapters. The quality of the observations can be measured by several factors including accuracy, stability and success rate etc.

When a time series of RSS values are received by a mobile device at a fixed point under the unchanged environmental settings, the smaller the variations in the RSSs, the more stable the RSS observations. For the success rate of the RSS observations, a mobile device may either fail to provide stable RSS observations or receive out of range RSS values. This failure is most likely caused by the poor quality of the Wi-Fi adapter.

Conclusion and Future Work

We discussed indoor Wi-Fi positioning technology; including the various phases and process of Wi-Fi fingerprinting technology and we classified the methods used across the phases. Tests show that applying proper RP interval for fingerprint-based positioning can significantly improve the positioning accuracy.

Several aspects can be further explored to enhance the performance of the proposed Wi-Fi based positioning system for future work. Two main aspects are listed as follows:

• Setup RSS database for different brand Wi-Fi adapters: The proposed indoor positioning system is device-dependent, thus different brand Wi-Fi adapters with various receiving capabilities need to be tested. The fingerprinting process must be done for each type of Wi-Fi adapter. Further experiment needs to be carried out to investigate new methods to reduce the impact of the device-dependent errors. High stability is expected for other mobile devices rather than LG smartphone.

• Multi-sensor fusion: most current smartphones are equipped with other types of sensors such as accelerometer, gyroscope and digital compass, in addition to the built-in Wi-Fi adapter. Data obtained from these sensors could be very useful sources of information for indoor positioning since it can provide auxiliary data such as speed and orientation of movement. The improved positioning system can therefore make best use of the observations from these sensors to improve the accuracy of the position estimates. New algorithms for the integrated system need to be developed and its performance needs to be assessed.

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