KADİR HAS UNIVERSITY
GRADUATE SCHOOL OF SCIENCE AND ENGINEERING
COMPUTER ENGINEERING

INDOOR LOCATION ESTIMATION THROUGH REDUNDANT LATERATION FOR INDOOR POSITIONING SYSTEM

MOHAMMED KHUDHURAGHA

MASTER'S THESIS

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ASST. PROF. DR. TAMER DAĞ

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Hereby declare that this Master's Thesis is my own original work and that due references have been appropriately provided on all supporting literature and resources.

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ABSTRACT

INDOOR LOCATION ESTIMATION THROUGH REDUNDANT LATERATION FOR INDOOR POSITIONING SYSTEM

MOHAMMED KHUDHURAGHA

Master of Science in Computer Engineering

Advisor: Asst. Prof. Dr. Tamer DAĞ

Istanbul, July, 2017

The simplest way to describe Indoor Positioning Systems (IPS) is that it's like a Global Positioning System (GPS) for indoor environments. IPS can be used to locate objects or people inside buildings, typically via a mobile device such as a smart watch or smart phone or tablet. Although the technology is newer than GPS, services that leverage IPS are quickly gaining attention in places like art galleries, museums, shopping malls, hospitals, airports and other indoor venues where navigation and other location-based services (LBS) can prove to be necessary.

In this thesis we are suggesting a new method of location estimation by inhancing the lateration method by using the redundant method which uses normal lateration to calculate the location of the point by calculating the location of the same point 4 times but with different groups of access points (123, 124, 134, and 345). Then we started collecting the RSSI for these groups and convert it in to distances and estimate the location from these distances and the results for these tests will be compared with the final results.

Our results are statistical results for comparison in real life. Our algorithm will chose the best result out of the 4 groups which is average error 2.470399, minimum error 0.254138, maximum error 9.822816, standard deviation 1.371947 and the number points with error above 3 meters 48.

Keywords: Indoor Positioning Systems, location-based serveces, global positioning system, lateration, redundant lateration.

ÖZET

KAPALI KONUMLANDIRMA SİSTEMİ İÇİN YEDEK LATERASYON İLE KAPALI KONUM TAHMİN

MOHAMMED KHUDHURAGHA

Bilgisayar Mühendisliği, Yüksek Lisans

Danışman: Yard. Doç. Dr. Tamer DAĞ

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Kapalı Konumlandırma Sistemlerini (IPS) tanımanın en basit yolu, kapalı ortamlar için bir Global Konumlandırma Sistemi'ne (GPS) benzer olmasıdır. IPS, binalarda nesneleri veya kişileri bulmak için genellikle bir akıllı saat veya akıllı telefon veya tablet gibi bir mobil cihaz aracılığıyla kullanılabilir. Teknoloji, GPS'den daha yeni olmasına rağmen, sanat galerileri, müzeler, alışveriş merkezleri, hastaneler, havaalanları ve navigasyon ve diğer yer-tabanlı servislerin (LBS) gerekli olduğunu kanıtlayabilecek diğer kapalı mekanlar gibi yerlerde IPS'den faydalanan hizmetler hızla dikkat çekiyor. .

Bu tezde, aynı noktanın yerini 4 kez hesaplayarak, ancak farklı erişim noktası grupları ile noktanın yerini hesaplamak için normal laterasyonu kullanan yedek yöntem kullanarak, laterasyon yöntemini yükselterek yeni bir konum tahmini yöntemi öneriyoruz. (123, 124, 134 ve 345). Ardından, bu gruplar için RSSI toplamaya başladık ve mesafelere dönüştürdük ve bu uzaklıklardan konumunu tahmin ettik ve bu testlerin sonuçları nihai sonuçlarla karşılaştırılacaktır.

Sonuçlarımız, gerçek hayatta karşılaştırma yapmak için istatistiksel sonuçlar. Bizim algoritmamız, ortalama hata 2.470399, minimum hata 0.254138, maksimum hata 9.822816, standart sapma 1.371947 ve sayı 3 metreden fazla hata içeren sayı gruplarından 4 gruptan en iyi sonucu seçecektir.

Anahtar Kelimeler: Kapalı Konumlandırma Sistemleri, konuma dayalı servisler, global konumlandırma sistemi, laterasyon, yedek laterasyon.

Acknowledgements

I would like to express my sincere thanks and deep gratitude to Asst. Prof. Tamer Dağ for supervising the present work and their support and encouragement throughout the research.

Last but not least, I would like to record my deep affection and thanks to my parents for their patience and moral support given to me throughout the work.

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List of Abbreviations

IPS	Indoor Positioning System
LBS	Location Based Service
NLoS	Non Line of Sight
IR	Infrared
NNSS	Nearest Neighbor's in Signal Space
RSSI	Received Signal Strength Indication
GPS	Global Positioning System
LOS	Line of Sight
UWB	Ultra Wide Band
RF	Radio Frequency
WLAN	Wireless Local Area Network
EW	Electromagnetic Wave
AP	Access Point
RFID	Radio Frequency Identification
TOA	Time of Arrival
TDOA	Time Difference of Arrival

CHAPTER 1

Introduction

For as long as we remember it's important to know where we are in the world. In the old days we used maps and compasses to find our way around. Today, we use GPS when traveling by car, bicycle or on foot; however there is one problem that the GPS system does not work inside buildings. To solve this problem one could create Indoor Positioning System (IPS). In this thesis the focus will be on the indoor positioning, and thus IPS. The development of usage of IPS systems have increased radically in the last few years. More and more wireless technologies are being used, resulting in more featured rich systems capable of solving numerous big and small tasks in many companies, factories or organization buildings. The big range of services the IPS systems can offer are mainly the reason for its extreme success and popularity in the recent years [1].

Location-based targeted promotions can lead customers to you, especially those in a position to purchase now. If loyalty programs could auto-detect clients and automatically check them in, venues would remain on the radar of their clients' social circle. Business intelligence gathered by knowing customers' behavior inside a store could provide advantages in displaying merchandise, planning specials etc. The convenience and safety provided by indoor navigation and the access to location-based content can facilitate and optimize human traffic in public areas such as airports, shopping malls, stadiums, museums, office parks [2]etc.

The accuracy of the cellular network solution is an issue. Users can be directed to within a room's boundaries of target but the ability to provide more precise location-based information is non-existent. In a shopping mall this could be a problem. Another trick is navigating through a wall – you might find yourself staring at a brick wall with your phone insisting that the store you need is a few steps forward. Integration with building blueprints and taking into account all possible use cases is required. A different problem is the fact that iPhones do not scan for a Wi-Fi signal. An innovative solution has the device and the building swapping roles, allowing the Wi-Fi points to detect the phone and provide location information to the users.

Indoor environments are particularly challenging for positioning, i.e. position finding, for several reasons [1]:

- Non Line of Sight (NLoS) conditions, high attenuation and signal scattering due to greater density of obstacles.
- Fast temporal changes due to the presence of people and opening of doors.
- High demand for precision and accuracy.
- Severe multipath from signal reflection from walls and furniture.

The ability to locate objects and people indoors remains a substantial challenge. Many applications of indoor positioning are waiting for a satisfactory technical solution. Indoor positioning performance improvements have the potential to create unprecedented opportunities for businesses.

So in the present thesis we will consternate on enhancing the trilateration method by trying to make it more accurate and more reliable for indoor use.

1.1 Existing Indoor Positioning Systems:

Many positioning systems have been developed over the years for indoor location estimations. We introduce a variety of IPSs in this section. The location technology and technique used in each IPS are addressed to give a scientific overview of the system. Since the evaluation of these IPSs is focusing on the need of users in personal networks (PNs), these IPSs are explained according to the criteria and requirements as specified in the subsection II-F. Thus we can know the advantages and limitations of these IPSs from the view of users in PNs [3].

1.1.1 Infrared (IR) Positioning Systems

Infrared (IR) positioning systems [4, 5] are the most common positioning systems, because IR technology is available on board of various wired and wireless devices, such as TV, printers, mobile phones, PDAs, etc. An IR-based positioning system, which offers absolute position estimations, needs line-of-sight communication between transmitters and receivers without interference from strong light sources. Thus the coverage range per infrastructure device is limited within a room [4].

1.1.2 Ultra-Sound Positioning Systems

Using ultrasound signal [6, 7] is another way of position measurement. Ultrasound signals are used by bats to navigate in the night, which inspire people to design a similar navigating system in the last hundred years.

1.1.3 Radio Frequency (RF) Positioning Systems.

Radio frequency (RF) technologies [7], [8] are used in IPSs, which provide some advantages as follows. Radio waves can travel through walls and human bodies easier, thus the positioning system has a larger coverage area and needs less hardware comparing to other systems. RF-based positioning systems can reuse the existing RF technology systems such as access points (Aps) in WLAN. Triangulation and fingerprinting techniques are widely used in RF-based positioning systems. For complicated indoor environments, location fingerprinting is an effective position estimation method, which uses location related characteristics such as RSS and location information of the transmitters to calculate the location of a user or a device.

1.1.3.1 Radio Frequency Identification (RFID):

The radio frequency identification (RFID) is a means of storing and retrieving data through electromagnetic transmission to an RF compatible integrated circuit [9]. The RFID positioning systems are commonly used in complex indoor environments such as office, hospital, etc. RFID as a wireless technology enables flexible and cheap identification of individual person or device [10]. RFID technology can replace the identification technique such as the barcodes, and be used to design various products and services [11]. There are two kinds of RFID technologies, passive RFID and active RFID [9]-[11]. With passive RFID, a tracked tag is a receiver. Thus the tags with passive RFID are small and inexpensive. But the coverage range of tags is short. Active RFID tags are transceivers, which actively transmit their identification and other information. Thus the cost of tags is higher. On the other hand, the coverage area of active tags is larger.

1.1.3.2 WLAN

WLAN technology is very popular and has been implemented in public areas such as hospitals, train stations, universities, etc. WLAN-based positioning systems reuse the existing WLAN infrastructures in indoor environments, which lower the cost of indoor positioning. The accuracy of location estimations based on the signal strength of WLAN signals is affected by various elements in indoor environments such as movement and orientation of the human body, the overlapping of APs, the nearby tracked mobile devices, walls, doors, etc. The influence of these sources and their impacts have been discussed and analyzed in the literatures [12]-[14]. In this section, some WLAN-based IPSs are introduced and discussed.

1.1.3.3 RADAR

RADAR [18] positioning system was proposed by a Microsoft research group as an indoor position tracking system, which uses the existing WLAN technology. RADAR system employs signal strength and signal-to-noise ratio with the triangulation location technique. The multiple nearest neighbor's in signal space (NNSS) location algorithm were proposed, which needs a location searching space constructed by a radio propagation model. The RADAR system can provide 2-D absolute position information and thereby enable location-based applications for users.

The Ekahau positioning system [13] uses the existing indoor WLAN infrastructures to continually monitor the motion of Wi-Fi devices and tags. The triangulation positioning technique is used for locating any Wi-Fi enabled device in the Ekahau positioning system. The received signal strength indication (RSSI) values of the transmitted RF signals recorded at different APs are used to determine the target locations. The Ekahau positioning system offers 2-D location information, which can be used by location aware services and applications.

1.1.3.4 Bluetooth

The IEEE 802.15.1 standard, is a specification for WPAN. Bluetooth enables a range of 100 m (Bluetooth 2.0 Standards) communication to replace the IR ports mounted on mobile devices. Piconets are formed under Bluetooth specifications by using a master/slave based MAC protocol. Bluetooth technology has been implanted in various types of devices such as mobile phone, laptop, desktop, PDA, etc. In addition, Bluetooth chipsets are low cost, which results in low price tracked tags used in the positioning systems. In Bluetooth-based positioning systems [15], [16], various Bluetooth clusters are formed as infrastructures for positioning. The position of a

Bluetooth mobile device is located by the effort of other mobile terminals in the same cluster.

Sensors are devices exposed to a physical or environmental condition including sound, pressure, temperature, light, etc., and generate proportional outputs. Sensors are typically divided into two kinds: active sensors and passive sensors. Active sensors can interact with the environment such as radars. Passive sensors only receive information from the outside world. The sensor-based positioning systems consist of a large number of sensors fixed in predefined locations [17]. From the measurements taken by these sensors, a person or device can be located.

1.1.4 Magnetic Positioning System

Using magnetic signals is an old and classic way of position measuring and tracking [18]. The magnetic positioning systems offer high accuracy and do not suffer from the line-of sight problems, where the positions are measured in the case of an obstacle between the transmitters and receivers.

1.1.5 Vision-based Positioning System

Vision-based positioning is a way of tracking the locations and identifying persons or devices in a complex indoor environment [19], [20]. The vision-based positioning does not need the tracked person carrying or wearing any device. And vision can easily provide some location-based information such as person A is drinking wine and sitting on his/her sofa.

1.2 IPS Topologies

An indoor wireless positioning system consists of at least two separate hardware components: a signal transmitter and a measuring unit. The latter usually carries the major part of the system "intelligence."

There are four different system topologies for positioning systems [21].

- In remote positioning system, signal transmitter is mobile and several fixed measuring units receive the transmitter's signal. The results from all measuring units are collected, and the location of the transmitter is computed in a master station.

- In self-positioning system the measuring unit is mobile. This unit receives the signals of several transmitters in known locations, and has the capability to compute its location based on the measured signals.
- If a wireless data link is provided in a positioning system, it is possible to send the measurement result from a self-positioning measuring unit to the remote side, and this is called indirect remote positioning, which is the third system topology.
- If the measurement result is sent from a remote positioning side to a mobile unit via a wireless data link, this case is named indirect self-positioning, which is the fourth system topology [22].

1.3 Global Positioning system (GPS)

The Global Positioning System (GPS) [23] is a network of about 30 satellites orbiting the Earth at an altitude of 20,000 km. The system was originally developed by the US government for military navigation but now anyone with a GPS device, be it a SatNav, mobile phone or handheld GPS unit, can receive the radio signals that the satellites broadcast.

Wherever you are on the planet, at least four GPS satellites are 'visible' at any time. Each one transmits information about its position and the current time at regular intervals. These signals, travelling at the speed of light, are intercepted by your GPS receiver, which calculates how far away each satellite is based on how long it took for the messages to arrive.

Once it has information on how far away at least three satellites are, your GPS receiver can pinpoint your location using a process called trilateration.

1.3.1 Trilateration:

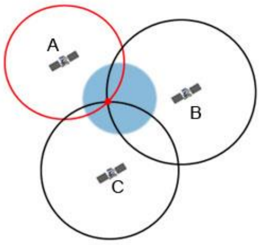

Fig. (1.1) Satellites Trilateration

Imagine you are standing somewhere on Earth with three satellites in the sky above you as shown in fig. (1.1). If you know how far away you are from satellite A, then you know you must be located somewhere on the red circle. If you do the same for satellites B and C, you can work out your location by seeing where the three circles intersect. This is just what your GPS receiver does, although it uses overlapping spheres rather than circles. The more satellites there are above the horizon the more accurately your GPS unit can determine where you are [23].

1.4 Related Work

The following literature review will briefly cover four main areas. First, an overview of some of the existing location estimation technologies is carried out.

GPS uses multiple orbiting satellites to triangulate the position of a mobile receiver on the earth's surface. It calculates location by triangulating the time of flight of transmissions from these satellites to the receiver. A user's position can be tracked to within a few meters and it is this accuracy over a wide geographical area that makes GPS so popular. However, it does have some major limitations. Its coverage and accuracy can vary with factors such as the weather [24], time of day [25] and use in built-up areas [27]. In particular, it does not work indoors [28].

Ultrasonic systems use time of flight of ultrasonic sound chips to triangulate position and work well indoors. The University of Bristol has developed a low cost version of this [29], and an example of its usage is in the 'City Project' [30] where it was used as part of a tour guide system in the Lighthouse museum in Glasgow.

Radio Frequency ID (RFID) tags are currently being built into many everyday objects. These tags can give position when they pass close to a reader but they usually need to be a few centimeters away from the reader, making them unsuitable for the purposes of this study.

Computer visual techniques are also in use in location based systems. One system described by [31] involves the use of special optical markers which a computer can be trained to recognize. Inertia tracking can be used as a means of determining location. Accelerometers can be embedded into mobile devices and these can be used to calculate velocity. Digital compasses can be added to these devices in order to measure orientation. It is important to know what direction you are facing, in order to know what you are looking at [32].

Each of these technologies has its own advantages and disadvantages. It is important to note that they are different in a wide variety of ways including: working indoors or outdoors, cost, potential for interference, resolution accuracy and whether position is determined by the device itself (greater privacy) or by a centralized technology (network). A number of different systems have previously used 802.11 access points as beacons from which to estimate location. Microsoft research group have developed a similar system called RADAR [33] describe this system as obtaining 1.5m accuracy within a precalibrated area. This was done by constructing a detailed "radio fingerprint" of the 802.11 Access Points (APs) within an office building. The strength of signal detected within a one foot by one foot grid was then used to determine location.

[13] has a software product that works like RADAR and claims to be able to pinpoint devices to a room level [34]. Both of these products are however expensive and require intense calibration and only work on the precalibrated area. The data required for PlaceLab can be collected while walking or driving. Another system that uses the radio services is the environment was also developed by Microsoft research. RightSPOT uses FM radio signals to determine position [35]. The current accuracy of this system is in the order of km and could not be used for our system. Numerous other indoor location systems have been developed that make use of the sensory technologies discussed earlier but the major drawback with these is that they all require the

installation of specialized hardware in the environment to be maintained. The costs of these technologies are also prohibitive making them unsuitable for personal or social applications that are to be used in people's daily lives. They do however offer very high accuracy levels and are therefore used by many commercial organizations. An example of such a system is the LA-200 from Trapeze Networks. This provides a hardware based solution to location tracking. Wireless devices located within the scope of the wireless network may be tracked and located to room level. This system uses the 802.1 network as a means of carrying out the operation and they claim accuracy at 99% with 10 meter precision in fewer than 30 seconds. Many applications utilizing location based technologies have recently been developed. There are two major types of these applications. First, those where users do not want to disclose their location to anyone. Mappoint.com [36] is an example of such an application where people may find their own location on a map and be directed to local places of interest. Second, those applications that reveal a user's location to a small group of selected friends. Two examples of these include dodgeball.com [37] and AT&T's developed in mMode's Friend Finder [37] these notify you if a friend is in the area and are becoming popular in big cities.

CHAPTER 2

Received Signal Strength Indicator (RSSI)

RSSI is the common name for the signal strength in a wireless environment network. It is a measure of the level of power that an RF client device is receiving from an access point, for example RSSI is the relative strength of signal in a wireless environment and can be measured in any unit of power. It is often expressed in decibels (dB), or as percentage values range between 1-100, and can be either a negative, or a positive value [36]. The closer the figure is to zero, the better signal strength. For example, RSSI of -65 is better than -85. As an example, the signal is good if it would be -50, a reasonable would be -75, and a bad one would be -90, while -100 would provide no service at all.

2.1 Ranging methods

Ranging is a process of measuring the distance between two WSN nodes, this distance Information allows to compute the position of each node. This information can be obtained using several techniques as described in [37]:

- ToA - by using time of arrival information;
- TDoA - by using time difference of arrival information;
- RSSI - by using received signal strength indicator.

2.1.1 Time of Arrival (ToA)

In the Time of Arrival (ToA) procedure, the signal traveling time is used to determine the distance between nodes. Imagine that the distance between two nodes A and B needs to be measured. At time t0, node A sends a message to node B. At time t1, node B receives the message, and at time t2 it sends another message back to node A. The second message is received by node A at time t3. Knowing the speed of propagation of the signal v, the distance d between nodes A and B can be calculated using the equation (2.1):

$$d = \frac{v((t_3 - t_0) - (t_2 - t_1))}{2} \tag{2.1}$$

Where t0 is the time when the first signal is sent, t1 is the time when the first message is received, t2 is the time when the second message is sent, and t3 is the time when the second message is received. This procedure is illustrated in Figure 2.1. Systems using time of arrival method for ranging often use signals with slow speed of propagation, such as ultrasound. It enables to use less precise hardware to keep track of the time.

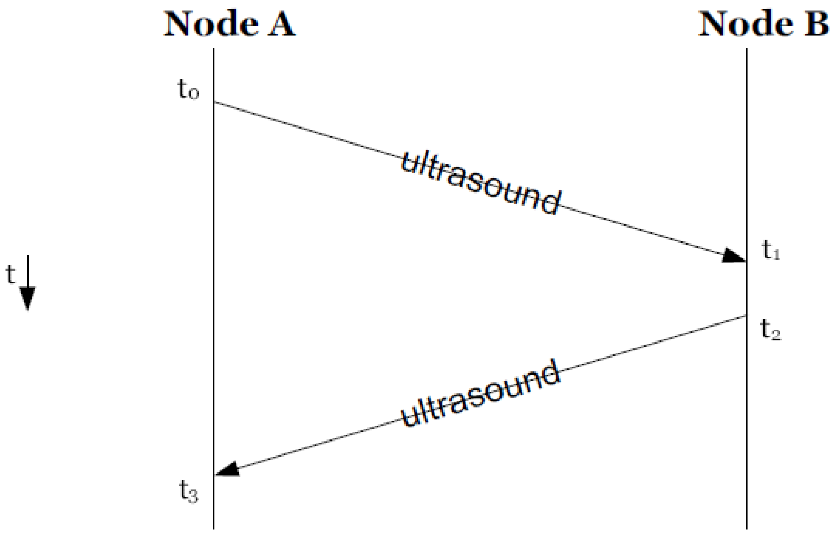

Fig (2.1) Ranging using time of arrival (ToA) method

2.1.2 Time Difference of Arrival (TDoA):

The Time Difference of Arrival (TDoA) method is similar to the Time of Arrival method. However, it uses two signals with different speed of propagation: a fast-speed signal. Usually radio signal, and a slow-speed signal, usually ultrasound signal. At time t_0, node A sends a radio signal. At time t_1, node B receives the radio signal. After, at time t_2, node A sends an ultrasound signal. At time t_3, node B receives the ultrasound signal. Considering the speed of propagation of the radio signal (v_{rf}) and the speed of propagation of the ultrasound signal (v_{us}), the distance d between nodes A and B can be calculated using equation (2.2):

$$d = v((t_3 - t_0) \; - (t_2 - t_1))\frac{v_{rf}v_{us}}{v_{rf}-v_{us}} \qquad (2.2)$$

where t_0 is the time when the radio signal is sent, t_1 is the time when the radio signal is received, t_2 is the time when the ultrasound signal is sent, and t_3 is the time when the ultrasound signal is received. This procedure is illustrated in Figure 2.2.

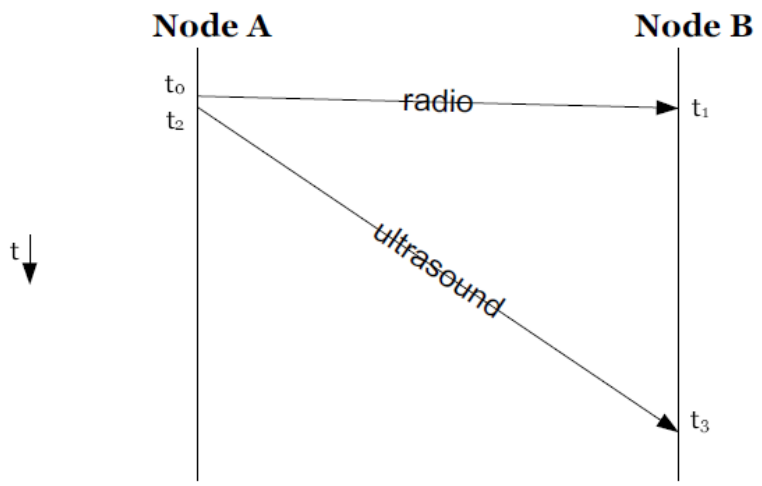

Fig. (2.2) Ranging using time difference of arrival (TDoA) method

2.1.3 Received Signal Strength Indicator (RSSI)

The Received Signal Strength Indicator (RSSI) method is based on the fact that the strength of radio signal decreases with the distance. In this context, the path loss is the attenuation in the signal during travelling over a path between two points. The mathematical model for path loss can be calculated using the following equation [38]:

$$PL(d) = PL(d_0) + 10nlog\left(\frac{d}{d_0}\right) \qquad (2.3)$$

where PL(d) is the path loss function with respect to the measured distance in decibels, PL(d_0) is the path loss over a measured reference distance close to transmitter, n is the loss exponent which defines the rate at which the loss increases with the distance. This constant depends on the conditions of the environment, and is usually ranged from 2.0 to 5.0. Using the strength of the signal for determining the distances usually yields to a number of errors [41], [42], [43], [44], because the path loss depends on many factors related to the environment, such as reflections, diffraction, scattering and antenna orientation. To model the error in the signal attenuation, a random variable is included in the path loss function:

$$PL(d) = PL(d_0) + 10nlog\left(\frac{d}{d_0}\right) + X_\rho \qquad (2.4)$$

where Xρ is a zero-mean Gaussian random variable with a standard deviation ρ In particular, it should be noted that choosing the proper function of probability distribution to represent radio irregularities is not trivial. It should be verified that the real statistical data fit into the chosen distribution.

2.2 Basic Methods of Propagation

Reflection, diffraction and scattering are the three fundamental phenomena that cause propagation of signal in a mobile system communication, apart from line of sight (LoS) communication. The parameter with most importance, predicted by propagation models based on above three phenomena, is the received power. The physics of the above phenomena may be used also to describe the small scale fading and multipath propagation. The following subsections give an outline of these phenomena.

2.2.1 Reflection

Reflection occurs when an electromagnetic wave (EM) falls on an object, with very large dimensions as compared to the wavelength of the propagated wave. As an example, such objects can be the earth, buildings and walls. When a radio wave propagated in another medium with different electrical properties, part of it is transmitted into it, while some energy is reflected back. For example, as a special cases if the medium on which the EM wave is incident is a dielectric, some energy is reflected back and some energy is transmitted. If the medium is a perfect conductor, all energy is reflected back to the first medium. The amount of reflected energy back depends on the electromagnetic wave polarization.

2.2.2 Diffraction

Diffraction is the phenomenon due to which an EM wave can propagate beyond the horizon, around the curved earth's surface and obstructions like tall buildings. As the user moves deeper into the shadowed region, the field strength received decreases. But the diffraction field still exists and its strength is enough to yield a good signal. This phenomenon can be explained by the Huygen's principle, according to which, every point on a wave front acts as point sources for the production of secondary wavelets, and they combine to produce a new wave front in the direction of propagation. The propagation of secondary wavelets in the shadowed region results in diffraction. The field in the shadowed region is the vector sum of the electric field components of all the secondary wavelets that are received by the receiver.

2.3.3 Scattering

The actual received power at the receiver is somewhat stronger than claimed by the models of reflection and diffraction. The cause is that the trees, buildings and lampposts scatter energy in all directions.

2.3 Log Distance Path Loss or Log Normal Shadowing Model

Electromagnetic waves differ in energy in accordance to their wavelengths. Their ability to propagate is also different in different propagation environments. In free space (vacuum) they propagate without obstruction and without atmospheric effects. The path loss under these conditions is said to be free space path loss. The log-distance path loss model is a radio propagation model that estimate the path loss of a signal in a given environment over distance. Propagation models such as this one show that the average strength of a received signal decreases logarithmically with distance [8]. The model of Log- distance path loss is a generic model and an extension to Friis Free space model. This model is used to predict the propagation loss for a wide range of environments, whereas, the Friis Free space model is restricted to unobstructed clear path between the transmitter and the receiver.

Fig (2.3) Log- distance path loss

In the far field region of the transmitter ($d \geq d_f$), if $PL(d_0)$ is the path loss measured in dB at a distance d_0 from the transmitter, then the path loss (the loss in signal power measure in dB when moving from distance (d_0 to d) at an arbitrary distance $d > d_0$ is given by equation:

$$PL_{d_0 \to d}(dB) = PL(d_0) + 10nlog\left(\frac{d}{d_0}\right) + x \qquad d_f \leq d_0 \leq d \qquad (2.6)$$

Where PL (d_0) = Path Loss in dB at a distance d_0,

$PL_{d>d0}$= Path Loss in dB at an arbitrary distance d,

n = Path Loss exponent.

χ = zero-mean Gaussian distributed random variable (in dB) with standard deviation – σ. This variable is used only when there is a shadowing effect. If there is no shadowing effect, then this variable is zero. Taking log of the Normal (Gaussian)-variable results in the name “Log-Normal” fading.

Usually to model real environments the shadowing effects cannot be neglected. By neglecting the shadowing effect, the Path Loss is simply a straight line (see figure 2.4 below). To add shadowing effect, a zero-mean Gaussian random variable with standard deviation – σ is added to the equation. The actual path loss may still vary due to other factors. Thus the path loss exponent (modeling the slope) and the standard deviation of the random variable should be known precisely for a better modeling.

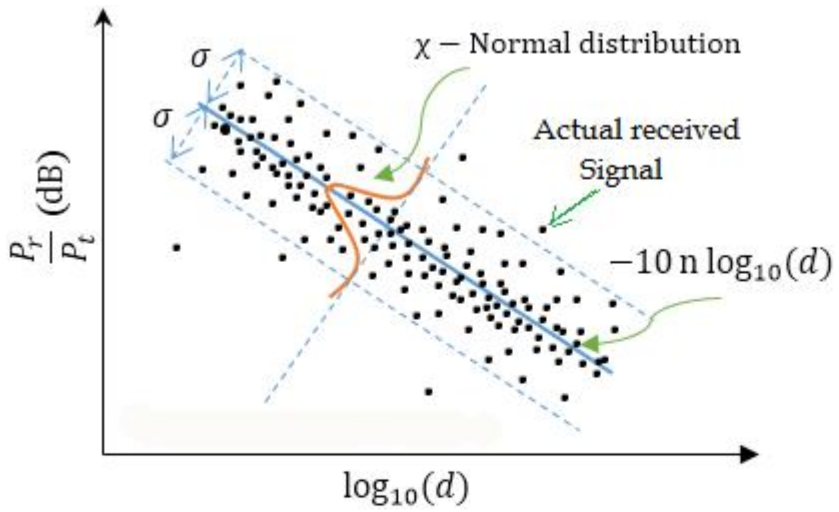

Fig. (2.4) The Path Loss Exponent (PLE) table given above is for reference only.

2.4 RSSI Measurement and distance calculating calibration

This section describes the measurement made to understand the behavior of the RSSI for access points used in the present work. That helps in the computation of signal propagation constant in order to determine the distance according to signal strength. These measurements were performed at Kadir Has University at Classroom 503 on the fifth floor, the classroom is almost empty it has one lecturer's table in the corner and a column at the middle of the room as shown in figure (2.5).

Fig. (2.5) KHU 503 Classroom

The RSSI values are measured from one meter to six meters at four access points that used in this experiment and the result for access point (TEST 1) are shown in figure (2.6)

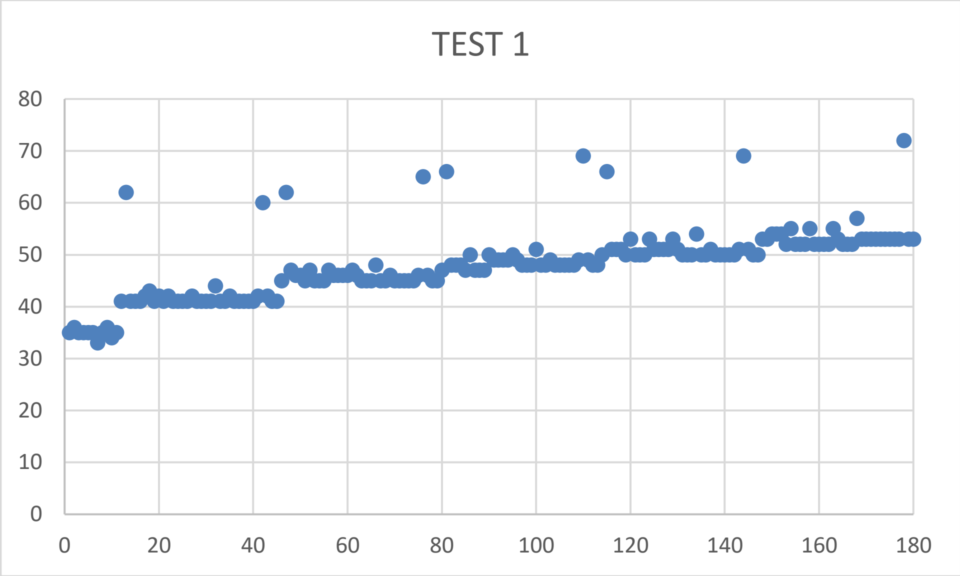

Fig. (2.6) the results for (TEST 1) from 1M to 6M for 180 sample

The first access point tested first at one meter distance for 3 mins with 1 second duration as shown in figures (2.7) and (2.8):

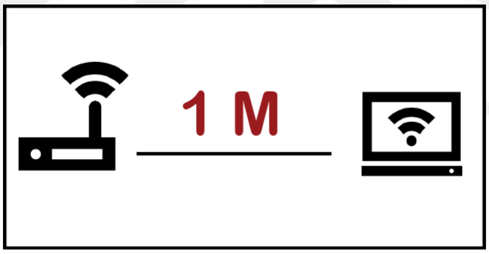

Fig. (2.7) the distance between the access point and the receiver (1M)

In figure (2.7) the Average RSSI value is: -35.7 dBm, and the standard deviation is: 1.57.

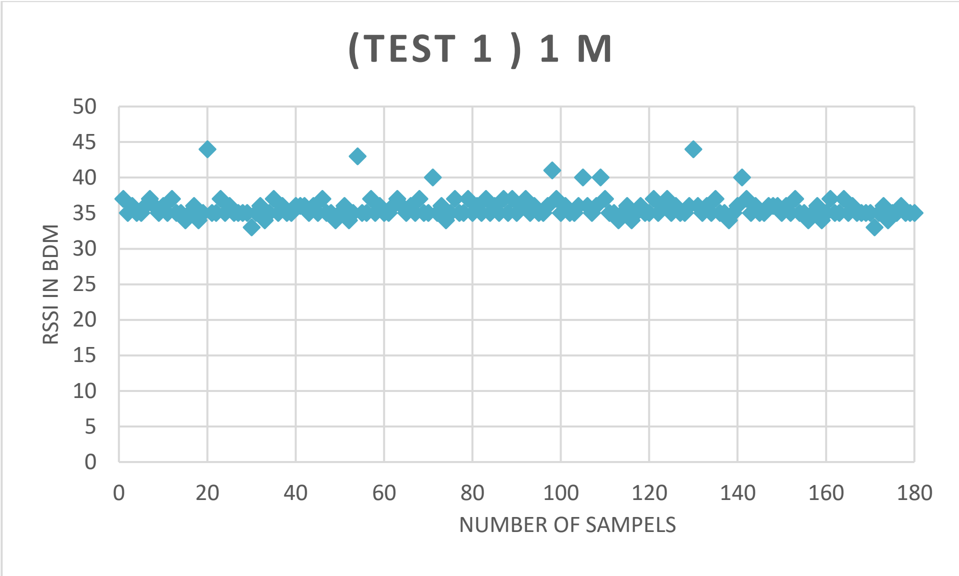

Fig. (2.7) RSSI for Access point (TEST 1) at one meter

In figure (2.8) the Average RSSI value is: -48.3 dBm, standard deviation is: 11.1

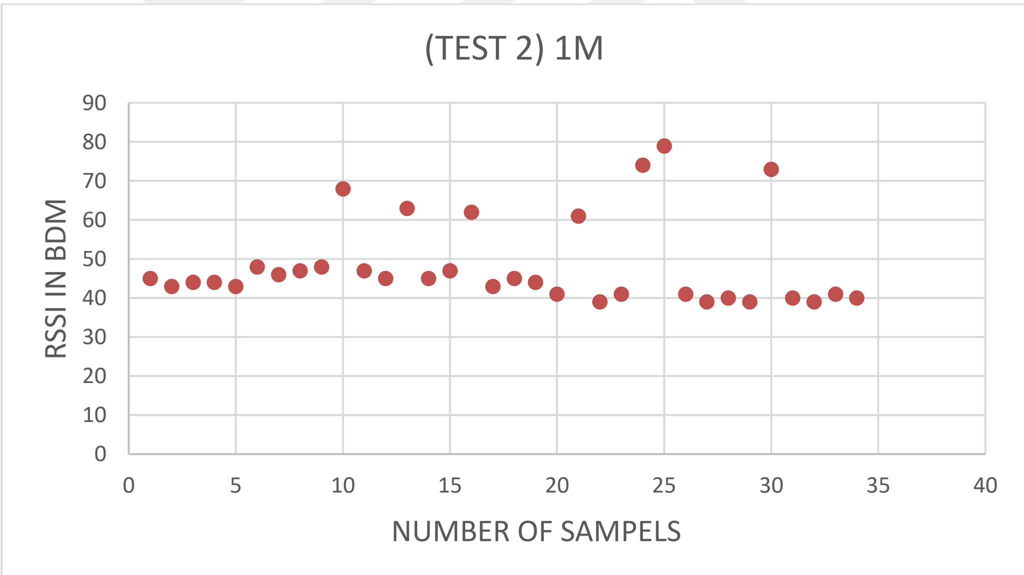

Fig. (2.8) RSSI for Access point (TEST 2) at one meter

In figure (2.9) the Average RSSI value is: - 44.1 dBm, standard deviation is: 9.9

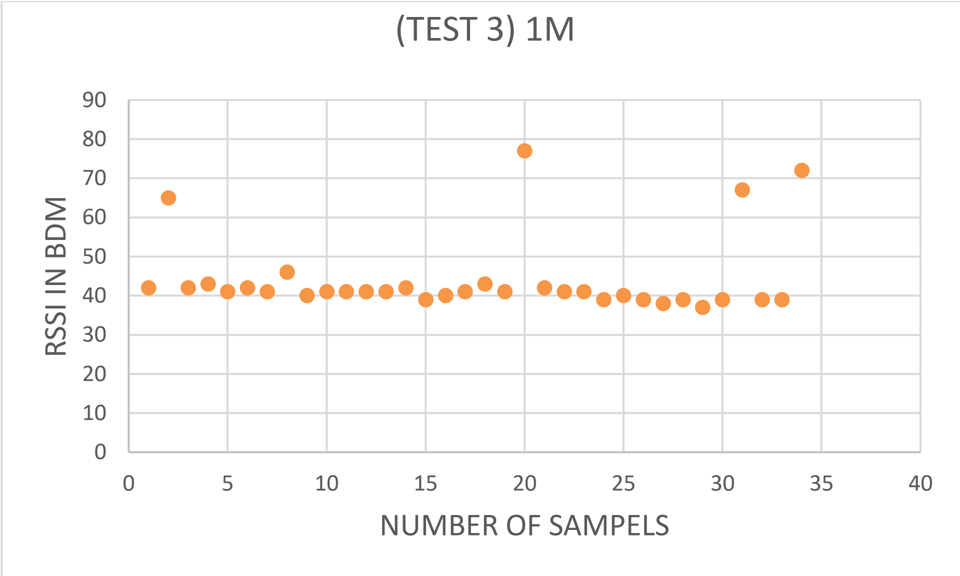

Fig. (2.9) RSSI for Access point (TEST 3) at one meter

In figure (2.10) the Average RSSI value is: - 46.08 dBm, standard deviation is: 5.1

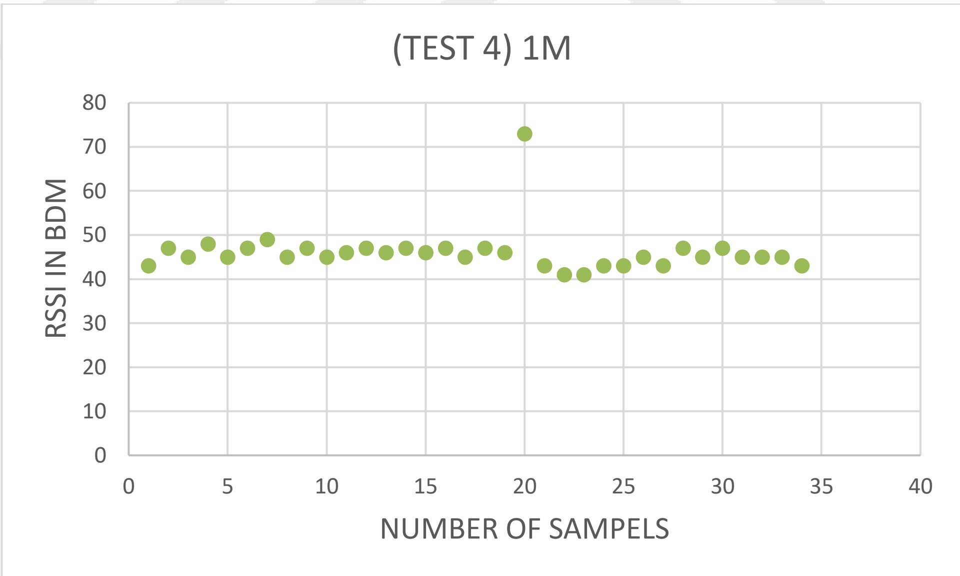

Fig. (2.10) RSSI for Access point (TEST 4) at one meter

From these results we see that the differences in RSSI values between different access points using the same access point model, distance and test conditions. This result is in agreement with [45] and shown in table (2.1):

Table (2.1) the average RSSI at one meter

Access point name	Average RSSI at one meter	standard deviation
TEST 1	-35.7 dBm	1.57
TEST 2	-48.3 dBm	11.1
TEST 3	- 44.1 dBm	9.9
TEST 4	- 46.08 dBm	5.1

Chapter 3

Deterministic Phase and Experimental Area

The deterministic phase involves calibrating RSSI values for each reference points as shown in figure (3.1). A series of calibrations shows that uniform computation of signal propagation constant in order to determine the distance according to signal strength exhibits some drawbacks. This verified that different mediums (free space, glass, and wall) surrounding the reference nodes affect the signal attenuation differently. Therefore, if only a single propagation constant is used for all reference nodes, incorrect calculations of the distance occurs. The calibrated propagation constant taken the obstacles into account can be calculated using reversing the linear RSSI equation as shown in (3.1):

$$n_i = -\left(\frac{RSSI_i - A}{10log_{10}\, d_i}\right) \qquad (3.1)$$

The value A is obtained in a no-obstacle one-meter distance signal strength measurements from the reference points see figure (2.7).

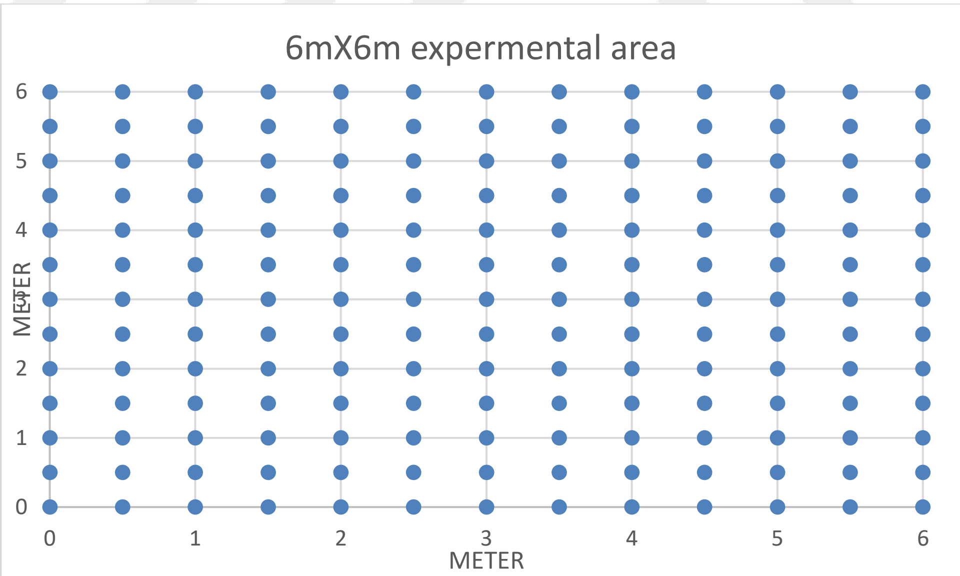

Fig. (3.1) the reference points in the experimental area

The experimental area is a 6m × 6m, with 165 reference points and 4 access points located at the corner of the experimental area, the distance between the reference points is 50cm as shown in fig (3.2)

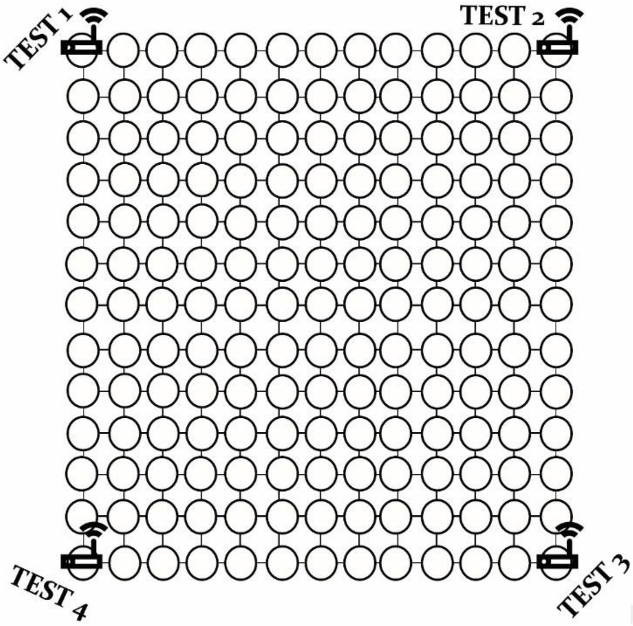

Fig. (3.2) the experimental area map

Path Loss exponent (n) are calculated with Brute Force technique for each RSSI values that measured. Brute Force algorithm is used to find optimum N values. Basically the algorithm finds path loss exponent values for each access point. The algorithm find exponent until the estimated distance and real distance is equal to each other for each RSSI values. Let assume there are N measurement point. Then the Path Loss exponent for each access point is;

$$n_{avg} = \sum_{i=0}^{N} n_i \qquad (3.2)$$

In the experimental area we find that the values of A are: -35.7, -48.3, - 44.1, and -46.08, and the values of Path Loss exponent are 2.36, 2.8, 2.69, and 2.63 respectively for each access points.

After collecting the RSSI values for the 165 points in the 6m × 6m area the distance for each point is calculated by using the RSSI , A and the path loss exponent (n) values using the following equation :

$$d_i = -10^{\frac{RSSI_i + A}{10n}} \qquad (3.3)$$

Which give us the distance values of the point to the access point.

Chapter 4
Lateration

Lateration is used when there is a point for which the exact position need to be calculated, knowing the absolute exact position of several other points called anchors, as well as the distances to them. To localize a point in two dimensions, its distances to at least three anchors need to be known. For points to be localized in three dimensions, the distances to at least four anchors need to be know.

For simplicity, assuming the case of two dimensions. If we know the distances to exactly three anchors, we obtain a system of equations which has a unique solution. This problem can be formalized as follows [27], [33].

Let $v_i = (x_i;\ y_i)$, where i = 1; 2; 3 be a position of each anchor, $v_u\ =\ (x_u; y_u)$ be the unknown position of the node to be localize, and r_i; i = 1; …; 3 be the precise (with no error) distances between the unknown position and each anchor. This situation is illustrated in Figure (4.1)

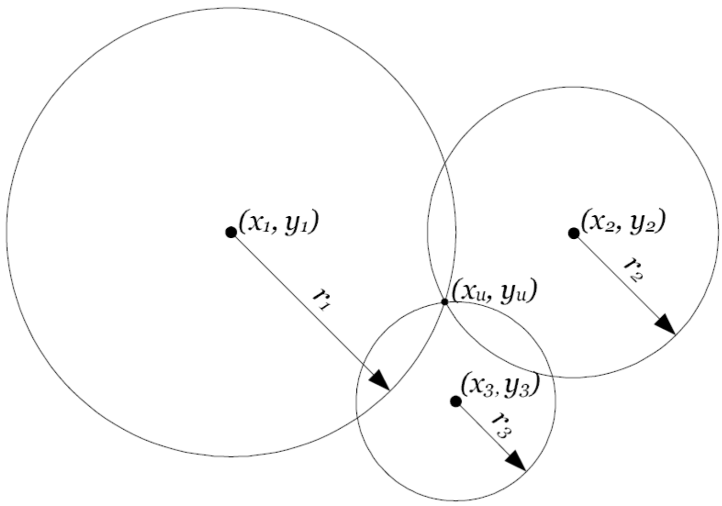

Fig. (4.1) The Lateration method for calculating the position of a point

The distance r_i which estimated from RSSI values are used to compute the intersection point of the circumferences of the three circles of the anchor points. Ideally, the target should be intersection of the circles like in Figure 4.1.

From the general Euclidean distance, radius can be found as:

$$r_i = dist(v_i, v_u) = \sqrt{(x_i - x_u)^2 + (y_i - y_u)^2} \tag{4.1}$$

$$\begin{aligned} r_1 &= \sqrt{(x_1 - x)^2 + (y_1 - y)^2} \\ r_2 &= \sqrt{(x_2 - x)^2 + (y_2 - y)^2} \\ r_3 &= \sqrt{(x_3 - x)^2 + (y_3 - y)^2} \end{aligned} \tag{4.2}$$

After re-arranging the basic equation, we have matrix form:

$$\begin{bmatrix} (r_1)^2 - (r_2)^2 + (x_2^2 + y_2^2 - x_1^2 - y_2^2) \\ (r_1)^2 - (r_3)^2 + (x_3^2 + y_3^2 - x_1^2 - y_2^2) \end{bmatrix} = \begin{bmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) \\ 2(x_3 - x_1) & 2(y_3 - y_1) \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

$$\bar{A} = \bar{B} * x \tag{4.3}$$

Target location can be estimated after the matrix equation is solved in (4.4):

$$\begin{bmatrix} x \\ y \end{bmatrix} = (\bar{A}^T A)^{-1} * (\bar{A}^T B) \tag{4.4}$$

Chapter 5
Method, Results and discussion

5.1 Lateration method

As we mentioned in Chapters 2 and 3 that our experiment was conducted in Classroom 503, four access points (TP link access points) are used in the test area. The test area has been set and the points marked with electrical tape 50cm apart from each other. Then we set the access points at the corners of the 6×6 area and start collecting the RSSI values for each point, the first test was to collect RSSI values for the access points (TEST 1, TEST 2, and TEST4) as shown in figure (4.1) the data collection was done using a HP laptop with (Ralink RT3290) WIFI adaptor, it was on a table one meter above the ground.

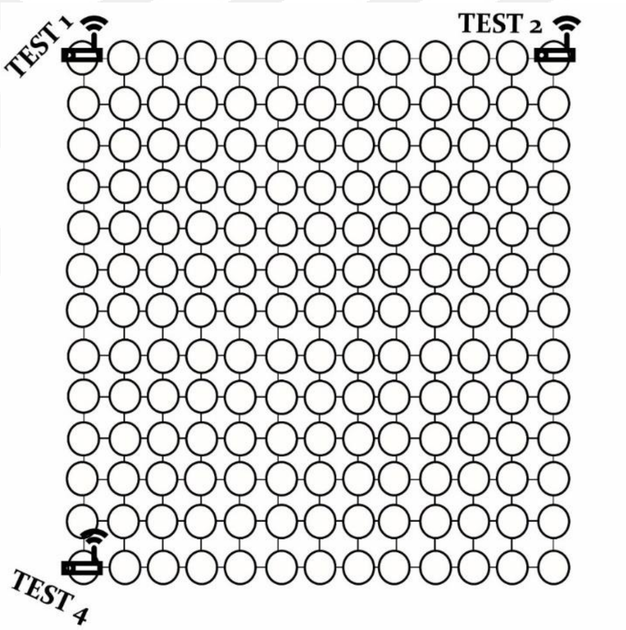

Fig (5.1) Access Point Placement for test one

After collecting the RSSI values for 165 points the data were stored in an excel sheet and the RSSI values were converted in to distances using the equation (3.3).

Then the point location is calculated using the distances with the help of a MATLAB code. The MATLAB code is very simple to run, you just need to set the reference points of your access points location and the program will give you your location calculated from the distances as shown in figure (5.2).

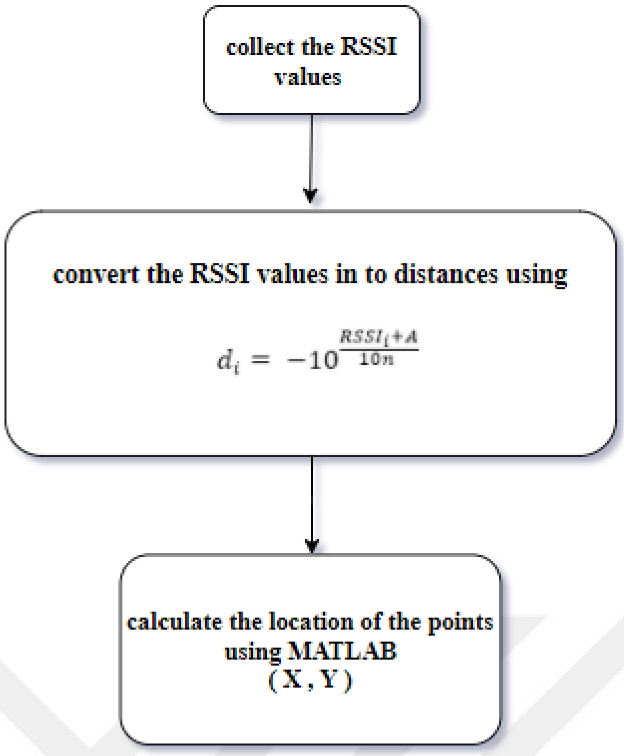

Fig (5.2) location calculation diagram

5.2 Test one results

Figure (5.3) represent our first test for the access points (1, 2, 4), the blue points represent the original points that the RSSI was measured from and the red points represent the points that have been calculated using Lateration method.

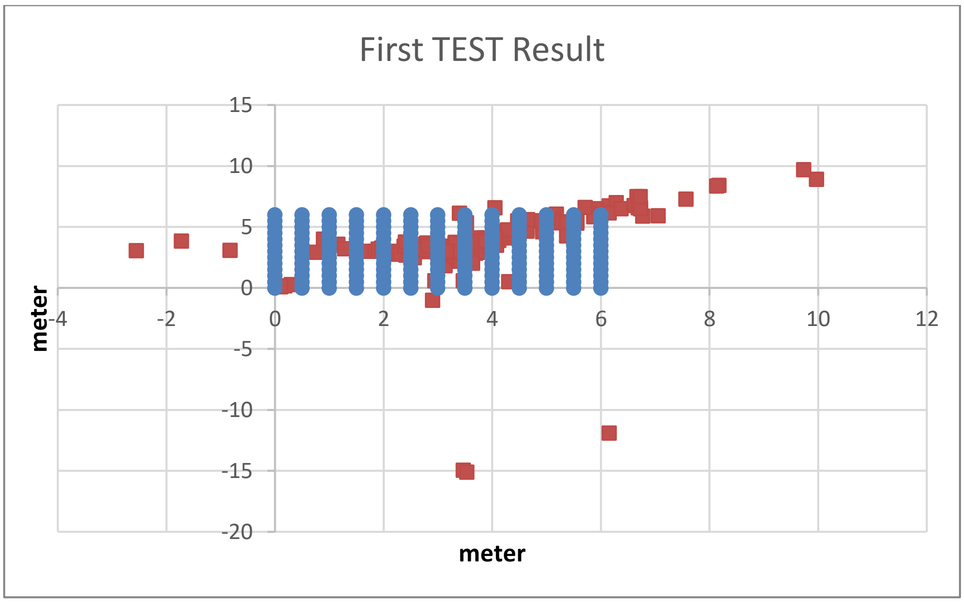

Fig (5.3) first test result for the access points (1, 2, 4)

But the problem with this method of calculation is that the RSSI is not stable or consistent especially with WIFI 2.4GHz so the accuracy of the distance calculation is very low dui to the instability of the RSSI as shown in table (5.1):

Table (5.1) first test result for the access points (1, 2, 4)

Average error	Minimum error	Maximum error	Standard deviations	Error above 3 meter
3.446217	0.289665	19.60226	2.580336	137

Table (5.1) represent the average error, the min. error, max. error, the standard deviation, and the number of points with error rate more than 3 meters for the access points (1, 2, 4).

5.3 Redundant Lateration method

The redundant method uses normal lateration to calculate the location of the point by calculating the location of the same point 4 times but with different groups of access points (123, 124, 134, and 345). Then we started collecting the RSSI for these groups and convert it in to distances and estimate the location from these distances and the results for these tests will be compared with the final results.

5.3.1 Normal lateration results

From figure (5.4) we see the position of the access points (1,2, and 3). Figure (5.5) represent the our first test for the access points (1, 2, 3), the blue points represent the original points that the RSSI was measured from, and the red points represent the points that have been calculated using Lateration.

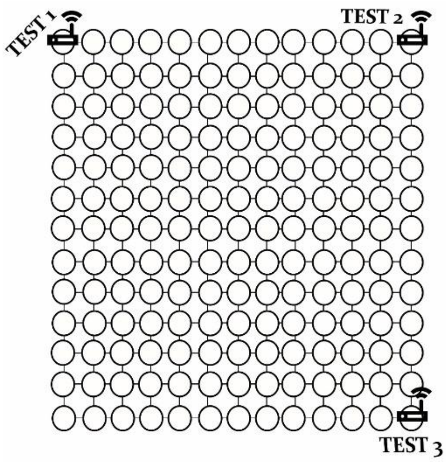

Fig (5.4) Access Point Placement for (1, 2 and 3)

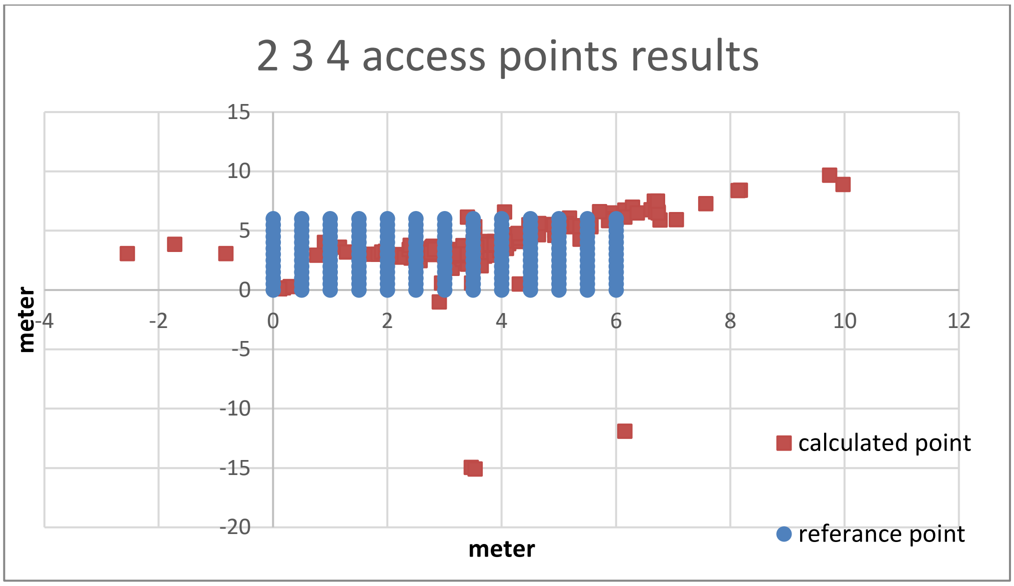

Fig (5.5) second test result for the access points (1, 2, and 3)

The results for the access point 1, 2 and 3 are calculated using the N values of 2.36, 2.87 and 2.69 respectively.

Table (5.2) represent the average error, the min. error, max. error, the standard deviation, and the number of points with error rate more than 3 meters for the access points (1, 2, and 3).

Table (5.2) second test result for the access points (1, 2, and 3)

Average error	Minimum error	Maximum error	Standard deviations	Error above 3 meter
2.757944	**0.253525**	**14.12121**	**1.689412**	**59**

Figure (5.6) represent our first test for the access points (1, 2, 4), the blue points represent the original points that the RSSI was measured from and the red points represent the points that have been calculated using Lateration method.

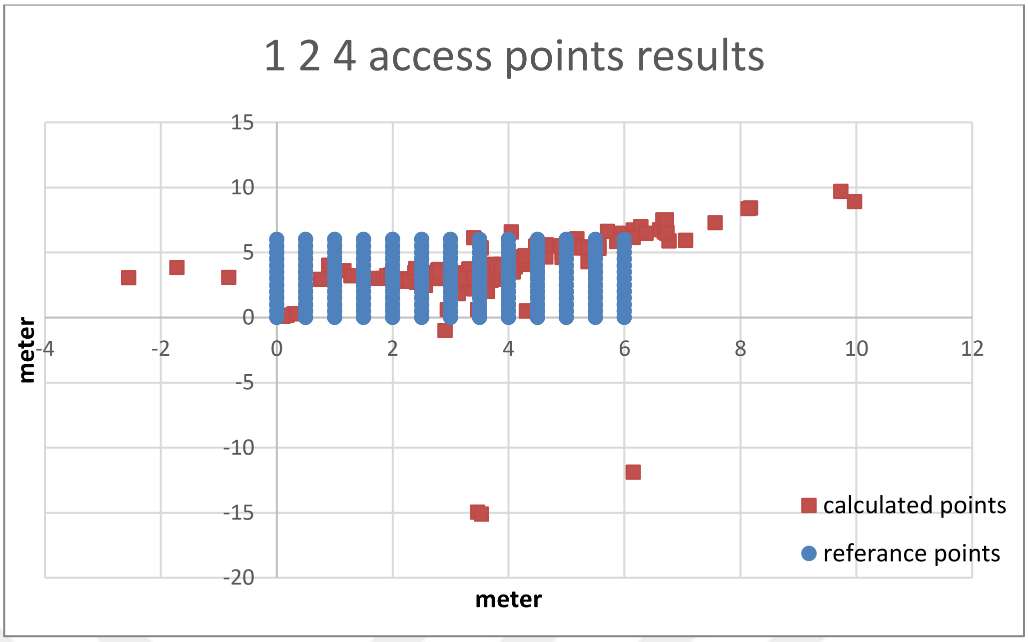

Fig (5.6) second test result for the access points (1, 2, and 4)

The results for the access point 1, 2 and 4 are calculated using the N values of 2.36, 2.87 and 2.63 respectively

Table (5.3) represent the average error, the min. error, max. error, the standard deviation, and the number of points with error rate more than 3 meters for the access points (1, 3, and 4).

Table (5.3) second test result for the access points (1, 3, and 4)

Average error	Minimum error	Maximum error	Standard deviations	Error above 3 meter
3.334999	**0.405204**	**13.13266**	**2.125518**	**76**

Figure (5.7) represent the position of the access points (1, 3, and 4). Figure (5.8) represent the our first test for the access points (1, 3, 4), the blue points represent the original points that the RSSI was measured from and the red points represent the points that have been calculated using Lateration method.

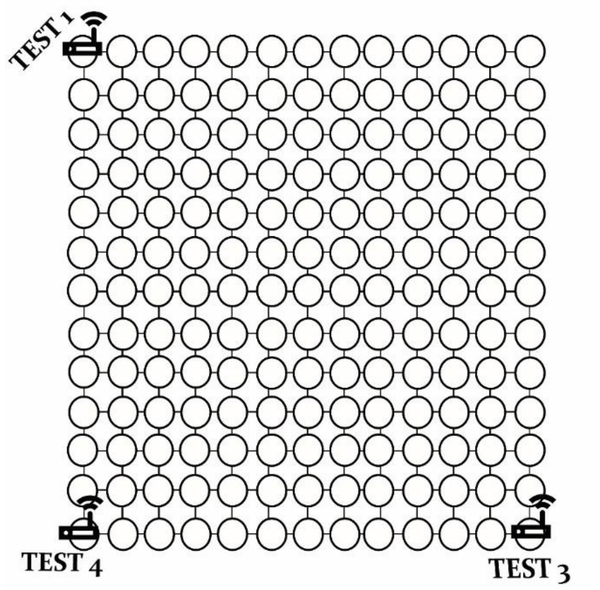

Fig (5.7) Access Point Placement for (1, 3 and 4)

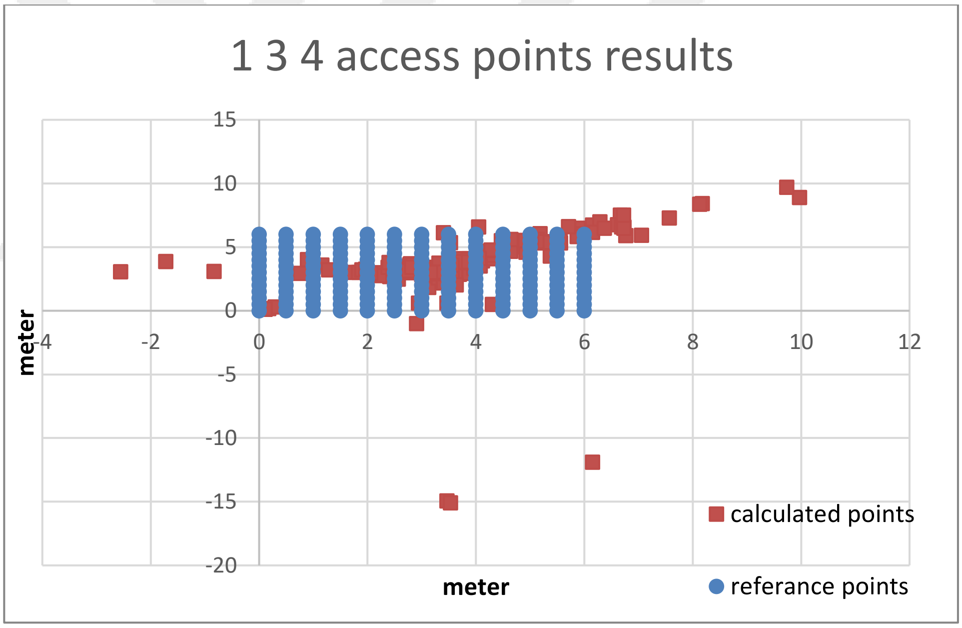

Fig (5.8) second test result for the access points (1, 3, and 4)

Table (5.4) represent the average error, the min. error, max. error, the standard deviation, and the number of points with error rate more than 3 meters for the access points (1, 3, and 4).

The results for the access point 1, 3 and 4 are calculated using the N values of 2.36, 2.69 and 2.63 respectively

Table (5.4) second test result for the access points (1, 3, and 4)

Average error	Minimum error	Maximum error	Standard deviations	Error above 3 meter
4.530283	**0.253093**	**31.46588**	**4.476831**	**93**

Figure (5.9) represent the position of the access points (2, 3, and 4).

Figure (5.10) shows the first test for the access points (2, 3, and 4), the blue points represent the original points that the RSSI was measured from and the red points represent the points that have been calculated using Lateration method.

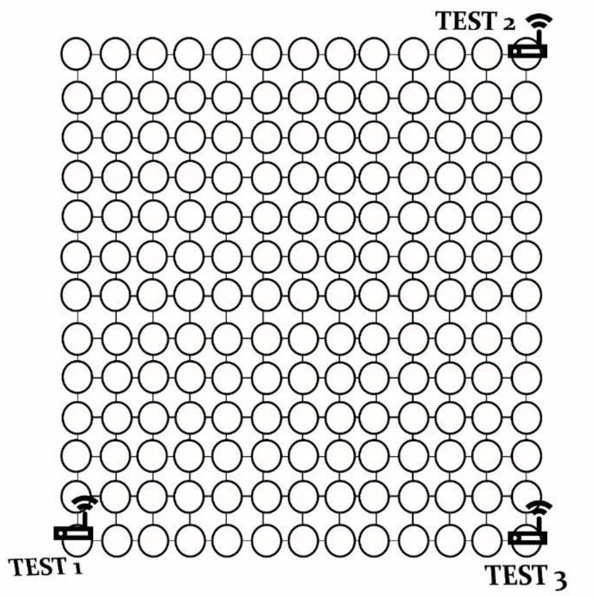

Fig (5.9) Access Point Placement for (2, 3 and 4)

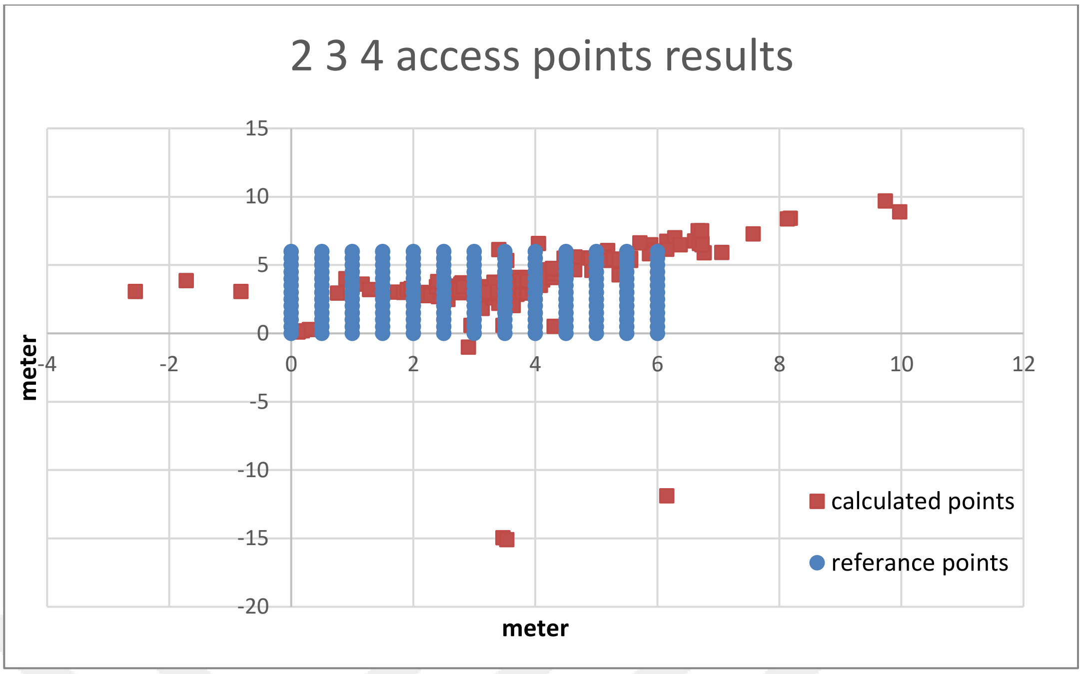

Fig (5.10) second test result for the access points (2, 3, and 4)

The results for the access point 1, 3 and 4 are calculated using the N values of 2.87, 2.69 and 2.63 respectively.

Table (5.5) represent the average error, the min. error, max. error, the standard deviation, and the number of points with error rate more than 3 meters for the access points (2, 3, and 4).

Table (5.5) second test result for the access points (2, 3, and 4)

Average error	Minimum error	Maximum error	Standard deviations	Error above 3 meter
3.174763	**0.396492**	**17.72853**	**2.108717**	**72**

5.3.2 Redundant method Groups results

After finding all these results now we have 4 locations for every point in our test area so in order to find the best results from those locations we calculated the Euclidian distance between the calculated locations and the original locations to find which one of the calculated points has the biggest error rate and eliminate it, after that we will calculate the average of the best 3 point locations and get the estimated point location. Table (5.6) below shows the groups of the locations that give us all the possible results of the average locations to compare it with the initial results

Table (5.6) the access points groups

Group name	Access points groups
A	123 134 234
B	123 134 124
C	124 134 234
D	123 124 234
E	123 124 134 234

Figure (5.11) represent the location of the access points of group A on the experimental area includes 3 sets of access point's locations (123 134 234).

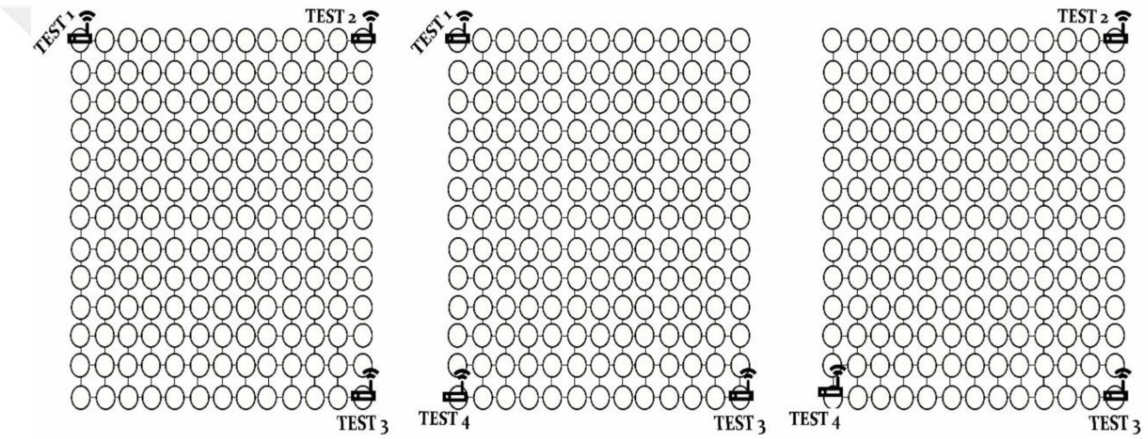

Fig (5.11) the location of the access points in group A

Figure (5.12) represent the results of group A the blue points represent the original points that the RSSI was measured from, and the red points represent the points that have been calculated using the redundant method.

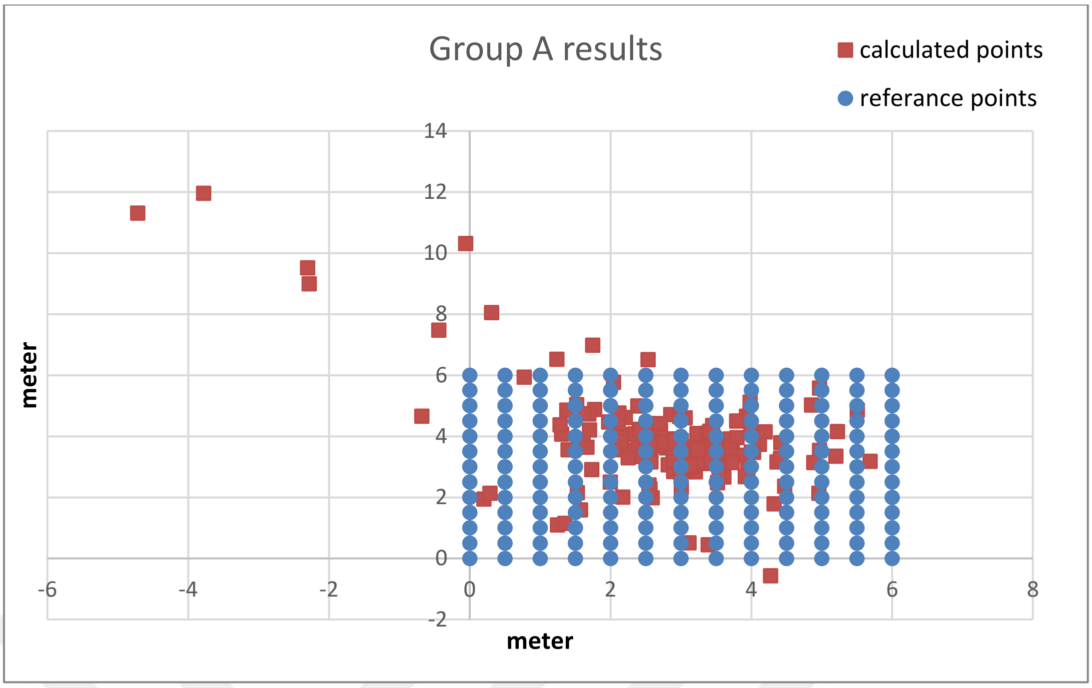

Fig. (5.12) Group A results

Table (5.7) represent the average error, the min. error, max. error, the standard deviation, and the number of points with error rate more than 3 meters for group A.

Table (5.7) Group A results

Average error	Minimum error	Maximum error	Standard deviations	Error above 3 meter
3.112498	**0.353648**	**14.54216**	**1.958009**	**75**

Figure (5.13) represent the location of the access points of group B on the experimental area includes 3 sets of access point's locations (123 134 124).

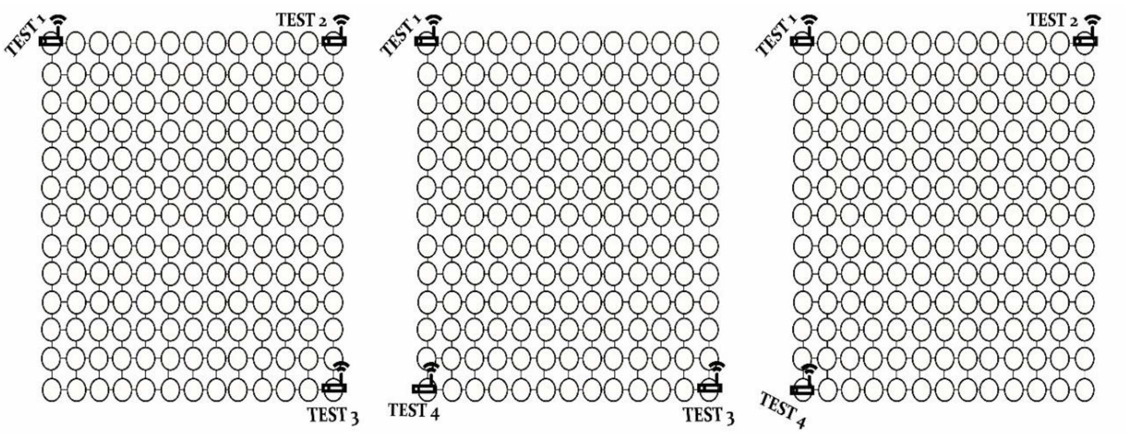

Fig (5.13) the location of the access points in group B

Figure (5.14) represent the results of group B, the blue points represent the original points that the RSSI was measured from, and the red points represent the points that have been calculated using the redundant method.

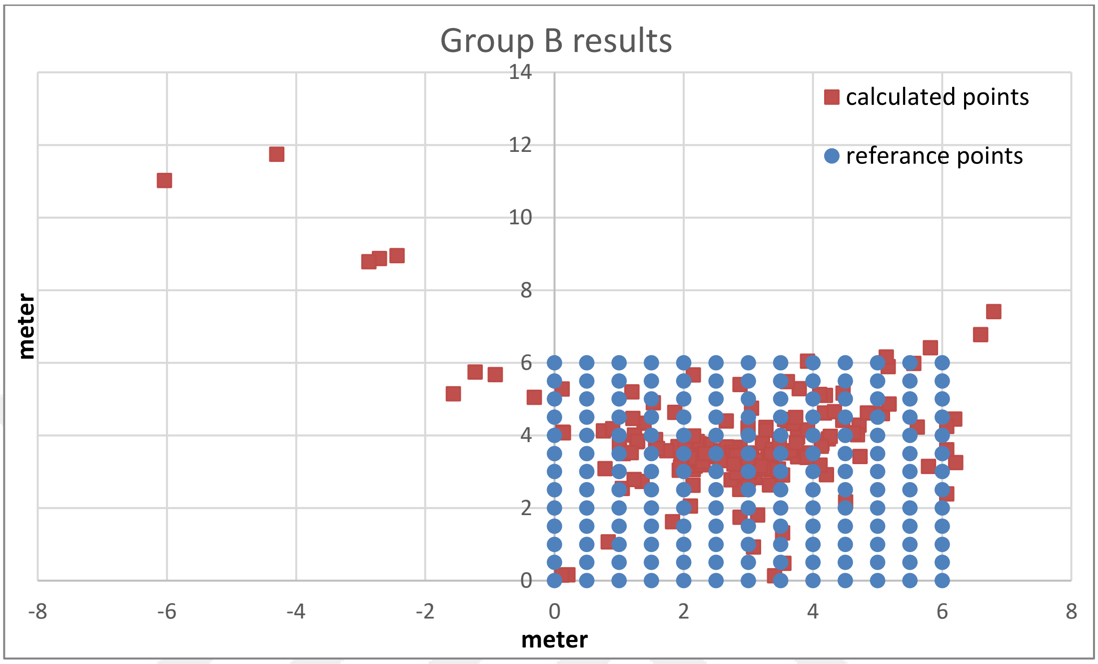

Fig. (5.14) Group B results

Table (5.8) represent the average error, the min. error, max. error, the standard deviation, and the number of points with error rate more than 3 meters for group B.

Table (5.8) Group B results

Average error	Minimum error	Maximum error	Standard deviations	Error above 3 meter
3.138262	0.254138	15.24648	2.033024	72

Figure (5.15) represent the location of the access points of group C on the experimental area includes 3 sets of access point's locations (124 134 234).

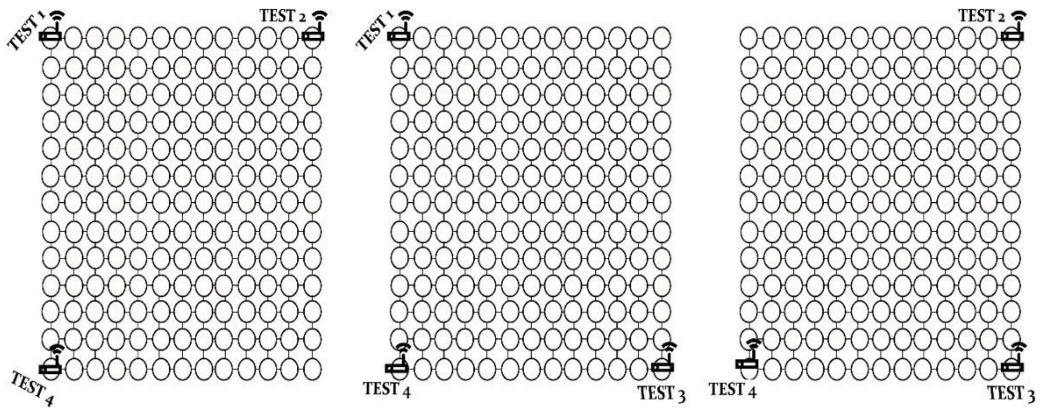

Fig (5.15) the location of the access points in group C

Figure (5.16) represent the results of group C the blue points represent the original points that the RSSI was measured from, and the red points represent the points that have been calculated using the redundant method.

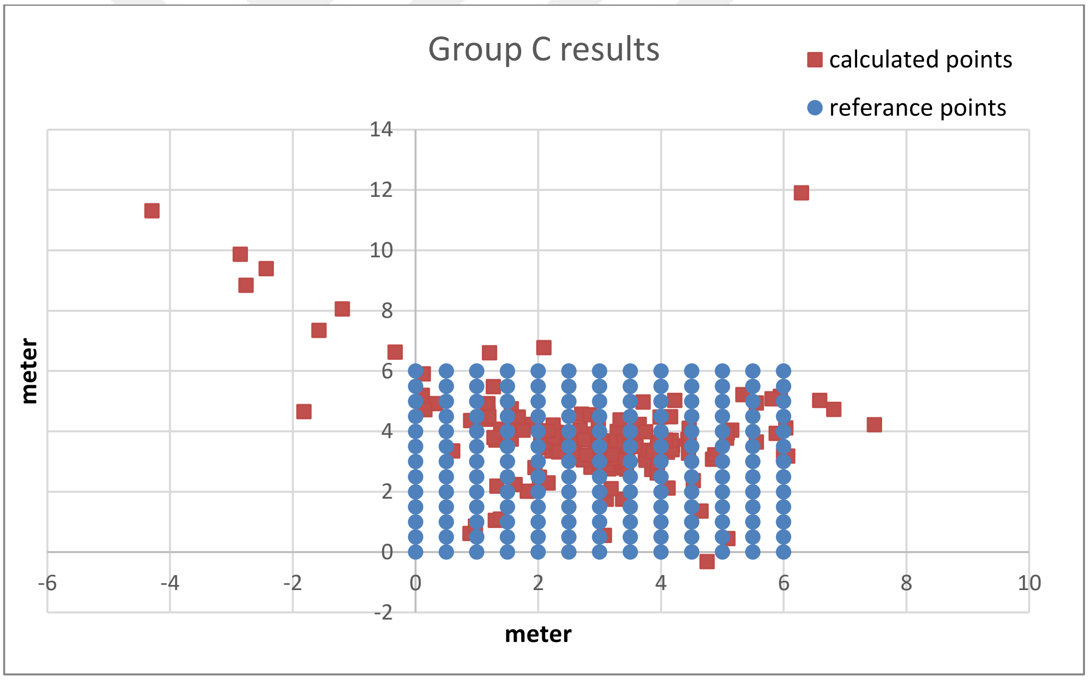

Fig. (5.16) Group C results

Table (5.9) represent the average error, the min. error, max. error, the standard deviation, and the number of points with error rate more than 3 meters for group C.

Table (5.9) Group C results

Average error	Minimum error	Maximum error	Standard deviations	Error above 3 meter
3.298127	**0.254943**	**12.93404**	**2.001209**	**82**

Figure (5.17) represent the location of the access points of group D on the experimental area includes 3 sets of access point's locations (123 124 234).

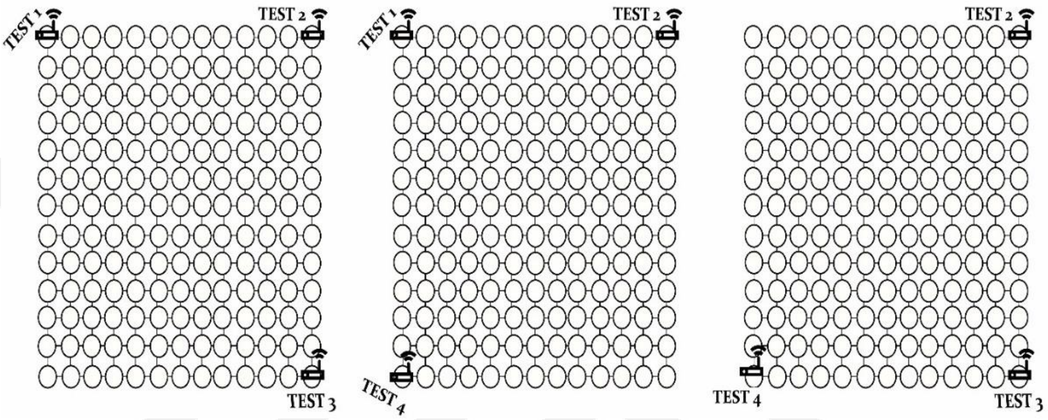

Fig (5.17) the location of the access points in group D

Figure (5.18) represent the results of group D, the blue points represent the original points that the RSSI was measured from and the red points represent the points that have been calculated using the redundant method.

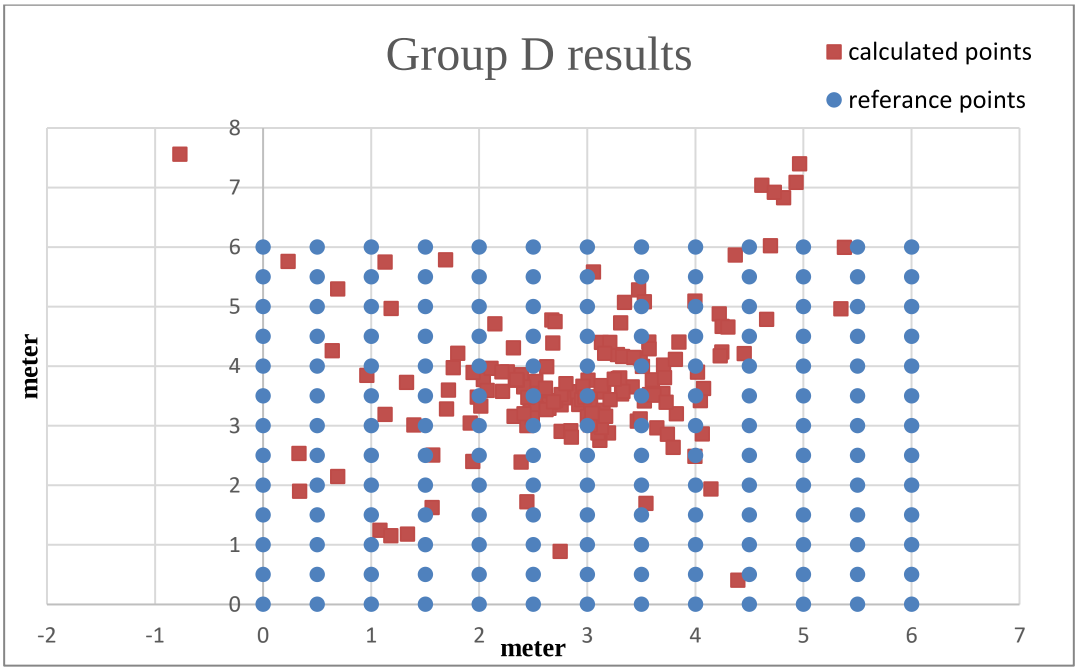

Fig. (5.18) Group D results

Table (5.10) represent the average error, the min. error, max. error, the standard deviation, and the number of points with error rate more than 3 meters for group D.

Table (5.10) Group D results

Average error	Minimum error	Maximum error	Standard deviations	Error above 3 meter
2.713196	**0.262651**	**9.822816**	**1.3766**	**64**

Figure (5.19) represent the location of the access points of group E on the experimental area includes all the sets of access point's locations (123 124 134 234).

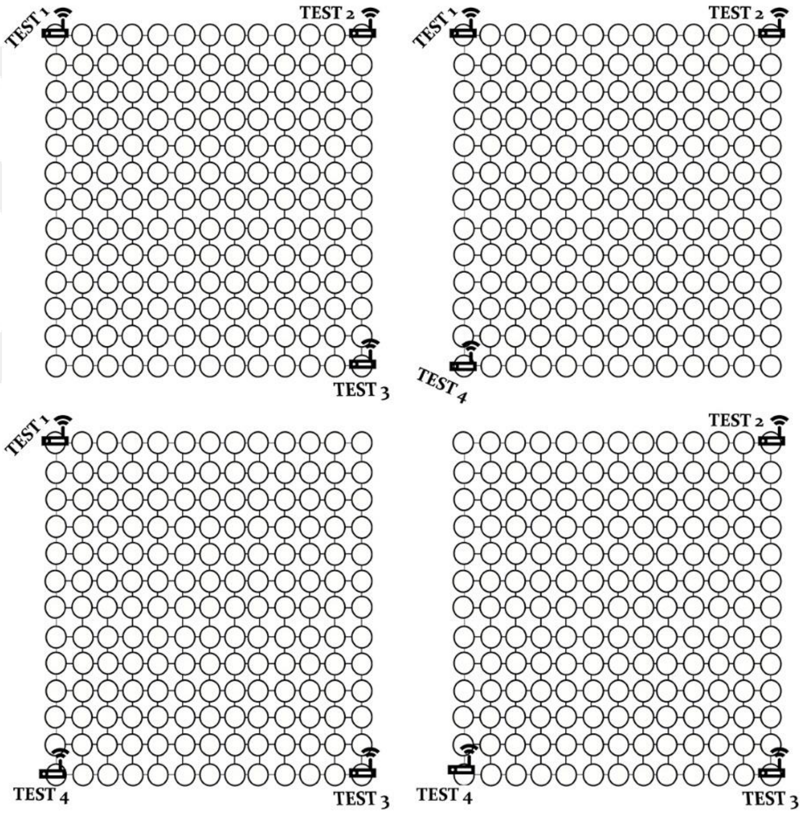

Fig (5.19) the location of the access points in group E

Figure (5.20) represent the results of group E the blue points represent the original points that the RSSI was measured from and the red points represent the points that have been calculated using the redundant method.

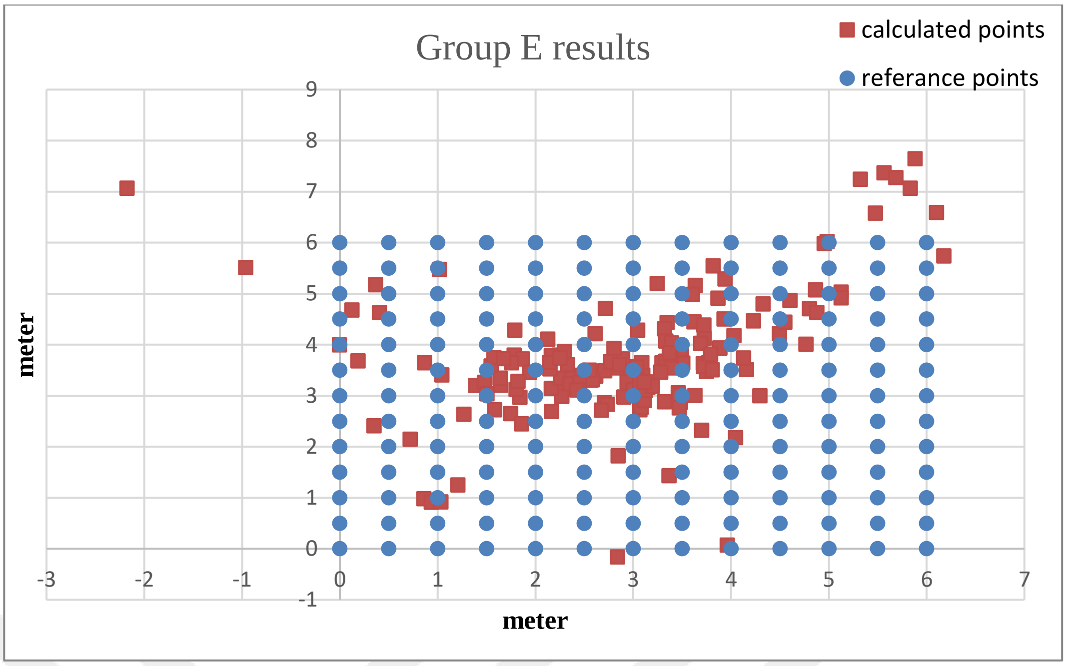

Fig. (5.20) Group E results

Table (5.10) represent the average error, the min. error, max. error, the standard deviation, and the number of points with error rate more than 3 meters for group E

Table (5.10) Group E results

Average error	Minimum error	Maximum error	Standard deviations	Error above 3 meter
2.808185	**0.246295**	**10.43262**	**1.471813**	**65**

After getting these results we calculated the minimum error of the 4 groups (A, B, C and D), by taking the minimum values of the Euclidian distances to get a realistic error calculation for our method because in results above we are getting the average results not the best results as shown in table (5.11) which represent the average error, the min. error, max. error, the standard deviation, and the number of points with error rate more than 3 meters for the redundant method .

Table (5.11) the minimum error rate for the groups (A, B, C and D)

Average error	Minimum error	Maximum error	Standard deviations	Error above 3 meter
2.470399	**0.254138**	**9.822816**	**1.371947**	**48**

5.3.3 Results Comparison

As a comparison between the results we see from table (5.12) that the average error in the normal calculations is between 2.75 and 4.5 and with the new method is between 2.7 and 3.29 but when we see the best of the group's results the average error is 2.47. For the minimum error it's almost the same in the normal results between 0.25 and 0.4 and in the new method is between 0.24 and 0.35. The big difference is in the maximum error which was in the normal results is between 13.1 and 31.4 and it decreases with the new method to be between 9.8 and 15.2. For the Standard deviations in the normal method it's between 1.68 and 4.47 but in the new method it's between 1.37 and 2.03. And last thing is the number of points that has error rate more than 3 meters, we see in the normal method it's between 59 and 137 out of 165. While in the new method it's between 64 and 82. All these results are statistical results for comparison in real life. The algorithm will chose the best result out of the 4 groups. The last row of table (5.12) are the best results of the 4 groups which shows an improvement in the overall accuracy of the method.

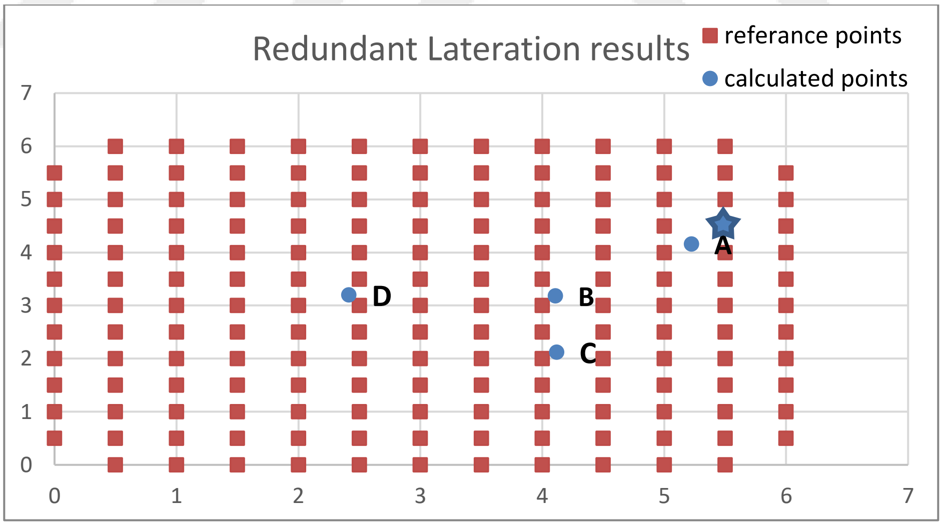

Fig. (5.21) point ★(5.5, 4.5) results for the four groups

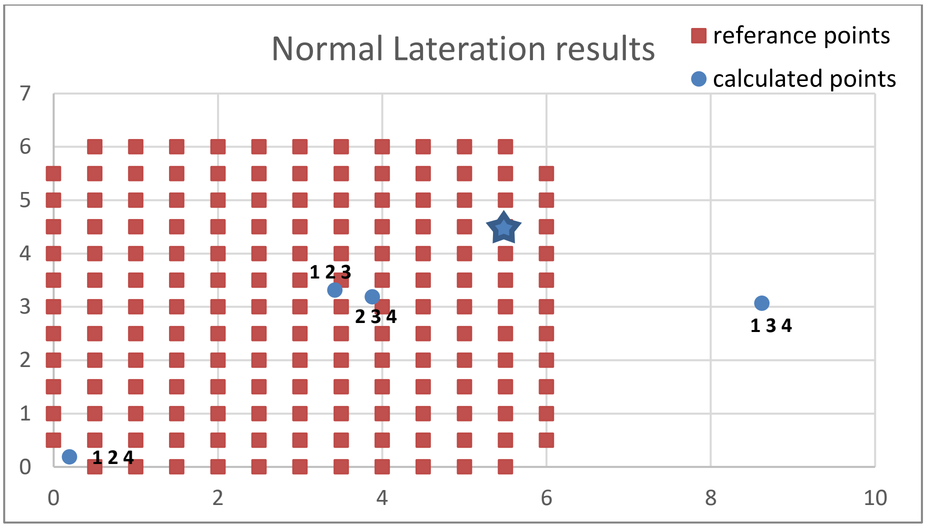

Fig. (5.22) point ★ (5.5, 4.5) results of the normal lateration

In the two figures (5.21) and (5.22) above shows the difference between the normal Lateration and the redundant Lateration .

Table (5.12) results comparison

Group Name	Average error	Minimum error	Maximum error	Standard deviations	Error above 3 meter
Access points (124) first	3.446217	0.289665	19.60226	2.580336	137
123	2.757944	0.253525	14.12121	1.689412	59
124	3.334999	0.405204	13.13266	2.125518	76
134	4.530283	0.253093	31.46588	4.476831	93
234	3.174763	0.396492	17.72853	2.108717	72
A	3.112498	0.353648	14.54216	1.958009	75
B	3.138262	0.254138	15.24648	2.033024	72
C	3.298127	0.254943	12.93404	2.001209	82
D	2.713196	0.262651	9.822816	1.3766	64
E	2.808185	0.246295	10.43262	1.471813	65
The best result	2.470399	0.254138	9.822816	1.371947	48

Chapter 6

Conclusion

The huge market potential and rapid development of wireless technologies and smartphones, tablet devices, smartwatches are used in our daily life. It is concluded that the integration of the devices that we carry every day and wireless technologies for indoor positioning is a mainstream direction in research and industry commercialization. The performances system was affected by the quality of the RSSI values collected from a laptops or smartphones.

From the results in chapter 5 we see that the results are more contained in the test area and the overall accuracy is better. the performance metric of an indoor positioning system is defined in terms of positional error accuracy and reliability. This thesis proposes an algorithm for indoor positioning systems: the redundant lateration. The overall average error calculated for all reported location estimation for the redundant lateration is less than 2.5 meters, which is comparable to existing methods. Moreover, the equipment and tools used are inexpensive and available off the shelf. There are also many other technologies for creating a positioning system, but none of them can work on existing infrastructure and using off the shelf tools with accuracy for min. error 0.25 m and max. error 9.6 m.

6.1 Future Work:

The Redundant Lateration method could be implemented with different kind of wireless signals not just Wi-Fi and the accuracy could be improved if two wireless techniques are combined like Wi-Fi and GSM signals or using Wi-Fi 2.4GHz and 5GHz at the same time.

An application (end product) can be developed based on research presented in this thesis. It will require some learning to get the most accurate distance from the RSSI values.

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