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DESIGN AND IMPLEMENTATION OF INDOOR MULTI-FLOOR LOCALIZATION MODEL BASED AOA/RSS USING 2.4 GHZ WI-FI ACCESS POINT

Sohaib ALAGELE

Master's Thesis

Supervisor

Asst. Prof. Dr. Ayça Kurnaz TÜRKBEN

Istanbul, 2022

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The thesis titled DESIGN AND IMPLEMENTATION OF INDOOR MULTI-FLOOR LOCALIZATION MODEL BASED AOA/RSS USING 2.4 GHZ WI-FI ACCESS POINT PREPARED by SOHAIB ALAGELE and submitted on 14/12/2022 has been **accepted unanimously** for the degree of Master of Science in Electrical and Computer Engineering.

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I hereby declare that this thesis meets all format and submission requirements of a Master's thesis.

Submission date of the thesis to Institute of Graduate Studies: ___/___/___

I hereby declare that all information/data presented in this graduation project has been obtained in full accordance with academic rules and ethical conduct. I also declare all unoriginal materials and conclusions have been cited in the text and all references mentioned in the Reference List have been cited in the text, and vice versa as required by the abovementioned rules and conduct.

Sohaib ALAGELE

Signature

DEDICATION

I would like to express my sincere gratitude to all the instructors that have taught me more than just science, especially my supervisor Asst. Prof. Dr. Ayça Kurnaz TÜRKBEN, for all the time, support and guidance provided to me along the journey to accomplish this work. Thank you all for all the knowledge and advice that made me overcome all the difficulties that I have faces.

ABSTRACT

DESIGN AND IMPLEMENTATION OF INDOOR MULTI-FLOOR LOCALIZATION MODEL BASED AOA/RSS USING 2.4 GHZ WI-FI ACCESS POINT

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It has been generally acknowledged by many searchers and associated companies that the ability to achieve indoor localization via the use of wireless signals provided inside the Wi-Fi signal is a significant component. Because of a variety of factors, including the GPS's inability to execute high precision estimations within the building and its low cost, the presence of Wi-Fi signals makes it more convenient for researchers to manage their research projects. This work develops a hybrid localization technique based on the use of a MATLAB program as a consequence of the research conducted. The Received Signal Strength (RSS) and Angle of Arrival (AoA) signals are used to operate the model that was developed. A multifloor based localization feature has also been included, which may boost the availability of the setup devices in an interior setting. It has been selected a case study of multifloor building that designed and implanted by using the software of Wireless InSite provided by Remcom company. Additionally, it has been distributed 3 Access Points (AP) in each floor and 25 Test Points (TP) in each floor. Also, three scenarios would be included in this thesis by showing the impact of multifloor on the proposed localization method.

It was shown that better accurate estimate was attained in all three instances, with an accuracy ranging between (97.4 and 99.7%) percent, even when the influence of interference induced by attenuation and signal distortion was taken into consideration, which differed from one case study to another. Thus, the suggested technique produced more accurate results in situations when the greatest range error was 50 cm or more. And by comparing with the related previous record, it showed the major contribution of the proposed algorithm model as it it reduces the estimation error and achieve multifloor localization between two relevant floors.

Keywords: 5G, RoF, WDM, BER, Quality Factor.

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ABBRERSSVIATIONS

5G	:	Fifth Generation
2D	:	Two Dimension
AoA	:	Angle of Arrival
AP	:	Access Point
DV	:	Distance Vector
GUI	:	Graphical User Interface
GNSS	:	Global Navigation Satellite system
GOS	:	Global Positioning System
HF	:	High Frequency
LOS	:	Line of Sight
LF	:	Low Frequency
LBS	:	Location Based Service
NLoS	:	Non-Line of Sight
RF	:	Radio Frequency
Rx	:	Receiver
RSSI	:	Received Signal Strength Indicator
RTT	:	Round Trip Time
RP	:	Received Power
SHF	:	Super High Frequency

TP	:	Test Point
ToA	:	Time of Arrival
ToF	:	Time of Flight
TDoA	:	Time Difference of Arrival
Tx	:	Transmitter
UHF	:	Ultra-High Frequency
WI	:	Wireless InSite
PLT	:	Position Location Technology
MAC	:	Test Point
ToA	:	Time of Arrival
APIT	:	Advance Personal Income Tax
DoA	:	Difference of Arrival
RSS	:	Received Signal Strength
DTED	:	Digital Terrain Eleration Data
BER	:	Bit Error Rate
SINR	:	Signal Intereference Noise Ratio
RTD	:	Round Trip Delay
LQI	:	Link Quality Indicator
APIT	:	Advance Personal Income Tax
GPS	:	Global Positioning System

1. INTRODUCTION

1.1 MOTIVATION

Position location of a user or a device in a given space is one of the most important elements of contextual information. The widespread use of sensors has produced an increasing wealth of such information. By itself, location has generated great attention because of its potential to leverage commercial applications such as advertisement and social networks [1].

The user context, constituted by all relevant items surrounding her/him, has been given paramount importance in the design of next-generation information systems and services. The adaptation to a changing context is precisely what makes those next-generation systems flexible and robust [1].

The environment in which we live is growing more complicated, with an excessive number of elements, which has an impact on localization operations, whether inside or outside. Due to the vast variety of applications that wireless localization methods have in both the public and military spheres [2, 3], they have gained prominence in recent decades. Although not all wireless technology users will be able to take use of one of the most crucial technologies, Positioning Location Technology (PLT), it will be made accessible to them. New positioning localization techniques leveraging a variety of applications have recently been presented [4] that are more reliable and less expensive than previous approaches. Target tracking, people surveillance, drone control, and patient monitoring are just a few of the location-based applications [5-13].

Many variables influence precision in PLT, including physical location (X and Y coordinates), environment (outdoor or indoor), network architecture (centralized, decentralized, or distant sensing), cost, and wireless protocol (Wi-Fi, Bluetooth, RF, and ZigBee) [5].

They transmit information by using electromagnetic waves such as satellites, infrared, and other technologies [14]. WiMAX, satellite, broadcast radio, microwave, and Wi-Fi are some of the outside wireless communication networks available [15].

A satellite for timing and ranging was launched in 1978 and was utilized for the first time. A GPS system was completely operational in 1993. GPS is currently a multi-purpose space-based radio navigation system that is used for navigation, aviation, surveying, communications, mapping, and geophysics [16]. GPS is also utilized in space-based laser navigation systems. GPS systems are now capable of locating themselves outside with an inaccuracy of just 5 meters [17]. Because of the limited visibility and poor signal reception in interior environments, GPS receivers work best when they are in a direct line of sight (LOS) with the source of the signal.

Because the vast majority of crucial communication takes place inside [18] and because we spend a significant amount of time in large places (e.g., airports), indoor localization is essential for personal tracking and monitoring. Since location-based services (LBS) can monitor people or items, they have become more popular for improving our quality of life [19-21].

While satellite communications provide a significant benefit in terms of location technology, they seem to work poorly when used inside buildings. For example, GPS accuracy is around five meters, which is satisfactory when used outdoors.

In an interior context, five meters might denote a distinct room or unit, leading the computer to believe that an item is in a different location than it is. This might fail in the LBS service and user dissatisfaction. As a consequence, researchers are always experimenting with new methods of obtaining precise location and time information inside [18]. Designing an appropriate indoor and outdoor localization system employing the Angle of Arrival (AoA) is a challenging task. The provided approach for constructing will be used in our experiment. A virtual model will be created with the help of the WI tool.

1.2 CLASSIFICATION OF LOCALIZATION TECHNIQUES

The localization-based method is classified into two main categories as shown in Figure 1.1

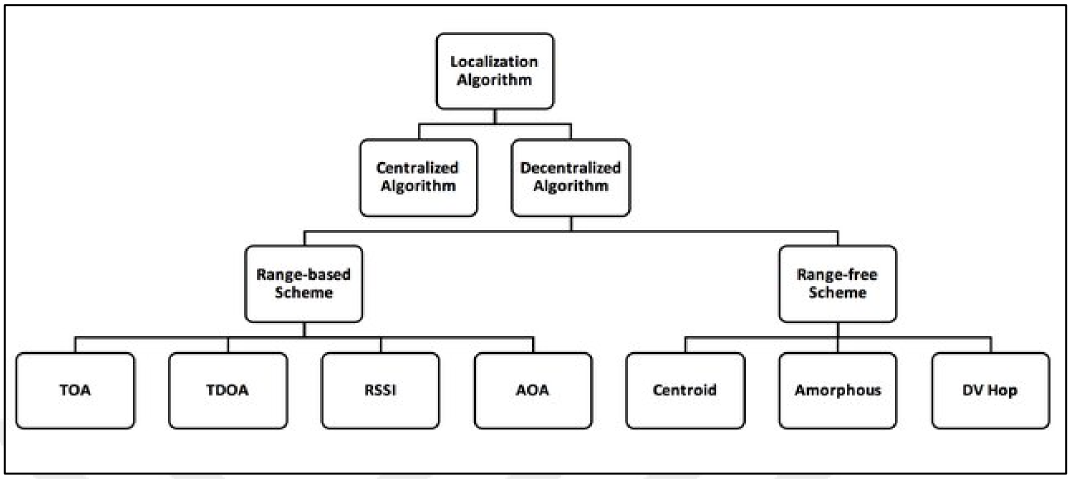

Figure 1.1: Classification of localization techniques.

For ranging-based techniques, RSSI is employed to estimate the distance between transmitters and receivers whereas the accuracy of this approach is highly influenced by interferences [20]. Ranging-free techniques are reported to have a more stable performance [21]. The main approach for ranging-free category is based on ’fingerprinting’ method. Other wireless signal parameters, such as the Time of Flight (ToF), Time of Arrival (ToA), Time Difference of Arrival (TDoA), Angle of Arrival (AoA), and Received Signal Strength Indication (RSSI) [22-28], are used to indirectly approximate the range. These parameters include having the disadvantage of being highly susceptible to timing inaccuracies, necessitating the use of correctly synchronized clocks to function effectively. Furthermore, these algorithms perform best in LOS circumstances to calculate accurate distances.

AoA is another active localization approach that is also known as Direction of Arrival (DoA), which is defined as "the incidence angle at which radio signals from the transmitter (TX) travel to the receiver (RX)" [29]. It is defined as "the angle at which radio signals from the transmitter (TX) travel to the receiver (RX)". By triangulation, if two AoAs are supplied, along with the coordinates of their corresponding RX, the two-dimensional (2D) coordinates of the TX may be computed as well. Because directional antennas or antenna arrays are necessary for reliable AoA measurements [22], radio frequency (RF) equipment is sophisticated and costly.

In conjunction with the Log-normal distance route loss model, RSSI is another measure that is used to calculate the TX-RX distance between two points. However, because of the multipath effect, RSSI measurements in the interior environment are subject to transient and locative signal shifts, resulting in the hazy and inaccurate location in most cases. Although noise has little impact on the RSSI, this is because the signal suffers from attenuation as it propagates, whereas noise does not exhibit this characteristic [23]. Approaches that do not need a range may be divided into three categories: proximity detection, Distance Vector Hop (DV-hop), and fingerprint matching [30-32]. AoA, on the other hand, has been classified as a range-free technique by certain authors, such as [22].

1.3 INDOOR ENVIRONMENT

Since Global Navigation Satellite Systems (GNSS) are regarded the primary localization approach outside, the supply of such a technology in an interior environment continues to be a difficulty that has yet to be satisfactorily resolved [66, 67].

The interior environment, on the other hand, facilitates the process of localization in a variety of ways [32]:

i. There is just a little area to be covered.

ii. There is little variation in weather (low-temperature fluctuations, slow air currents)

iii. It is quite simple to install targets because of the availability of infrastructures, including wall and electrical infrastructure, as well as intranet access availability.

iv. Lower dynamics as compared to the outside, such as walking or driving speeds, for example.

1.4 INDOOR LOCALIZATION PROBLEMS

Even though almost all localization techniques can theoretically be used in both in and out-based scenarios, in practice, the performance of these techniques will differ significantly between the two environments because there are several genuine differences between two environments.

Indoor localization is a difficult task since it must contend with a variety of issues, such as:

1.4.1 Multipath Phenomena

As shown in Figure 1.2, In radio communication, multipath is the propagation phenom-enon that results in radio signals reaching the receiving antenna by two or more paths. Causes of multipath include atmospheric ducting, ionospheric reflection and refraction, and reflection from water bodies and terrestrial objects such as mountains and buildings. When the same signal is received over more than one path, it can create interference and phase shifting of the signal. Destructive interference causes fading; this may cause a radio signal to become too weak in certain areas to be received adequately. For this reason, this effect is also known as multipath interference or multipath distortion. [33].

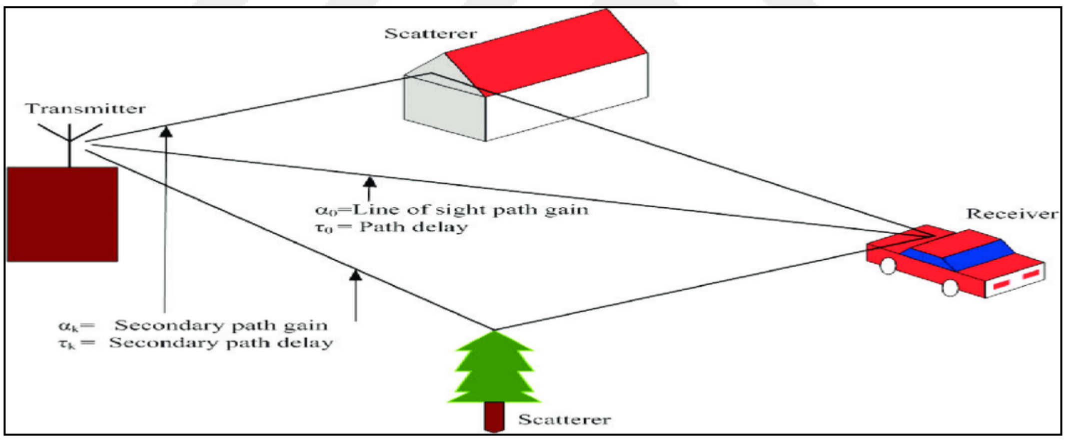

Figure 1.2: Multipath Propagation Phenomenon [34].

1.4.2 Non-Line of Sight (NLOS) Conditions

Non-line of sight (NLOS) refers to the path of propagation of a radio frequency (RF) that is obscured (partially or completely) by obstacles, thus making it difficult for the radio signal to pass through. Common obstacles between radio transmitters and radio receivers are tall buildings, trees, physical landscape and high-voltage power conductors.

While some obstacles absorb, and others reflect the radio signal; they all limit the transmission ability of signals. Non-line of sight is also known as near line of sight. [32].

1.4.3 Signal Attenuation

As radio signals travel in all directions and penetrate solid objects it suffers from attenuation Figure 1.3.

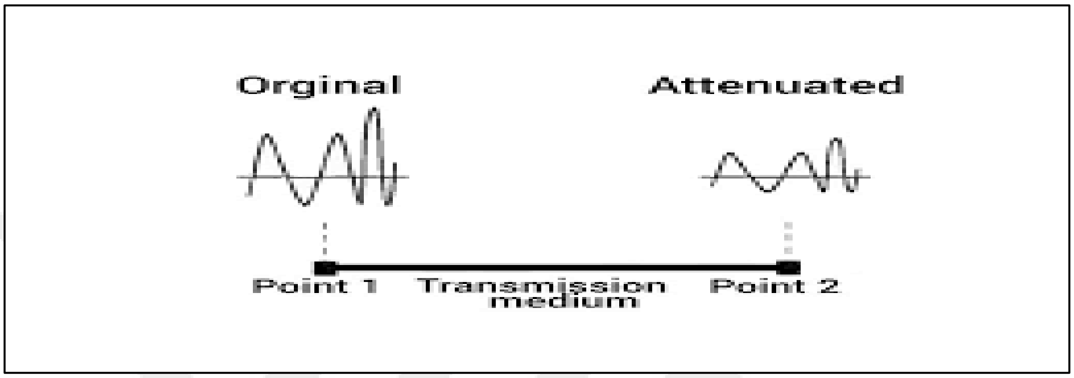

Figure 1.3: Signal Attenuation.

Attenuation is the loss of signal strength in networking cables or connections. This typically is measured in decibels (dB) or voltage and can occur due to a variety of factors. It may cause signals to become distorted or indiscernible. An example of this is Wi-Fi signal and strength getting noticeably weaker the further that your device is from the router. This categorization is explained in the following Table 1.1. Depending on the electrical qualities of the material, building materials may create more attenuation of radio signals in the interior environment [32]. For example, wooden materials can cause less signal attenuation than brick and concrete, which cause higher signal loss. [32].

Table 1.1: Frequency Ranges [32].

No.	Frequency	Range
1	Low Frequency (LF)	(30-500) kHz
2	High Frequency (HF)	(3-30) MHz
3	Ultra-High Frequency (UHF)	(433 and 868) MHz to 930 MHz
4	Super High Frequency (SHF)	from 2.4 GHz to (2.5 and 5.8) GHz

1.4.4 Signal Scattering

Scattering is when an RF wave encounters an object and scatters into multiple waves. Some examples of common objects that cause scattering include dust, smog, humidity, and chain link fences. If a signal has been scattered, then the integrity and strength of the signal will suffer tremendously. Scattering is more unpredictable than the other issues mentioned in this post, but with proper planning, a solution can at least be addressed in the setup. The phenomenon of signal scattering can be seen in Figure 1.4 [35].

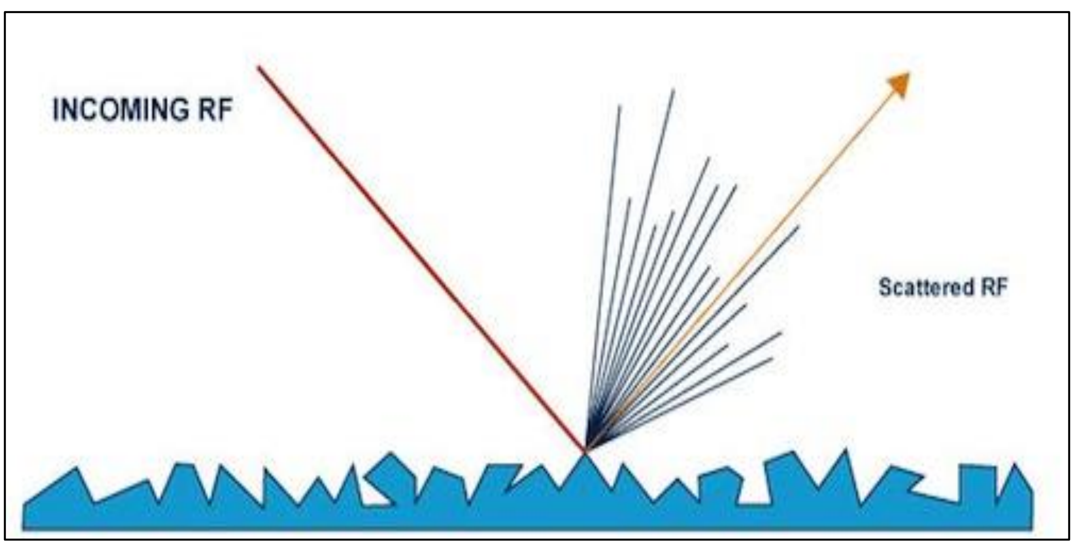

Figure 1.4: Signal scattering.

1.4.5 Effect of Furniture, Human Body, and Other Indoor Objects

The presence of these items is regarded to be one of the major significant issues in indoor localization since they have the potential to impair signal transmission, as shown in [36], in which the researchers discovered that indoor bulbs may cause considerable dispersion in radio signals. When a signal is sent via the human body, it creates an impedance to the signal and is regarded to be one of the signal disruptions, particularly in a crowded situation.

1.5 THESIS OBJECTIVES

This thesis is constructed aiming for the following objectives:

i. Investigate the accuracy of AoA-based indoor localization technique using WI software and for two related floors-based localization.

ii. Including the effects of different building materials between the two studied floors for indoor localization based on Wi-Fi signals.

iii. Compare the results obtained from WI (actual coordination) and the results obtained by the proposed model (estimated coordination), which was designed using MATLAB program.

1.6 PROBLEM STATEMENT

In response to the rising demands of modern life, new advances have been achieved in a wide range of fields of science and technology, with target localization regarded to be one of the most important of them. When working in an indoor location, the surrounding environment has a significant impact on the localization process. As a result, the need for an accurate result localization model that could effectively work in indoor places is a very important issue to be handled. Also, the need for a localization model that could handle multi-floor localization with higher accurate results based on the utilization of Wi-Fi router signal, is a very important issue to be handled.

1.7 AIM OF THE THESIS WORK

The proposed localization model aim's is to design and implement a model for indoor localization based on the parameters of Angle of Arrival (AoA) and Received Signal Strength (RSS) obtained from each received point (Rx) within the case study that would be selected. this work considers a lower cost, higher effectiveness indoor localization method that works based on Wi-Fi signal generate from regular routers. The proposed model would effectively handle the multi-floor scenario localization to calculate the accurate results for the Received points (Rx).

1.8 THESIS OUTLINE

The thesis involves five chapters, these are:

i. Chapter one involves general considerations in the localization process in indoor environments, it also briefly discussed the classification of localization methods, and then the thesis aim, objectives, and problem statement would be formed in this chapter.

ii. Chapter two will demonstrate the recent publication that was related to the proposed thesis topic by clarifying the significance of each work and the drawback of each method proposed by other researchers.

iii. Chapter Three introduced the proposed design for study adapted in this thesis in addition to studying models which are indoor models.

iv. Chapter Four contains the results obtained from applying the localization algorithms to investigate the accuracy of AoA measurement and target localization under the influence of the experimental circumstances proposed in this thesis.

v. Chapter Five includes the most important conclusions highlighted by the results of the thesis.

2. LITERATURE REVIEW

i. In 2016 Mohd Ezanee Rusli et.al. [37] A superior RSS - a trilateration-based technique for Wi-Fi indoor restriction has been proposed, in which trilateration is executed for target position assurance and afterward further developed utilizing a particular reference point is utilized to work on the outcome. The typical blunder viewed as 2 meters has been decreased to 1 meter with the better plan. The suggested approach was shown to be successful in an indoor setting. In estimating, however, accuracy was reached to a maximum of two meters, which has to be further improved and increased by employing different approaches or relying on a variety of data, among other things.

ii. In 2017 Stijn Wielandt and Lieven De Strycker [38], The use of multipath effect manipulation to improve AoA accuracy localization systems was looked at in this study. The proposed multipath-assisted approach, which is similar to fingerprinting in that it compares an AoA measurement vector with several reference vectors, is used to localize a mobile TX. Additionally, a single fixed receiving antenna array was needed to complete this operation. It is evaluated in both LOS and NLOS scenarios, and the results demonstrate a large gain in accuracy while simultaneously decreasing setup time when compared to a traditional fingerprinting technique, which is a major improvement. On the other hand, relying on a fingerprint would be regarded as an offline-based technique, which would then need to be further handled via an online approach, which might have an impact on the accuracy of the suggested method.

iii. In 2017 Mohammed A.G.Al-Sadoon et.al. [39] proposed low-intricacy AoA estimation to appraise the transmission bearing in remote correspondence frameworks straightforwardly from the got signals and contrasting the outcomes and other normal and as of late presented AoA estimation techniques, the benefits of this new methodology incorporate intricacy decrease, exactness improvement, and a decrease in the number of depictions required. The framework, then again, still should be grown further.

iv. In 2017 Stijn Wielandt et.al. [40], a single anchor node indoor localization system was explored, with the location of an omnidirectional mobile TX being estimated by the use of fingerprinting AoA at a carrier frequency of 2.47 GHz being estimated. According to the results, spatial smoothing had a substantial impact on the quantity of performance, and there was a considerable gain in accuracy when compared to previously reported RSS systems.

v. In 2018 Stijn Wielandt et.al. [41], At 2.4 GHz frequency bands, an AoA multipath aided technique was used in conjunction with ray tracing in indoor-based cases to take advantage of signal reflections under both scenarios. This technique was proven to have improved precision, particularly in non-line-of-sight settings, and to have much better performance at 2.4 GHz than previous approaches.

vi. In 2018 Boyi Wang et.al. [42], suggesting a low complexity GNSS signal estimation method, findings demonstrate that the technique can effectively estimate AoA and have a low RX complexity and simple implementation with calculated AoA values may be utilized to increase the noise ratio.

vii. In 2018 Slavisa Tomic et.al. [43], A mixture RSS/AoA estimation framework was utilized to resolve the issue of target restriction, and the reproduction results showed the viability of the proposed calculation. Moreover, an examination was made between a half and half framework and the old-style frameworks (RSS and AoA), and it was found that there was a critical advantage from the estimation mix. The aftereffects of the correlation show that embracing the half and half methodology for restriction enjoys a significant upper hand over not utilizing it by an enormous degree.

viii. In 2018 Yinan Hou et.al. [22], they proposed a wireless indoor localization strategy that makes use of the AoA and coordinates, which are supplied by the Wi-Fi AP, to provide wireless indoor localization for outpatient wayfinding in a hospital where only two APs were placed. When analyzing the results, it was discovered that the localization error was approximately two and a half meters in approximately 80 percent of the cases, which was sufficient to satisfy the users. The main disadvantages were the high cost of the infrastructure and the fact that the algorithm was designed primarily for LOS conditions, which made this algorithm only useful in limited situations in real-world applications.

ix. In 2018 Mohamed A. Landolsi, Razan Shubair [44], The use of ML estimation for efficient data fusion of ToA, AoA, and RSS measurements, as well as the use of a small number of measurements, for the provision of more accurate mobile target localization in comparison to other techniques that rely on using a single parameter only (e.g. ToA-, AoA-, or RSS-only approach), was investigated. The results showed that localization error reduction was achieved in poor signal strength situations.

x. In 2019 Oras A. Al-Ani et.al. [45], provided a two-step localization approach for optimal Access Points (APs) site deployment based on RSS simulation measurements acquired from the WI tool and based on the RSS simulation measurements obtained from the WI tool. When compared to the other sites tested, the best position had a 0.74 RSS range probability and the greatest mean received power value (-45) dBm, as well as lower route loss values than the others. The researchers' strategy is to discover the most optimal spot for AP placement among four potential corner-based locations that have been identified by the researchers. This would be followed by a strategy that was developed based on the findings acquired from the Wireless InSite (WI) simulation program to locate the most optimal AP position. There will be no localization of the target node or the user node using this strategy. Because it is assumed that the user node and the receiving node are both fixed and have a known position, this is the case.

xi. In 2019 Oras A. Shareef Al-Ani, Karrar S. Mutter, and Mahmood F. Mosleh [46], utilized the WI tool to simulate a case study analyzing an ideal TX site with a suitable RSS to give improved coverage in an outdoor setting the findings revealed that the existence of obstacles, as well as the material, attributes associated with them, had a substantial impact on location determination in both LOS and NLOS areas. The RSS signals were the sole ones used in the suggested technique. In addition, the obstacles associated with the surrounding environment had a significant impact on this parameter. As a result, to get the highest overall performance, a hybrid-based approach must be used.

xii. In 2020 Mosleh, et al., [47] A localization approach based on the ToA/AoA/RSS methods has been suggested. The case study was built and modeled with the help of the WI software. The suggested approach made use of three APs and was designed to determine the estimate of distinct user nodes that were situated across the indoor facility. The ToA/RSS technique was used to calculate the distances between the AP and each user node. Then, using the AoA/RSS approach to identify the coordination for all of the tested user nodes in conjunction with the case study, the results are presented. In this case, the power used for AP was around 6 dBm, and the gain was less than 5.5 dB. However, no input power value has been provided to either the user node or the target node, therefore it is impossible to determine the purpose of implementing such a localization procedure without knowing the user node or the target node. The collected findings demonstrated that the suggested technique was unable to attain greater accuracy results for certain of the distributed testing nodes, resulting in a poor estimate for some places. Furthermore, the suggested solution only handles localization for a single-floor situation, which is a limitation.

xiii. In 2020 Riam et al., [48] A hybrid localization approach based on the characteristics of AoA/RSS has been proposed and has shown to be successful when used in conjunction with one another. The WI simulator was used to design, develop, and test the desired building in real-time. APs were employed in this research to determine the number of receiving nodes or target nodes present in the chosen case study using two of them. The results produced through WI were checked for accuracy in terms of localization and were found to be accurate in all cases. However, the inaccuracy ratio reached up to 60 cm, which indicates a potential weakness, particularly when dealing with localization for interior case studies, and which requires further improvement. In addition, this research only considered a localization for a single floor scenario connection and did not evaluate the two important floors-based scenarios that were considered in the previous study.

As a result of their observations, a large number of APs must be installed on each level in order to localize distinct target nodes that are situated on the same floor.

3. THEORETICAL BACKGROUND AND HYPOTHESES

3.1 INTRODUCTION

This chapter will cover the subjects associated with the many kinds of localization methods, as well as the key assumptions associated with each type. After then, a high-level overview of the WI software will be developed. This chapter would comprise the proposed case study, as well as the specifications and criteria that have been chosen for inclusion. Additionally, the suggested hybrid model for AoA/RSS localization for multi-floors scenario will be clarified as a step-by-step procedure with diagrams to support it will be shown. Finally, the parameter to be studied and utilized in conjunction with the suggested model, which has been generated via the use of WI software, will be shown.

3.2 WIRELESS INSITE (WI) SOFTWARE

Is a suite of RF propagation models, providing 3D raytracing, fast ray-based methods, and empirical models for the analysis of site-specific radio wave propagation and wireless communication systems. Through its combined modeling, simulation, and post-processing capabilities, it provides efficient and accurate predictions of EM propagation and communication channel characteristics in complex urban, indoor, rural and mixed path environments. WI needs extensive three-dimensional (3D) building data to simulate propagation in an urban setting. Using the WI tool, we were able to generate a simulated model as shown in Figure 3.1. If you choose another method, the virtual environment may be created by utilizing particular editing tools inside WI or imported from frequently used file formats (shapefile, DXF, DTED). There are two options for determining the location of TX and RX: either utilizing the program's built-in site definition tool or importing them from other external data sources. A particular work area may be formed as a section of the overall area, using separate calculations, for a big obstacle area. If the overall region is vast, it may be possible to establish a specific work area as a piece of the overall area. Metrics including throughput and capacity, BER, noise, interference, and SINR make Wireless InSite a powerful tool for determining whether a device will meet 5G performance requirements in a realistic operating environment.

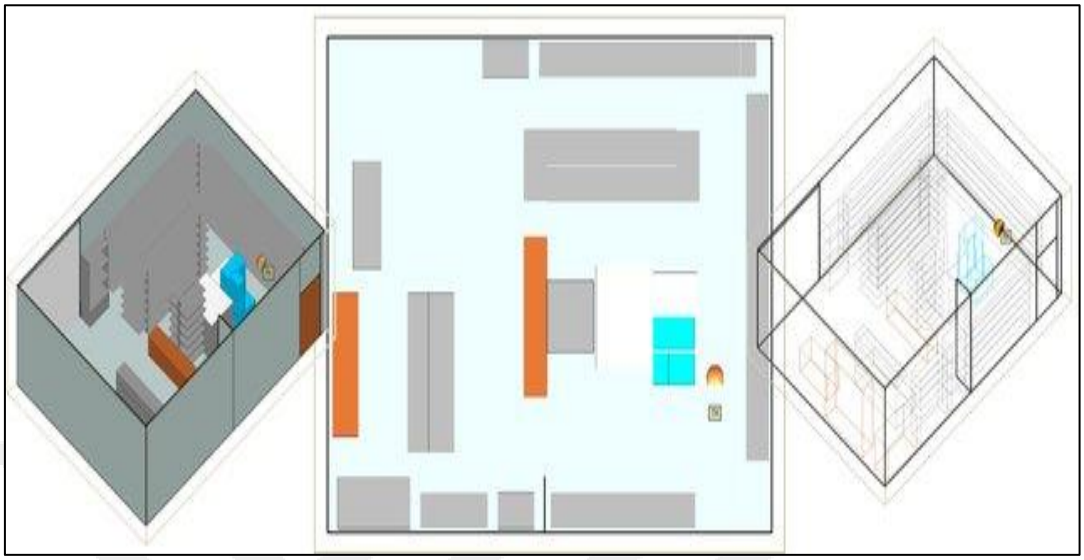

Figure 3.1: Design an example model using WI software.

Alternatively, the virtual environment may be created inside WI or imported from popular formats (shapefile, DXF, DTED). TX and RX may be located using the program's own site definition tool or by importing data from other external files. In vast obstacle areas, a particular work region may be determined by doing independent calculations on that piece of the total area.

WI calculates electromagnetism by studying propagating beams from TXs to RXs and their interactions with ambient elements such as:

i. Reflection off the ground;

ii. Reflection off the face of the building surface;

iii. Diffraction off the building's edges;

iv. Transmission through multiple walls.

To compute the resulting signal level, each interaction along the signal's path from the source to the receiver is continuously evaluated. Each RX measures and analyzes signal metrics such as latency, delay spread, route loss, DoA, RSS, and impulse response. The ray paths for each

TX/RX pair may also be shown. For more exact findings, a frequency range of 50 MHz to 40 GHz was used. WI may play movies of time-domain E-field development in addition to visual representations (such as TX coverage area and power distributions). It also has a complex charting system.

3.3 LOCALIZATION TECHNIQUES

"Location" refers to the factor of finding the place of an item either in a coordinate system or about another well-known location [32]. This may be accomplished via the use of a variety of localization methods with varying degrees of precision. Range-based methods and range-free methods are the two primary groups of approaches.-

3.3.1 Range-Based Localization Techniques

The positioning procedure of these techniques is based on range or angle data, which include:

i. Time of Arrival (ToA)

ToA depends on the idea of estimating the sign's one-way proliferation time as it goes from the transmitter to the recipient. Since the sign's engendering speed in space approaches the speed of light, the TX - RX distance (d) might be Figured utilizing the condition:

$$d= c \times t \qquad (3.1)$$

Where c is light velocity, t one way propagation time [6]. ToA principle can be illustrated in Figure 2.7.

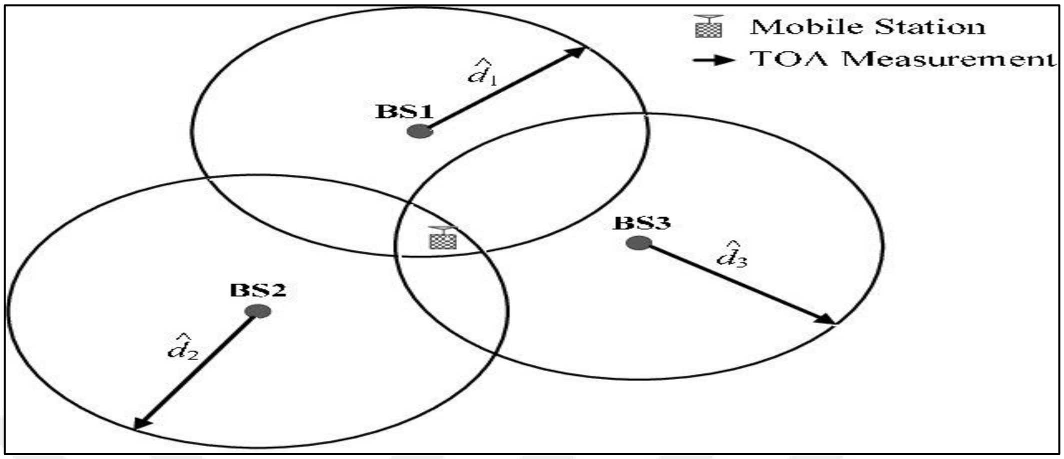

Figure 3.2: ToA localization [4].

Because of the multipath propagation in an interior setting, the time is denoted by the symbol t. The value of t may be computed as shown in equation (3.2):

$$t=\frac{\sum_{1}^{np} p_i t_i}{P_R} \tag{3.2}$$

Where np is the quantity of the ways and Pi is the time-found the middle value of force in watt of the *ith* way, PR is absolute power gets, ti is the ToA for every proliferation way which can be determined from condition (3.3):

$$t_i = \frac{L_i}{c} \tag{3.3}$$

Where Li is the overall link length [47].

When dealing with electrical signals in an indoor environment, understanding the electrical properties of the building material is critical. This is because signals penetrate through building materials and wave propagation velocity is highly dependent on the characteristics of the transferring medium. Since the ToA is particularly sensitive to timing, the TX and RX clocks must be kept in precise synchronization at all times while the device is in operation. An RF signal may cause millisecond variations in timers, which can result in a 30 cm disparity in distance measurement when used with a radio frequency signal. Time synchronization is, however, difficult to achieve due to the multipath effect, shadowing, and noise; as a result, greater bandwidth is desired in order to mitigate the multipath impact [32].

ii. Time Difference of Arrival (TDoA)

Generally, the TDOA measurement is made by measuring the difference in received phase at each element in the antenna array. This can be thought of as beamforming in reverse. In beamforming, the signal from each element is weighed to "steer" the gain of the antenna array. In AoA, the delay of arrival at each element is measured directly and converted to an AoA measurement.. It is necessary to employ perfectly synchronized TXs to remove RX bias in this technique [49] to achieve success.

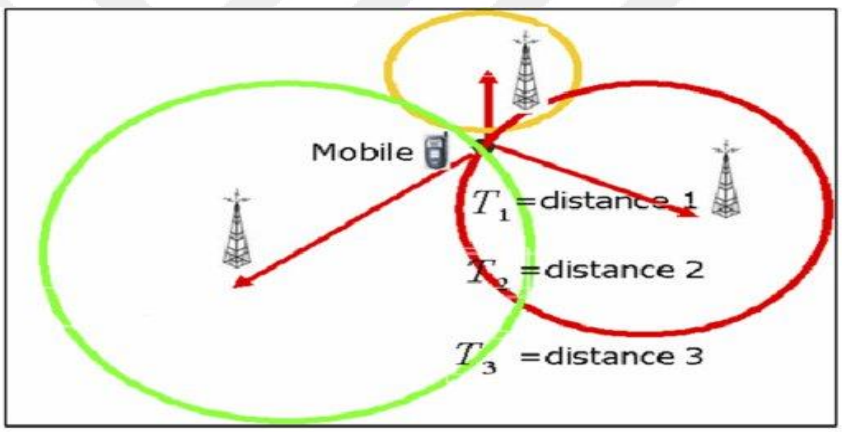

Figure 3.3: TDoA methods [4].

iii. Round Trip Time (RTT) or Two Way Ranging.

In networking, Round-Trip Time (RTT), also known as Round-Trip Delay time (RTD) is defined as a metric that measures in milliseconds the amount of time it takes for a data packet to be sent plus the amount of time it takes for acknowledgement of that signal to be received. This time delay includes propagation times for the paths between the two communication endpoints [32].

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v. D- Angle of Arrival (AoA)

The angle of arrival (AOA) positioning method has not been applied to short-range location to the extent of RSS and TOF. Short-range device antennas are for the most part omnidirectional, and also their electrical size, on the order of a half wavelength, is not suitable for narrow beam patterns in small UHF band devices [38]. Angle-based techniques estimate the position of an agent by measuring the AOA of signals arriving at the measuring station. The signal source is located on the straight line formed by the measurement station and the estimated AOA.[44]. An advantage of AOA-based techniques is that they do not require clock synchronization; however, accurate angle measurements may require directional antennas, multiple-element antenna arrays, and possibly computationally expensive array processing algorithms. Also, is a method for determining the direction of propagation of a radio-frequency wave incident on an antenna array or determined from maximum signal strength during antenna rotation.

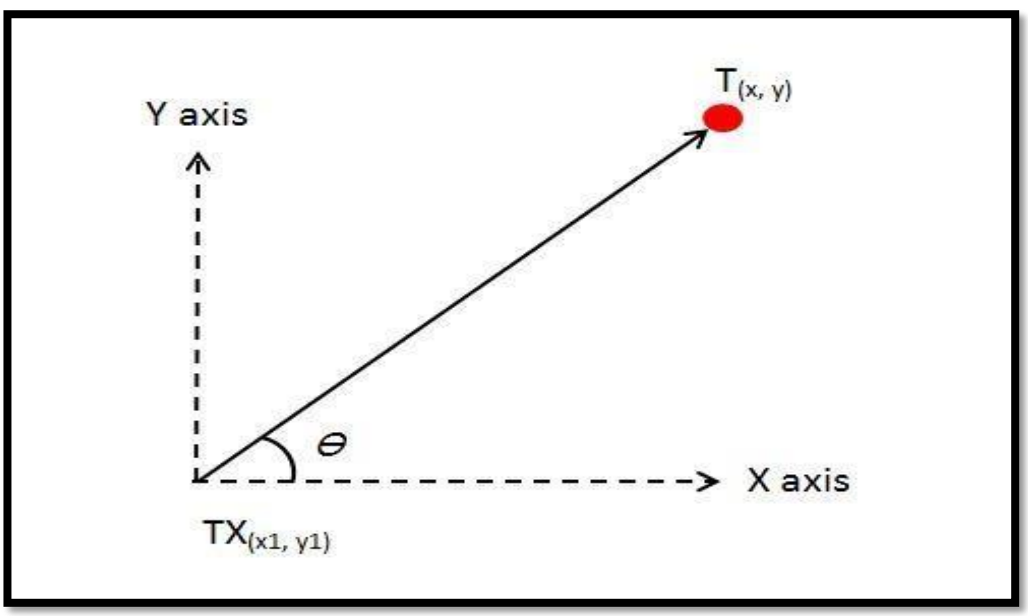


Figure 3.4: AoA method.

vi. Received Signal Strength (RSS)

The RSS or denoted as (energy) can be measured for each received packet. The measured signal energy is quantized to form the Received Signal Strength Indicator (RSSI). The RSSI and the time at which the packet was received (timestamp) are available to MAC layers for any type of analysis. For example, the simplest way to generate the link quality indicator (LQI) is to use the RSSI as an indication of link quality. The RSSI can also be used to develop a coarse but simple method of location estimation. The availability of RSSI means that a location-estimation system can be implemented without the need for any additional hardware for the individual nodes in the network. When it comes to the first kind, is based on the idea of comparing the actual RSSI values to the virtual RSSI values that have already been stored in the signal map to anticipate the target location. When two locations are separated by a certain distance, the second type estimates that distance by measuring the received signal energy at one of them. In part, this is due to channel characteristics, which can be divided into two categories: constant components and variable components. The constant components follow a path loss propagation model, while the variable components follow a complicated spectrum of effects such as attenuation, shadowing, and multipathing. On the contrary, all radio broadcasts are subject to a phenomenon known as "free space loss," in which the signal strength decreases as the signal propagates further away in space [4, 34]. The received power may be computed using the Friis equation, which is shown in Figure 3.4:

$$R_p = \frac{P_T G_T G_R \lambda^2}{(4\pi R)^2} \tag{3.4}$$

Where PT is the sent power, R is the distance isolated between the transmitter and beneficiary, GT *and* GR is the addition for transmitter and collector individually. Moreover, the got power can be determined as a distance reliance way misfortune as communicated in equation (3.5) [24]

$$P_R(d) = P_T + G_R + G_T - L_{Cable} - P_L(d) \tag{3.5}$$

Where $P_R(d)$ is the received power at a distance of d is, L_{Cable} is the cablelosses for both transmitter and receiver and $P_L(d)$ is the path loss at distance of d.

Table 3.1: The Most Common Localization Techniques with TheirAdvantages and Disadvantages.

Technique	Advantage	Disadvantage
ToA	High accuracy	Time synchronization acrosstransmitter and receiver. LOS conditions
TDoA	High accuracy. No synchronization at target is required	LOS conditions
AoA	Only two reference points Require data least. No time synchronization	Expensive and complex. LOS conditions
RSS	Simple and inexpensive No time synchronization	Low accuracy

3.3.2 Range-Free Localization Techniques

Range-free localization requires no distance or angle measurements among nodes. This technique can be further divided into two categories: local techniques and hop-counting techniques.

In the local technique, a node with unknown coordinates collects the position information of its neighboring beacon nodes with known coordinates to estimate its own coordinate. In the simple centroid algorithm proposed in, each sensor estimates its position as the centroid of the locations of the neighboring beacons. A density-adaptive algorithm can reduce the number of computation errors if beacons are well positioned. However, this is unfeasible for ad hoc deployment. Later, He et al. proposed the APIT method [50], which divides the environment into triangular regions between beacon nodes.

Each sensor determines its relative position based on the triangles and estimates its own location as the center of gravity of the intersection of all the triangles that the node may reside in. However, APIT requires long-range beacon stations and expensive, high-power transmitters. A hop-counting technique, called the DV-Hop method, was proposed by Niculescu and Nath in. In the DV-Hop method, each unknown node asks its neighboring beacon nodes to provide their estimated hop sizes and then attempts to obtain the smallest hop count from its neighbor beacon nodes using the designated routing protocol. The hop counts to them and the hop size of the closest beacon node are used by each unknown node to estimate the distances to its neighboring beacon nodes. The unknown nodes then apply trilateration to estimate their position based on the estimated distances to three suitable neighboring beacon nodes [50].

3.4 CASE STUDY

In this thesis, the case study has been developed and implemented as a two-story structure with a footprint of (50 by 50) m and with many rooms divided between each level. The two stories are structurally similar and have the same room, wall, and window construction on both floors as well. Each level has a height of 3 meters. The outside appearance of the intended structure is shown in Figure 3.5.

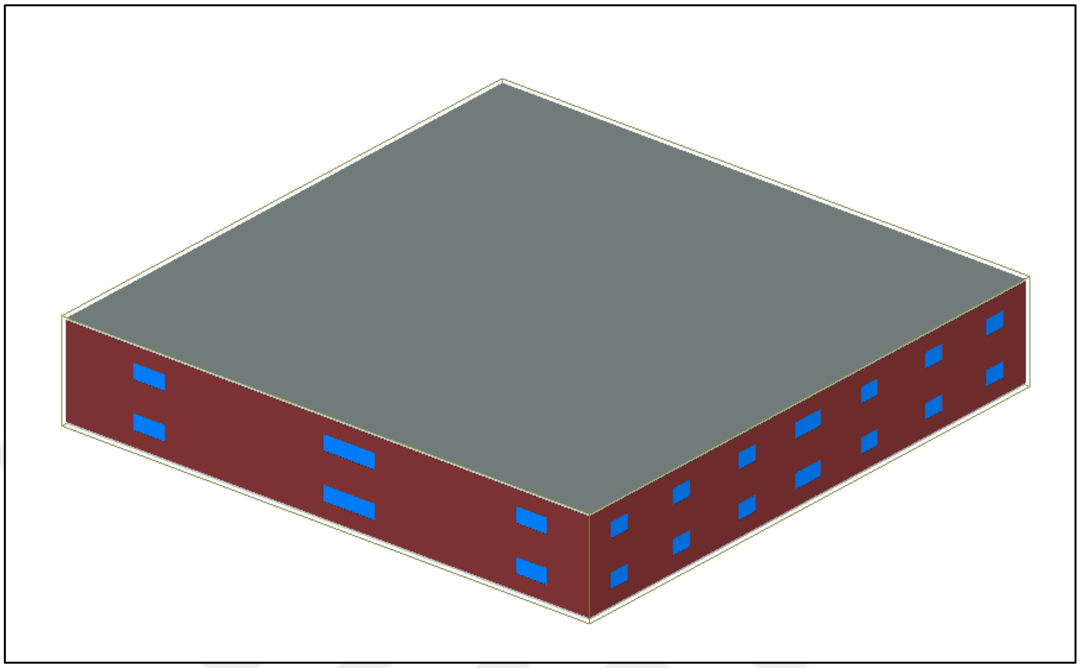


Figure 3.5: The outdoor view for the targeted building using WI.

Inside the building, it has been set 3 AP on each floor with the same locations for both floors, and these AP's was set to the height of 2.90 m above the floor ground on each floor. The parameters set for the AP's were shown in Table 3.2 which has been taken from an example Router/Access point device from TP-link Company. The received points or Target Points (TP's), it has been deployed a total of 25 points on each floor and with the same locations per each floor to make the estimation easier for the proposed model. The height of the received points was 1.70 m which represents the average height of a human. The parameters set for the TP's antenna are shown in Table 3.2. The distribution of the AP's and TP's inside each room within the designed building can be shown in Figure 3.6.

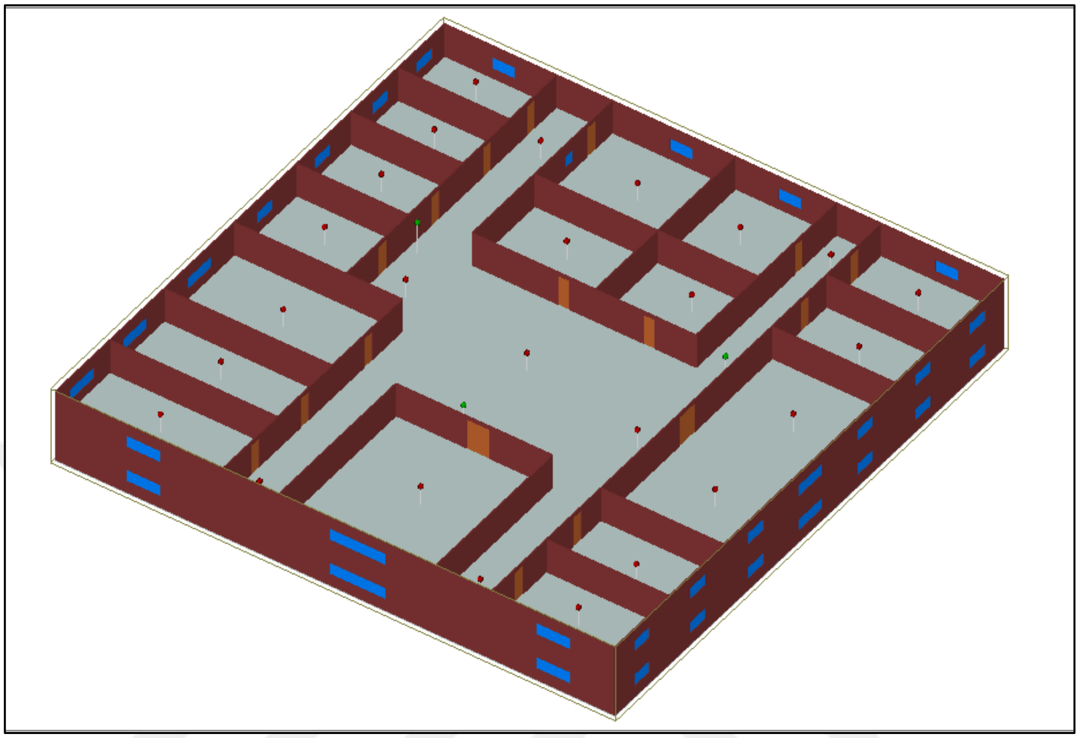


Figure 3.6: The deployment of AP's (green points) and TP's (red points).

Table 3.2: Parameters selected for AP and TP antennas.

Antenna properties	**Transmitter Antenna**	**Receiver Antenna**
Antenna type	Omni-Directional	Omni-Directional
Input Power (dBm)	30	-
Gain (dBi)	10	2
E-Plane HPBW	90˚	90˚
H-Plane HPBW	360˚	360˚
Waveform	Sinusoid	Sinusoid
Temperature (k)	293	293
Polarization	V	V
Received Threshold (dBm)	-250	-250

The first step handled with WI software is to specify the waveform profile and the type of Sinusoidal waveform and select the value of frequency utilized which has been set to be 2.4 GHz and the bandwidth of 30 MHz to meet the exampled router device that takes its parameters of input power and antenna gain. Figure 3.7 shows the capture of the waveform profile.

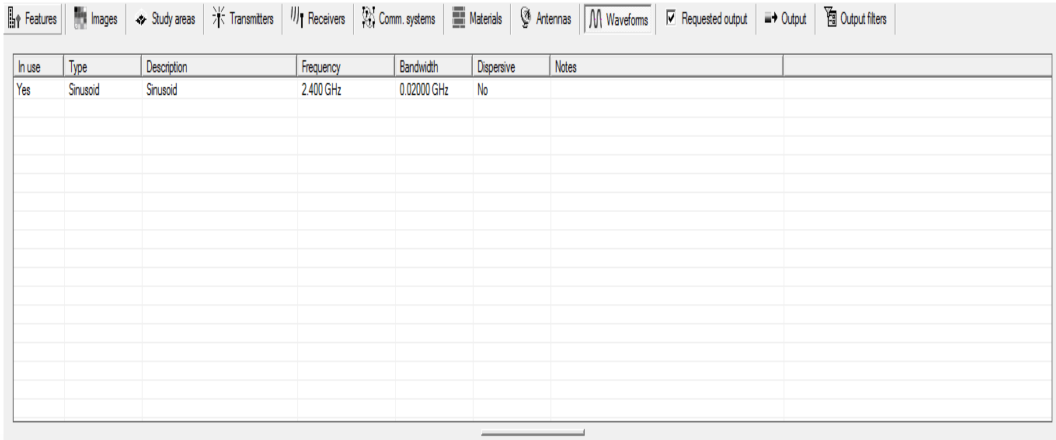


Figure 3.7: Waveform profile creation.

Then a second profile must be built which is the antenna profile in which there are two antenna one for the AP and the second for the TP's the antenna parameters selected for both were showed previously in Table 3.2. The antenna profile created with WI is captured as shown in Figure 3.8.

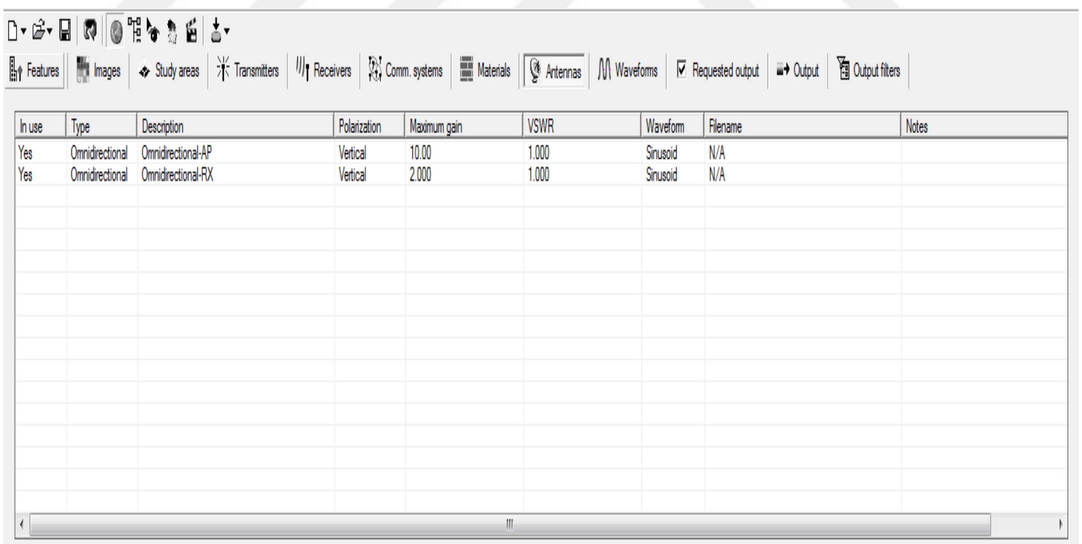


Figure 3.8: Antenna profile creation.

Then a profile for AP's should be created to put and distribute there three AP's per each floor and in each specified locations. The locations for placement of the three AP's can be shown in Figure 3.9 and the AP's profile as a transmitter can be shown in Figure 3.10.

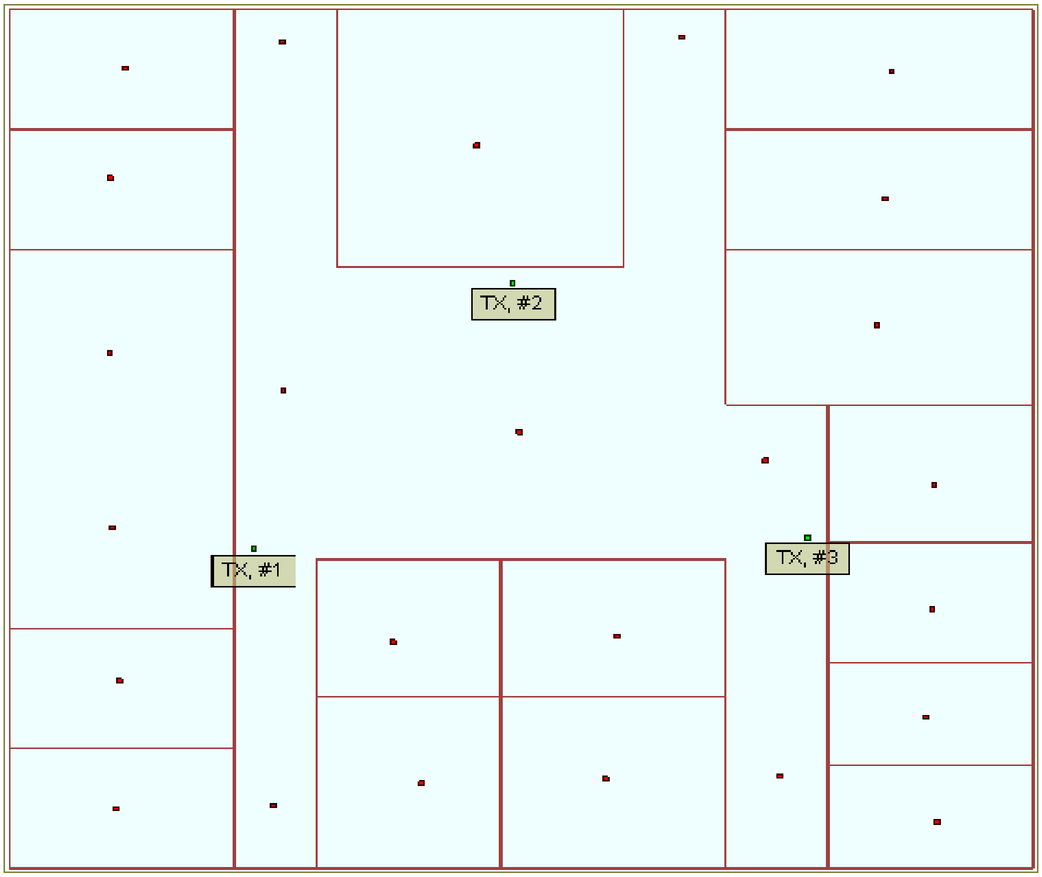
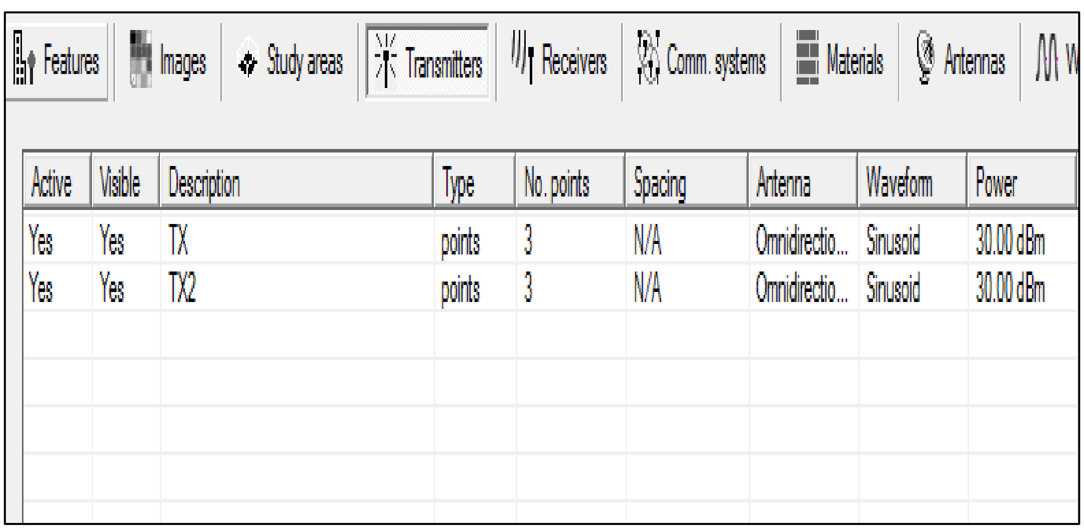


Figure 3.9: The placement locations for AP's in each floor inside the targeted case study.



Active	Visible	Description	Type	No. points	Spacing	Antenna	Waveform	Power
Yes	Yes	TX	points	3	N/A	Omnidirectio...	Sinusoid	30.00 dBm
Yes	Yes	TX2	points	3	N/A	Omnidirectio...	Sinusoid	30.00 dBm

Figure 3.10: Transmitter profile creation.

For the TP's another profile should be created that include the distribution of the TP's in each floor of the case study building. The placement of each TP with its sequenced number can be shown in Figure 3.11. Also, Figure 3.12 shows the creation of receiver profile.

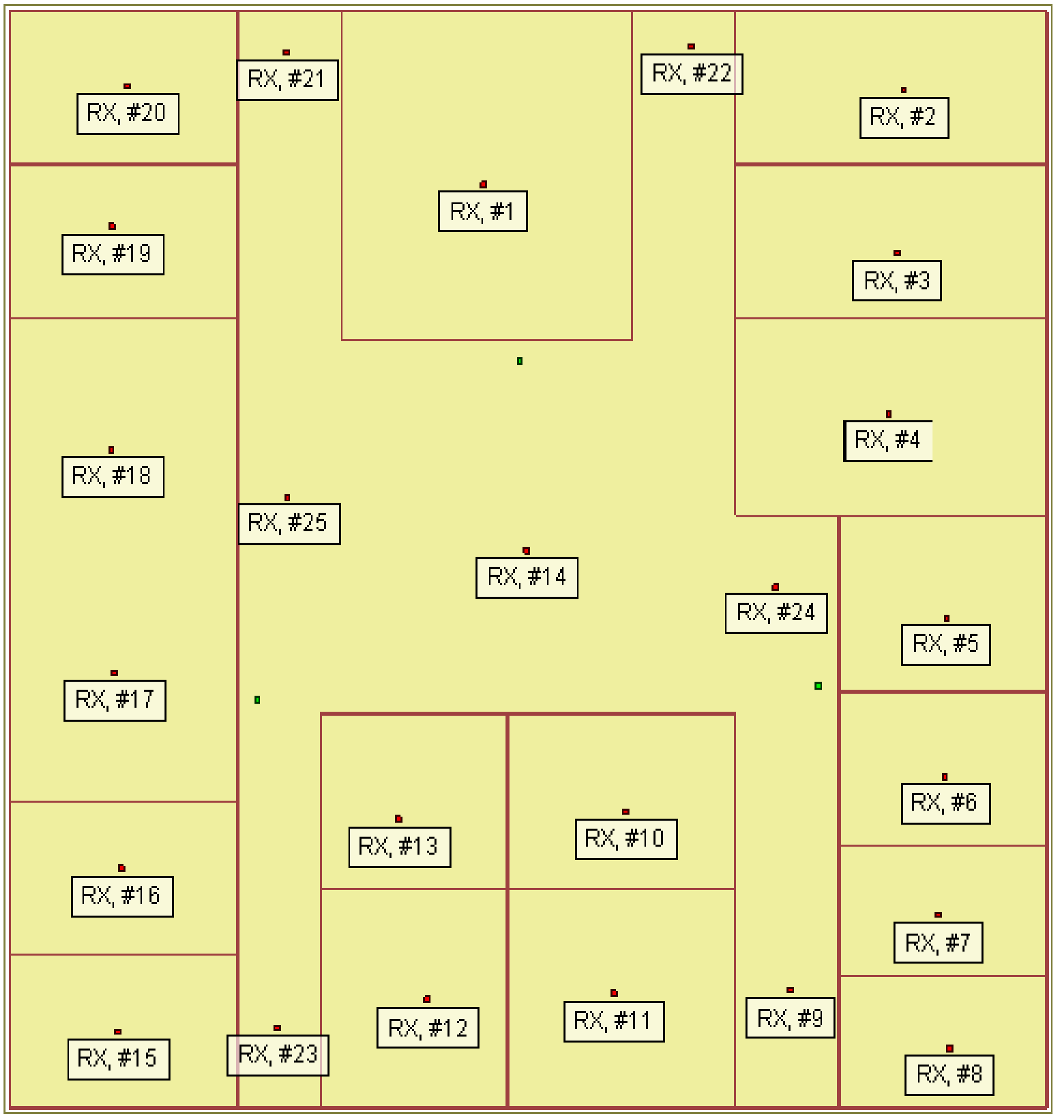


Figure 3.11: The placement locations for TP's on each floor inside the targeted case study.

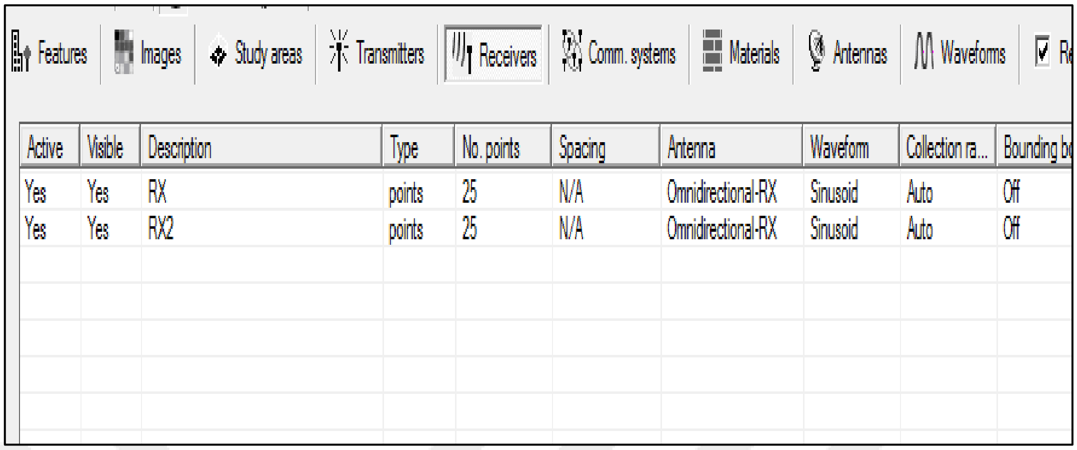


Figure 3.12: Receiver profile creation.

Then the studied parameters should be selected from the specific tab within the WI software, in which in our thesis it has been select the received power, propagation path and the AoA. To be later used with the proposed model for localization. The selection of parameters tab can be shown in Figure 3.13.

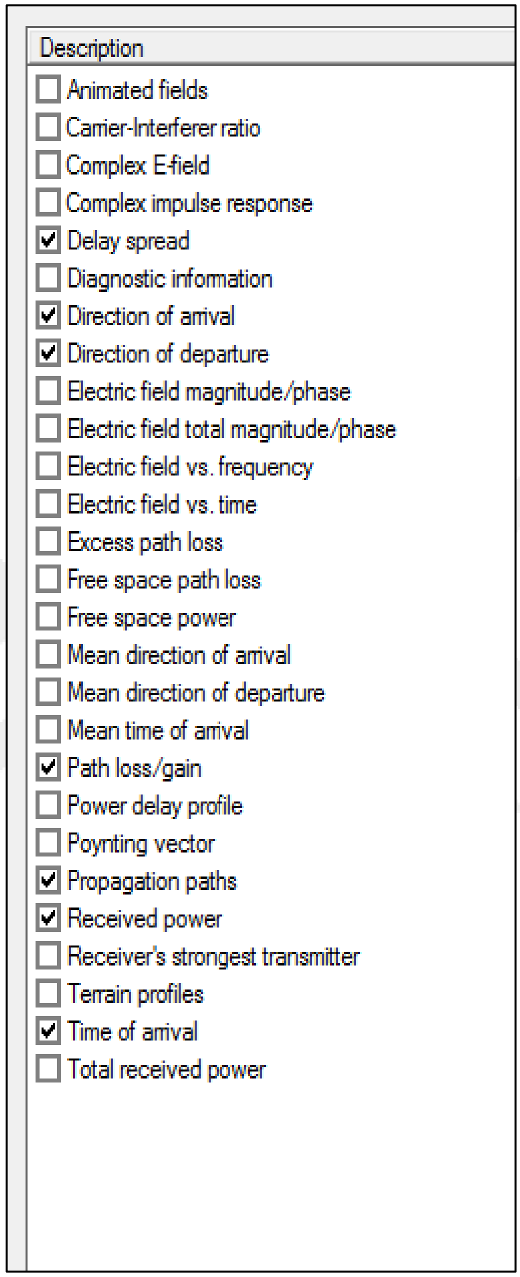


Figure 3.13: Output parameter selection inside WI software.

Finally, after setting all the required profiles and designing the building, and setting the appropriate parameters, the WI would be run by clicking the run button then a calculation by the WI would be performed as shown in the Log Window in Figure 3.14.

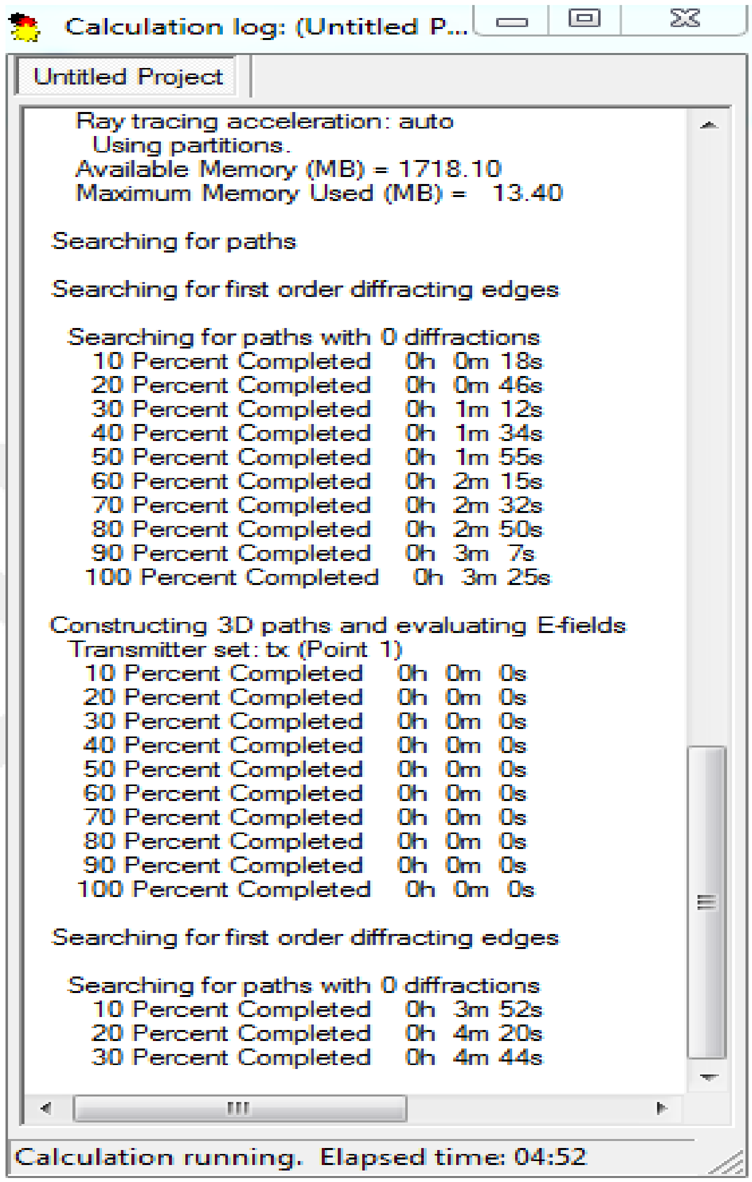


Figure 3.14: Calculation Log window by WI software.

3.5 METHODOLOGY OF THE PROPOSED MODEL

The proposed model for indoor-based multi-floor localization is formed based on the below steps:

Step1**:** Collect the data of RSS and AoA two angles represented by the theta and phi angle which represent the angles of arrival from the vertical and horizontal plane respectively. These data were collected from each TP located on the two floors of the case study building and from each AP on the two floors. So there will be 3 main scenarios that will be performed by the proposed model. The first scenario includes the connection between the 3 AP's on the first floor (F1-AP) and the TP's located on the first floor (F1-TP). While the second scenario includes the connection of (F1-AP) with the TP's located on the second floor (F2-TP). And the last scenario includes the connection between the 3 AP's located on the second floor (F2-AP) and the TP's on the first floor (F1-TP). The aim of performing such three scenarios is to test the proposed model concerning multi-floor localization in which several obstacles may affect the signal quality between the two floors. The data collected are set in an Excel database for further calculation.

Step2**:** in this step, the data stored in the Excel database would be inserted into the proposed model which has been designed using the MATLAB program. These data inserted would be classified into three scenarios and shown in Table 3.3 and 3.4 and 3.5 respectively. It is worth mentioning that the RSS value obtained in these tables represents the optimum value from the optimum path that has been predicted from WI software. The other parameter specified and shown in the three tables were collected from the optimum path that has the highest RSS value from each AP and per each TP.

Table 3.3: Data obtained from the first scenario per each of the three AP's.

RX	AP1				AP2				AP3			
	RSS	**Distance**	**Theta**	**Phi**	**RSS**	**Distance**	**Theta**	**Phi**	**RSS**	**Distance**	**Theta**	**Phi**
rx1	-31.482	25.93245	87.36	245.04	-21.39	8.31175	82.05	282.28	-32.758	28.00599	87.42	305.07
rx2	-43.703	41.77758	87.86	222.42	-52.187	26.86053	87.79	133.72	-45.645	29.69287	88.02	246.32
rx3	-43.059	37.02445	88.04	213.96	-45.654	18.9123	86.53	195.3	-45.135	23.97982	87.37	236.03
rx4	-33.53	33.13398	88.05	203.33	-27.895	17.98713	86.45	172.41	-31.808	12.87858	84.67	254.98
rx5	-33.245	33.46481	88.2	186.68	-38.019	27.54485	88.13	221.45	-20.419	6.98966	80.54	206.58
rx6	-47.7	53.74456	89.13	231.22	-40.196	27.9258	87.21	136.98	-21.378	7.44484	81.14	145.89
rx7	-47.166	53.69778	85.88	124.79	-41.575	32.33731	87.7	129	-33.796	11.98134	84.47	119.25
rx8	-55.397	59.02681	87.23	121.71	-43.192	37.59619	88.22	124.28	-37.61	21.83923	86.96	130.99
rx9	-52.071	28.92594	87.47	152.07	-38.199	36.64694	87.89	130.17	-21.025	13.98479	85.28	84.38
rx10	-33.119	18.49307	86.3	164.29	-29.4	21.19165	86.49	104.03	-24.484	11.01243	84.01	31.6
rx11	-44.134	21.80416	86.92	142.01	-32.863	29.20764	87.71	99.12	-36.299	17.20715	86.01	55.21
rx12	-36.014	15.95124	86.06	121.18	-36.877	29.45675	87.82	80.8	-44.834	23.70783	87.1	37.16
rx13	-23.073	8.76529	82.43	141.37	-29.647	21.71857	86.85	74.06	-40.068	23.75612	87.18	327.33
rx14	-21.464	14.7205	85.52	207.69	-17.012	8.71663	82.42	92.24	-21.857	15.40952	85.72	336.35
rx15	-36.689	19.78697	86.46	49.61	-42.951	36.21393	89.57	57.52	-59.542	37.31476	88.16	25.63
rx16	-31.579	10.16595	83.51	49.57	-40.902	30.0973	88.21	51.24	-51.743	52.04007	88.57	49.05
rx17	-20.077	7.11505	80.69	349.79	-26.934	24.20757	87.34	36.23	-33.369	34.00475	88.35	359.6
rx18	-28.998	13.46667	85.12	301.63	-28.915	20.13336	86.67	11.43	-34.019	35.78474	87.74	342.94
rx19	-41.455	22.72561	87.51	288.52	-39.97	20.63762	88.05	342.83	-35.593	40.01387	88.83	328.78
rx20	-50.337	28.69887	87.39	282.97	-37.994	22.74108	87.36	327.6	-52.846	51.05121	88.46	328.93
rx21	-27.483	29.56966	87.77	267.26	-36.533	18.03863	86.65	308.73	-43.021	38.63145	88.68	311.76
rx22	-38.223	36.42823	87.82	234.97	-36.428	16.59307	86.07	240.13	-35.111	33.1944	88.17	299.63
rx23	-21.628	15.00383	85.6	93.71	-36.757	36.08865	87.62	58.52	-48.068	30.42183	88.8	30.42
rx24	-26.219	25.55424	87.42	191.66	-22.242	16.11648	85.91	140.17	-12.637	5.08695	76.93	294.67
rx25	-17.683	9.44142	83	261.09	-20.304	12.85575	84.87	28.94	-26.711	27.04893	87.56	341.44

Table 3.4: Data obtained from the second scenario per each of the three AP's.

RX	AP1				AP2				AP3			
	RSS	**Distance**	**Theta**	**Phi**	**RSS**	**Distance**	**Theta**	**Phi**	**RSS**	**Distance**	**Theta**	**Phi**
rx1	-26.387	25.97289	94.08	245.1	-17.004	8.43713	102.67	282.26	-27.047	28.04327	93.78	305.28
rx2	-30.494	41.80201	92.54	221.72	-25.088	22.32519	94.75	213.68	-26.881	27.50676	93.86	261.41
rx3	-29.45	37.05252	92.86	213.46	-23.696	18.96771	95.6	195.2	-24.231	20.19637	95.26	259.1
rx4	-28.493	33.16562	93.2	203.17	-23.271	18.04534	95.88	172.24	-20.483	12.95975	98.21	254.76
rx5	-28.579	33.49608	93.17	186.42	-25.619	23.75097	94.47	150.35	-15.728	7.1383	105.02	206.59
rx6	-28.552	33.39222	93.18	174.03	-27.022	27.96306	93.79	137.29	-16.184	7.58456	104.12	145.89
rx7	-28.789	34.32369	93.09	163.43	-28.284	32.36964	93.28	128.67	-19.892	12.0686	98.82	118.99
rx8	-29.442	37.01738	92.86	154.54	-29.583	37.62365	92.82	123.47	-23.158	17.80642	95.96	110.88
rx9	-27.325	28.96192	93.66	152.79	-28.063	31.55349	93.36	114.47	-21.164	14.05967	97.56	84.38
rx10	-23.506	18.54963	95.72	164.01	-24.662	21.24099	95	103.91	-19.209	11.10736	99.59	31.61
rx11	-24.905	21.85225	94.86	142.09	-27.408	29.24353	93.63	98.92	-22.897	17.26782	96.15	54.82
rx12	-22.261	16.01682	96.63	120.99	-27.481	29.49216	93.6	81.27	-25.619	23.75206	94.47	37.13
rx13	-17.41	8.88427	102.02	141.37	-24.871	21.76679	94.88	74.3	-24.667	21.25399	94.99	16.69
rx14	-21.59	14.79166	97.18	207.69	-17.367	8.83627	102.09	92.24	-21.971	15.47751	96.86	336.35
rx15	-22.586	16.64423	96.38	65.99	-29.259	36.24152	92.93	57.61	-29.518	37.34242	92.84	25
rx16	-18.569	10.2687	100.38	49.45	-27.666	30.13141	93.52	50.27	-28.884	34.70151	93.06	13.91
rx17	-15.856	7.26112	104.76	349.77	-25.798	24.2508	94.38	35.98	-28.716	34.03513	93.12	359
rx18	-20.851	13.54441	97.85	301.63	-24.226	20.18542	95.26	11.57	-29.156	35.81361	92.96	342.48
rx19	-25.258	22.7714	94.66	288	-24.436	20.68623	95.13	342.69	-30.121	40.03966	92.65	328.45
rx20	-27.257	28.73531	93.69	282.67	-25.263	22.78562	94.66	326.54	-30.77	43.15961	92.46	320.68
rx21	-27.514	29.60515	93.58	267.26	-23.295	18.09665	95.87	308.65	-29.817	38.65851	92.74	311.64
rx22	-29.31	36.45692	92.91	234.89	-22.592	16.65619	96.38	239.96	-27.577	29.82407	93.56	281.88
rx23	-21.748	15.07365	97.05	93.71	-28.346	32.6058	93.25	68.96	-27.758	30.45589	93.48	30.84
rx24	-26.261	25.5953	94.14	191.66	-22.347	16.1815	96.56	140.17	-13.654	5.28934	110.47	294.67
rx25	-17.986	9.55198	101.17	261.09	-20.469	12.93717	98.22	28.94	-26.748	27.08772	93.92	341.44

Table 3.5: Data obtained from the third scenario per each of the three AP's.

RX	AP1				AP2				AP3			
	RSS	Distance	Theta	Phi	RSS	Distance	Theta	Phi	RSS	Distance	Theta	Phi
rx1	-31.804	26.23742	81.24	245.04	-19.313	9.21874	63.25	282.26	-33.014	28.28941	82.26	305.62
rx2	-37.422	46.96995	82.18	129.96	-32.515	27.15476	81.19	133.72	-31.858	27.75679	80.71	261.63
rx3	-35.635	42.07137	81.92	137.52	-24.186	19.32807	77.6	195.2	-29.423	20.53533	78.85	258.96
rx4	-33.727	33.37323	83.19	203.33	-23.812	18.42374	76.98	172.24	-21.512	13.48166	72.07	254.76
rx5	-33.445	33.70166	82.53	186.68	-31.344	24.04031	80.24	151.03	-18.851	8.04707	58.95	206.59
rx6	-29.479	33.59912	82.38	174.87	-34.853	32.65498	79.02	230.69	-18.986	8.44545	60.57	145.89
rx7	-33.824	34.52494	82.19	163.73	-41.81	32.58235	82.22	129	-26.481	12.62788	71.53	119.25
rx8	-34.764	37.20486	82.78	155.43	-43.366	37.80719	83.26	124.28	-28.73	18.18984	77.06	110.89
rx9	-32.783	29.1997	82.52	152.07	-33.05	33.96272	82.88	57.22	-22.043	14.54216	73.42	84.38
rx10	-28.887	18.92011	78.57	164.29	-29.883	21.5635	78.56	104.03	-20.59	11.71211	69.25	31.61
rx11	-31.239	22.16612	79.7	142.01	-32.354	29.47876	81.44	99.12	-29.272	17.66751	78.21	55.21
rx12	-22.944	16.44197	75.38	120.99	-32.413	29.72542	81.85	80.8	-31.834	24.04086	80.29	37.16
rx13	-19.51	9.62965	64.47	141.37	-30.114	22.08193	78.89	74.89	-29.948	21.5763	78.66	16.87
rx14	-22.387	15.251	74.21	207.69	-19.488	9.58538	64.34	92.24	-22.701	15.91708	74.89	336.35
rx15	-28.379	17.05391	75.64	66.36	-34.965	36.43392	83.14	59.48	-34.822	37.53054	81.98	25.63
rx16	-20.172	10.91999	67.66	49.45	-34.042	30.36407	79.8	51.24	-33.869	34.90268	81.54	14.09
rx17	-18.885	8.15622	59.42	349.77	-26.316	24.53436	80.86	36.23	-33.543	34.23769	83.22	359.6
rx18	-21.796	14.04461	72.81	301.63	-29.434	20.52522	79.08	11.43	-34.196	36.00636	82.84	342.94
rx19	-30.524	23.07283	79.18	288.52	-29.218	23.22607	79.69	30.86	-35.728	40.21193	84.43	328.78
rx20	-32.256	28.9745	81.87	282.97	-31.276	23.08804	79.37	327.6	-43.774	47.84087	85.33	46.22
rx21	-27.717	29.83731	82	267.26	-30.971	21.57075	78.7	221.5	-36.893	38.8373	84.88	311.76
rx22	-35.958	39.20922	80.57	308.46	-30.285	19.45722	77.44	311.24	-30.84	31.68884	82.44	247.52
rx23	-22.517	15.52465	74.5	93.71	-32.022	34.30654	83.5	116.43	-29.003	30.68171	81.95	30.42
rx24	-26.533	25.86348	80.77	191.66	-23.017	16.60243	75.52	140.17	-18.878	6.46352	50.05	294.67
rx25	-19.821	10.24892	66.11	261.09	-21.501	13.45995	72.04	28.94	-26.991	27.34126	81.27	341.44

Step3: the first step of the model is to insert the x and y coordination for each AP in the two floors as the proposed model proposed the knowing location for each AP and being in a fixed manner. The x and y location for each AP are showed in Table 3.6.

Table 3.6: AP's coordination.

AP	x	y
AP1	11.9406	18.6009
AP2	24.5968	34.0553
AP3	39.0104	19.2563

Step4**:** Include the calling of the Phi value and the separation distance from the database to the proposed model from each AP and per each of the 25 TP's. It should be mentioned that the proposed model will consider the optimum path between the AP and each TP which will have the best overall results from the obtained parameters.

Step5**:** The first calculation procedure would be performed based on equation (3.6), in which the Beta (β) parameter would be calculated from the addition of Phi angle with (PI). This parameter would be obtained from each AP and for each of the 25 TP.

$$\beta_{AP,TP} = Phi\ angle + \pi. \tag{3.6}$$

Step6**:** include the calculation of the estimated x and y coordination for the selected TP based on the value of Beta obtained from equation (3.6) and on the fixed known coordination for each AP as shown in Table 3.3 and clarify in step 3. The calculation of each TP x and y coordination would be based on equations (3.7) and (3.8) respectively.

$$X_{Rx}(i) = X_{Tx} + distance(i) \times \cos(\beta_{AP,TP}) \tag{3.7}$$

$$Y_{Rx}(i) = Y_{Tx} + distance(i) \times \sin(\beta_{AP,TP}) \tag{3.8}$$

Step7: The final step starts when the three set of TP coordination obtained from each AP per floor is then averaged to quantify the final x and y coordination for each TP. Then these results would be compared with the results of the actual coordination for each TP to obtain the impact of accuracy percentage and the ranging error based on equation (3.9) and (3.10) respectively.

$$Accuracy = \frac{Actual\ value}{Estimated\ value} * 100\ \% \qquad (3.9)$$

$$Ranging\ error = |Actual\ value - Estimated\ value| \qquad (3.10)$$

4. PRESENTED SYSTEM RESULTS

4.1 INTRODUCTION

Based on the suggested model for multi-floor localization in an indoor case study, the findings obtained in this chapter will be discussed and analyzed. To deal with the influence of multi-floor objects having an impact on the projected coordination for each TP, these findings would be categorized according to the three scenarios that had been completed. Then, handle the difference between the estimated results and the actual results in terms of x and y coordination would be shown to manage the comparison in conjunction with the actual coordination to acquire the suggested model performance would be presented.

4.2 RESULTS BASED FIRST SCENARIO

This scenario will handle the connection between the AP on first floor F1-AP1 and the TP in the same floor (F1-TP) in which the localization would be performed between them. After applying the data obtained for this scenario in the proposed model the results of x and y coordination estimated and from each AP of the three placed and per each TP have been showed as shown in Table 4.1.

Table 4.1: Actual coordination and first scenario estimated coordination.

RX	Actual coordination		Estimated / AP1		Estimated / AP2		Estimated / AP3	
	x	y	x	y	x	y	x	y
TP1	22.8488	42.0994	22.88372	42.11133	22.82898	42.17688	22.91881	42.17782
TP2	43.1112	46.3927	42.78164	46.78239	43.16105	46.6425	43.93589	46.44911
TP3	42.8136	39.0049	42.64971	39.28328	42.8388	39.04575	42.40933	39.14349
TP4	42.3828	31.6321	42.36552	31.72283	42.42634	31.6795	42.34796	31.69489
TP5	45.1756	22.3422	45.17823	22.49366	45.24259	22.28906	45.26133	22.3838
TP6	45.1005	15.1316	45.60252	15.49783	45.01379	15.00282	45.17445	15.08136
TP7	44.7905	8.8246	44.57896	8.498338	44.94733	8.92449	44.86474	8.802629
TP8	45.3219	2.7091	45.96628	2.6105	45.77239	2.989758	45.33535	2.771523
TP9	37.6453	5.3859	37.49726	5.052207	37.23619	6.052131	37.64087	5.338731
TP10	29.6834	13.5155	29.74285	13.59356	29.73429	13.49582	29.63082	13.48594
TP11	29.1199	5.223	29.12486	5.179918	29.22629	5.216887	29.19251	5.124949
TP12	20.1316	4.9619	20.19901	4.953896	19.88722	4.977474	20.1164	4.935754
TP13	18.7289	13.1762	18.78799	13.12883	18.63222	13.17181	19.01265	13.07984
TP14	24.9348	25.4214	24.97523	25.44133	24.93749	25.34533	24.89508	25.43781
TP15	5.2095	3.4913	5.281099	3.530126	5.149732	3.505991	5.367182	3.115506
TP16	5.3745	10.9256	5.347793	10.86259	5.754097	10.58617	4.903329	10.64862
TP17	5.0307	19.8479	4.938219	19.86209	5.06974	19.74795	5.006479	19.4937
TP18	4.9044	30.0255	4.87825	30.06713	4.862734	30.06546	4.800258	29.75458
TP19	4.9268	40.1861	4.722136	40.14962	4.878935	40.14769	4.791203	39.99651
TP20	5.6513	46.5783	5.499401	46.5676	5.395871	46.24058	5.116872	45.60306
TP21	13.3537	48.1144	13.35414	48.13675	13.31091	48.12729	13.2814	48.07309
TP22	32.8827	48.3853	32.8506	48.43021	32.86071	48.44411	32.59919	48.11007
TP23	12.9089	3.6726	12.91144	3.628513	12.75127	3.278087	12.77653	3.852669
TP24	36.9423	23.7594	36.96751	23.7655	36.97342	23.7325	36.88715	23.87895
TP25	13.3917	27.859	13.40291	27.92839	13.34639	27.83449	13.36826	27.86591

The deployment for the three obtained set of results and as compared to the actual deployment-based locations from the first scenario has been clarified as shown in Figure 4.1. These results effectively showed estimation that is near to the red points which represent the actual estimation.

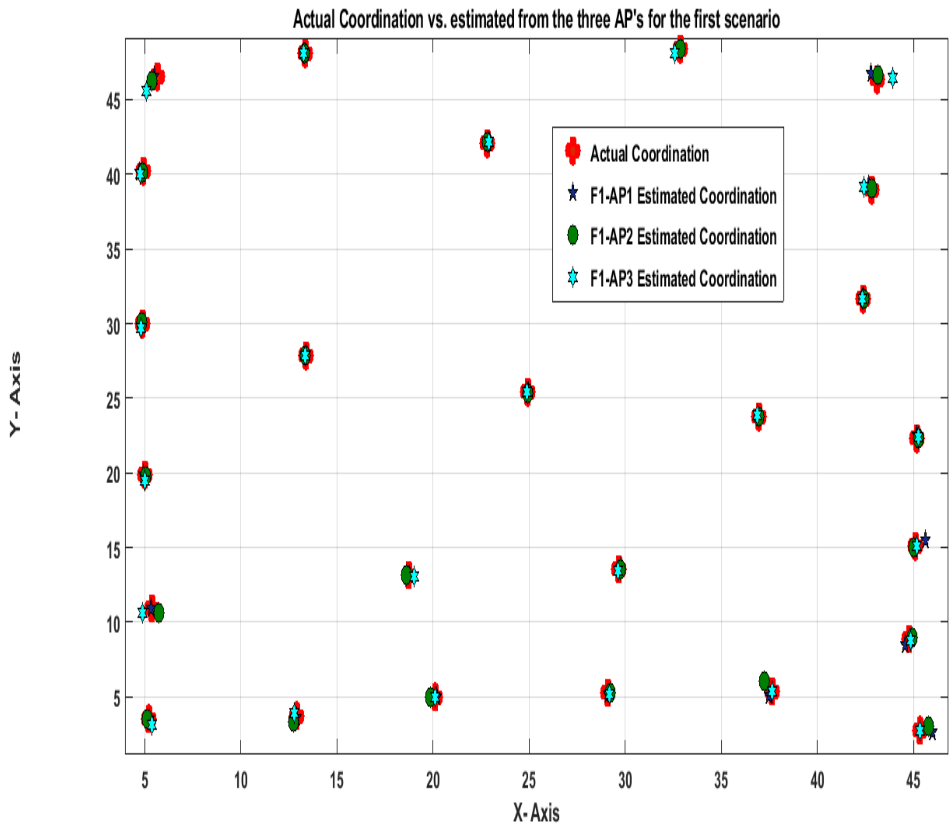


Figure 4.1: The Actual Coordination vs. estimated from 3 AP's for the first scenario.

4.3 RESULTS BASED SECOND SCENARIO

In this scenario will handle the connection between the AP in first floor (F1-AP) and the TP on the second floor (F2-TP) in which the localization would be performed between them. After applying the data obtained for this scenario in the proposed model the results of x and y coordination estimated and from each AP of the three placed and per each TP has been showed as shown in Table 4.2.

Table 4.2: Actual coordination and second scenario estimated coordination.

RX	Actual coordination		Estimated / AP1		Estimated / AP2		Estimated / AP3	
	x	y	x	y	x	y	x	y
TP1	22.8488	42.0994	22.87612	42.15945	22.80519	42.30001	22.81337	42.14912
TP2	43.1112	46.3927	43.14187	46.41976	43.17466	46.43582	43.11889	46.4545
TP3	42.8136	39.0049	42.85244	39.02998	42.90095	39.02843	42.82944	39.0883
TP4	42.3828	31.6321	42.43113	31.65026	42.47689	31.61875	42.41704	31.7603
TP5	45.1756	22.3422	45.22662	22.34629	45.2379	22.30568	45.3937	22.45142
TP6	45.1005	15.1316	45.15172	15.12785	45.14395	15.08829	45.29013	15.003
TP7	44.7905	8.8246	44.8389	8.812245	44.82245	8.782455	44.85953	8.699844
TP8	45.3219	2.7091	45.36306	2.687837	45.34625	2.670603	45.35682	2.619246
TP9	37.6453	5.3859	37.69749	5.357971	37.66678	5.335999	37.63353	5.264211
TP10	29.6834	13.5155	29.77254	13.49104	29.70308	13.43721	29.55098	13.43455
TP11	29.1199	5.223	29.18152	5.174377	29.13116	5.165447	29.0616	5.142515
TP12	20.1316	4.9619	20.18748	4.870366	20.12053	4.90482	20.07364	4.91895
TP13	18.7289	13.1762	18.88094	13.05455	18.7067	13.10059	18.65178	13.1523
TP14	24.9348	25.4214	25.03824	25.4744	24.94217	25.22578	24.8328	25.46508
TP15	5.2095	3.4913	5.168128	3.396821	5.182963	3.452184	5.166674	3.474711
TP16	5.3745	10.9256	5.264801	10.79834	5.337689	10.88229	5.326528	10.91415
TP17	5.0307	19.8479	4.794912	19.89048	4.972516	19.80789	4.980454	19.85029
TP18	4.9044	30.0255	4.837481	30.13332	4.82154	30.00681	4.858114	30.03758
TP19	4.9268	40.1861	4.90385	40.25779	4.847472	40.21031	4.889247	40.20675
TP20	5.6513	46.5783	5.63793	46.63649	5.587419	46.61826	5.621303	46.60443
TP21	13.3537	48.1144	13.35584	48.1722	13.29433	48.18834	13.32383	48.14713
TP22	32.8827	48.3853	32.90873	48.42446	32.93496	48.47417	32.87074	48.44157
TP23	12.9089	3.6726	12.91596	3.558839	12.89068	3.623328	12.86091	3.643319
TP24	36.9423	23.7594	37.00772	23.7738	37.02335	23.69086	36.80268	24.06287
TP25	13.3917	27.859	13.42004	28.03761	13.27513	27.79509	13.33149	27.87826

The deployment for the three obtained set of results and as compared to the actual deployment-based locations from the second scenario has been clarified as shown in Figure 4.2. These results effectively showed a multi-floor estimation that is near to the red points which represent the actual estimation.

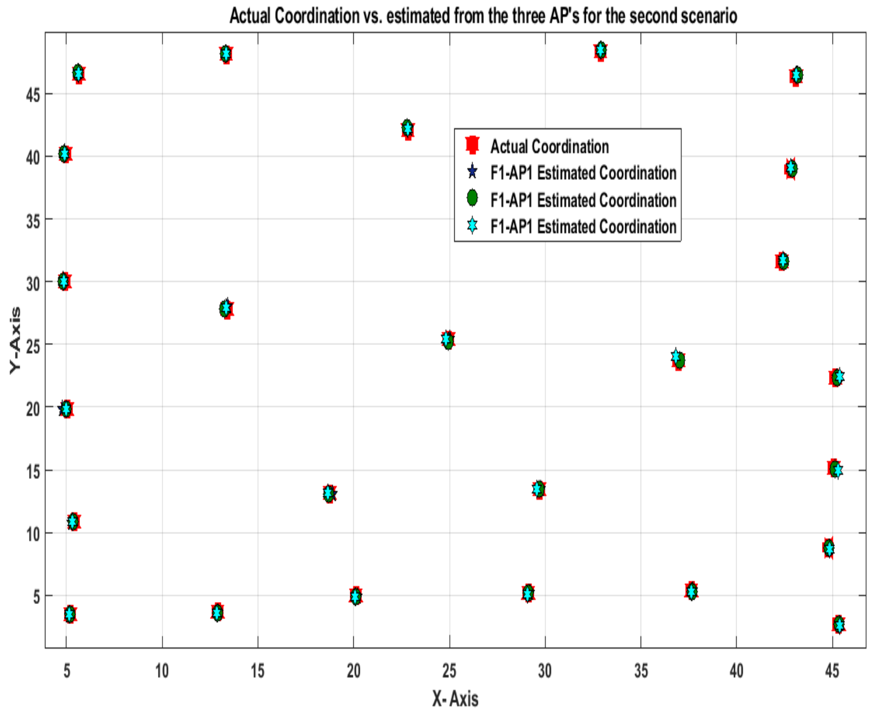


Figure 4.2: The Actual Coordination vs. estimated from 3 AP's for the second scenario.

4.4 RESULTS BASED THIRD SCENARIO

In this scenario will handle the connection between the AP in second floor (F2-AP) and the TP on the first floor (F1-TP) in which the localization would be performed between them. After applying the data obtained for this scenario in the proposed model the results of x and y coordination estimated and from each AP of the three placed and per each TP has been showed as shown in Table 4.3. The deployment for the three obtained set of results and as compared to the actual deployment-based locations from the third scenario has been clarified as shown in Figure 4.3. These results effectively showed a multi-floor estimation that is near to the red points which represent the actual estimation. Also, it can be noticed that this scenario is higher effective by the obstacle related between the two floors and the degree of AoA that the signal arrived has a great impact on the accuracy of estimation.

Table 4.3: Actual coordination and third scenario estimated coordination.

RX	Actual coordination		Estimated / AP1		Estimated / AP2		Estimated / AP3	
	x	**y**	**x**	**y**	**x**	**y**	**x**	**y**
TP1	22.8488	42.0994	23.01241	42.38781	22.63922	43.0638	22.53446	42.25269
TP2	43.1112	46.3927	42.10718	46.40124	43.3644	46.42985	43.05082	46.71744
TP3	42.8136	39.0049	42.96879	38.81128	43.24871	39.12291	42.9428	39.4116
TP4	42.3828	31.6321	42.58521	31.81758	42.85182	31.56766	42.55423	32.26385
TP5	45.1756	22.3422	45.41347	22.52121	45.62903	22.41134	45.20635	22.85819
TP6	45.1005	15.1316	45.40513	15.59661	45.28425	15.32143	45.00292	14.52023
TP7	44.7905	8.8246	45.08289	8.928251	45.10154	8.734058	45.18065	8.238525
TP8	45.3219	2.7091	45.77671	3.130946	45.89123	2.81541	45.49644	2.262138
TP9	37.6453	5.3859	37.73913	4.92398	37.20888	5.500951	37.58628	4.78404
TP10	29.6834	13.5155	30.15394	13.47793	29.82444	13.13506	29.03595	13.11758
TP11	29.1199	5.223	29.41012	4.957123	29.26926	4.949195	28.92984	4.746879
TP12	20.1316	4.9619	20.40638	4.505903	19.84426	4.71226	19.85099	4.73459
TP13	18.7289	13.1762	19.46322	12.58922	18.84064	12.73681	18.36262	12.99483
TP14	24.9348	25.4214	25.44498	25.68785	24.97145	24.47724	24.43015	25.64141
TP15	5.2095	3.4913	5.102175	2.978103	6.094231	2.669229	5.172634	3.022169
TP16	5.3745	10.9256	4.84139	10.30347	5.587083	10.37815	5.157784	10.75939
TP17	5.0307	19.8479	3.914041	20.04944	4.806135	19.5548	4.773544	19.49532
TP18	4.9044	30.0255	4.57516	30.55922	4.478645	29.98781	4.58839	29.81959
TP19	4.9268	40.1861	4.611846	40.47885	4.659002	40.14167	4.621826	40.09917
TP20	5.6513	46.5783	5.437539	46.83619	5.102923	46.42649	5.909724	46.28489
TP21	13.3537	48.1144	13.36694	48.4041	13.75234	48.34851	13.1443	48.22664
TP22	32.8827	48.3853	32.44628	49.30339	31.77032	48.68625	32.12697	48.5372
TP23	12.9089	3.6726	12.94515	3.108784	12.86678	3.33452	12.55243	3.721082
TP24	36.9423	23.7594	37.27036	23.828	37.34661	23.42125	36.31258	23.12987
TP25	13.3917	27.859	13.52798	28.72614	12.81764	27.54212	13.09114	27.95896

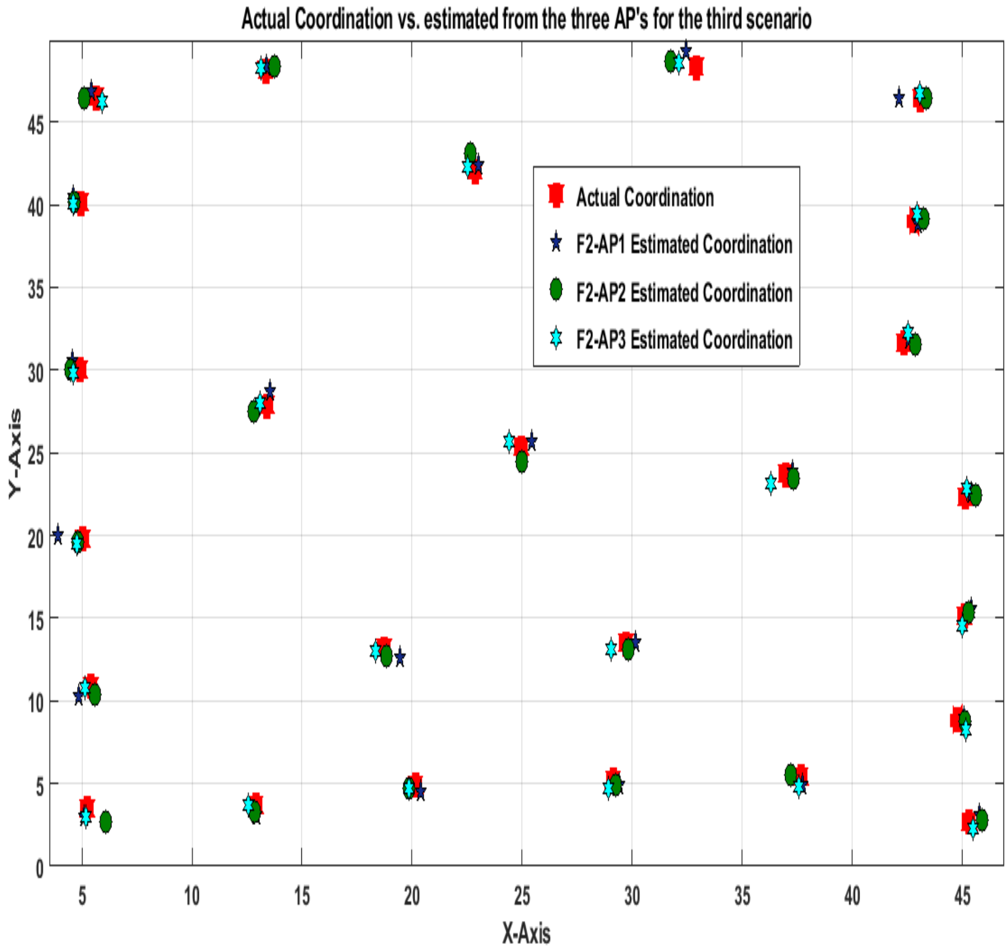


Figure 4.3: The Actual Coordination vs. estimated from 3 AP's for the third scenario.

4.5 COMPARISON BETWEEN ESTIMATED AND ACTUAL RESULTS

After getting all the required data from the proposed model as shown in previous section these data per each scenario and each TP would be averaged and compared with the actual value of coordination per each TP in the implemented case study. The comparison between the averaged results from each scenario with the actual results were showed in Table 4.4 and 4.5 and 4.6 for the first three scenarios respectively. Performing the average from 3 AP's in each scenario increase the results reliability obtained in achieving accurate estimation for the TPs along with the proposed model.

To get closer look for these results, it has been drawn as shown in Figure 4.4 and 4.5 and 4.6 for the three scenarios respectively. These Figures showed a much optimum results for estimation which would improve the system overall performance in localization.

Table 4.4: Actual location vs. averaged estimated locations for the first scenario.

Actual location		Average Estimated	
x	**y**	**x**	**y**
22.8488	42.0994	22.87717	42.15534
43.1112	46.3927	43.29286	46.62467
42.8136	39.0049	42.63261	39.1575
42.3828	31.6321	42.37994	31.69907
45.1756	22.3422	45.22738	22.38884
45.1005	15.1316	45.26359	15.194
44.7905	8.8246	44.79701	8.741819
45.3219	2.7091	45.69134	2.790594
37.6453	5.3859	37.45811	5.481023
29.6834	13.5155	29.70265	13.52511
29.1199	5.223	29.18122	5.173918
20.1316	4.9619	20.06754	4.955708
18.7289	13.1762	18.81095	13.12683
24.9348	25.4214	24.93593	25.40816
5.2095	3.4913	5.266004	3.383875
5.3745	10.9256	5.335073	10.69913
5.0307	19.8479	5.004813	19.70124
4.9044	30.0255	4.847081	29.96239
4.9268	40.1861	4.797425	40.09794
5.6513	46.5783	5.337381	46.13708
13.3537	48.1144	13.31548	48.11238
32.8827	48.3853	32.77016	48.32813
12.9089	3.6726	12.81308	3.586423
36.9423	23.7594	36.94269	23.79232
13.3917	27.859	13.37252	27.87626

Table 4.5: Actual location vs. averaged estimated locations for the second scenario.

Actual location		Average Estimated	
x	**y**	**x**	**y**
22.8488	42.0994	22.83156	42.20286
43.1112	46.3927	43.14514	46.43669
42.8136	39.0049	42.86095	39.0489
42.3828	31.6321	42.44168	31.67644
45.1756	22.3422	45.28608	22.3678
45.1005	15.1316	45.19527	15.07305
44.7905	8.8246	44.84029	8.764848
45.3219	2.7091	45.35538	2.659229
37.6453	5.3859	37.66594	5.319393
29.6834	13.5155	29.67553	13.45427
29.1199	5.223	29.12476	5.16078
20.1316	4.9619	20.12722	4.898045
18.7289	13.1762	18.74647	13.10248
24.9348	25.4214	24.93774	25.38842
5.2095	3.4913	5.172588	3.441239
5.3745	10.9256	5.309673	10.86492
5.0307	19.8479	4.915961	19.84955
4.9044	30.0255	4.839045	30.05924
4.9268	40.1861	4.88019	40.22495
5.6513	46.5783	5.615551	46.61973
13.3537	48.1144	13.32467	48.16923
32.8827	48.3853	32.90481	48.44673
12.9089	3.6726	12.88918	3.608496
36.9423	23.7594	36.94458	23.84251
13.3917	27.859	13.34222	27.90365

Table 4.6: Actual location vs. averaged estimated locations for the third scenario.

Actual location		Average Estimated	
x	**y**	**x**	**y**
22.8488	42.0994	22.72869	42.5681
43.1112	46.3927	42.8408	46.51618
42.8136	39.0049	43.05343	39.11526
42.3828	31.6321	42.66375	31.88303
45.1756	22.3422	45.41628	22.59691
45.1005	15.1316	45.23077	15.14609
44.7905	8.8246	45.12169	8.633611
45.3219	2.7091	45.72146	2.736164
37.6453	5.3859	37.51143	5.069657
29.6834	13.5155	29.67144	13.24352
29.1199	5.223	29.20308	4.884399
20.1316	4.9619	20.03388	4.650918
18.7289	13.1762	18.88883	12.77362
24.9348	25.4214	24.94886	25.26884
5.2095	3.4913	5.456347	2.889833
5.3745	10.9256	5.195419	10.48034
5.0307	19.8479	4.497907	19.69986
4.9044	30.0255	4.547398	30.12221
4.9268	40.1861	4.630891	40.2399
5.6513	46.5783	5.483395	46.51586
13.3537	48.1144	13.42119	48.32642
32.8827	48.3853	32.11453	48.84228
12.9089	3.6726	12.78812	3.388129
36.9423	23.7594	36.97652	23.45971
13.3917	27.859	13.14558	28.07574

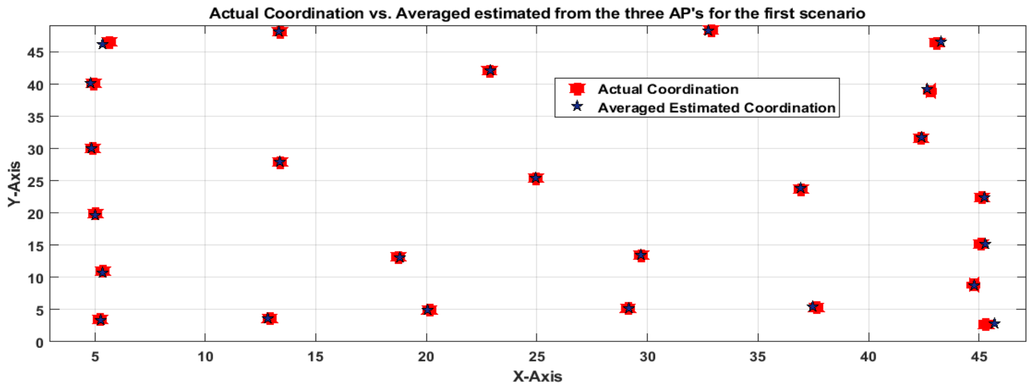


Figure 4.4: Comparison between the actual location vs. averaged estimated locations for the first scenario.

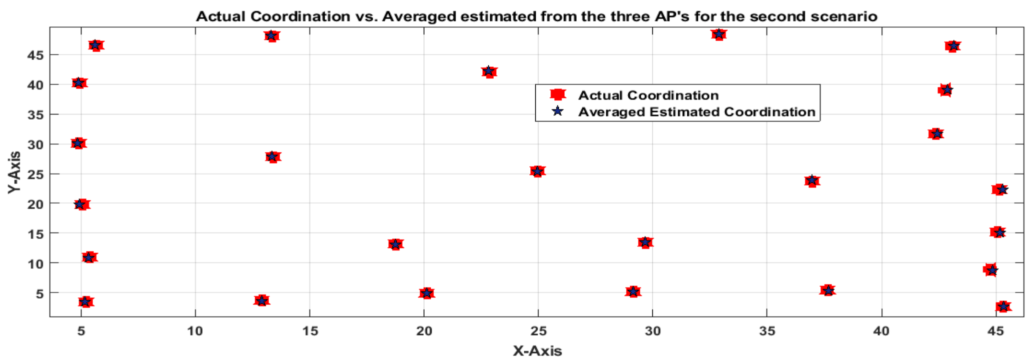


Figure 4.5: Comparison between the actual location vs. averaged estimated locations for the second scenario.

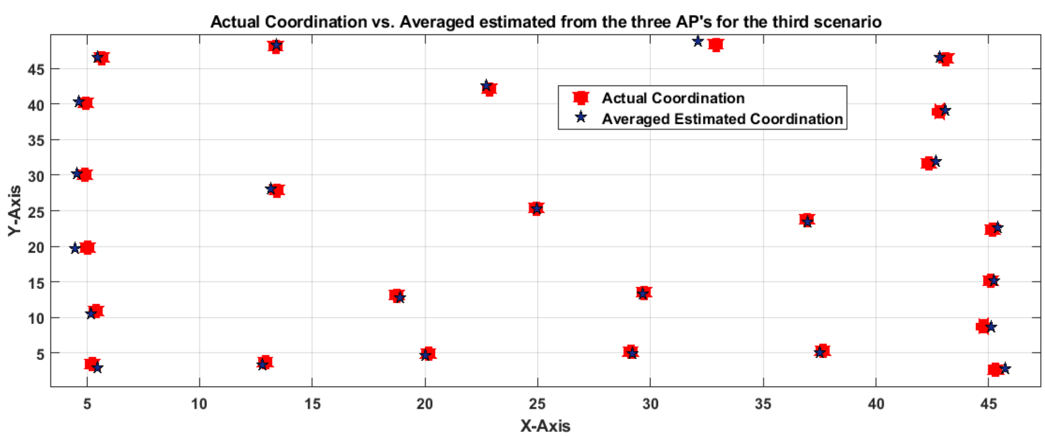


Figure 4.6: Comparison between the actual location vs. averaged estimated locations for the third scenario.

To achieve a final understanding for the estimation as compared to the actual results it has been calculate the accuracy and ranging error between the two values. For the accuracy it has been showed in Tables 4.7 and 4.8 and 4.9 for the three scenarios respectively.

Table 4.7: The accuracy obtained from the first scenario.

Accuracy	
x	**y**
99.9	99.9
99.6	99.5
99.6	99.6
100.0	99.8
99.9	99.8
99.6	99.6
100.0	99.1
99.2	97.1
99.5	98.3
99.9	99.9
99.8	99.1
99.7	99.9
100.4	99.6
100.0	99.9
98.9	96.9
99.3	97.9
99.5	99.3
98.8	99.8
97.4	99.8
94.4	99.1
99.7	100.0
99.7	99.9
99.3	97.7
100.0	99.9
99.9	99.9

Table 4.8: The accuracy obtained from the second scenario.

Accuracy	
x	**y**
99.9	99.8
99.9	99.9
100.1	99.9
100.1	99.9
99.8	99.9
99.8	99.6
99.9	99.3
99.9	98.2
99.9	98.8
100.0	99.5
100.0	98.8
100.0	98.7
99.9	99.4
100.0	99.9
99.3	98.6
98.8	99.4
97.7	100.0
98.7	99.9
99.1	99.9
99.4	99.9
99.8	99.9
99.9	99.9
99.8	98.3
100.0	99.7
99.6	99.8

Table 4.9: The accuracy obtained from the third scenario.

Accuracy	
x	**y**
99.5	98.9
99.4	99.7
99.4	99.7
99.3	99.2
99.5	98.9
99.7	99.9
99.3	97.8
99.1	99.0
99.6	94.1
100.0	98.0
99.7	93.5
99.5	93.7
99.2	96.9
99.9	99.4
95.5	82.8
96.7	95.9
89.4	99.3
92.7	99.7
94.0	99.9
97.0	99.9
99.5	99.6
97.7	99.1
99.1	92.3
99.9	98.7
98.2	99.2

The average accuracy from these three tables was obtained and for the x and y axis estimation these values were showed in Table 4.10. Such results indicate higher performance estimation for the three scenarios. Even though the third scenario has achieved the lowest estimation accuracy at some TPs. however, the utilization of the averaged mechanism would raise the accuracy of the proposed model in handling the accurate estimation for the indoor localization.

Table 4.10: The averaged accuracy values obtained from the three scenarios.

Scenarios	Average Accuracy	
	x	y
Scenario1	99.4	99.2
Scenario2	99.7	99.5
Scenario3	98.1	97.4

Ranging error is another important factor the indelicate the difference between the obtained estimation via the proposed model for AoA/RSS localization and the actual locations, which have been obtained from each scenario and for the x and y Axis and for the Max and Min ranging error. These values were showed in Table 4.11. Such results indicate higher accurate and less error estimation. It can be shown that the third scenario has got the largest error in estimation which it was about 50 cm, and this is done for the TP number 22. As a result, the multi-floor-based localization (second scenario) model had showed significant results for the case study with maximum error ratio of 11 cm in estimation as compared to the (third scenario).

Table 4.11: Ranging error for (x,y) coordination in the three scenarios.

Scenarios	Max Ranging error		Min Ranging error	
	x	y	x	y
Scenario1	0.369439	0.441221	0.000393	0.002023
Scenario2	0.114739	0.103463	0.002283	0.001652
Scenario3	0.508175	0.501467	0.011957	0.014488

4.6 COMPARISON WITH REFERENCE WORK

In this section a final comparison with the recent previous publication proposed by authors in [48] have been carried out to show the significant of the proposed model and algorithm of this thesis and as it has been summarized in Table 4.12.

Table 4.12: A final comparison with the reference work proposed.

Parameter	Proposed	Reference [48]
No. of AP	3	2
Multi-floor	yes	no
No. of TP	25	11
Max range error	50 cm	60 cm
Min Range error	0.000393 cm	0.014 cm
AP height	2.9 m	2 m
TP height	1.7 m	1.1 m
X- Axis accuracy	(98.1-99.4) %	--
Y- Axis accuracy	(97.4-99.2)%	--

5. CONCLUSION AND FUTURE WORK SUGGESTIONS

5.1 CONCLUSIONS

i. In this paper it has been designed and model a hybrid localization algorithm to localize several points within an indoor case study.

ii. The algorithm designed by using MATLAB and based on the results obtained from the WI software and also based on the AoA and RSS parameters.

iii. The significant of the designed algorithm model is to achieve a higher accurate estimation for multi floor scenario of indoor communication.

iv. Three scenarios have been studied and showed a higher accurate estimation with accuracy percentage ranged between (97.4-99.7)% without respect to the impact of interferences that caused by attenuations and signal distortion, which is varied from one case study to another.

v. As a result, the proposed algorithm showed higher accurate results where the maximum ranging error was 50 cm.

5.2 FUTURE SUGGESTIONS

In the future work several aspects could be handled such as :

i. Consider another localization-based method using other parameters such as ToA, TDoA for example.

ii. Proposed algorithm that could handle more than two floors and localize different points within these floors.

iii. Study the localization with respect to the millimeter waves frequencies to illustrate the impact of increasing the frequency on the localization performance.

iv.

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APPENDIX A

Programming code with MATLAB

Based on data collected from WI program

```
clc
close all
clear all
data_table=xlsread('table2');
 DT1=data_table(:,1);
 TT1=data_table(:,2);
 PT1=data_table(:,3);
 m= length(data_table)
DT2=data_table(:,4);
 TT2=data_table(:,5);
 PT2=data_table(:,6);
 DT3=data_table(:,7);
 TT3=data_table(:,8);
 PT3=data_table(:,9);
%%%%%%%%%%%%%%%
xtx1= input ('Enter AP1 x coordination :');
ytx1= input ('Enter AP1 y coordination :');
```

```
%%%%%%%%%%%%%%%%%%%%%
xtx2= input ('Enter AP2 x coordination :');
ytx2= input ('Enter AP2 y coordination :');
%%%%%%%%%%%%%%%%
xtx3= input ('Enter AP3 x coordination :');
ytx3= input ('Enter AP3 y coordination :');
for i = (1:1:m)
%%%%%%%%% AP1 %%%%%%%%%%%%%%%%%%%%%%%%%%%
theta1(i)= TT1(i);
phi1(i)=PT1(i);
d1(i)=  DT1(i);
beta1(i)= phi1(i)+180;
beta11(i)= deg2rad(beta1(i));
xrx1(i) = xtx1+d1(i)*cos(beta11(i));
yrx1(i) = ytx1+d1(i)*sin(beta11(i));
%%%%%%%%%%%%%%% AP2 %%%%%%%%%%%%%%%%%%%%%%%5
theta2(i)= TT2(i);
phi2(i)=PT2(i);
d2(i)=  DT2(i);
beta2(i)= phi2(i)+180;
beta22(i)= deg2rad(beta2(i));
xrx2(i) = xtx2+d2(i)*cos(beta22(i));
yrx2(i) = ytx2+d2(i)*sin(beta22(i));
```

```
%%%%%%%%% AP3 %%%%%%%%%%%%%%%%%%%%%%%%%%%%
theta3(i)= TT3(i);
phi3(i)=PT3(i);
d3(i)=  DT3(i);
beta3(i)= phi3(i)+180;
beta33(i)= deg2rad(beta3(i));
xrx3(i) = xtx3+d3(i)*cos(beta33(i));
yrx3(i) = ytx3+d3(i)*sin(beta33(i));
xrx1(i)
yrx1(i)
xrx2(i)
yrx2(i)
xrx3(i)
yrx3(i)
i=i+1;
%%%%%%%%% Average %%%%%%%%%%%%%%%%%%%%%%%%%%%
end
% Xrx_total = (xrx1+xrx2+xrx3)/3
% yrx_total = (yrx1+yrx2+yrx3)/3
```