M1 Electrical Engineering for Communications & Information Processing (EECIP)

Track Electrical and Optical Engineering (EOE)

PHY7509 – Radio Frequency for Connected Objects

Project: INDOOR POSITIONING WITH WiFi

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1. Abstract

In recent times, an indoor positioning is highly researched and challenging domain because of the unavailability of GNSS signals. There are different methods available to employ positioning in an indoor environment. In this project, we use the WiFi' based RSS approach to model positioning in an indoor environment. In particular, we studied and experimented the RSSI lateration method to find the positioning. Lateration methods are generally error prone in comparison to the fingerprinting method, which is well reflected in our results too. For this reason, we propose to optimize the path loss exponent by choosing different n_{sf} for each Access point (AP) rather than using single value for all APs. We also showed how increasing number of APs will give us multiple combinations and therefore resulted in more accurate results. We also observed and measured the LOS and NLOS effect in our measurements in our experiments. For regions with less than 3 AP available, we called them blind regions and proposed the intuitive solution for these regions. Finally, we displayed the results, the limitations of trilateration, and shared future recommendations. In this project, we generated the Excel and C++ code file which automatically generates the calculations providing user friendly interface.

2. Introduction and Background

Nowadays localization have become the most promising technology in radio frequency domain. Localization can be performed in indoor and outdoor. In this part of the project we will only discussed about the indoor positioning through Wi-Fi. There are many techniques used for indoor localization such as Time Difference of Arrival (TDoA), Time of Arrival (ToA), Angle of Arrival (AoA) and Received Signal Strength (RSS).

In our project we used RSS based localization method. To determine the distance between wireless devices and access point RSS based lateration method, we used the WiFi signal propagation model. In order to calculate the distance between access points and wireless device we used log-distance path loss model.

$$P(d)_{(dBm)} = P(d0)_{(dBm)} - 10 * n_{sf} * \log(d/d0)$$

P(d0) is transmitted power by access points at reference distance d0. Where d is the distance between access points and wireless device. n_{sf} is path loss exponent.

We also observed if we reduced the floor attenuation factor for same floor it can be also very helpful to improve the accuracy of indoor positioning.

$$P(d)_{(dBm)} = P(d0)_{(dBm)} - 10 * n_{sf} * \log(d/d0) + FAF_{(dB)}$$

The following simultaneous equation can be used for trilateration localization:

$$(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2 = {d_1}^2$$
$$(x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2 = {d_2}^2$$
$$(x - x_3)^2 + (y - y_3)^2 + (z - z_3)^2 = {d_3}^2$$
$$(x - x_4)^2 + (y - y_4)^2 + (z - z_4)^2 = {d_4}^2$$

Where (x,y,z) is the wireless device coordinate, (x_i,y_i,z_i) the position of access point and d_i is the distance between access point and wireless device.

Generally because of so many factors involved with WiFi propagation, lateration methods are relatively inaccurate than fingerprinting method. For a correct model, multiple factors have to be modeled for final proposition of model for positioning.

3. Motivation for Selected approach

The major motivations behind choosing the proposed approach are as follows:

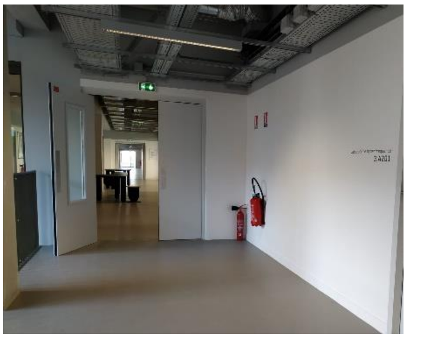
a) Lateration is less accurate and therefore more room for learning with challenging situations. As explained before, fingerprinting is relatively more accurate than fingerprinting. But the purpose of this mini project was to experience challenges related to WiFi propagation. Therefore, we opted for more natural and generic method.
b) Another reason was already an implementation of fingerprinting by other groups. This was an opportunity to experience and share the results with others through different approach.

4. Proposed Model Space, Nomenclature, and Validity

In this section, we introduce the space we picked for proposition of our model. We are also going to introduce the nomenclature we used for difference components. And finally we are going to express the validity of our model.

4.1 Model Space

Our positioning model is proposed for the two continuous sides of 3rd floor A-block of Telecom SudParis building in Palaiseau, France. Our reference origin is the corner between room 3A201 and hallway 3.Axx as shown in figure. This is the point for x=0, y=0, and z=0 in our reference system.



4.2 Nomenclature

In this document and all other files, we use following keywords:

AP = Access point
MP = Measuring/test point
2nd Floor = A
3rd Floor = B
4th Floor = C
On every floor moving counter clockwise from the origin reference, we label routers numerically. For instance, the router in front of room 3A201 is called B1. Here B indicates the floor and 1 indicates the number of router from the origin in counter clockwise direction.

We also labelled sides of floor as alpha, beta, gamma, and delta. The side with origin reference is alpha (as shown in picture). And moving counter clockwise, we come across beta, gamma, and delta respectively. This is symmetrical for all three floors.

Knowing this nomenclature, we conducted our experiments and proposed our model in sides: gamma (starting with room 3A305) and delta (ending with room 3A432).

For regions, where we had access of less than 3 APs, we called them **blind region** in our project and in this document.

4.3 Validity

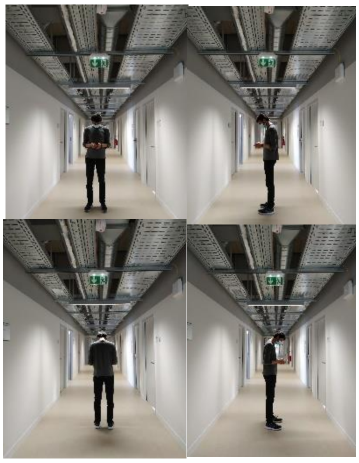
Following are the important points to be considered for our model to be valid:

a) It's valid in corridors not inside the rooms. However, with greater scope, it can be extended.

b) The accuracy isn't consistent in all region especially in blind regions and it is discussed in detail in following sections.

c) To find accurate positioning, we propose to hold your mobile device horizontally at the height of belly button. This is shown in figure on left.

d) Another condition for the accurate positioning, we propose to move (90 degrees) and face all four sides (North, South, East, West) for the maximum of 20s and minimum of 7s.



e) Assumption of FAF = 25 dBm

5. Experimental Setup

The following table include the details about the experimental setup:

Measuring points (MP)	20
Average distance between MPs	7.5
Identification of AP	Through MAC address
Access Point	17
Average number of APs for one MP	4.55
Total N_{sf} evaluated	238
N_{sf}/AP	14
Total optimum Nsf evaluated	17
Number of power measurements for n_{sf}	612
Number of overall power measurements	573
Power measurements/MP	28.65
Model Space area	420 squares meters
Total lateration combinations	200
Combinations/MP	10
Measuring Instrument	Digital Distance meter, Measuring tape
Instrument mounting	Vertical Phone Holder
WiFi Measurement Application	WiFi Analyzer

6. Activity Timeline and Experiments

This section describes our experience in this project and our journey from our first measurement to final proposed model.

1st activity: We started with observing the power readings at certain distances from the one specific access point. This gave us the idea of how power values decrease with the increase in distance. However, it was difficult to find simpler relationship between these two variables.

2nd activity: We defined the reference origin in our model space and then calculated the XYZ coordinates of model measuring (test) points as well as the access points (AP).

3rd activity: We tried to execute multilateration on our 20 measuring (test) points. We experienced the limited number of APs in our model space for this approach to execute. To compensate this, we added APs from two more floors.

4th activity: We evaluated the path loss exponent (nsf) of the AP. With this evaluation, we immediately realized that there is no consistent value of path loss exponent which works for even one AP (at different distances) let alone for all APs. To fix this issue, we tried to implemet the optimization of nsf, which is the core part of our project and mentioned in the detail in section 8.2.

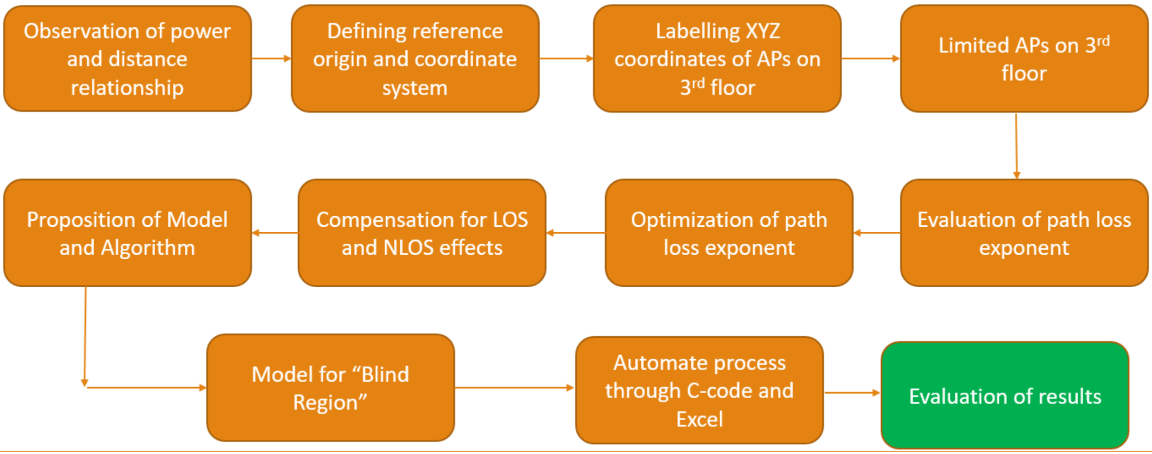
5th activity: In addition to the availability of AP and inconsistent nsf, another challenge was the irregular power values received by the same AP at the same distance at the same time. This was because of the Line of Sight (LOS) and Non-line of Sight (NLOS) measurements. Depending on the direction, the power value varies and therefore the estimation of the position is inaccurate.

To reduce this variability in measurements, we observed the variation of power with change in direction from AP. This affect was compensated by increasing power measurements and directions as mentioned in Section 8.3 in detail.

6th activity: Finally, on two test points, we observed the available APs less than 3. We named this region blind region, and proposed the solution based on intuitive reasoning mentioned in section 8.4. However, the basic idea revolves around the abstract understanding of “no information is an information itself”.

7th activity: To automate the process of calculation and estimation of position, we implemented C code application and a detailed Excel file with easy to use implementation. Both files are attached alongside this report. The ReadMe file for both applications is also available to assist the usage.

The purpose of this section was to provide reader the information about our journey from our first measurement to our proposed model with its limitations and validity conditions. The details about the implementation, challenges, observations, and future variations are mentioned in sections given below. Indeed, there are lot of factors which have to be included for the accurate indoor positioning, but with limited scope of this mini project, we tried to observe and optimize 2-3 factors.



7. Key Challenges

As it has been mentioned before that indoor positioning is no short of challenges. However, for this project we focused on following key challenges and tried to solve them:

a) Limited Access Points (APs) at the model space
b) Inconsistency in path loss exponent (nsf) values
c) Impact of Line of Sight (LOS) and Non-line of Sight (NLOS) power measurements
d) Blind Regions (availability of less than 3 APs)

8. Solutions for Challenges

As mentioned in previous section, in our project, we tried to focus on four challenges affecting our results.

8.1 Limited APs

As discussed above, the first problem we faced was the unavailability of 3 APs on 3rd floor to apply trilateration or multilateration. Initially we had only 50% (10/20) of the measurement points which had availability of 3 or more APs with an average of 2.7 APs per measuring point. To fix this, we decided to add AP from 2 more floors (2nd and 3rd floors). After adding the two floors, we got coverage of 3 or more APs on 90% (18/20) of the measuring points with an average of 4.55 APs per measuring point. The picture below shows the availability of AP for each measuring point. The first column indicate the measuring points and rest of the columns are for all APs. In each row (MP), we highlight the available APs with red. The data is available in Excel file 16.1

MP	A5	A7	A9	A10	A11	B1	B4	B5	B7	B8	B9	B10	C7	C8	C9	C11	C12	C13
M1	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No
M1a	Yes	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No
M2	Yes	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No
M2a	Yes	No	No	No	No	No	Yes	Yes	No	No	No	Yes	No	No	No	No	No	No
M3	Yes	No	No	No	No	No	Yes	Yes	No	No	No	No	Yes	No	No	No	No	No
M3a	Yes	Yes	No	No	No	No	Yes	Yes	No	No	No	No	Yes	Yes	No	No	No	No
M4	Yes	Yes	No	No	No	No	Yes	Yes	No	No	No	No	Yes	Yes	No	No	No	No
M4a	No	Yes	No	No	No	No	Yes	Yes	No	No	No	No	Yes	Yes	No	No	No	No
M5	No	Yes	No	No	No	No	Yes	Yes	No	No	No	No	No	Yes	No	No	No	No
M5a	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	Yes	No	No	No	No
M6	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No
M6a	No	No	No	No	No	No	Yes	Yes	Yes	No	No	No	No	No	Yes	No	No	No
M7	No	No	Yes	Yes	No	No	No	No	Yes	Yes	No	No	No	No	Yes	No	No	No
M8	No	No	Yes	Yes	No	No	No	No	Yes	Yes	Yes	No	No	No	Yes	No	No	No
M9	No	No	No	No	No	No	No	No	Yes	Yes	Yes	No	No	No	No	Yes	No	No
M10	No	No	No	No	Yes	No	No	No	Yes	Yes	Yes	No	No	No	No	Yes	No	No
M11	No	No	No	No	Yes	No	No	No	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No
M12	No	No	No	No	Yes	No	No	No	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No
M13	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No
M14	No	No	No	No	No	Yes	No	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes

Available AP is highlighted

Minimum APs at any point	2
Maximum APs at any point	7
Average APs at any point	4.55

8.2 Inconsistent n_{sf}

The biggest challenge and core part of our experiments was an inconsistent value of path loss exponent. The value of n_{sf} wasn't even consistent for one AP, let alone for all APs. Therefore we went through optimization of the n_{sf} in our project. Here we explain the optimization of nsf for one AP. We repeated the same extensive procedure for 17 APs. This is explained as follows:

a) For each AP, we defined two d0, at the same distance (2.92m) on both sides of the router.
b) We then marked 7 points for 'd' at distance 7m, 12m, 15m, 17m, 23m, 25m, and 29m.
c) Of these 7 points we marked 5 points on one side, and two on other.
d) So total of 9 points we have (2 for Pd0 and 7 for Pd).
e) Then we measured the power levels at each point in all four directions (North-South-East-West). This is consistent with the validity of our proposed model.
f) This makes a total of (9x4) 36 power measurements for each AP.
g) At the end we use two d0 and seven d, to find total of 14 n_{sf} for one AP using Excel formulas.
h) Using each n_{sf}, we calculated the estimated xy coordinates of our measuring/test point.
i) We then evaluated error by using mean square error between estimated and actual xy coordinates.
j) We picked the optimum nsf which resulted in least error.

As you might have noticed, we are proposing an unconventional method which doesn't have a single n_{sf} but 17 n_{sf} for 17 APs. The fundamental reason is that range of n_{sf} varies a lot as we calculated and selecting one value for all APs will result in huge errors. This is shown in figure on right. The difference between maximum and minimum nsf is 2.85 which is significant in impacting results.

AP	nsf
B4	3.21
B5	3.26
B7	2.95
B8	3.21
B9	3.65
B10	3.86
A5	2.90
A7	2.96
A9	3.79
A10	5.25
A11	3.64
C7	3.48
C8	3.39
C9	3.90
C11	3.56
C12	2.40
C13	4.71
Averarge	3.54
Min	2.40
Max	5.25
Range	2.85

We conducted this process for all 17 APs with total of (17 x 36) 612 power measurements, (17 x 14) 238 nsf, and finally 17 optimum nsf (one for each AP).

8.3 Impact of LOS and NLOS

The third challenge was variations in power measurements recorded at the same point from the same AP. Few of the measurements were extraordinarily higher and few lower. This was because of the orientation of the device. It experiences higher power when it is in line of sight and lower if it is in non-line of sight.

To fix this, as we proposed in section 4.3 of validity, we conducted experiments in all four directions and finally we had multiple power recordings at given point. We considered the median of these recordings which resulted in discarding of the outliers and extreme values.

In our 573 measurements at test point, we observed an average 4.36dBM more power in LOS direction than median value. And on average 3.76dBm less power in NLOS direction than median value.

8.4 Blind Regions

In our project, we labelled the regions where we had an availability of just 2 APs as "Blind Regions". In our experiments, there are two points labelled as "M1" and "M6" which exist in blind region.

So in these regions, the proposed model of lateration can't be applied. For these regions, our solution is based on the abstract concept of "no information is an information itself". This means that we know the approximate values of power levels received at these two points from two available AP. And we also know that we don't receive power measurement from any other third AP. This information is enough to identify that the user exist somewhere in the region.

For instance, the point M1 have power levels received: B4: -71dBM and B5: -80.5 dBM. In our extensive experiments there is no other point in our proposed space where these three conditions satisfy:

a) B4 and B5 exist
b) B4 > B5 (dBm)
c) No other AP exists

9. Positioning Process Flow

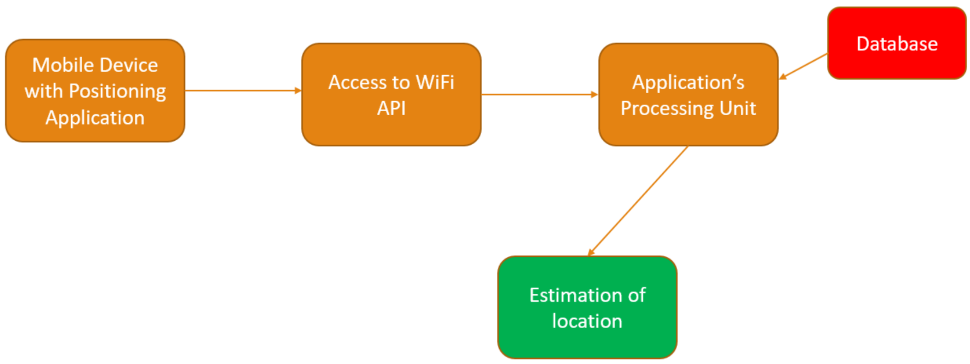
This section describes the flow of the process using the algorithm mentioned in section 10. This section helps reader to get the basic overview of how our proposed model works for the user.

Step-1: For any user, the first step to find the position is to open a mobile application which implements our proposed model. Because of limited time and scope, it's important to mention that we haven't developed the mobile application in this project but we have given C code and Excel datasheets which automatically evaluates the calculations and provide user with the simplified results.

Step-2: After opening the positioning application, the application will access to WiFi API (Access point interface) from the mobile software to automatically obtain WiFi signal strength (RSS) from different APs.

Step-3: This information will be forwarded to the positioning application's processing unit which works in synchronization with application's database. The positioning application's processing unit is the decision block of the application which implements the algorithm mentioned in the section 10. The positioning application's database is the required information by the algorithm to evaluate calculations. The database contains all the information about the APs.

Step-4: After the processing of the data, the algorithm will give results in the final XY coordinates to the application to display on the map. This will eventually allow user to know where he/she is present at that time.



This was the overview of the positioning process flow. The details on the algorithm and measurements are explained in the sections below.

10. Algorithm of Model

a) The algorithm takes the power measurements in dBm with respective AP point's MAC address. In our proposed model, the user is asked to keep the mobile device steady. Moreover, the user has to position the device in each four North-South-East-West directions. Based on our extensive measurements, it's advised to keep the mobile device for at least 7s in each direction. However, the accurate determination of this time is a dedicated task, which is beyond the scope of this project.

In our model, we have proposed 3 timers namely T1, T2, T3 with configurable values. T1 is the initial wait timer designed to wait before taking the power measurements. The purpose of this timer is to not record the initial false values from the sensor/application. T2 is the measurement timer which starts upon expiry of the T1. The purpose of this timer is to define the maximum time for an application to record measurements for the user.

b) After recording the power measurements with respective MAC addresses, the known access points are found by traversing the AP database. This will provide the list of available APs at given point.

c) If there are no available APs, the user is notified that it is not possible to determine the position. In our model space, we didn't find any such point meeting this undesirable condition.

d) As previously mentioned in step-a, the user have numerous power measurements from each AP because of the timers and positioning in four directions. In our algorithm, we take median of all the power values received for each AP. At the end of this operation, we would have one median power level for each available AP at user current position.

e) Based on Wifi Propagation equation mentioned in section 1, we would estimate the distance of each AP from user location. We use the optimized parameters which we obtained in Section 8.

f) If there is only one available AP, we propose the circle centered at that AP position with radius equal to the value of estimated distance (step-e) of user from this access point. The user is predicted to be located within this region.

g) If there are 2 APs available at user location, we propose the "Blind Region" model proposed in Section 8.4.

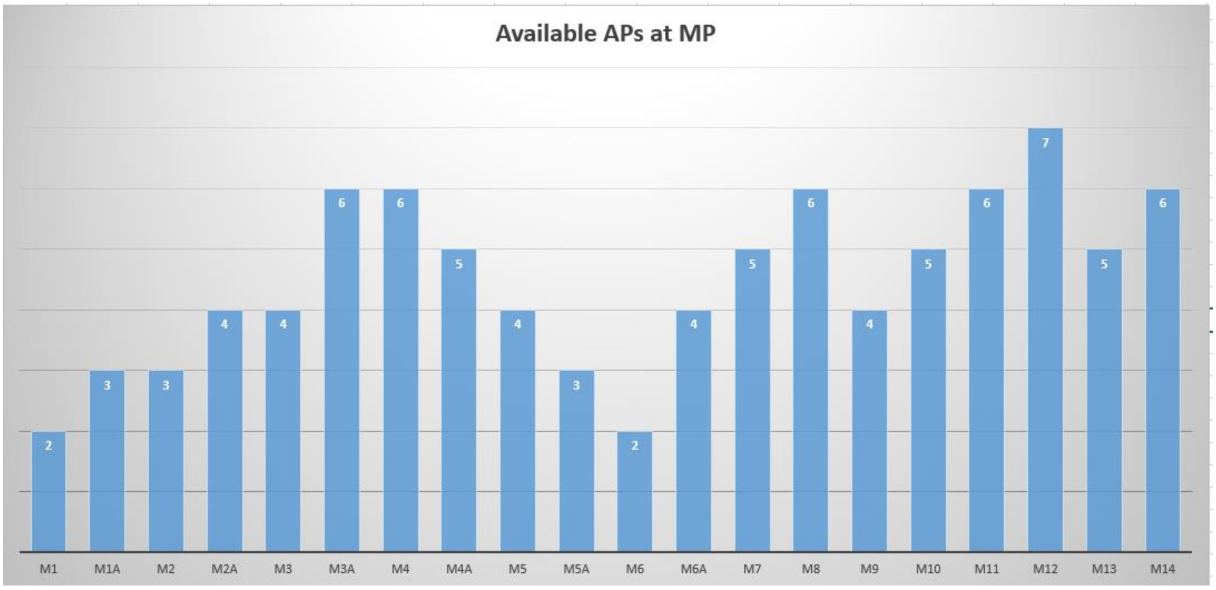
h) If the available APs are 3 or more, we make unique combinations each with 3 APs. Using each combination, we use the simultaneous equations mentioned in section 1 to estimate the user XY coordinates. The total number of XY coordinates are equal to the total number of combinations we have.

i) If we have more than 1 combination (more than 1 estimated XY coodinates), we take median XY and predict it to be the user's location.

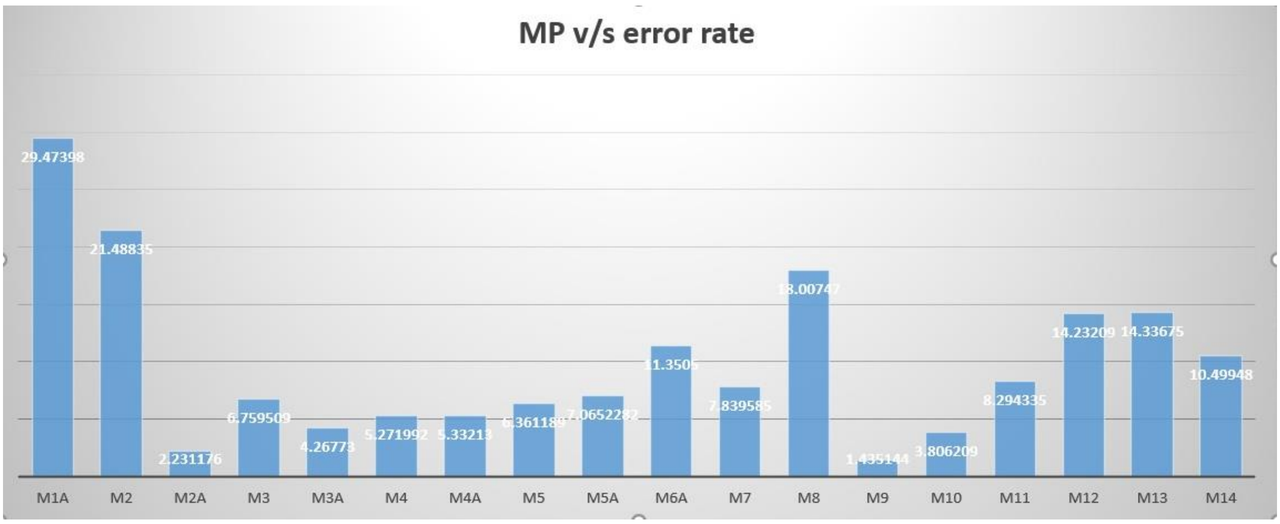
In this section, we described the basic structure of our algorithm. The results and observations based on this algorithm are mentioned in the sections below.

11. Results

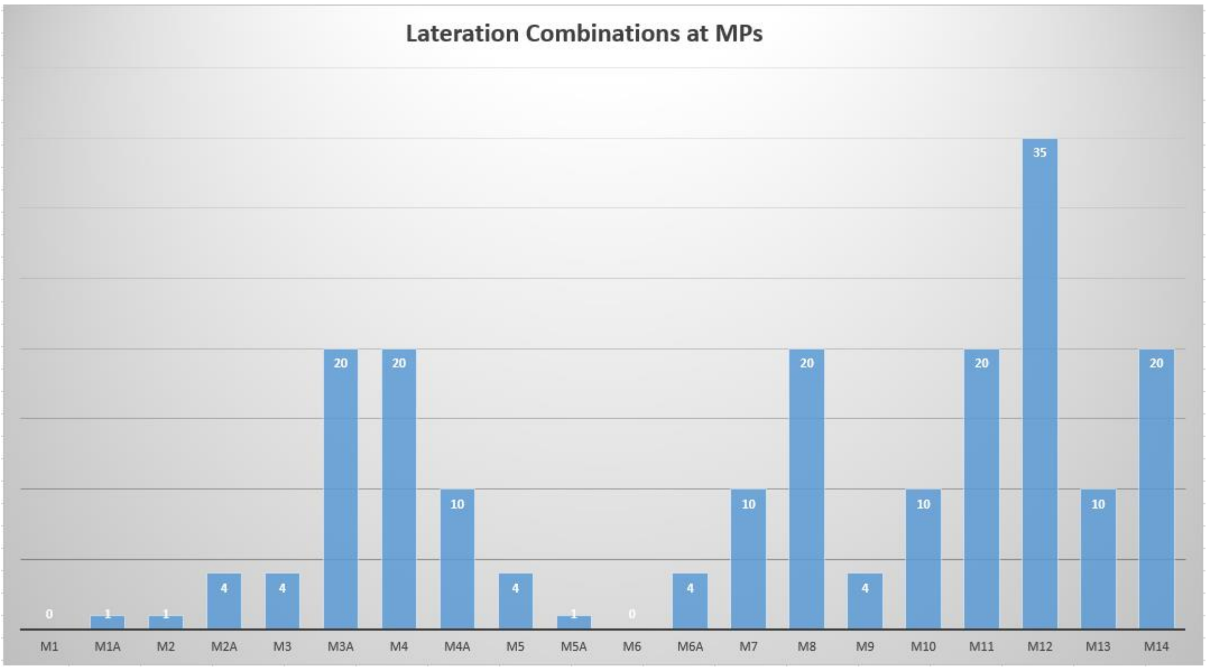
The number of available APs at each measuring/test point is shown below:



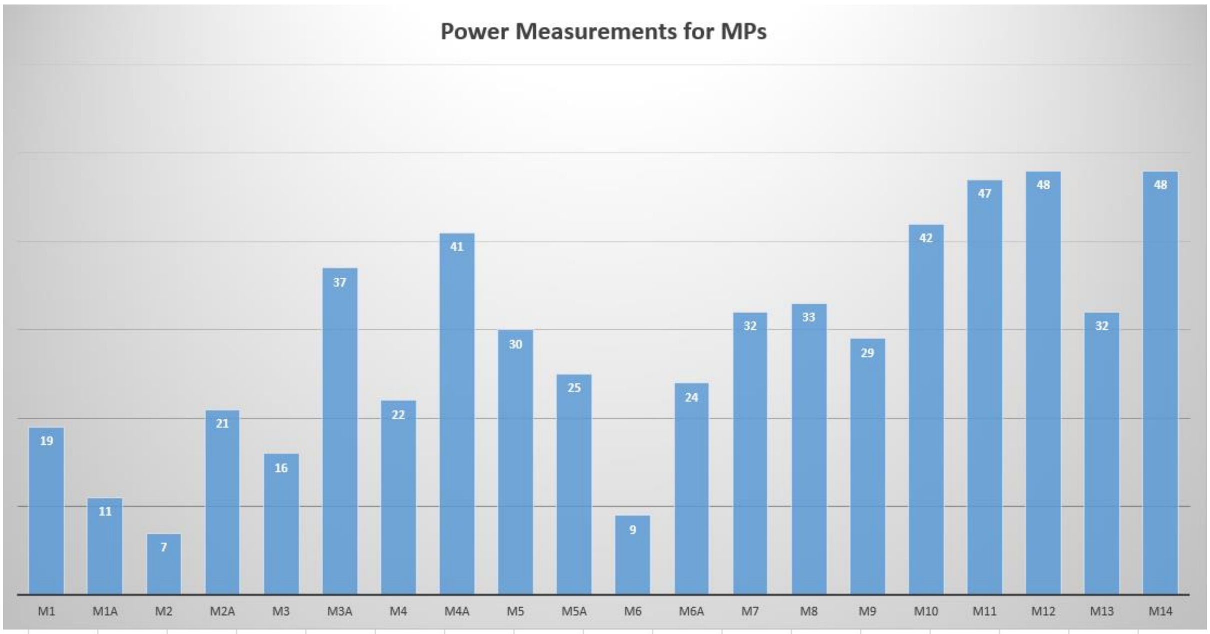
The average error (in meters) at each measuring/test point is shown below:



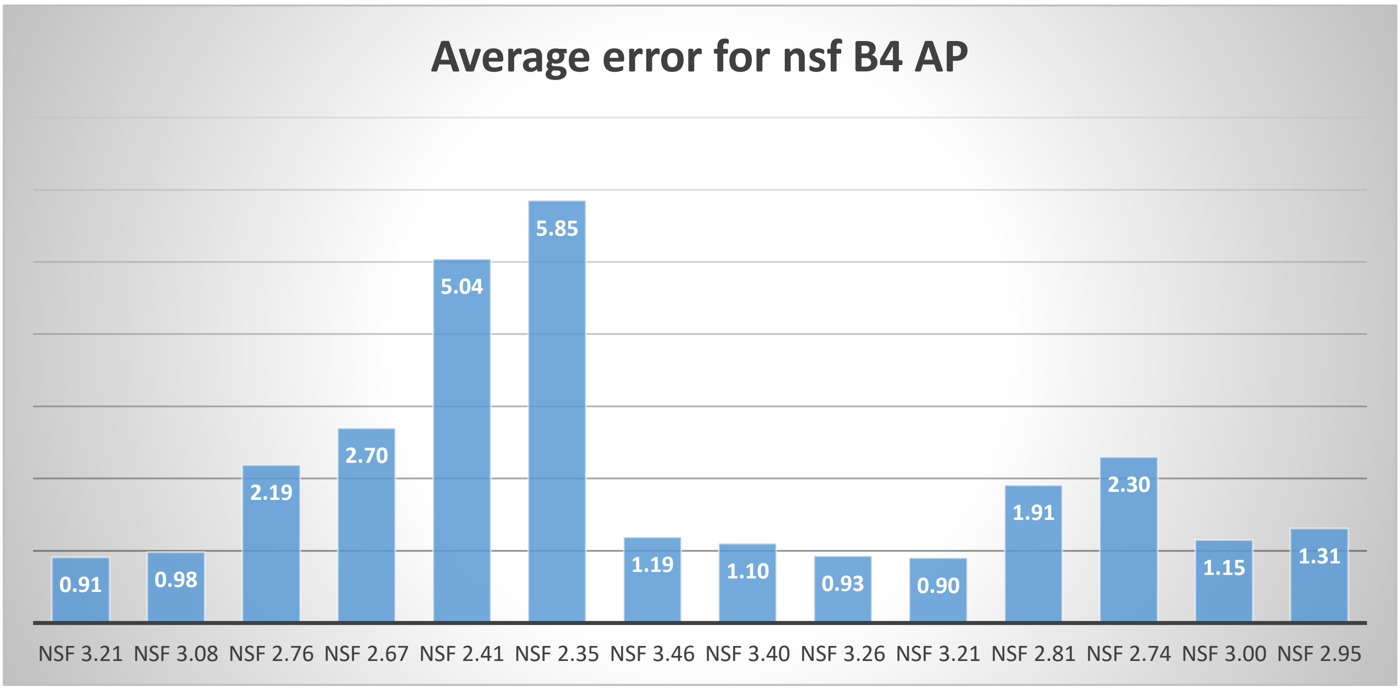
The total of combinations for trilateration at each measuring/test point is shown below:



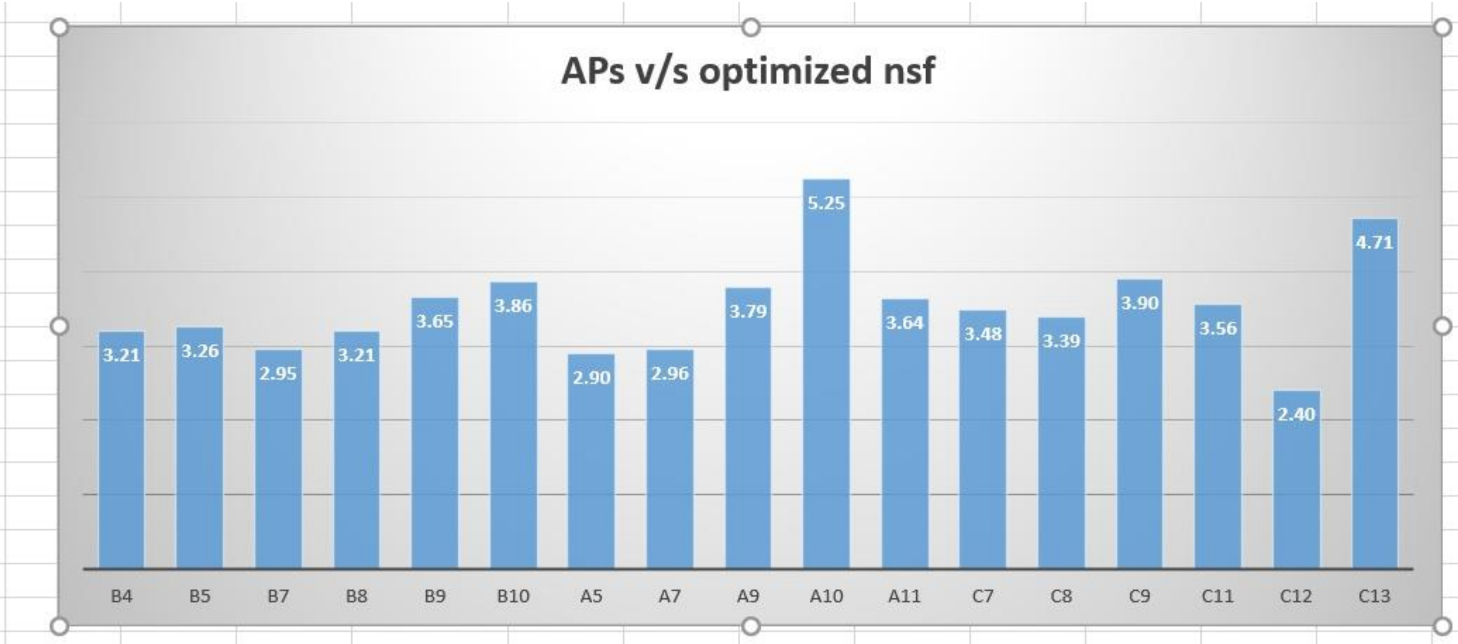
The total number of power measurements taken at each measuring/test point is shown below:



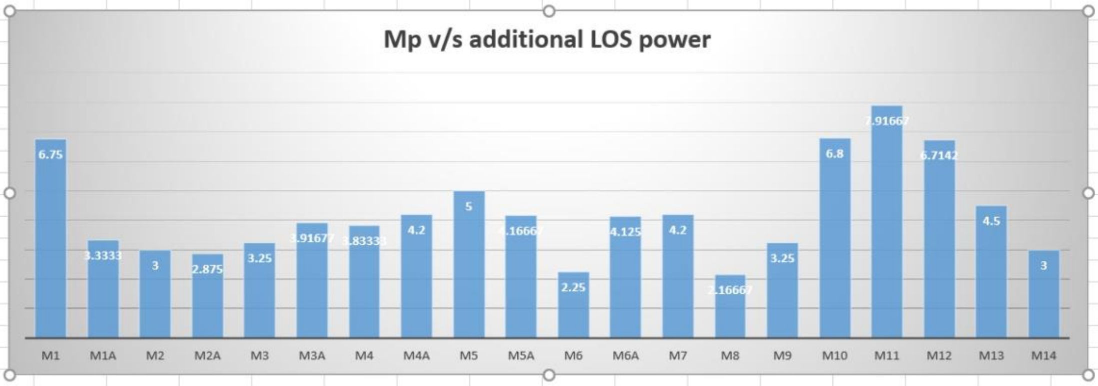
The different evaluated nsf for one AP (B4) are shown below. The different values show average error (in meters) for each nsf.



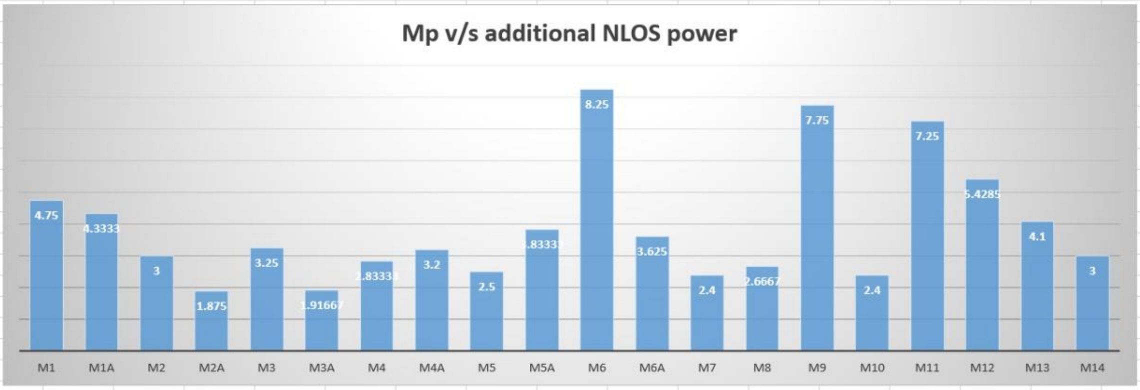
The optimum nsf for each AP are shown below. The different values show average error (in meters) for each nsf.



The average additional power (LOS) received at each measuring/test point



The average less power (NLOS) received at each measuring/test point



12. Observations and Remarks

The key observations from the results in this project are:

- Increasing the number of combinations for laterations increases the performance till a threshold point (10-20 combinations)
- Beyond the point, performance falls (low power APs affect)
- Least accuracy with points with just 1 combination of APs
- Higher nsf value for a weak router and vice versa
- Practically, the antenna is not omnidirectional in horizontal plane
- Orientation of body (LOS/NLOS) and elevation of hand drastically affect the results (our solution)
- Nsf optimization is core part for the WiFi propagation modeling
- The initial time measurements in mobile application are corrupted/old and need time for updates (our solution: timers)

12.1 Case of AP: A10

It has highest nsf recorded which is equal to 5.25. This was mainly because it was surrounded with high walls and corners and these walls acted like floor in attenuation. Even with smaller distance of 12m, the power level dropped to -80dBms. This is shown in picture.

13. Limitations of Proposed Model

The proposed model has following limitations

- For future, a maintenance service needed for the optimization of the nsf. This is because in long term the optimum nsf doesn't remain same. But in large indoor offices, this maintenance is implementable.
- This model doesn't implement other important factors in propagation (like FAF). Mainly, because of the limited scope, which is why our model is limited by FAF.
- We incorporated the median as statistic measure to decide the quality of measurements, which is not perfect. In future, better statistic model can be employed to identify the quality of data.

14. Future Variations

Following are the few future recommendations regarding our proposed model:

- Can be extended to other floors
- Can be extended to find the 3d coordinates
- Can be added with the feature of finding the route by entering the destination point (i.e. room no).
- We can employ UWB for accurate mapping of XY coordinates in indoor space (Reference)
- Can be used with Inertial Sensors in Fusion for better accuracy especially indoor
- Can be modeled with better statistical models to evaluate quality of data (power measurements)

15. Conclusion

In this report, we discussed the literature background of indoor positioning using WiFi signals. We presented our model specifications and validity. We presented the experimental details and setup. Following on, we described our timeline of the project and what challenges we experienced. The solutions for those challenges especially limited number of APs and optimization of nsf. We proposed the solutions for these challenges. We presented our proposed algorithm and displayed results indicating the performance of our approach especially in measuring points when there are multiple access points. At the end, we commented on the results and discussed few limitations in our approach and what future modifications can be employed to enhance performance.

16. Software Tools

Alongside this report, we are attaching the software tools we used during this project and which can be used by another user.

16.1 Project_DataSheet.xlsx

Sheet title	Description
APs database	This sheet contains all information about the Access points
Measuring point (MP) database	This sheet contains all information about the measuring points
APs availability at MPs	This sheet shows presence of available AP for each MP
Estimated positioning	This sheet shows the estimated positioning for MPs and respective error
MP power values combined data	This sheet contains all the power measurements recorded for the experiments at test points
Nsf and Nmf for AP derivation	This sheet contains all the power measurements recorded for n_{sf} optimization

16.2 Evaluation_and_Optimization_of_nsf.xlsx

In this file, we have shared the extensive data for each AP in optimization of best nsf we found for each AP.