KADIR HAS UNIVERSITY

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PROGRAM OF COMPUTER ENGINEERING

THE PERFORMANCE OF THE RSS-BASED LEAST SQUARES LATERATION ALGORITHM FOR INDOOR LOCALIZATION

LUBANA BARODI

MASTER THESIS

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DECLARATION OF RESEARCH ETHICS

I, Lubana Barodi, 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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This work entitled "The Performance of the RSS-Based Least Squares Lateration Algorithm for Indoor Localization" prepared by Lubana Barodi has been judged to be successful at the defense exam on 21, MAY 2019 and accepted by our jury as Master Thesis.

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ABSTRACT

Localization methods have evolved over the years until the invention of the technology of global positioning system (GPS). As the technology developed and seeing that people spend most of their times in indoor environments, the need for indoor localization has arised. For localization in outdoor environments the GPS works extremely well, but it is useless for indoor localization, because the signals from the GPS satellites are too weak to penetrate the buildings. Because of that reason, the indoor positioning systems became an important research topic nowadays.

There are many various methods and algorithms for locating position indoors. One of these methods is the RSS-based lateration algorithm. This method has the advantage of low cost since it uses the existing infrastructure. In addition, it provides a high level of accuracy. For these reasons, the performance of this algorithm is evaluated in this thesis.

Simulation is designed to test the performance of this algorithm under different cases by using different parameters. Synthetic data is generated and used for the simulations. The algorithm is first tested with knowledge of the path loss exponent value. Then, the path loss exponent is estimated and used in the simulations. Finally, the values of RSS are estimated by using the least squares method. In this thesis, the impact of different parameters on the average error of estimated position is tested.

The RSS-based least squares algorithm showed that it has a high level of accuracy which didn't exceed 2 meters in most testing areas when tested with 1 dBm noise level. It has also been shown that increasing the room size or noise level have a negative impact on the average error. However increased path loss exponent values have a positive impact on average error.

Keywords: Indoor positioning systems, Received Signal strength, Path Loss Exponent, Least Squares Lateration.

İÇ MEKÂN KONUMLANDIRMA İÇİN RSS TABANLI EN KÜÇÜK KARELER LATERASYON ALGORİTMASININ PERFORMANSI

ÖZET

Konumlandırma yöntemleri, küresel konumlandırma sistemi (GPS) teknolojisinin icat edilmesine kadar yıllar içerisinde gelişmiştir. Teknoloji geliştikçe ve insanların zamanlarının çoğunu iç mekânlarda geçirdikleri görüldükçe, iç mekân konumlandırmasına duyulan ihtiyaç artış göstermiştir. Bina dışı ortamların konumlandırılmasında GPS çok iyi bir şekilde çalışmakta, fakat iç mekân konumlandırması için faydasız kalmaktadır çünkü GPS uydularından gelen sinyaller binalara nüfuz edemeyecek kadar zayıftır. Bu nedenle, iç mekân konum belirleme sistemleri günümüzde önemli bir araştırma konusu haline gelmiştir.

İç mekânlardaki konumu saptamak için çeşitli yöntem ve algoritmalar mevcuttur. Bu yöntemlerden biri, RSS tabanlı laterasyon algoritmasıdır. Bu metotta, mevcut altyapı kullanıldığından dolayı düşük maliyet avantajına sahiptir. Bununla beraber, yüksek düzeyde doğruluk sağlamaktadır. Bu nedenlerden dolayı, bu tezde bahsi geçen algoritmanın performansı değerlendirilmektedir.

Simülasyon, bu algoritmanın performansını farklı durumlarda farklı parametreler kullanarak test etmek için tasarlanmıştır. Sentetik veri oluşturulmakta ve benzetimler için kullanılmaktadır. Algoritma ilk olarak yol kaybı üstel değeri bilgisiyle test edilmektedir. Daha sonra, yol kaybı üsteli tahmin edilmekte ve benzetimlerde kullanılmaktadır. Son olarak, en küçük kareler metodu kullanılarak RSS değerleri hesaplanmaktadır. Bu tez çalışmasında, farklı parametrelerin tahmini pozisyonun ortalama yanılgı üzerindeki etkisi test edilmiştir.

RSS tabanlı en küçük kareler algoritması, 1 dBm gürültü seviyesiyle test edildiğinde çoğu test alanında 2 metreyi geçmeyen yüksek bir doğruluk seviyesine sahip olduğunu göstermiştir. Ayrıca, oda büyüklüğünün veya gürültü seviyesinin arttırılmasının ortalama yanılgı üzerinde olumsuz bir etkiye sahip olduğu gösterilmiştir. Bununla birlikte, arttırılmış yol kaybı üstel değerleri, ortalama hata üzerinde olumlu bir etkiye sahiptir.

Anahtar Kelimeler: İç mekân konum belirleme sistemleri, alınan sinyal gücü, yol kaybı üsteli, en küçük kareler laterasyonu.

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To my family …

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LIST OF ABBREVIATIONS

GPS	The Global Positioning System
IPS	Indoor Positioning System
IR	Infrared
RSS	Received Signal Strength
AOA	Angle of Arrival
TOA	Time of Arrival
TDOA	Time Difference of Arrival
RSSI	Received Signal Strength Indicator
dBm	Decibel-milliwatts
AP	Access Point
RF	Radio Frequency
LOS	Line-of-Sight
m	Meter
CI	Confidence Interval
WLAN	Wireless Local Area Network

1. INTRODUCTION

For thousands of years people have used different ways of localization. They started the basic localization without using any type of special instruments. For instance, the sailors have used celestial objects for sea-based localization. This method involved observing landmarks "sights," or angular measurements taken between a celestial body (the sun, the moon, a planet or a star) and the visible horizon [1].

To provide more accurate localization, many specialized tools have been developed, most notably the astrolabe, sextant, compass as well as maritime charts and maps. The astrolabe was used for many different purposes, including timekeeping during both the day and night, determining the latitude of the user, and calculating the positions of stars, planets and other celestial objects. The sextant is another navigational instrument which relies on mirrors that reflect light along a path to the observer. The sextant mirrors were arranged in such a way that they double the size of the angle that can be measured from one-eighth of a circle to one hundred and twenty (120°) degrees [2].

One of the well-known instruments which were invented more than 2,000 years ago in China, is the compass. A compass is a navigational tool with a magnetic needle (a piece of lodestone) which has its own magnetic field so that, when allowed to rotate freely around its axis, it will align its own magnetic field with that of the Earth and will point towards the magnetic north pole [2]. To use the compass more effectively, maps are used. A map is a graphic representation or scale model of spatial concepts. It is a means for conveying geographic information. The oldest known maps are preserved on Babylonian clay tablets from about 2300 B.C. [3]. Throughout history, maps have evolved. Currently the maps are electronic and they are using satellite for positioning.

In the late 1960s, the U.S. Department of Defense began developing a satellite-based localization system for military purposes, which eventually evolved into the Global Positioning System (GPS). The system was first used in 1990 [4] and became fully operational in 1995.

The GPS is a space-based satellite navigation system that provides location and time information for all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to three or more GPS satellites [5]. The GPS system consists of up to 24 operational satellites [Figure 1.1] orbiting the Earth on 6 different orbital planes (four to five satellites per plane). The satellites' orbits are distributed in such a way that from any point on the ground there is line-of-sight contact to at least 4 satellites [6]. Any of these satellites complete its orbit in around 12 hours. Due to the rotation of the Earth, a satellite will be at its initial starting position above the earth's surface after approximately 24 hours (23 hours 56 minutes to be precise) [6].

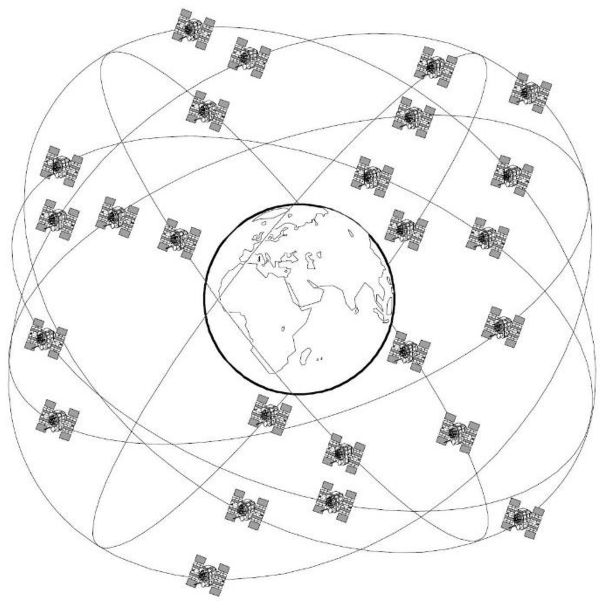

Figure1.1: GPS satellites orbit the Earth on 6 orbital planes

The GPS receiver uses the triangulation process to determine physical locations. It communicates with three satellites in sight (using radio signals that travel at the speed of light) and then calculates the distance between those satellites and the device by using the signal travel time. If the distance to the three satellites is known, all possible positions are located on the surface of three spheres whose radius correspond to the distance calculated. The position is the point where all three of the spheres intersect [Figure 1.2].

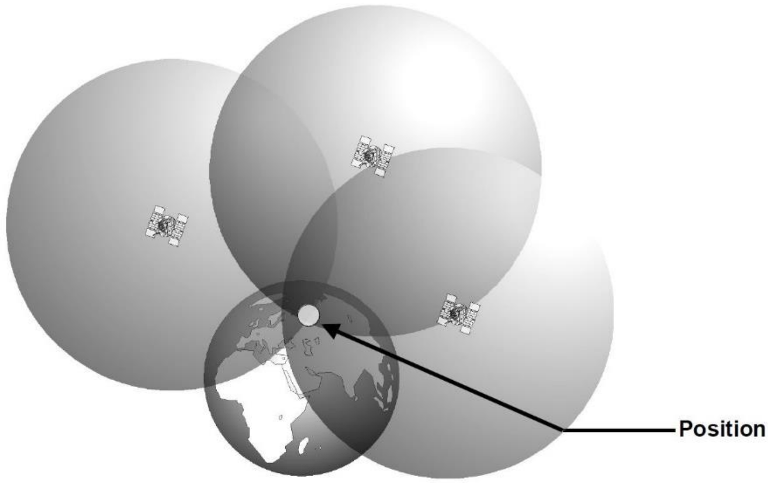

Figure 1.2: The three satellite spheres intersect

Since the satellites have a fixed orbital pattern and are synced with atomic clocks from the U.S. Naval Observatory, this process tends to yield an accurate location reading. But to improve accuracy, GPS devices typically seek data from four or more satellites.

Nowadays with the development of localization technologies and seeing that people spend most of their time in indoor environments, the need for indoor localization has arised. The importance of indoor localization appears more within large buildings. A user can use an Indoor Positioning System (IPS) just like a GPS to be guided to specific destinations. For example, one can use it to find a gate in an airport, specific room or clinic in a hospital, specific chair or facility in a stadium as well as finding a store in a shopping center. Other applications for IPS include real-time tracking, activity recognition, emergency detection and among others [7]. One of the most important uses of indoor localization is in emergencies due to disaster scenarios, such as earthquakes, floods and fires. In these cases, terminals are meant to provide persist exact position within an appropriate lapse of time to the rescuers which will help to save their lives [8].

For localization in outdoor environments, the Global Positioning System (GPS) is used. GPS works extremely well in outdoors but unfortunately, the signal from the GPS satellites are too weak to penetrate most buildings, making GPS useless for indoor localization [5].

GPS signals are carried through waves at a frequency that cannot penetrate easily through solid objects and it works better when there is a clear line of sight to the sky. The next generation of positioning technology is being designed to overcome the limitations of GPS. Because of that IPS has become an important research topic.

In previous work, a Received Signal Strength (RSS) based least squares lateration algorithm was introduced [9]. In this thesis, this work is extended by testing the performance of the algorithm based on estimation for many different parameters.

The rest of this thesis is organized as follows: Chapter 2 introduces different techniques for indoor localization and most common IPS algorithms. Chapter 3 describes the Received Signal Strength (RSS) based least squares lateration algorithm. To examine the performance of the algorithm different parameters are used. The experiment description and simulation are described in Chapter 4. Then the simulation results with knowledge of n value introduced in Chapter 5. After that the simulation results with estimated n value shows in Chapter 6. In Chapter 7 the simulation results for the least squares approximation produced. This thesis is completed with conclusions in Chapter 8.

2. DIFFERENT TECHNIQUES FOR INDOOR LOCALIZATION

As indoor positioning has become an important research topic, many researches have been done in this field in the last few years. However, most of the techniques, algorithms and constituents of the positioning technologies are not new, as they are also implemented at outdoors. But how they apply to indoors differ from outdoors.

Nowadays, many different Indoor Positioning Systems exist [5]. Some of these systems are:

- Infrared Positioning system: This system uses infrared light pulses (like a TV remote) to locate signals inside a building. Infrared (IR) receivers are installed in every room, and when the IR tag pulses, it is read by the IR receiver device [5].
- Ultrasonic positioning systems: There are three different types of ultrasonic positioning systems. These are Active bats, Crickets and Dolphin. In these systems the position can be achieved by measuring distances between transmitters and receivers and applying trilateration [5].
- The RSS positioning systems: In the Received Signal Strength (RSS)-based positioning system, the location of the objects can be determined by calculating the distance of the object from the transmitters using triangulation or trilateration techniques.

Positioning systems can be classified by the signal measurement and/or techniques they employ [10]. The dominant techniques for signal measurement are: Angle of Arrival (AOA), Time of Arrival (TOA), Time Difference of Arrival (TDOA) and Received Signal Strength Indicator (RSSI). In this chapter, these techniques will be briefly introduced.

Algorithms used in positioning systems translate recorded signal properties into distances and angles, and then compute the actual position or location of a target object. Thus, a user is able to use the position information in a navigation system during a navigation activity, and the position information can be used to track objects [10]. Triangulation, Trilateration, Proximity and fingerprinting are the algorithms that will be explained later in this chapter.

2.1 Indoor Localization Techniques

2.1.1 Angle of Arrival (AOA)

This technique includes the calculation of the angle at which the signal arrives from the unlocated device to the anchor nodes [11]. The angle and distance are calculated relative to two or multiple reference points through the intersection of direction lines between the reference points [Figure 2.1]. The calculation of the angle and distance are used to estimate and determine the position of a transmitter, and the information is used for tracking or for navigation purposes [10]. The advantage of this technique that it only needs two measuring units for 2D positioning and 3 for 3D. Also, it doesn't need synchronization between the measuring units. And it works well in situations with LoS (Line of Sight) but the accuracy and precision decrease when there are signal reflections (Multipath). So, it is not good at indoor localization.

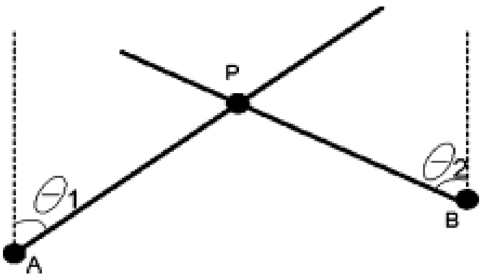

Figure 2.1: Positioning based on AOA measurement

2.1.2 Time of Arrival (TOA)

TOA is a distance-based measurement. It calculates the distance between the transmitting node and the receiving node from the transmission time delay and the corresponding speed of signal as follows [7]:

$$d = t * c \qquad (2.1)$$

where *c* denotes the traveling speed of the signal, *t* the amount of time spent by the signal traveling from the transmitting to the receiving node, and *d* the distance between the transmitting node and the receiving node. Since speed can be regarded as a known constant (usually the speed of light), *d* can be computed by observing time. TOA provides high accuracy but at a cost of higher hardware complexity [10].

2.1.3 Time Difference of Arrival (TDOA)

TDOA is also a distance-based measurement. TDOA determines the relative position of a transmitter based on the difference in the propagation time of arrival of the transmitter and multiple reference points or sensors [10]. Once the signal is received at two reference points, the difference in arrival time can be used to calculate the difference in distances between the target and the two reference points. This difference can be calculated using the equation:

$$\Delta d = c * \Delta t \tag{2.2}$$

where c is the speed of light and Δt is the difference in arrival times at each reference point. TDOA provides high accuracy, and less complexity comparing with TOA.

2.1.4 Received Signal Strength Indicator (RSSI)

RSSI is a measure of the power level of the Received Signal Strength (RSS) present in a radio infrastructure that can be used to estimate the distance between the transmitter node and receiver node [7]. RSSI is typically measured in units of decibel-milliwatts (dBm) which are represented as negative numbers. The closer the values are to 0, the stronger the received signal is. In order to locate an object with the RSSI, the RSSI values between the sensor attached to an object and surrounding access points (APs) with fixed locations are measured. The combination of these multiple RSSI values can be used to calculate the approximate position of the object. Typically, at least 3 access points are required for the localization. The location of the objects is determined by calculating the distance of the object from the transmitters using triangulation or trilateration algorithms [5]. RSSI-based localization is simple to deploy compared to the techniques that use the angle of arrival (AOA) and time difference of arrival (TDOA), there is no need for specialized hardware at the mobile station beside the wireless network interface card [12].

2.2 Indoor Positioning System Algorithms

2.2.1 Triangulation

Triangulation (or angulation) uses the geometric properties of triangles to estimate the position of a target object by computing angular measurements relative to two known reference points [10]. With triangulation, the position of the target node can be determined by the intersection of several pairs of angle direction lines [7], as shown in Figure 2.2 where *A* and *B* represent reference nodes, after obtaining the angles θ_1, and θ_2, the physical position of *T* (representing the target to be located) could then be calculated based on the predetermined coordinates of the reference nodes.

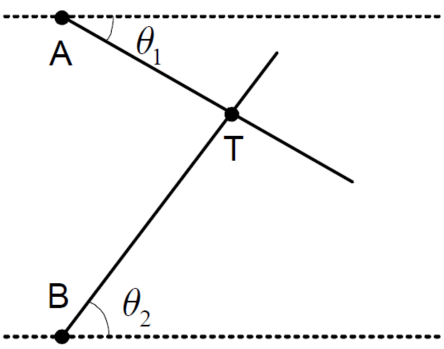

Figure 2.2: Triangulation algorithm

2.2.2 Trilateration

The trilateration-based positioning algorithm uses three fixed reference nodes to calculate the physical position of a target node [7]. The position of the target object is determined using TOA to measure the time taken by a signal to arrive at a receiver from a transmitter. As seen in Figure 2.3, to find the position of the object *T* based on the coordinates of three reference nodes: *A*, *B* and *C* and the corresponding distances from each reference node to the target node: *R1*, *R2*, and *R3*, the location of object *T* can be calculated.

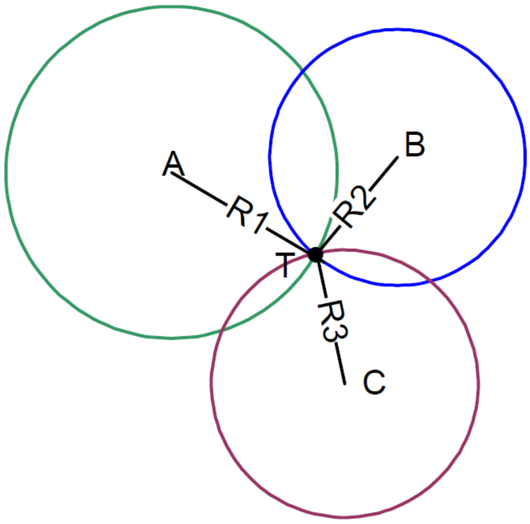

Figure 2.3: Trilateration algorithm

This algorithm is currently heavily used in indoor positioning due to its accuracy and low cost. The accuracy depends on the signal received and the environmental conditions. The signal strength received from Wi-Fi access points is commonly used in trilateration for indoor positioning. The advantages of using Wi-Fi networks are that they are becoming much more common, and that the received signal strength is available as part of the networking statistics available on the mobile device. This means that specialist equipment is not required to provide location information [13].

2.2.3 Proximity

The proximity algorithm helps to estimate the location of the target using the proximity relationship between the target and access points (AP). To provide the information, a grid of APs with known positions is used to determine position. When a target (mobile device) is detected in motion, the closest AP is used to calculate its position. But if the mobile device is detected by more than one APs, the AP with the strongest signal is used to calculate its position. The position of the mobile device is determined using RSSI, which is generally used in proximity to estimate the distance between mobile devices in order to acquire the device's position information [10]. The accuracy of this algorithm is determined by the distribution density and signal range of the access points.

2.2.4 Fingerprinting

The basis of this algorithm is constructing a fingerprint database. Fingerprinting approach can be divided into two stages: Sampling (offline) and matching (online) [14]. During the sampling stage, the fingerprint database constructed. This includes a series of steps, such as measuring the site in advance, designing the layout of reference points, and repeating the steps to collect received signal strength (RSS) samples on each reference point. During the matching stage, a location positioning technique uses the currently observed signal strengths and previously collected information to figure out an estimated location. The main challenge to the techniques based on location fingerprints is that the received signal strength could be affected by diffraction, reflection, scattering and absorption during the propagation in indoor environments. The advantages of this algorithm are low cost, a wide range of applications, and good performance.

3. THE RECEIVED SIGNAL STRENGTH (RSS) BASED LEAST SQUARES LATERATION ALGORITHM

Position determination by means of distance measurement using signal strengths is called lateration. This algorithm is used in indoor positioning due to its accuracy and low cost. In this chapter, lateration and least square methods are described.

3.1 Lateration

The lateration method is based on the knowledge of reference point positions and the distances to them. If we have 3 APs and they are located in a room with the following coordinates: AP_1 (x_1, y_1) , AP_2 (x_2, y_2) and AP_3 (x_3, y_3) the distance from each AP to a specific point at coordinate (x, y) in the room can be found by using the following set of equations:

$$r_1 = \sqrt{(x_1 - x)^2 + (y_1 - y)^2} \quad (3.1)$$

$$r_2 = \sqrt{(x_2 - x)^2 + (y_2 - y)^2} \quad (3.2)$$

$$r_3 = \sqrt{(x_3 - x)^2 + (y_3 - y)^2} \quad (3.3)$$

where r_1 is the distance from AP_1, r_2 is the distance from AP_2 and r_3 is the distance from AP_3. Then to find the location of the point (x, y), the following equations can be derived:

$$r_1^2 - r_2^2 = -2x_1x - 2y_1y - x_2^2 - y_2^2 + 2x_2x + 2y_2y + x_1^2 + y_1^2 \quad (3.4)$$

$$r_1^2 - r_3^2 = -2x_1x - 2y_1y - x_3^2 - y_3^2 + 2x_3x + 2y_3y + x_1^2 + y_1^2 \quad (3.5)$$

The Equations (3.4) and (3.5) can be represented as matrix operation as shown in Equation (3.6):

$$\begin{bmatrix} r_1^2 - r_2^2 + x_2^2 + y_2^2 - x_1^2 - y_1^2 \\ r_1^2 - r_3^2 + x_3^2 + y_3^2 - x_1^2 - y_1^2 \end{bmatrix} = \begin{bmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) \\ 2(x_3 - x_1) & 2(y_3 - y_1) \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \quad (3.6)$$

If we have more than three access points located in a room and we want to use more than 3 APs (says N APs) to increase the accuracy of the estimated location, Equation (3.6) can be extended to N access points as in Equation (3.7):

$$\begin{bmatrix} r_1^2 - r_2^2 + x_2^2 + y_2^2 - x_1^2 - y_1^2 \\ r_1^2 - r_3^2 + x_3^2 + y_3^2 - x_1^2 - y_1^2 \\ \cdots \\ r_1^2 - r_N^2 + x_N^2 + y_N^2 - x_1^2 - y_1^2 \end{bmatrix} = \begin{bmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) \\ 2(x_3 - x_1) & 2(y_3 - y_1) \\ \cdots & \cdots \\ 2(x_N - x_1) & 2(y_N - y_1) \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \qquad (3.7)$$

From Equation (3.7) we can define A and B as:

$$A = \begin{bmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) \\ 2(x_3 - x_1) & 2(y_3 - y_1) \\ \cdots & \cdots \\ 2(x_N - x_1) & 2(y_N - y_1) \end{bmatrix} \qquad (3.8)$$

and

$$B = \begin{bmatrix} r_1^2 - r_2^2 + x_2^2 + y_2^2 - x_1^2 - y_1^2 \\ r_1^2 - r_3^2 + x_3^2 + y_3^2 - x_1^2 - y_1^2 \\ \cdots \\ r_1^2 - r_N^2 + x_N^2 + y_N^2 - x_1^2 - y_1^2 \end{bmatrix} \qquad (3.9)$$

Then Equation (3.7) can shown as in Equation (3.10) below:

$$B = A \begin{bmatrix} x \\ y \end{bmatrix} \qquad (3.10)$$

To find the coordinates of the point (x, y), we solve the equation (3.10) and there is a unique solution for this system as shown in Equation (3.11):

$$\begin{bmatrix} x \\ y \end{bmatrix} = (A^T A)^{-1} A^T B \qquad (3.11)$$

3.2 RSSI Measurement:

Received signal strength indicator (RSSI) is defined by the IEEE 802.11 standard [11]. It is a measurement of the radio frequency (RF) energy, and the unit is dBm. The mobile client can get the RSSI from an access point on the WLAN. In indoor environments where it is difficult to obtain line-of-sight (LOS), the RSSI and positioning may be affected by multipath and shadow, hence decreasing accuracy. The RSSI is decreased exponentially as the distance from AP increased, and this can be expressed by the log path loss model. There is a log-normal path loss model for estimation of the distance between receiver and transmitters shown in Equation (3.12) below:

$$RSSI(dBm) = -10n\ log(d) + A \tag{3.12}$$

where RSSI is the received signal strength in dBm, *d* is the true distance from the sender to the receiver in meters, *n* is the path-loss exponent, and *A* is received signal strength in dBm at a1-meter distance from the transmitter. Then to calculate the distance of a target from the transmitter, Equation (3.13) can be used:

$$r = 10^{\left(\frac{A-RSSI}{10 * n}\right)} \tag{3.13}$$

To calculate *A* values for the access points, the following procedure can be followed. The received power 1 meter away from each of the four access points is collected over 10 minutes time interval and then the sampled values are averaged [9].

The path loss exponent (*n*) is one of the most important parameters, which characterizes the power loss of the signal caused by environmental factors. Path loss is intimately related to the environment where the transmitter and receiver are located. Path loss directly affects the link quality of the network and its applications, like distance-based localizations, when the power of the received signal is an important factor [15].

Path loss models are developed using a combination of numerical methods and empirical approximations of measured data collected in channel sounding experiments. It depends on frequency, antenna orientation, penetration losses through walls and floors, the effect of multipath propagation, the interference from other signals, among many other factors [16][17].

In different environments the path loss and standard deviation change based on the environmental conditions. In Table 3.1 the path loss exponent for various environments are presented [15].

Table 3.1: Path loss exponent for different environments

Environment	Path Loss Exponent
Free Space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in buildings	4 to 6
Obstructed in factories	2 to 3

For the calculation of the path loss exponent the following steps are taken [9]:

- In a room of size 6*6 m, a set of 196 reference point, 40 cm apart from each other, determined.
- At each point the RSS values are measured with a sampling interval of 100 milliseconds over a time interval of 1 minute.
- Then the measured values averaged for each access point at each reference point.
- The following matrix (3.14) obtained:

$$P_r = \begin{bmatrix} P_r(AP_1)_1 & P_r(AP_2)_1 & P_r(AP_3)_1 & P_r(AP_4)_1 \\ P_r(AP_1)_2 & P_r(AP_2)_2 & P_r(AP_3)_2 & P_r(AP_4)_2 \\ \vdots & \vdots & \vdots & \vdots \\ P_r(AP_1)_{196} & P_r(AP_2)_{196} & P_r(AP_3)_{196} & P_r(AP_4)_{196} \end{bmatrix} \tag{3.14}$$

where $P_r(AP_i)_j$ is the average RSS value from access point *i* measured at reference point *j*.

- The distance $r_{j,i}$ calculated using Equation (3.15) where $r_{j,i}$ represent the distance for reference point j with coordinates (x_j, y_j) to AP_i at coordinates (x_i, y_i).

$$r_{j,i} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{3.15}$$

Equation (3.15) resulted a distance matrix shown in (3.16):

$$R = \begin{bmatrix} r_{1,1} & r_{1,2} & r_{1,3} & r_{1,4} \\ r_{2,1} & r_{2,2} & r_{2,3} & r_{2,4} \\ \vdots & \vdots & \vdots & \vdots \\ r_{196,1} & r_{196,2} & r_{196,3} & r_{196,4} \end{bmatrix} \tag{3.16}$$

- Then the path loss exponent measured at reference point *j* for AP_i is calculated by using Equation (3.17) below:

$$n = \frac{A - P_r(AP_i)_j}{10\log_{10}(r_{j,i})} \tag{3.17}$$

Since *n* value is a constant in the measurement environment, the calculated *n* values from Equation (3.17) averaged to approximate the path loss exponent using Equation (3.18).

$$n \approx \frac{1}{k \times N} \sum_{j=1}^{k} \sum_{i=1}^{N} \frac{A - P_r(AP_i)_j}{10\log_{10}(r_{j,i})} \tag{3.18}$$

where k is the number of points in the measurement area. N is the number of access points used.

In this thesis, the n value will be estimated by using synthetic data in Chapter 6.

3.3 Least Square Approximation for The RSS Values

Least squares estimation is the standard method to obtain a unique set of values for a set of unknown parameters from a redundant set of observables through a known mathematical model [18]. In particular, the line (the function shown in (3.19), where x_i is the values at which y_i is measured and i denotes an individual observation) that minimizes the sum of the squared distances (deviations) from the line to each observation is used to approximate a linear relationship.

$$y_i = b + mx_i \tag{3.19}$$

The graph of the distance with received signal strength in Figure 3.1 shows that the relationship between distance and RSS value is exponentially decreasing which means that when the distance increases the signal strength decreases.

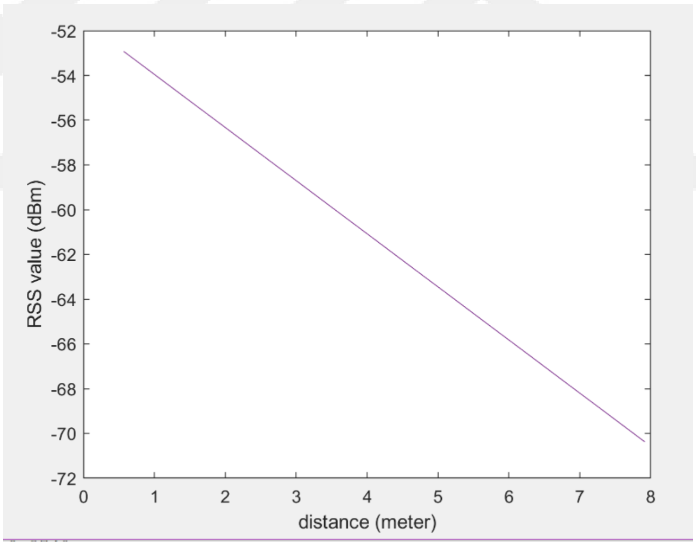

Figure 3.1: The relationship between RSS value and distance

RSSI is usually expressed in decibels relative to a milliwatt (dBm) from zero to -120 dBm. When the RSS value is closer to zero, the signal is stronger. If RSSI level is less than -80 dBm then it is counted as unusable, because of the noise [19]. Table 3.2 shows the signal strength according to the RSSI values.

Table 3.2: Signal Strength

RSSI (dBm)	Signal strength
> -50	Excellent
-50 to -60	Good
-60 to -70	Fair
< -70	Weak

In indoor localization, the RSS values measured at any reference point is affected by many different factors. Such as the Wi-Fi antenna of the transmitter or receiver and the environment of the measurement area. Because of that data fitting by least squares can be a way to increase the accuracy of the algorithm [9].

In Equation (3.19), x_i is represent the distance and y_i is represent the RSS values and the aim is to find m and b to minimize the root mean square error in the approximation of the data $\{(x_i, y_i)\}$ which can be achieved by Equation (3.20):

$$E = \sqrt{\frac{1}{n}\sum_{i=1}^{n}[b + mx_i - y_i]^2} \tag{3.20}$$

Minimizing E is equivalent to minimizing the sum in Equation (3.20). So, to calculate the minimum value of m and b the following Equations used:

$$\frac{dG(b,m)}{db} = \sum_{i=1}^{n} 2[b + mx_i - y_i] = 0 \tag{3.21}$$

$$\frac{dG(b,m)}{dm} = \sum_{i=1}^{n} 2[b + mx_i - y_i]x_i = 0 \tag{3.22}$$

The solution of Equations (3.21) and (3.22) can be shown in the following equations:

$$m = \frac{\sum_{i=1}^{n} x_i y_i - \frac{1}{n} \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i^2 - \frac{1}{n} (\sum_{i=1}^{n} x_i)^2} \tag{3.23}$$

$$b = \frac{1}{n} \sum_{i=1}^{n} y_i - \frac{m}{n} \sum_{i=1}^{n} x_i = \bar{y} - m\bar{x} \tag{3.24}$$

Let

$$S_{xy} = \sum\nolimits_{i=1}^{n} x_i y_i - \frac{1}{n} \sum\nolimits_{i=1}^{n} x_i \sum\nolimits_{i=1}^{n} y_i \tag{3.25}$$

And

$$S_{xx} = \sum\nolimits_{i=1}^{n} x_i^2 - \frac{1}{n} \left(\sum\nolimits_{i=1}^{n} x_i \right)^2 \tag{3.26}$$

Then *m* and *b* can be represented as in Equations (3.27) and (3.28) below:

$$m = \frac{S_{xy}}{S_{xx}} \tag{3.27}$$

$$b = \bar{y} - \frac{S_{xy}}{S_{xx}} \bar{x} \tag{3.28}$$

4. THE EXPERIMENT DESCRIPTION AND SIMULATION

In order to investigate the performance of RSS-based least squares lateration algorithm for indoor localization under different conditions, I developed a computer simulation using MATLAB for this thesis. This simulation allows the user to enter different parameters and then display the results on the interface. The experiment description and simulation setup will be discussed in this chapter.

4.1 The Experiment Description

Suppose that we have a measurement area of size $(s \times s)$ meters. In this area 4 access points are placed at the corners of the measurement area. The coordinates of the APs are: AP_1 at coordinate $(0,0)$, AP_2 at coordinate $(0, s)$, AP_3 at coordinate (s, s) and AP_4 at coordinate $(s, 0)$. Then the measurement area is divided into grids of size $(m \times m)$ cm. The corners of this grids marked as reference points as shown in Figure 4.1. Points at edges are ignored since it is unexpected to locate an object at edges as in many cases it is concrete walls. In this measurement area the position of any point can be defined. For example, in Figure 4.1the red point is at position (m, m), the green point is at position $(m, 3m)$ and the black point in the position $(3m, 2\ m)$.

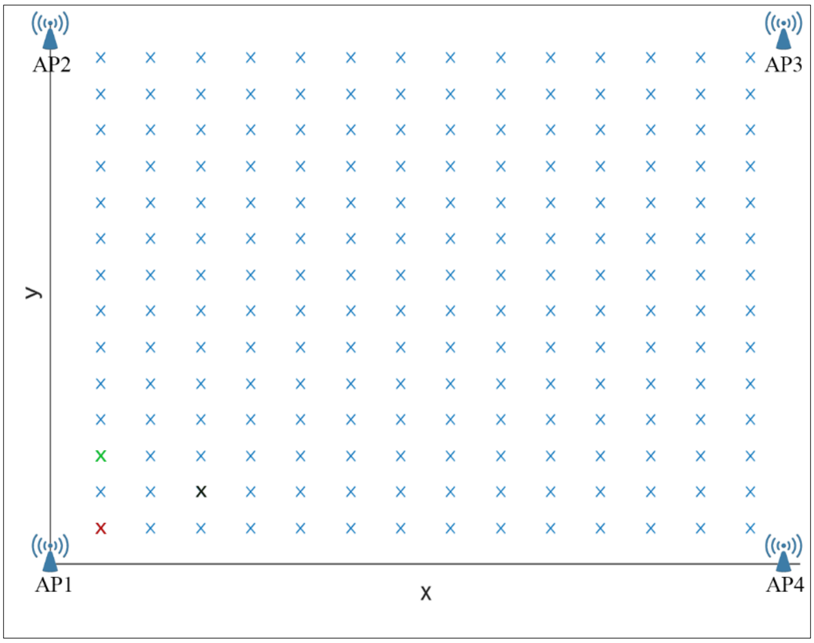

Figure 4.1: Measurement area and the reference points

These points used in our experiment as reference points to calculate the distance between them and the estimated points which the algorithm will estimate. And then calculate the average error of the position estimation.

As an illustration in Figure 4.2 a measurement area of size (6×6) meter used. The grid size is 40 cm. The total number of the marked points is 196 reference point. The access points placed at the following coordinates: AP_1 at coordinate (0,0), AP_2 at coordinate (0,6), AP_3 at coordinate (6,6) and AP_4 at coordinate (6,0).

In Figure 4.2 the red point is at position $(0.4, 0.4)$, the green point is at position $(0.4, 1.2)$ and the black point in the position $(1.2, 0.8)$.

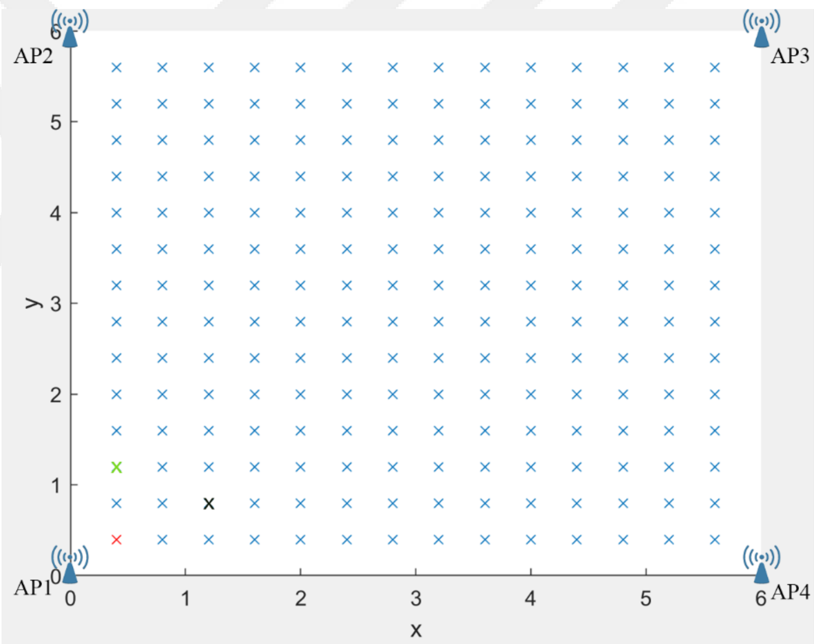

Figure 4.2: Measurement area for 6*6 room size and the reference points

4.2 The Simulation Setup

To examine the performance of the algorithm, the simulation interface is designed in a way that allows to test it using different parameters as in Figure 4.3.

The user can choose one of the five room sizes in the list (6*6 m, 12*12 m, 18*18m, 24*24 m, 30*30 m). Sizes bigger than 30*30 m was not added, since it is a very large room and does not exist frequently.

Besides the room size the user can choose the grid size from these options (20 cm,30 cm, 40 cm, 50 cm, 60 cm and 100 cm). Additionally, the path loss exponent and the RSS for each access points can be entered. To test the results under different noise levels, the user can enter the noise level and see the calculated results.

The graph, the calculated average error, maximum error, minimum error and number of points generated displayed in the results section of the interface.

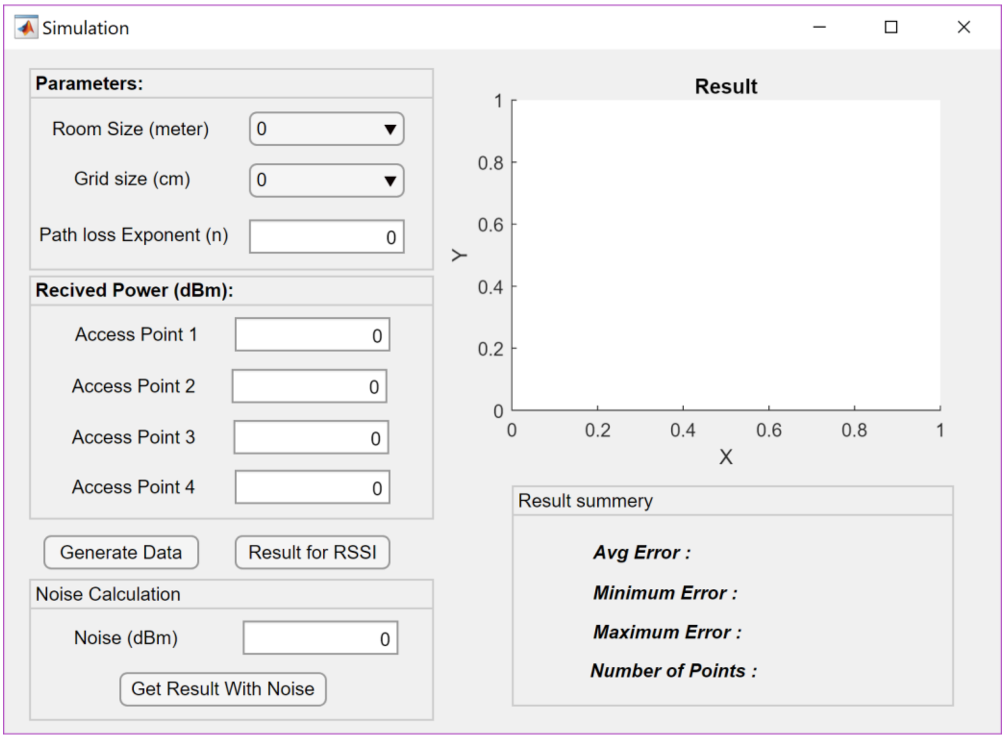

Figure 4.3: Simulation interface

When the code is run, first a set of synthetic data is generated according to the room size and grid size parameters. Assuming that each access point is located at a corner of the measurement room. And the number of points generated according to the grid size excluding points at edges.

Then the distance between each point and the four access points calculated. Next the estimated point calculated using Equation (3.11). After that the average error calculated and the results shown on the screen.

Since in real life the signal affected with room furniture and the nature of building materials and most environments contain a noise level, the code was improved by adding a noise when calculating the received signal strength values. To do that a random number from the normal distribution with mean parameter μ and standard deviation parameter σ generated using MATLAB function in (4.1).

$$normrnd(\mu, \sigma) \tag{4.1}$$

After adding different noise levels, the code is run, and the results recorded. The results of the simulation are shown in the following chapters.

5. THE SIMULATION RESULTS WITH KNOWLEDGE OF n

5.1 Results with different room sizes

In each room the simulation is runs 4 times. First the simulation is runs without adding any noise. Then to add noise Equation 5.1 used.

$$RSSI_{measured} = RSSI_{ideal} + noise \tag{5.1}$$

where noise is calculated with mean zero and variance 1,3 or 5 dBm using Equation 4.1.

5.1.1 Results in Room Size 6*6

To run the simulation, the path loss exponent *n* assumed to be 2.18. and the *A* values for the four access points assumed to be equaled and the value of *A* is -50. And 40 cm grid size is used.

5.1.1.1 Results with error-free synthetic data

Figure 5.1 shows that when running the simulation without any noise the average error is equal to 0. The number of points generated is equal to 196.

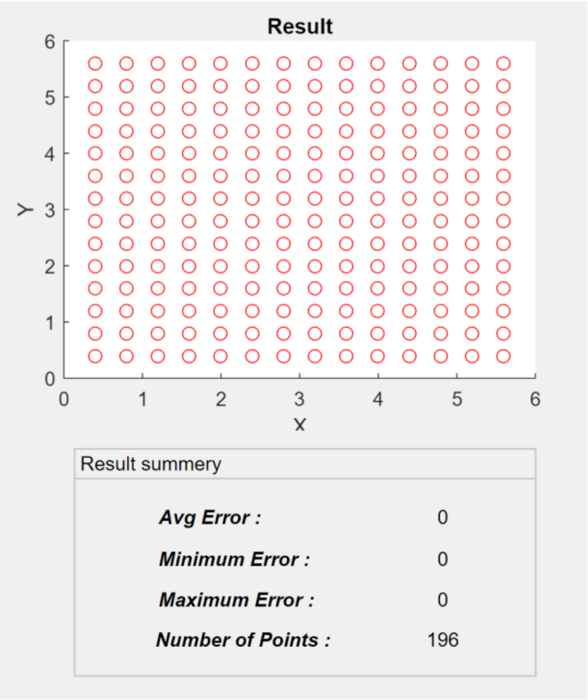

Figure 5.1: Results with error-free synthetic data in room size 6*6

5.1.1.2 Results with synthetic data with 1 dBm noise

Figure 5.2: Results with synthetic data with 1dBm in room size 6*6

Figure 5.2 shows that when adding a 1 dBm noise to the data the average error is 0.603 meter, and the maximum error is 2.4 meter.

5.1.1.3 Results with synthetic data with 3 dBm noise

As shown in Figure 5.3 when the noise increased the average error also increased. With 3 dBm noise the average error increased to 1.948 m, and the maximum error is 10.363 m.

Figure 5.3: Results with synthetic data with 3 dBm in room size 6*6

5.1.1.4 Results with synthetic data with 5 dBm noise

When the noise increased to 5 dBm the average error increased a lot. As in Figure 5.4 the average error is 4.8 m, and the maximum error reached 34.67m.

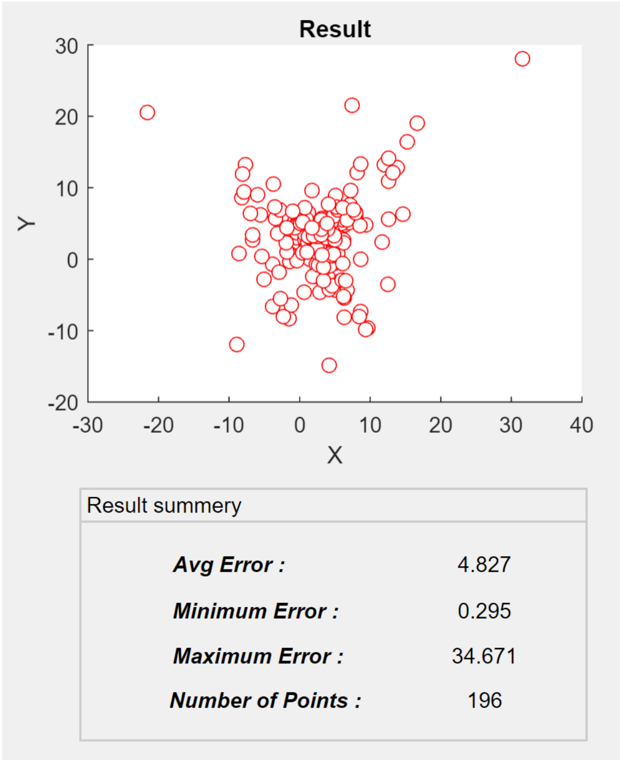

Figure 5.4: Results with synthetic data with 5 dBm in room size 6*6

5.1.2 Results in room size 12*12

In this section, the room size changed while the other parameters will be the same. The path loss exponent *n* assumed to be 2.18. and the *A* values for the four access points assumed to be equaled and the value of *A* is -50. And 40 cm grid size is used.

5.1.2.1 Results with error-free synthetic data

When the room size is 12*12 meter and the grid size is 40 cm, 841 points are generated. With error-free synthetic data, the average error calculated is 0. Figure 5.5 shows the distribution of the 841 points.

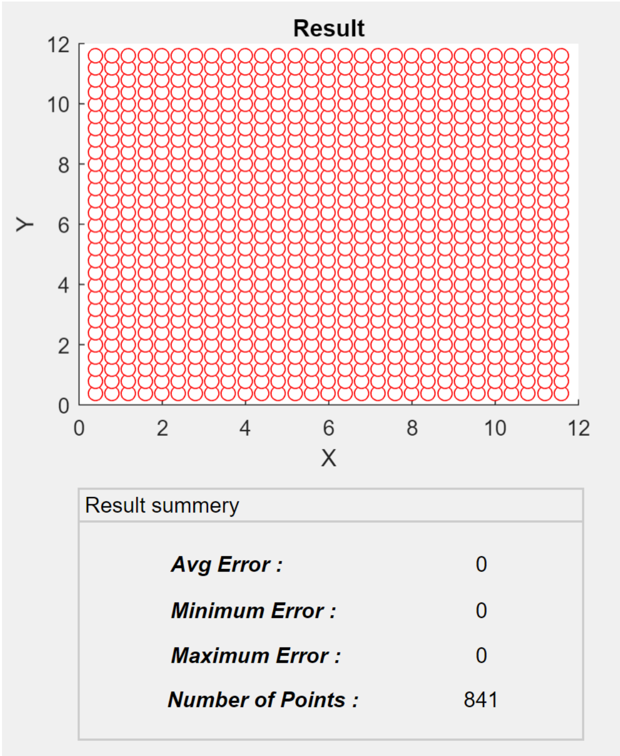

Figure 5.5: Results with error-free synthetic data in room size 12*12

5.1.2.2 Results with synthetic data with 1 dBm noise

Figure 5.6: Results with synthetic data with 1dBm in room size 12*12

When the room size is 12 *12 meters with grid size 40 cm and 1 dBm noise, the average error calculated is 1,295 m. The maximum error is 8.407m, and minimum error is 0.065 m as in Figure 5.6.

5.1.2.3 Results with synthetic data with 3 dBm noise

With 3 dBm noise the maximum error reached 35.2 m while the minimum error is 0.191. In this case the average error is 4.39 m. Figure 5.7 shows the results and the estimated point distribution.

Figure 5.7: Results with synthetic data with 3 dBm in room size 12*12

5.1.2.4 Results with synthetic data with 5 dBm noise

Figure 5.8 shows the distribution of the points and the results of synthetic data with 5 dBm noise. The average error is 9.79 m. The minimum error is 0.719 m, and the maximum error is 91.308 m.

Figure 5.8: Results with synthetic data with 5 dBm in room size 12*12

5.1.3 Results in room size 18*18

In this section, the room size is changed to a size of 18*18 meter. The other parameters used are the same. The path loss exponent *n* is assumed to be 2.18. and the *A* values for the four access points are assumed to be equaled and the value of *A* is -50. And 40 cm grid size is used.

5.1.3.1 Results with error-free synthetic data

In a room with size 18*18 meter, if the grid size is 40 cm, 1936 points are generated. With error-free synthetic data, the average error calculated is 0. Figure 5.9 shows the distribution of the 841 points.

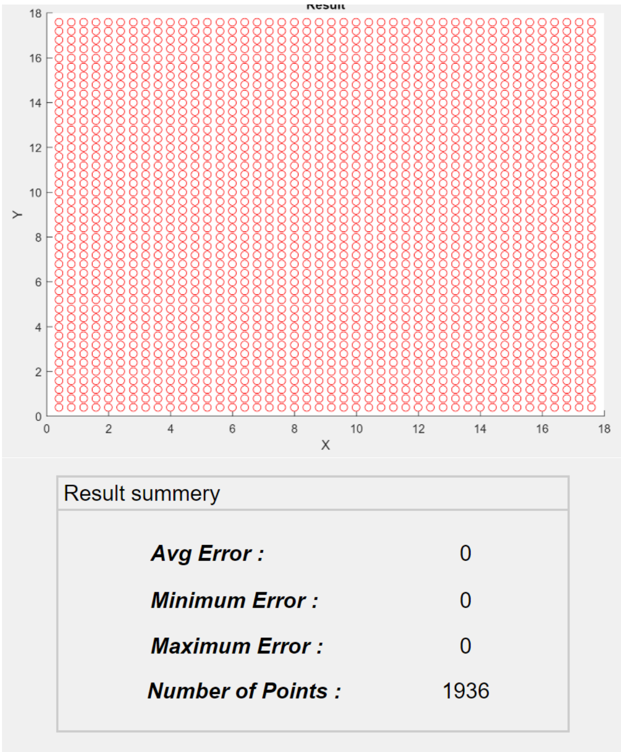

Figure 5.9: Results with error-free synthetic data in room size 18*18

5.1.3.2 Results with synthetic data with 1 dBm noise

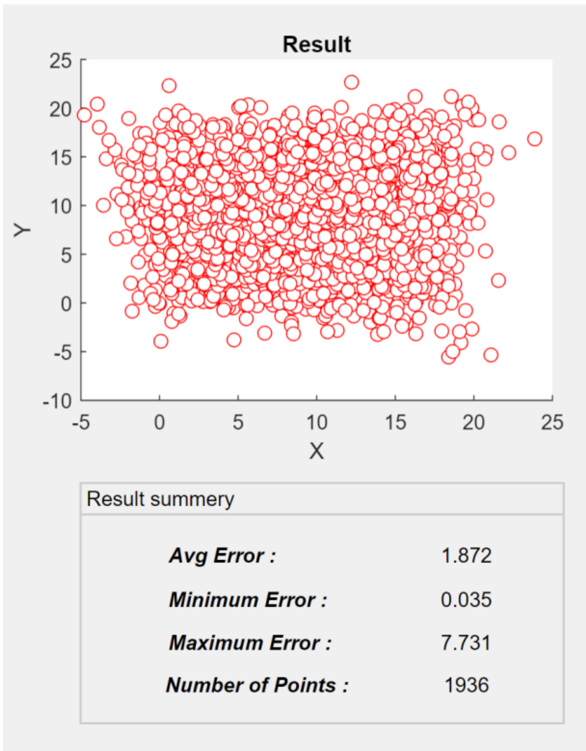

Figure 5.10: Results with synthetic data with 1 dBm in room size 18*18

With 1 dBm noise in a room of size 18*18 m, with 1936 points, the average error is 1.872 m. The minimum error is 0.035 m while the maximum error is 7.731 m. Figure 5.10 shows the results.

5.1.3.3 Results with synthetic data with 3 dBm noise

When the noise level is increased to 3 dBm, the maximum error reaches 48.197 m while the minimum error is 0.109. Figure 5.11 shows that the average error is 6.74 m.

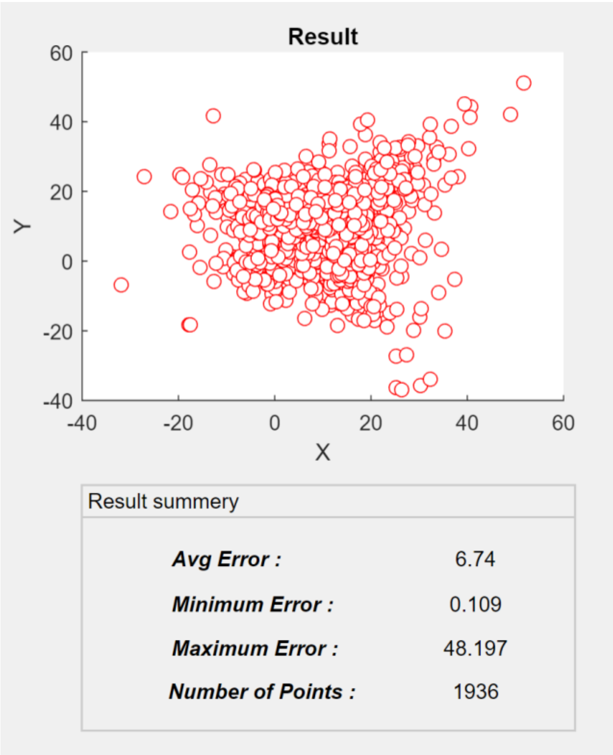

Figure 5.11: Results with synthetic data with 3 dBm in room size 18*18

5.1.3.4 Results with synthetic data with 5 dBm noise

Figure 5.12 shows the distribution of the points and the results of synthetic data with 5 dBm noise. The average error is 14.649 m. The minimum error is 0.178 m, and the maximum error is 186.996 m.

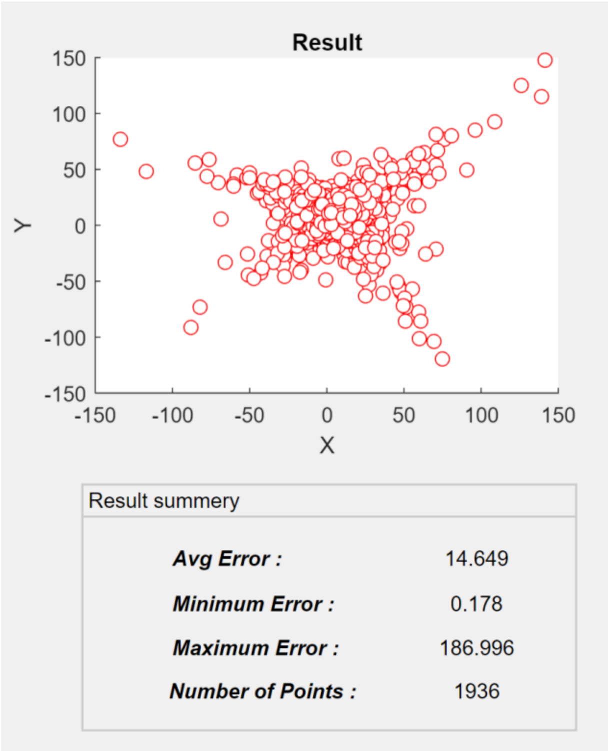

Figure 5.12: Results with synthetic data with 5 dBm in room size 18*18

5.1.4 Results in Room Size 24*24

Although 24*24 room size considered as big room size and it is only available in large buildings, the algorithm examined with this size. All other parameters used as the previous sections. The path loss exponent *n* is assumed to be 2.18. and the *A* values for the four access points are assumed to be equaled and the value of *A* is -50. And 40 cm grid size is used.

5.1.4.1 Results with error-free synthetic data

With 24*24 room size and 40 cm grid size, the number of points generated is 3481 point. The error-free synthetic data has an average error equal to 0. Figure 5.13 shows the distribution of the 3481 points.

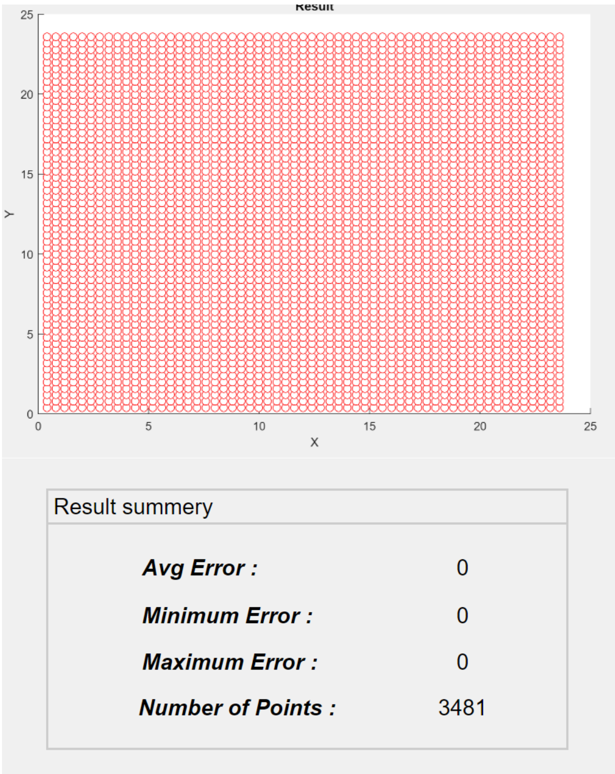

Figure 5.13: Results with error-free synthetic data in room size 24*24

5.1.4.2 Results with synthetic data with 1 dBm noise

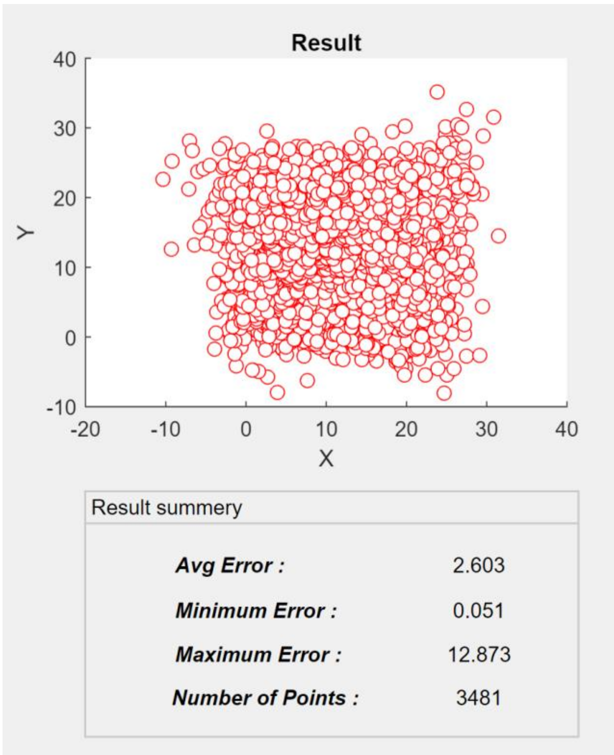

Figure 5.14: Results with synthetic data with 1dBm in room size 24*24

In this case with 1 dBm noise in Figure 5.14, the average error calculated is 2.603 m. The minimum error is 0.051 m, while the maximum error is 12.873 m.

5.1.4.3 Results with synthetic data with 3 dBm noise

With 3 dBm noise the maximum error reaches 82.314 m while the minimum error is 0.072. The average error calculated and found equal to 8.997 m. Figure 5.15 shows the results and the estimated point distribution.

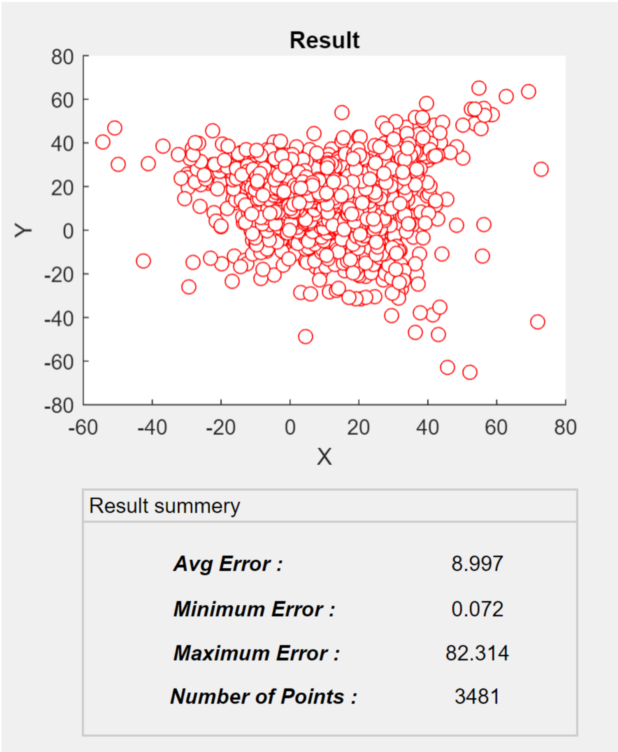

Figure 5.15: Results with synthetic data with 3 dBm in room size 24*24

5.1.4.4 Results with synthetic data with 5 dBm noise

The 5 dBm noise level considered as high noise level. And in a big room with size 24*24 this noise level resulted in a very high average error. Figure 5.16 shows the distribution of the points and the results of synthetic data with 5 dBm noise. The average error is 19.564 m. The minimum error is 0.244 m, and the maximum error is 338.918 m.

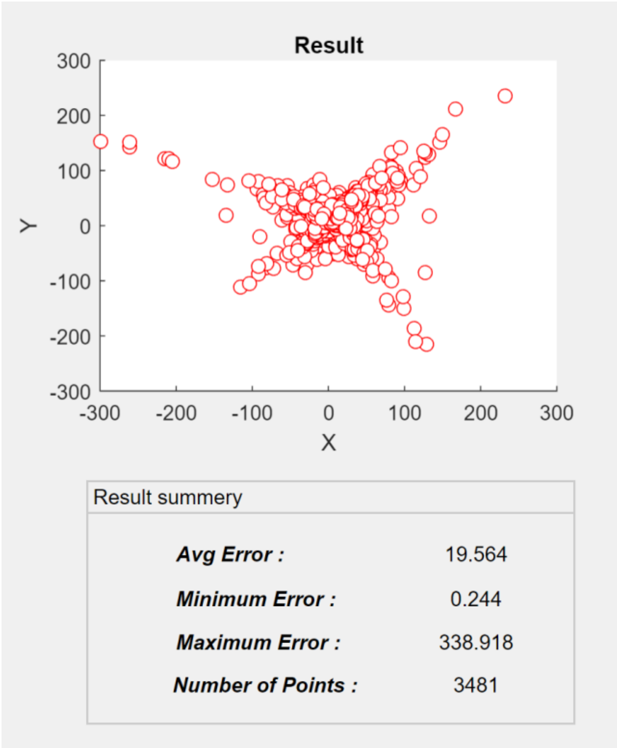

Figure 5.16: Results with synthetic data with 5 dBm in room size 24*24

5.2 Impact of Different Parameters on The Average Error

In order to examine the impact of different parameters on the average error the confidence interval is used, and the simulation program modified to calculate the confidence interval and to show the results.

In this section, the confidence interval, the simulation modification and the results are discussed.

5.2.1 Confidence interval (CI)

A confidence interval, calculated from a given set of sample data, gives an estimated range of values which is likely to include an unknown population parameter. The CI is expressed as 2 numbers, known as the confidence limits with a range in between. These two numbers are known as upper CI and lower CI. This range, with a certain level of confidence, carries the true but unknown value of the measured variable in the population [20].

To calculate the confidence interval first the confidence level should be defined. A confidence level refers to the percentage of all possible samples that can be expected to include the true population parameter [21]. The confidence level is usually set to 95%; hence named "95% confidence interval". In other words, it can be said that this range has a 95% probability of including the true value of the variable [22].

The confidence interval can be calculated using the formula in Equation (5.2) below:

$$\bar{X} \pm Z \frac{s}{\sqrt{(n)}} \tag{5.2}$$

where: $\bar{X}$ is the mean, s is the standard deviation, n is the number of observations and Z is the value from the Z-table shown in Table 5.1.

The Z-table is short for the "Standard Normal z-table". The Standard Normal model is used in hypothesis testing, including tests on proportions and on the difference between two means. The area under the whole of a normal distribution curve is 1, or 100 percent. The Z-table helps by telling us what percentage is under the curve at any particular point [21].

Table 5.1: The Z-table

Confidence level	80%	85%	90%	95%	99%	99.5%	99.9%
Z-value	1.282	1.440	1.645	1.960	2.576	2.807	3.291

5.2.2 The simulation modification

To test the impact of different parameters on the average error the simulation interface modified, shown in Figure 5.17, to display a graph of the average error and confidence interval and a table contain the average error, upper CI and lower CI.

Also, the cod has been modified by adding a loop to run the code for 100 times each time the simulation is run. Then the average error results of the 100 runs are averaged and the mean and standard deviation is calculated. The CI then calculated using Equation 5.2. A 95% confidence level is used.

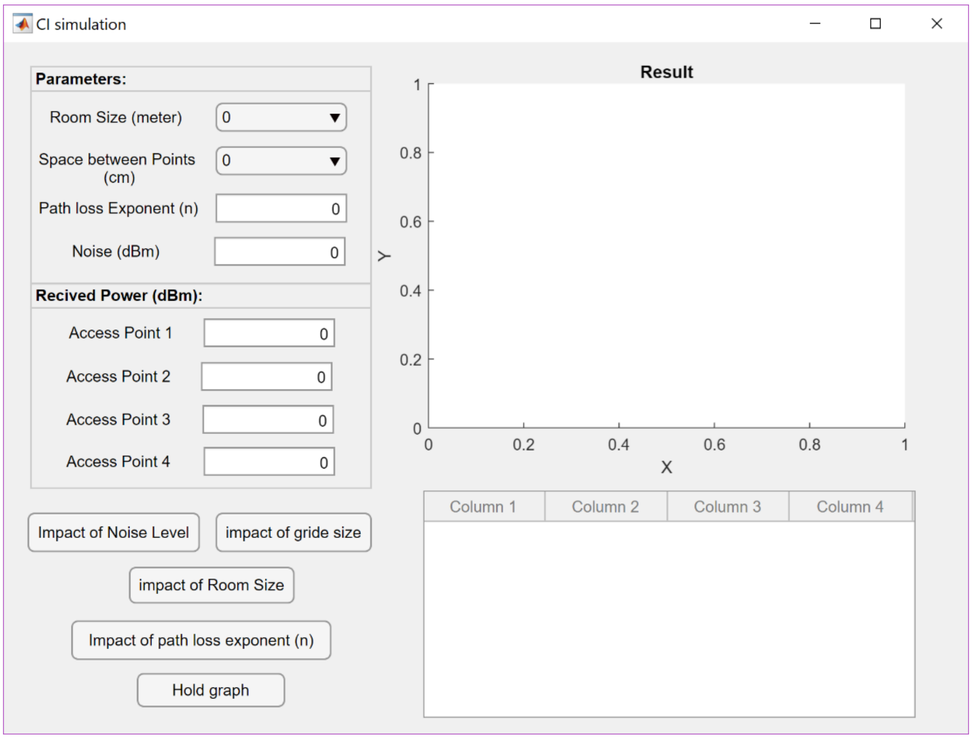

Figure 5.17: Confidence interval simulation interface

5.2.3 The Simulation Results

In this simulation, the impact of following parameters tested: noise level, grid size, room size and the path loss exponent *n*.

5.2.3.1 Impact of noise level

The algorithm tested with 10 noise level values. The initial parameters used are as following: the room size is 6*6, the grid size is 40 cm, the path loss exponent *n* is 2 and the *A* values for the four access points are assumed to be equaled and equal to -50. Figure 5.18 shows the graph of the average error with upper and lower CI. The results are shown in Table 5.2. The results show that when the noise increased, the average error increased.

Table 5.2: Impact of noise level

Noise Level (dBm)	Average Error (m)	Upper CI (m)	Lower CI (m)
0.5	0.335	0.337	0.332
1	0.682	0.688	0.676
1.5	1.051	1.063	1.039
2	1.465	1.480	1.449
2.5	1.937	1.962	1.912
3	2.466	2.499	2.433
3.5	3.107	3.151	3.063
4	3.819	3.880	3.758
4.5	4.814	4.892	4.736
5	5.998	6.137	5.859

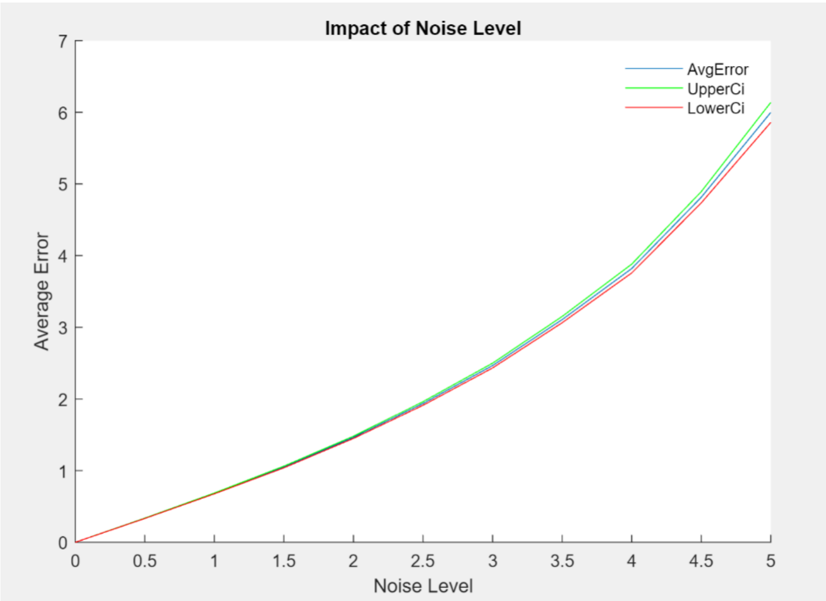

Figure 5.18: Impact of noise level

5.2.3.1.1 Impact of noise level with room size

The simulation has been run with 5 different room sizes to examine the impact of noise level with room size. The results, in Figure 5.19, shows that when the room size increased with the increasing of the noise level the average error is also increased.

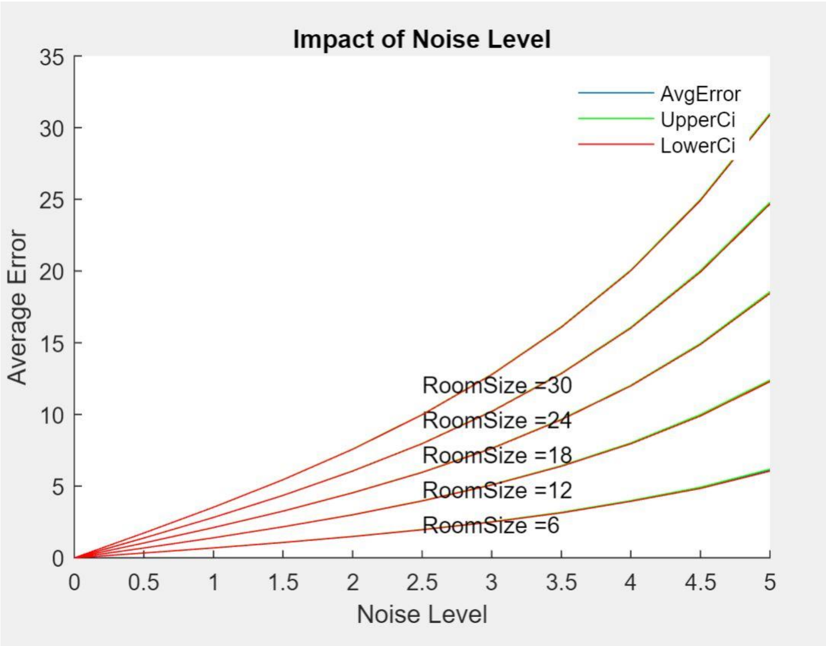

Figure 5.19: Impact of noise level with room size

5.2.3.1.2 Impact of noise level with n value

The noise level impact tested with 4 different path loss exponent values from Table 3.1. The results show when the noise level increased and the n value decreased the average error is increased. Figure 5.20 displays the graph of these results.

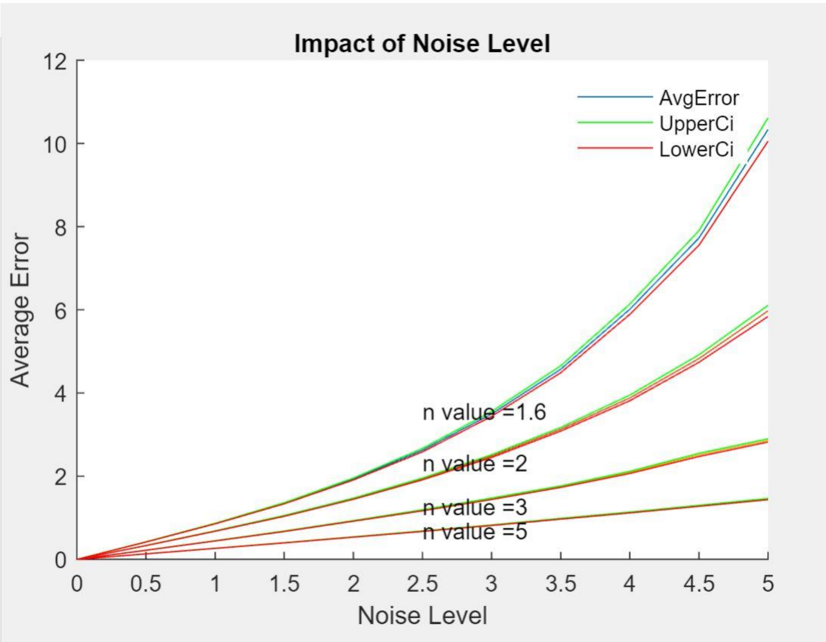

Figure 5.20: Impact of noise level with *n* value

5.2.3.2 Impact of path loss exponent

The simulation runs to test the impact of path loss exponent. Based on Table 3.1, 6 different *n* values used in the simulation. The initial parameters used as follows: room size 6*6, grid size 40 cm, noise level 1 dBm and the *A* values for the four access points are assumed to be equaled and equal to -50.

The results show that when the path loss exponent increased the average error decreased. Which means there is an inverse relationship between path loss exponent and the average error calculated.

Table 5.3 and Figure 5.21 show the results.

Table 5.3: Impact of path loss exponent value

***n* value**	**Average Error (m)**	**Upper CI (m)**	**Lower CI (m)**
1.6	0.865	0.871	0.859
1.8	0.76	0.766	0.754
2	0.674	0.679	0.669
2.7	0.494	0.498	0.49
3	0.448	0.452	0.444
3.5	0.384	0.387	0.381
4	0.334	0.337	0.331
5	0.267	0.269	0.265
6	0.221	0.223	0.219

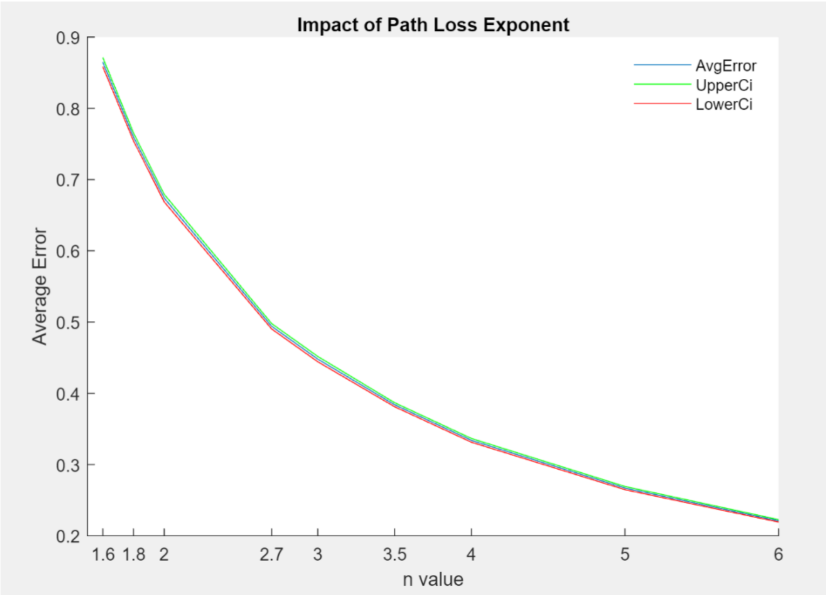

Figure 5.21: Impact of path loss exponent value

5.2.3.2.1 Impact of path loss exponent with room size

The simulation has been run with 5 different room sizes to examine the impact of path loss exponent with room size. The room sizes used as follows: 6*6, 12*12, 18*18, 24*24 and 30*30. The results, in Figure 5.22, shows that when the room size increased with the increasing of the path loss exponent the average error is decreased.

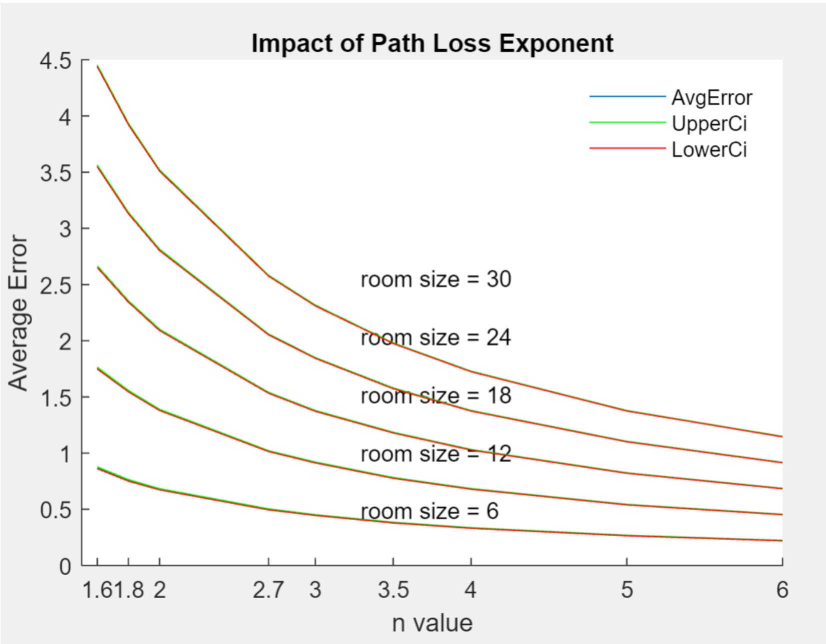

Figure 5.22: Impact of path loss exponent with room size

5.2.3.2.2 Impact of path loss exponent with the noise level

To examine the impact of path loss exponent with the noise level, 5 noise level used as in Figure 5.23. the results show that as the n value increased and the increasing of noise level, the average error decreased.

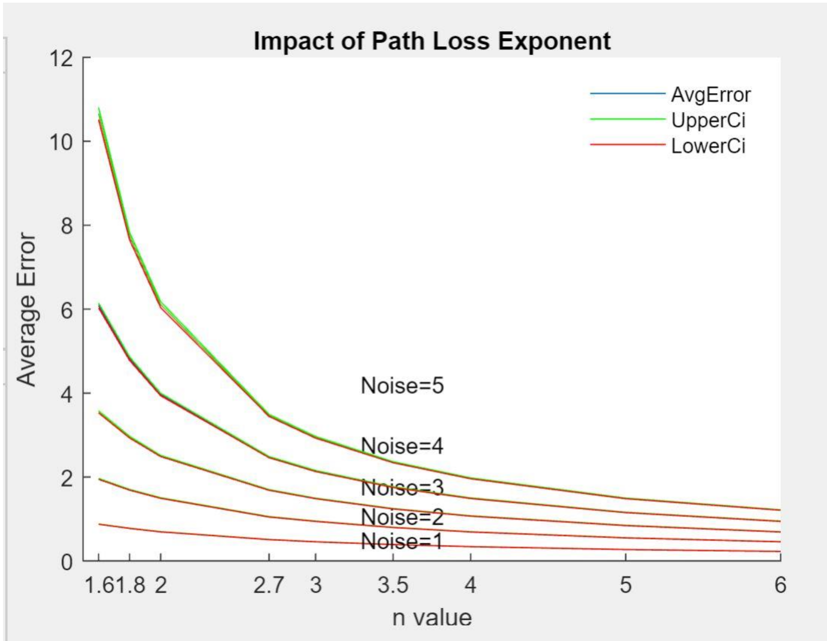

Figure 5.23: Impact of path loss exponent with the noise level

5.2.3.3 Impact of grid size

To test the impact of grid size the algorithm tested with 5 different grid sizes. Changing the grid size affect the number of points generated. For example, in a room of size 6*6 using 40 cm grid generates 196 points while in the same room if 20 cm grid size used, 841 points are generated. The initial parameters used are as following: the room size is 6*6, the noise level is 1 dBm, the path loss exponent n is 2 and the A values for the four access points are assumed to be equaled and equal to -50.

Figure 5.24 shows the graph of the average error with upper and lower CI. Although the graph seems like a decreasing graph, the results numbers in Table 5.4 shows that the average error decreased in a very small range.

Table 5.4: Impact of grid size

Grid Size (cm)	Average Error (m)	Upper CI (m)	Lower CI (m)
20	0.695	0.698	0.692
30	0.691	0.695	0.687
40	0.678	0.684	0.672
50	0.674	0.681	0.667
60	0.668	0.676	0.66

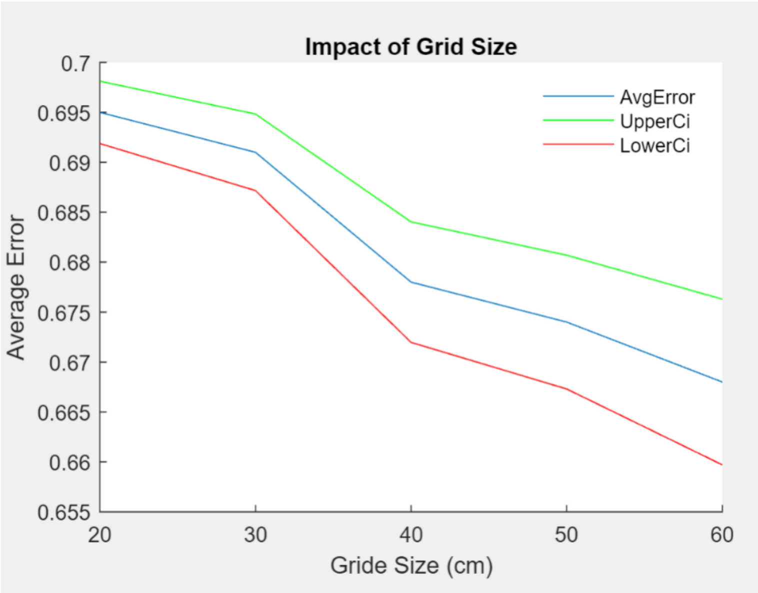

Figure 5.24: Impact of grid size

5.2.3.3.1 Impact of grid size with room size

The simulation has been run with 5 different room sizes to examine the impact of grid size with room size. The room sizes used as follows: 6*6, 12*12, 18*18, 24*24 and 30*30. The results, in Figure 5.25, shows that when the grid size increased with the increasing of the room size the average error is almost a constant.

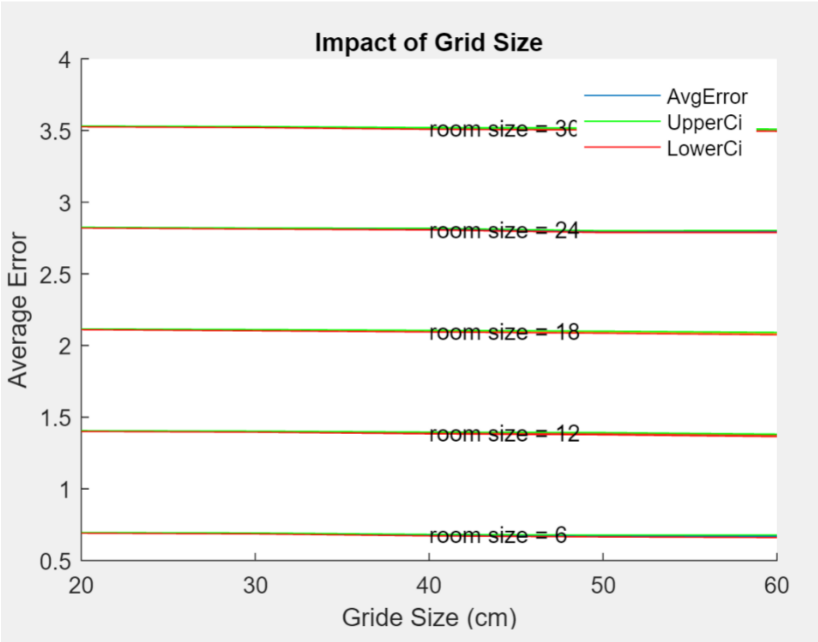

Figure 5.25: Impact of grid size with room size

5.2.3.3.2 Impact of grid size with noise level

To examine the impact of grid size with noise level, 5 noise levels are used as in Figure 5.26. The results show that as the grid size increased with the increasing of noise level, the average error is almost a constant.

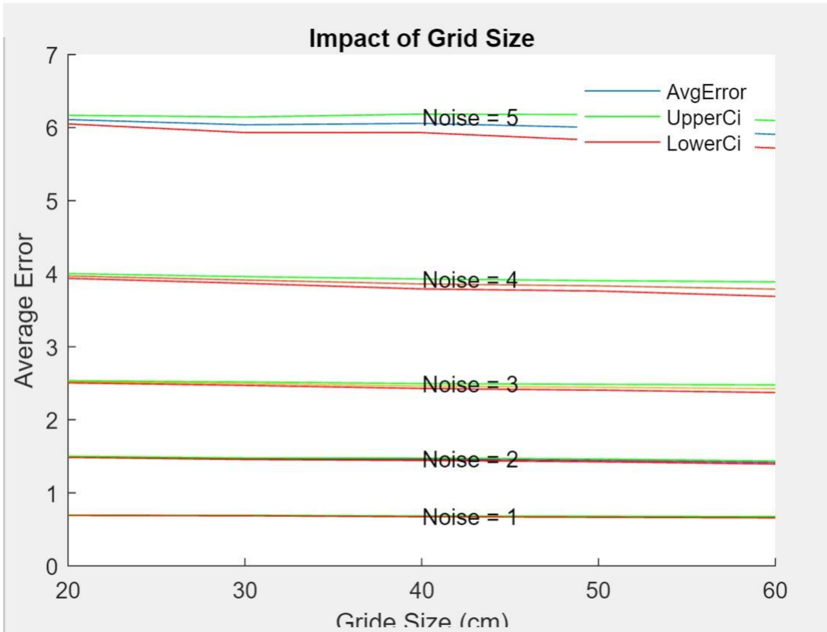

Figure 5.26: Impact of grid size with noise level

5.2.3.3.3 Impact of grid size with n value

In order to examine the impact of grid size with n value, 5 n values from Table 3.1 is used. Figure 5.27 shows that when the grid size increased the average error is almost a constant. While when decreasing the n value the average error increased.

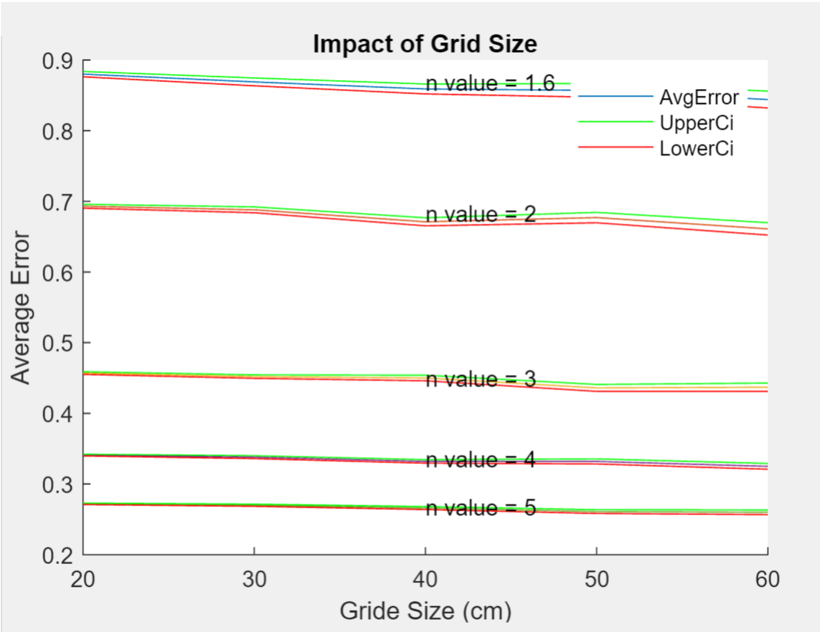

Figure 5.27: Impact of grid size with n value

5.2.3.4 Impact of room size

The simulation has been run to explore the algorithm performance in different room sizes. The sizes used as follows: 6*6, 12*12, 18*18, 24*24 and 30*30. Although 30*30 meter is very big room size, it was added to inspect the impact of room size. The initial parameters used are as following: The grid size is 40 cm, the noise level is 1 dBm, the path loss exponent n is 2 and the A values for the four access points are assumed to be equaled and equal to -50. As seen in Table 5.5 and Figure 5.28, the results of this simulation show that when the room size increased the average error also increased.

Table 5.5: Impact of room size

Room size (m)	Average Error (m)	Upper CI (m)	Lower CI (m)
6*6	0.676	0.682	0.67
12*12	1.391	1.397	1.385
18*18	2.097	2.103	2.091
24*24	2.807	2.813	2.801
30*30	3.517	3.523	3.511

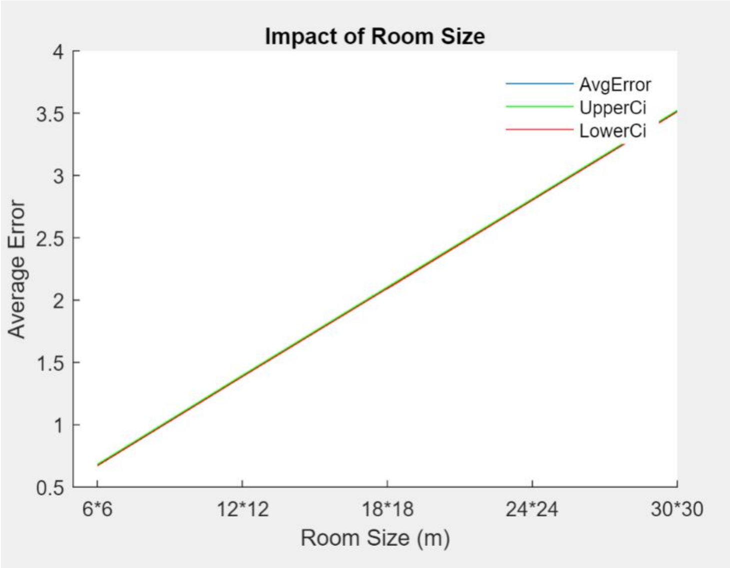

Figure 5.28: Impact of room size

5.2.3.4.1 Impact of room size with the noise level

To examine the impact of room size with noise level, 5 noise levels are used as in Figure 5.29. The results show that as the room size increased with the increasing of noise level, the average error is increased.

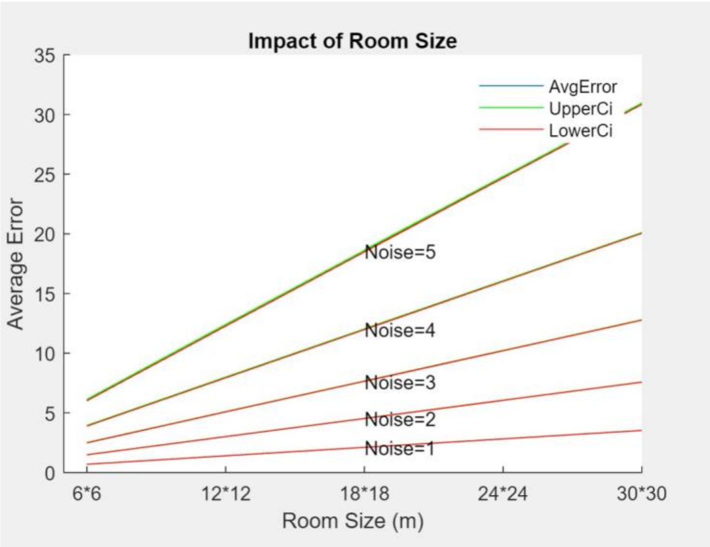

Figure 5.29: Impact of room size with noise level

5.2.3.4.2 Impact of room size with n value

In order to examine the impact of room size with n value, 5 different n values from Table 5.3 are used. Figure 5.30 shows that when the room size increased and the n value decreased, the average error increased.

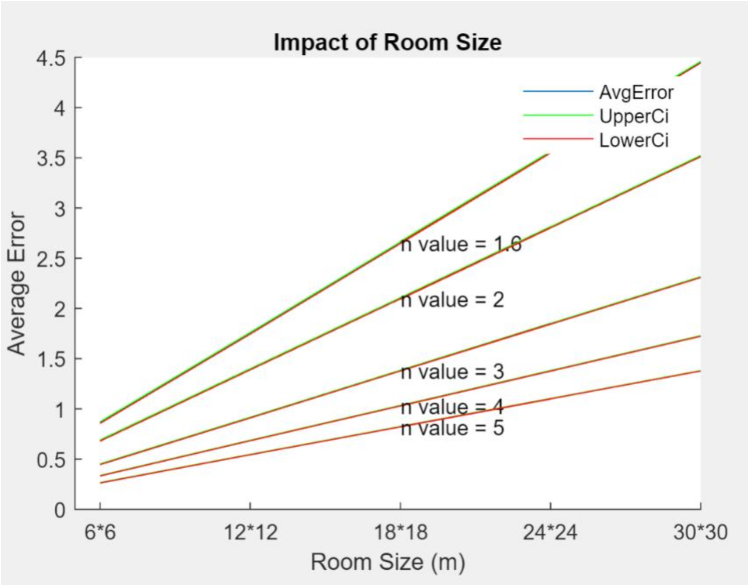

Figure 5.30: Impact of room size with n value

6. THE SIMULATION RESULTS WITH ESTIMATION OF n

In Chapter 5, the path loss exponent n value and A value used were assumed values. In this chapter, the n value will be estimated using synthetic data and then used to calculate the average error for the received signal strength RSS-based least squares lateration algorithm.

6.1 The Estimated n Value

There are many different methods to estimate the value of n, however these methods either require some information of the wireless network, which is unknown in most cases, or the assistance from auxiliary systems [23][24]. Some other methods start with an initial guess of the path loss exponent to approximate the location which is then used to update the n value estimate. In this thesis, the method which based on an initial n value is used.

For this estimation to calculate the value of n, a MATLAB code was written using Equations (3.15), (3.16), (3.17) and (3.18). The initial values used for this estimation as follows: n value is 2 which is the value of free space as in Table 3.1. The value of A for the four APs is assumed to be equaled and equal to -50.

The estimation is done for different room sizes, different grid sizes and different noise levels as in the following sections.

6.1.1 Estimation with noise level equal to 1 dBm.

In this experiment, the n value estimated in three room sizes: 6*6, 12*12 and 18*18. In each room size three different grid sizes are used: 1 m, 60 cm and 40 cm. The estimated n values are shown in Table 6.1.

Using the estimated n values in Table 6.1, the performance of the RSS-based least square algorithm tested again. And the results are shown in Sections 6.1.1.1, 6.1.1.2 and 6.1.1.3.

Table 6.1: Estimated n value with 1 dBm noise level

Room size (m)	Grid size (cm)	Estimated n (dBm)
6*6	1	2.04
	0.6	2.03
	0.4	1.98
12*12	1	2.009
	0.6	2.005
	0.4	1.99
18*18	1	1.997
	0.6	1.998
	0.4	2.001

6.1.1.1 Results for room size 6*6

In this room 3 different grid sizes are used. For a grid size of 100 cm, the average error calculated is 0.671 m, the maximum error is 1.384 m while the minimum error is 0.164 m, as shown in Figure 6.1.

For a grid size of 60 cm, the average error calculated is 0.648 m, the maximum error is 1.94 m while the minimum error is 0.046 m, as shown in Figure 6.2.

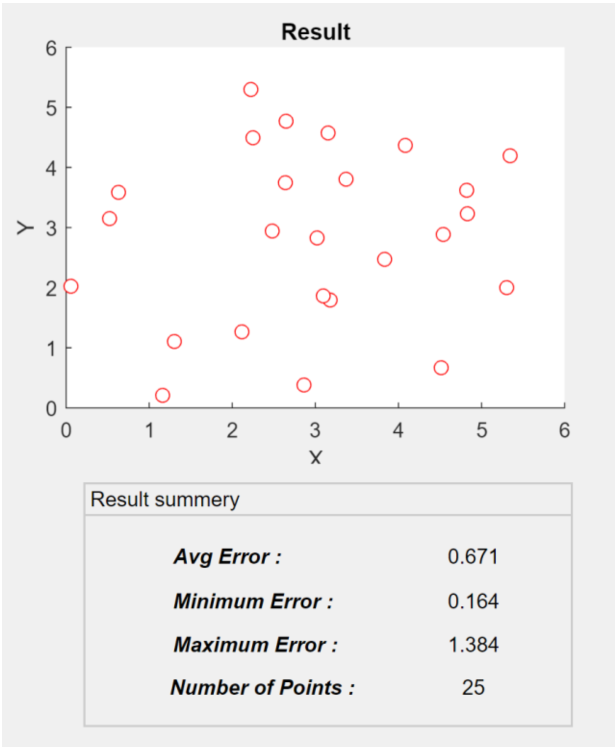

Figure 6.1: Results with est. n in 6*6 room size with 100cm grid size, 1dBm noise

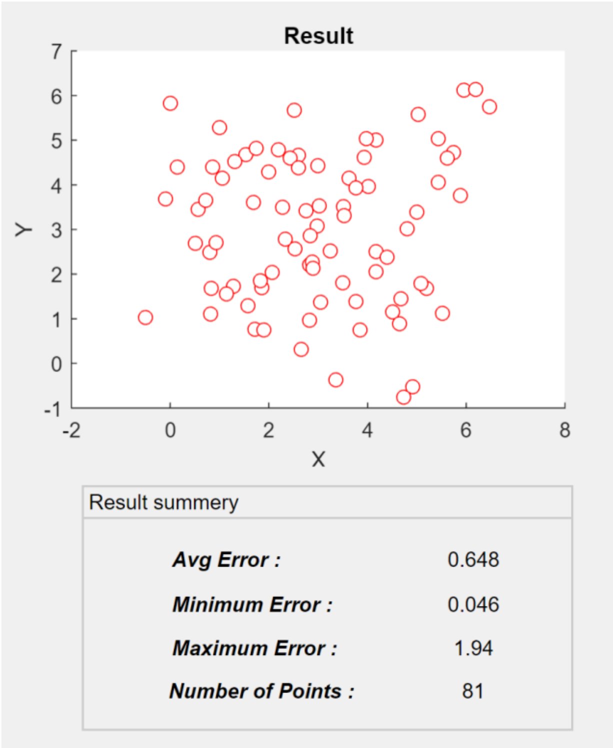

Figure 6.2: Results with est. n in 6*6 room size with 60 cm grid size, 1dBm noise

For a grid size of 40 cm, the average error calculated is 0.672 m, the maximum error is 1.799 m while the minimum error is 0.043 m, as shown in Figure 6.3.

Figure 6.3: Results with est. n in 6*6 room size with 40 cm grid size, 1dBm noise

6.1.1.2 Results for room size 12*12

In this room 3 different grid sizes are used. For a grid size of 100 cm, the average error calculated is 1.179 m, the maximum error is 3.194 m while the minimum error is 0.076 m, as shown in Figure 6.4.

For a grid size of 60 cm, the average error calculated is 1.406 m, the maximum error is 6.507 m while the minimum error is 0.033 m, as shown in Figure 6.5.

Figure 6.4: Results with est. n in 12*12 room size with 100 cm grid size, 1dBm noise

Figure 6.5: Results with est. n in 12*12 room size with 60 cm grid size, 1dBm noise

For a grid size of 40 cm, the average error calculated is 1.344 m, the maximum error is 9.066 m while the minimum error is 0.027 m, as shown in Figure 6.6.

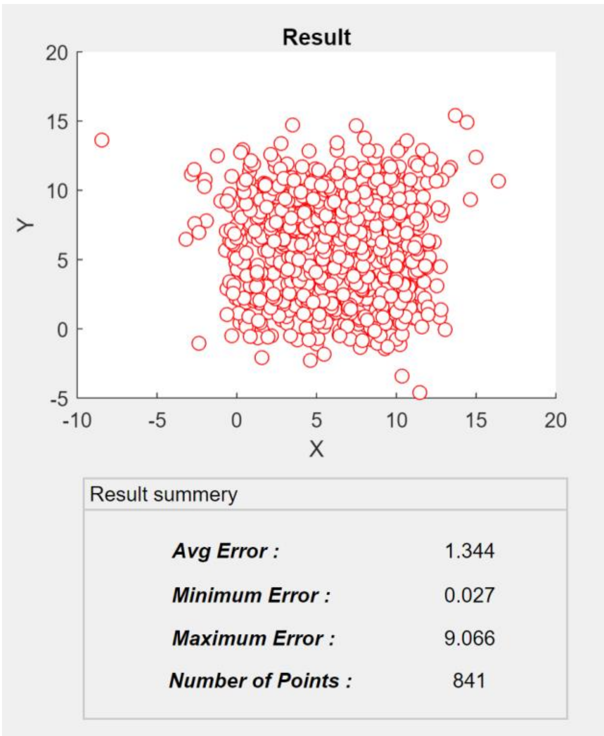

Figure 6.6: Results with est. n in 12*12 room size with 40 cm grid size, 1dBm noise

6.1.1.3 Results for room size 18*18

In this room 3 different grid sizes are used. For a grid size of 100 cm, the average error calculated is 2.038 m, the maximum error is 8.22 m while the minimum error is 0.156 m, as shown in Figure 6.7.

For a grid size of 60 cm, the average error calculated is 2.151 m, the maximum error is 9.303 m while the minimum error is 0.109 m, as shown in Figure 6.8.

Figure 6.7: Results with est. n in 18*18 room size with 100 cm grid size, 1dBm noise

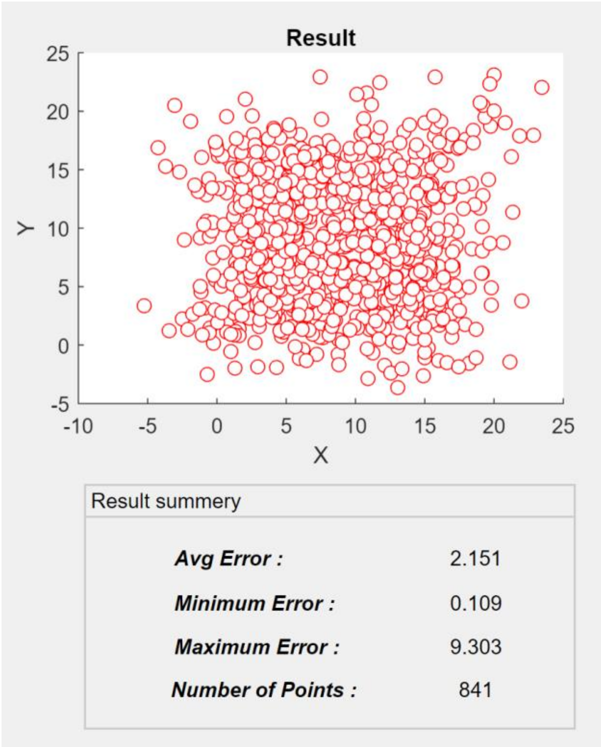

Figure 6.8: Results with est. n in 18*18 room size with 60 cm grid size, 1dBm noise

For a grid size of 40 cm, the average error calculated is 2.059 m, the maximum error is 9.251 m while the minimum error is 0.009 m, as shown in Figure 6.9.

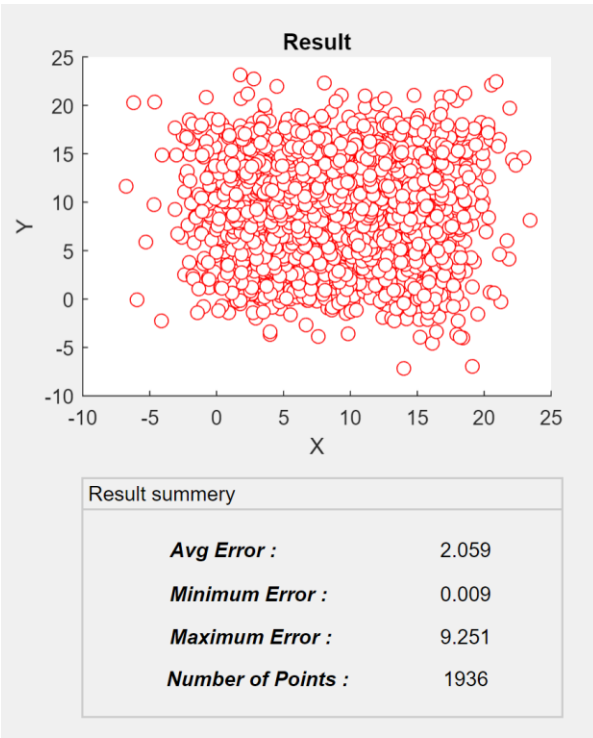

Figure 6.9: Results with est. n in 18*18 room size with 40 cm grid size, 1dBm noise

6.1.2 Estimation with noise level equal 3 dBm.

With 3 dBm noise level, the n value is estimated in three room sizes: 6*6, 12*12 and 18*18. In each room size three different grid sizes are used: 1 m, 60 cm and 40 cm. the estimated n values shown in Table 6.2.

Using the estimated n values in Table 6.2, the performance of the RSS-based least square algorithm tested again, and the results are shown in Sections 6.1.2.1, 6.1.2.2 and 6.1.2.3.

Table 6.2: Estimated n value with 3 dBm noise level

Room size (m)	Grid size (cm)	Estimated n (dBm)
6*6	1	1.93
	0.6	2.06
	0.4	1.97
12*12	1	1.96
	0.6	2.03
	0.4	1.99
18*18	1	2.01
	0.6	1.998
	0.4	1.996

6.1.2.1 Results for room size 6*6

In this room 3 different grid sizes are used. For grid size of 100 cm, the average error calculated is 1.845 m, maximum error is 5.009 m while minimum error is 0.108 m, as shown in Figure 6.10.

For grid size of 60 cm, the average error calculated is 1.749 m, maximum error is 6.218 m while minimum error is 0.167 m, as shown in Figure 6.11.

Even with 3 dBm noise level the average error is less than 2 m which can be considered as good performance.

Figure 6.10: Results with est. n in 6*6 room size with 100 cm grid size, 3 dBm noise

Figure 6.11: Results with est. n in 6*6 room size with 60 cm grid size, 3 dBm noise

For grid size of 40 cm, the average error calculated is 2.386 m, maximum error is 11.974 m while minimum error is 0.114 m, as shown in Figure 6.12.

Figure 6.12: Results with est. *n* in 6*6 room size with 40 cm grid size, 3 dBm noise

6.1.2.2 Results for room size 12*12

In this room 3 different grid sizes are used. For grid size of 100 cm, the average error calculated is 4.297 m, maximum error is 18.4 m while minimum error is 0.402 m, as shown in Figure 6.13.

For grid size of 60 cm, the average error calculated is 4.437 m, maximum error is 19.835 m while minimum error is 0.235 m, as shown in Figure 6.14.

Figure 6.13: Results with est. n in 12*12 room size with 100 cm grid size, 3 dBm noise

Figure 6.14: Results with est. n in 12*12 room size with 60 cm grid size, 3 dBm noise

For grid size of 40 cm, the average error calculated is 4.926 m, maximum error is 35.55 m while minimum error is 0.078 m, as shown in Figure 6.15.

Figure 6.15: Results with est. *n* in 12*12 room size with 40 cm grid size, 3 dBm noise

6.1.2.3 Results for room size 18*18

In this room 3 different grid sizes are used. For grid size of 100 cm, the average error calculated is 6.572 m, maximum error is 43.503 m while minimum error is 0.379 m, as shown in Figure 6.16.

For grid size of 60 cm, the average error calculated is 7.154 m, maximum error is 59.639 m while minimum error is 0.278 m, as shown in Figure 6.17.

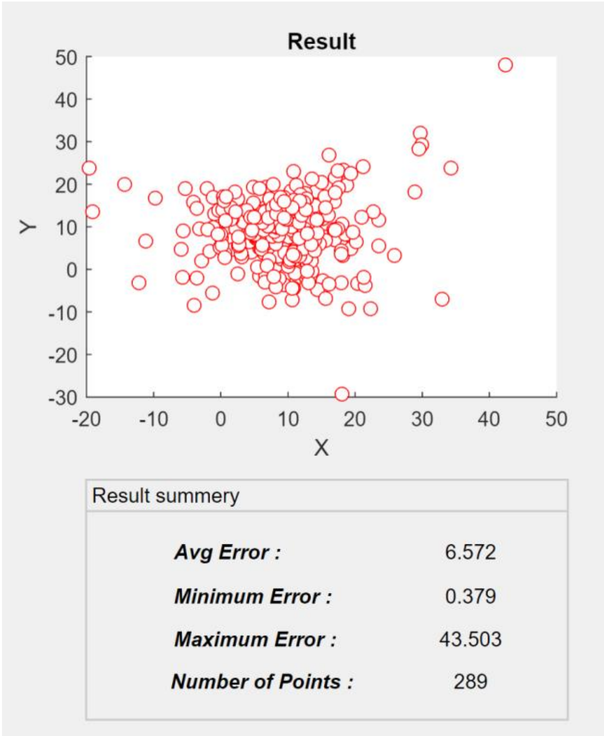

Figure 6.16: Results with est. n in 18*18 room size with 100 cm grid size, 3 dBm noise

Figure 6.17: Results with est. n in 18*18 room size with 60 cm grid size, 3 dBm noise

For grid size of 40 cm, the average error calculated is 7.501m, maximum error is 84.518 m while minimum error is 0.133 m, as shown in Figure 6.18.

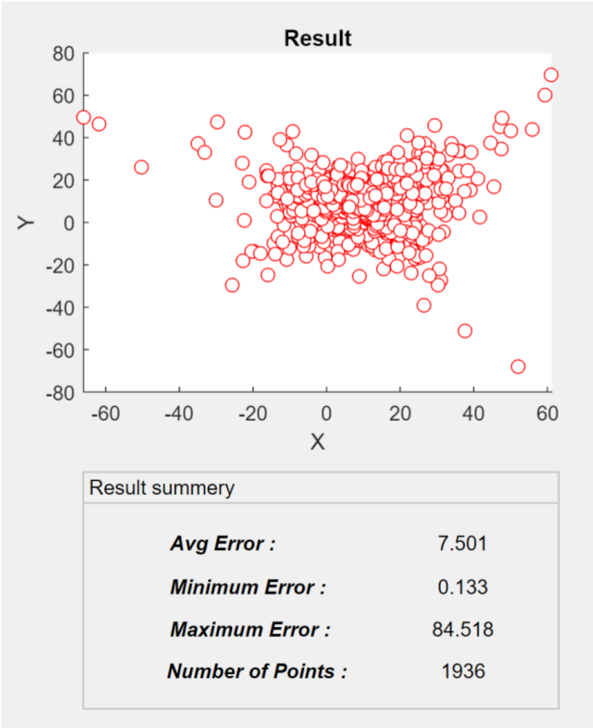

Figure 6.18: Results with est. n in 18*18 room size with 40 cm grid size, 3 dBm noise

7. THE SIMULATION RESULTS WITH LEAST SQUARES APPROXIMATION FOR RSS VALUE

In this thesis, for least squares lateration algorithm the estimators in Equations (3.27) and (3.28) are used for RSS value estimation. To do that a code in MATLAB was written and used.

When the code is run the equations explained in Section 3.3 applied to find the estimators m an b. Then these estimators used to estimate the RSS values. After that these values used to estimate location in the way described in Section 3.1. Then the average error is calculated.

The simulation has run for 3 different room sizes (6*6 m, 12*12 m and 18*18 m) with 3 different grid sizes (40 cm, 60 cm and 100 cm) in each room. In this chapter, the simulation results with least squares approximation for RSS value are presented.

7.1 Results for 6*6 Room size

7.1.1 Results with 40 cm grid size

For each access point the fitting line is calculated using Equation 3.19. The fitting line for $AP1$, $AP2$, $AP3$ and $AP4$ represented in Equations (7.1), (7.2), (7.3) and (7.4) respectively. The generated RSS values with distance are represented in Appendix A.1.

$$y_i = -51.88 - 2.32\ x_i \tag{7.1}$$

$$y_i = -51.81 - 2.34\ x_i \tag{7.2}$$

$$y_i = -51.29 - 2.45\ x_i \tag{7.3}$$

$$y_i = -51.58 - 2.39\ x_i \tag{7.4}$$

After estimating the location depending on the generated RSS values, the average error is calculated. The results shown in Table 7.1 as follows: average error is 0.575 m maximum error is 3.215 m while minimum error is 0.008 m.

Table 7.1: Estimated RSS value in 6*6 room size with 40 cm grid size

Average error (meter)	0.575
Maximum error (meter)	3.215
Minimum error (meter)	0.008

7.1.2 Results with 60 cm grid size

For each access point the fitting line is calculated using Equation 3.19. The fitting line for $AP1$, $AP2$, $AP3$ and $AP4$ are represented in Equations (7.5), (7.6), (7.7) and (7.8) respectively. The generated RSS values with distance are represented in Appendix A.2.

$$y_i = -51.618 - 2.37\, x_i \tag{7.5}$$

$$y_i = -51.26 - 2.44\, x_i \tag{7.6}$$

$$y_i = -51.99 - 2.27\, x_i \tag{7.7}$$

$$y_i = -52.13 - 2.24\, x_i \tag{7.8}$$

Based on the generated RSS values the location is estimated, and the average error is calculated. The results shown in Table 7.2 as follows: average error is 0.416 m maximum error is 2.472 m while minimum error is 0.011 m.

Table 7.2: Estimated RSS value in 6*6 room size with 60 cm grid size

Average error (meter)	0.416
Maximum error (meter)	2.472
Minimum error (meter)	0.011

7.1.3 Results with 100 cm grid size

For each access point the fitting line is calculated using Equation 3.19. The fitting line for $AP1$, $AP2$, $AP3$ and $AP4$ are represented in Equations (7.9), (7.10), (7.11) and (7.12) respectively. The generated RSS values with distance are represented in Appendix A.3.

$$y_i = -52.47 - 2.22\, x_i \tag{7.9}$$

$$y_i = -52.16 - 2.29\, x_i \tag{7.10}$$

$$y_i = -52.71 - 2.17\, x_i \tag{7.11}$$

$$y_i = -52.23 - 2.28\, x_i \tag{7.12}$$

After estimating the location depending on the generated RSS values, the average error is calculated, and the results are shown in Table 7.3 as follows: average error is 0.297 m the maximum error is 1.166 m while the minimum error is 0.0 m.

Table 7.3: Estimated RSS value in 6*6 room size with 100 cm grid size

Average error (meter)	0.297
Maximum error (meter)	1.166
Minimum error (meter)	0.0

7.2 Results for 12*12 Room size

7.2.1 Results with 40 cm grid size

The fitting line for $AP1$, $AP2$, $AP3$ and $AP4$ are represented in Equations (7.13), (7.14), (7.15) and (7.16) respectively. These fitting lines are calculated for each access point using Equation 3.19.

$$y_i = -57.37 - 1.21\, x_i \tag{7.13}$$

$$y_i = -57.38 - 1.21\, x_i \tag{7.14}$$

$$y_i = -57.29 - 1.22\, x_i \tag{7.15}$$

$$y_i = -57.34 - 1.21\, x_i \tag{7.16}$$

After estimating the location depending on the generated RSS values, the average error is calculated, and the results are shown in Table 7.4 as follows: average error is 1.46 m maximum error is 10.129 m while minimum error is 0.002 m.

Table 7.4: Estimated RSS value in 12*12 room size with 40 cm grid size

Average error (meter)	1.46
Maximum error (meter)	10.034
Minimum error (meter)	0.002

7.2.2 Results with 60 cm grid size

For each access point the fitting line is calculated using Equation 3.19. The fitting line for $AP1$, $AP2$, $AP3$ and $AP4$ are represented in Equations (7.17), (7.18), (7.19) and (7.20) respectively.

$$y_i = -57.99 - 1.15\, x_i \tag{7.17}$$

$$y_i = -57.57 - 1.2\, x_i \tag{7.18}$$

$$y_i = -57.58 - 1.19\, x_i \tag{7.19}$$

$$y_i = -57.47 - 1.21\, x_i \tag{7.20}$$

After estimating the location depending on the generated RSS values, the average error is calculated, and the results are shown in Table 7.5 as follows: average error is 1.27 m maximum error is 7.075 m while minimum error is 0.004 m.

Table 7.5: Estimated RSS value in 12*12 room size with 60 cm grid size

Average error (meter)	1.27
Maximum error (meter)	7.075
Minimum error (meter)	0.004

7.2.3 Results with 100 cm grid size

For each access point the fitting line is calculated using Equation 3.19. The fitting line for $AP1$, $AP2$, $AP3$ and $AP4$ are represented in Equations (7.21), (7.22), (7.23) and (7.24) respectively. The generated RSS values with distance are represented in Appendix A.4.

$$y_i = -58.13 - 1.16\, x_i \tag{7.21}$$

$$y_i = -58.23 - 1.15\, x_i \tag{7.22}$$

$$y_i = -58.21 - 1.15\, x_i \tag{7.23}$$

$$y_i = -57.7 - 1.2 x_i \tag{7.24}$$

After estimating the location depending on the generated RSS values, the average error is calculated, and the results are shown in Table 7.6 as follows: average error is 1.24 m maximum error is 6.34 m while minimum error is 0.009 m.

Table 7.6: Estimated RSS value in 12*12 room size with 100 cm grid size

Average error (meter)	1.24
Maximum error (meter)	6.34
Minimum error (meter)	0.009

7.3 Results for 18*18 Room size

7.3.1 Results with 40 cm grid size

For each access point the fitting line is calculated using Equation 3.19. The fitting line for $AP1$, $AP2$, $AP3$ and $AP4$ are represented in Equations (7.25), (7.26), (7.27) and (7.28) respectively.

$$y_i = -61.03 - 0.802\, x_i \tag{7.25}$$

$$y_i = -61 - 0.804\, x_i \tag{7.26}$$

$$y_i = -61.02 - 0.802\, x_i \tag{7.27}$$

$$y_i = -61.01 - 0.803\, x_i \tag{7.28}$$

After estimating the location depending on the generated RSS values, the average error is calculated, and the results are shown in Table 7.7 as follows: average error is 2.17 m the maximum error is 15.26 m while the minimum error is 0.003 m.

Table 7.7: Estimated RSS value in 18*18 room size with 40 cm grid size

Average error (meter)	2.17
Maximum error (meter)	15.26
Minimum error (meter)	0.003

7.3.2 Results with 60 cm grid size

For each access point the fitting line is calculated using Equation 3.19. The fitting line for $AP1$, $AP2$, $AP3$ and $AP4$ are represented in Equations (7.29), (7.30), (7.31) and (7.32) respectively.

$$y_i = -61 - 0.81\, x_i \tag{7.29}$$

$$y_i = -61.24 - 0.79\, x_i \tag{7.30}$$

$$y_i = -61.2 - 0.8\, x_i \tag{7.31}$$

$$y_i = -60.9 - 0.81\, x_i \tag{7.32}$$

After estimating the location depending on the generated RSS values, the average error is calculated, and the results are shown in Table 7.8 as follows: average error is 2.29 m maximum error is 15.34 m while minimum error is 0.007 m.

Table 7.8: Estimated RSS value in 18*18 room size with 60 cm grid size

Average error (meter)	2.29
Maximum error (meter)	15.34
Minimum error (meter)	0.007

7.3.3 Results with 100 cm grid size

For each access point the fitting line is calculated using Equation 3.19. The fitting line for $AP1$, $AP2$, $AP3$ and $AP4$ are represented in Equations (7.33), (7.34), (7.35) and (7.36) respectively. The generated RSS values with distance are represented in Appendix A.5.

$$y_i = -61.47 - 0.77\, x_i \tag{7.33}$$

$$y_i = -61.36 - 0.78\, x_i \tag{7.34}$$

$$y_i = -60.97 - 8\, x_i \tag{7.35}$$

$$y_i = -61.19 - 0.79\, x_i \tag{7.36}$$

After estimating the location depending on the generated RSS values, the average error is calculated, and the results are shown in Table 7.9 as follows: average error is 1.73 m maximum error is 10.29 m while minimum error is 0.005 m.

Table 7.9: Estimated RSS value in 6*6 room size with 100 cm grid size

Average error (meter)	1.73
Maximum error (meter)	10.29
Minimum error (meter)	0.005

8. CONCLUSION

Many algorithms are used in indoor positioning systems. For this thesis the performance of the RSS-based least squares lateration algorithm was evaluated because it provides acceptable accurate localization within one room. Beside it can be implemented widely at low cost since it uses mobile phones and the existing infrastructure of access points in indoor environments. In this thesis, the performance of this algorithm was tested under different conditions.

A simulation was designed for this thesis to test the algorithm performance. This simulation has been run in 3 different cases. For the first case the simulation run with knowledge of n value in Chapter 5. For the second case, n value was estimated in Chapter 6. For the third case the least squares approximation used to estimate the RSS values in Chapter 7. In each case the average error, maximum error and minimum error recorded. Table 9.1 summarize the results for the 3 cases under the same conditions. The results are shown in Table 9.1 were measured using 1 dBm noise.

When these results analyzed, the best results found in a room of size 6*6 using the least squares approximation. With 1 dBm noise most of the measurements resulted with an average error of less than 2 meters which indicate a good performance of the algorithm in the three simulation cases.

Additionally, in this thesis the impact of different parameters on the average error was tested. It was found that when the noise level and room size increased the average error increased. While when the path loss exponent increased the average error decreased. Whereas the grid size has a little impact on the average error.

Table 8.1: Results for the 3-cases simulation

Simulation Case	Room size (m)	Grid size (cm)	**Avg. Error (m)**	**Max. Error (m)**	**Min. Error (m)**
Known n	6*6	40 cm	0.603	2.405	0.036
		60 cm	0.679	2.058	0.108
		100 cm	0.712	1.632	0.078
	12*12	40 cm	1.295	8.407	0.065
		60 cm	1.231	7.504	0.027
		100 cm	1.3	5.36	0.056
	18*18	40 cm	1.872	7.731	0.035
		60 cm	1.846	9.602	0.037
		100 cm	1.875	9.08	0.111
Est. n	6*6	40 cm	0.672	1.799	0.043
		60 cm	0.648	1.94	0.046
		100 cm	0.671	1.384	0.164
	12*12	40 cm	1.344	9.066	0.027
		60 cm	1.406	6.507	0.033
		100 cm	1.179	3.194	0.076
	18*18	40 cm	2.059	9.251	0.009
		60 cm	2.151	9.303	0.109
		100 cm	2.038	8.22	0.156
Est. RSS	6*6	40 cm	0.575	3.215	0.008
		60 cm	0.416	2.472	0.011
		100 cm	0.297	1.166	0.0
	12*12	40 cm	1.46	10.034	0.002
		60 cm	1.27	7.075	0.004
		100 cm	1.24	6.34	0.009
	18*18	40 cm	2.17	15.26	0.003
		60 cm	2.29	15.34	0.007
		100 cm	1.73	10.29	0.005

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APPENDIX A: ESTIMATED RSS VALUES

A.1 Estimated RSS Values for Room Size 6*6 With 40 Cm Grid Size

Distance	RSS for AP1	Distance	RSS for AP2	Distance	RSS for AP3	Distance	RSS for AP4
0.565685	-53.1924	5.614268	-64.935	7.919596	-70.7084	5.614268	-64.9893
0.894427	-53.9559	5.656854	-65.0346	7.641989	-70.0278	5.215362	-64.0364
1.264911	-54.8165	5.727128	-65.1989	7.375636	-69.3748	4.816638	-63.084
1.649242	-55.7091	5.824088	-65.4256	7.121798	-68.7525	4.418144	-62.1321
2.039608	-56.6158	5.946427	-65.7116	6.88186	-68.1642	4.01995	-61.181
2.433105	-57.5298	6.092618	-66.0534	6.657327	-67.6138	3.622154	-60.2308
2.828427	-58.448	6.26099	-66.4471	6.449806	-67.105	3.224903	-59.2819
3.224903	-59.3689	6.449806	-66.8885	6.26099	-66.6421	2.828427	-58.3348
3.622154	-60.2916	6.657327	-67.3737	6.092618	-66.2293	2.433105	-57.3905
4.01995	-61.2156	6.88186	-67.8986	5.946427	-65.8709	2.039608	-56.4506
4.418144	-62.1405	7.121798	-68.4596	5.824088	-65.571	1.649242	-55.5182
4.816638	-63.066	7.375636	-69.0531	5.727128	-65.3333	1.264911	-54.6001
5.215362	-63.9922	7.641989	-69.6758	5.656854	-65.161	0.894427	-53.7151
5.614268	-64.9187	7.919596	-70.3248	5.614268	-65.0566	0.565685	-52.9299
0.894427	-53.9559	5.215362	-64.0024	7.641989	-70.0278	5.656854	-65.091
1.131371	-54.5063	5.261179	-64.1095	7.353911	-69.3215	5.261179	-64.1459
1.442221	-55.2283	5.336666	-64.286	7.076722	-68.642	4.86621	-63.2024
1.788854	-56.0334	5.440588	-64.529	6.811755	-67.9924	4.472136	-62.2611
2.154066	-56.8817	5.571355	-64.8347	6.560488	-67.3764	4.079216	-61.3226
2.529822	-57.7545	5.727128	-65.1989	6.324555	-66.798	3.687818	-60.3876
2.912044	-58.6422	5.905929	-65.6169	6.105735	-66.2615	3.298485	-59.4576
3.298485	-59.5398	6.105735	-66.0841	5.905929	-65.7717	2.912044	-58.5346
3.687818	-60.4441	6.324555	-66.5957	5.727128	-65.3333	2.529822	-57.6216
4.079216	-61.3532	6.560488	-67.1473	5.571355	-64.9514	2.154066	-56.724
4.472136	-62.2659	6.811755	-67.7347	5.440588	-64.6308	1.788854	-55.8516
4.86621	-63.1812	7.076722	-68.3542	5.336666	-64.3761	1.442221	-55.0236
5.261179	-64.0986	7.353911	-69.0023	5.261179	-64.191	1.131371	-54.2811
5.656854	-65.0176	7.641989	-69.6758	5.215362	-64.0787	0.894427	-53.7151
1.264911	-54.8165	4.816638	-63.0702	7.375636	-69.3748	5.727128	-65.2589
1.442221	-55.2283	4.86621	-63.1861	7.076722	-68.642	5.336666	-64.3262
1.697056	-55.8202	4.947727	-63.3767	6.788225	-67.9347	4.947727	-63.3971
2	-56.5238	5.059644	-63.6383	6.511528	-67.2563	4.560702	-62.4727
2.332381	-57.2959	5.2	-63.9665	6.2482	-66.6108	4.176123	-61.554
2.683282	-58.1109	5.366563	-64.3559	6	-66.0023	3.794733	-60.643
3.046309	-58.9541	5.556978	-64.8011	5.768882	-65.4357	3.417601	-59.7422
3.417601	-59.8165	5.768882	-65.2965	5.556978	-64.9162	3.046309	-58.8553
3.794733	-60.6925	6	-65.8369	5.366563	-64.4493	2.683282	-57.9881
4.176123	-61.5783	6.2482	-66.4172	5.2	-64.041	2.332381	-57.1499
4.560702	-62.4716	6.511528	-67.0328	5.059644	-63.6969	2	-56.356
4.947727	-63.3705	6.788225	-67.6797	4.947727	-63.4225	1.697056	-55.6324

5.336666	-64.2739	7.076722	-68.3542	4.86621	-63.2227	1.442221	-55.0236
5.727128	-65.1808	7.375636	-69.0531	4.816638	-63.1012	1.264911	-54.6001
1.649242	-55.7091	4.418144	-62.1385	7.121798	-68.7525	5.824088	-65.4905
1.788854	-56.0334	4.472136	-62.2648	6.811755	-67.9924	5.440588	-64.5744
2	-56.5238	4.560702	-62.4718	6.511528	-67.2563	5.059644	-63.6645
2.262742	-57.1341	4.68188	-62.7551	6.22254	-66.5479	4.68188	-62.7621
2.56125	-57.8275	4.833218	-63.109	5.946427	-65.8709	4.308132	-61.8694
2.884441	-58.5781	5.011986	-63.5269	5.685068	-65.2302	3.939543	-60.9889
3.224903	-59.3689	5.215362	-64.0024	5.440588	-64.6308	3.577709	-60.1246
3.577709	-60.1884	5.440588	-64.529	5.215362	-64.0787	3.224903	-59.2819
3.939543	-61.0288	5.685068	-65.1006	5.011986	-63.5801	2.884441	-58.4686
4.308132	-61.8849	5.946427	-65.7116	4.833218	-63.1418	2.56125	-57.6966
4.68188	-62.753	6.22254	-66.3572	4.68188	-62.7708	2.262742	-56.9836
5.059644	-63.6305	6.511528	-67.0328	4.560702	-62.4737	2	-56.356
5.440588	-64.5153	6.811755	-67.7347	4.472136	-62.2566	1.788854	-55.8516
5.824088	-65.406	7.121798	-68.4596	4.418144	-62.1242	1.649242	-55.5182
2.039608	-56.6158	4.01995	-61.2076	6.88186	-68.1642	5.946427	-65.7827
2.154066	-56.8817	4.079216	-61.3461	6.560488	-67.3764	5.571355	-64.8868
2.332381	-57.2959	4.176123	-61.5727	6.2482	-66.6108	5.2	-63.9997
2.56125	-57.8275	4.308132	-61.8813	5.946427	-65.8709	4.833218	-63.1236
2.828427	-58.448	4.472136	-62.2648	5.656854	-65.161	4.472136	-62.2611
3.1241	-59.1348	4.664762	-62.7151	5.38145	-64.4858	4.118252	-61.4158
3.44093	-59.8707	4.882622	-63.2245	5.122499	-63.851	3.773592	-60.5925
3.773592	-60.6434	5.122499	-63.7853	4.882622	-63.2629	3.44093	-59.7979
4.118252	-61.4439	5.38145	-64.3907	4.664762	-62.7288	3.1241	-59.0411
4.472136	-62.2659	5.656854	-65.0346	4.472136	-62.2566	2.828427	-58.3348
4.833218	-63.1046	5.946427	-65.7116	4.308132	-61.8545	2.56125	-57.6966
5.2	-63.9565	6.2482	-66.4172	4.176123	-61.5309	2.332381	-57.1499
5.571355	-64.819	6.560488	-67.1473	4.079216	-61.2933	2.154066	-56.724
5.946427	-65.6902	6.88186	-67.8986	4.01995	-61.148	2.039608	-56.4506
2.433105	-57.5298	3.622154	-60.2775	6.657327	-67.6138	6.092618	-66.1319
2.529822	-57.7545	3.687818	-60.431	6.324555	-66.798	5.727128	-65.2589
2.683282	-58.1109	3.794733	-60.681	6	-66.0023	5.366563	-64.3976
2.884441	-58.5781	3.939543	-61.0196	5.685068	-65.2302	5.011986	-63.5506
3.1241	-59.1348	4.118252	-61.4374	5.38145	-64.4858	4.664762	-62.7212
3.394113	-59.7619	4.326662	-61.9246	5.091169	-63.7742	4.326662	-61.9136
3.687818	-60.4441	4.560702	-62.4718	4.816638	-63.1012	4	-61.1333
4	-61.1692	4.816638	-63.0702	4.560702	-62.4737	3.687818	-60.3876
4.326662	-61.928	5.091169	-63.712	4.326662	-61.8999	3.394113	-59.6861
4.664762	-62.7133	5.38145	-64.3907	4.118252	-61.389	3.1241	-59.0411
5.011986	-63.5198	5.685068	-65.1006	3.939543	-60.9509	2.884441	-58.4686
5.366563	-64.3433	6	-65.8369	3.794733	-60.5959	2.683282	-57.9881
5.727128	-65.1808	6.324555	-66.5957	3.687818	-60.3337	2.529822	-57.6216
6.092618	-66.0298	6.657327	-67.3737	3.622154	-60.1728	2.433105	-57.3905
2.828427	-58.448	3.224903	-59.3488	6.449806	-67.105	6.26099	-66.5341
2.912044	-58.6422	3.298485	-59.5208	6.105735	-66.2615	5.905929	-65.686
3.046309	-58.9541	3.417601	-59.7993	5.768882	-65.4357	5.556978	-64.8524
3.224903	-59.3689	3.577709	-60.1736	5.440588	-64.6308	5.215362	-64.0364
3.44093	-59.8707	3.773592	-60.6316	5.122499	-63.851	4.882622	-63.2416

3.687818	-60.4441	4	-61.1609	4.816638	-63.1012	4.560702	-62.4727
3.959798	-61.0759	4.252058	-61.7502	4.525483	-62.3874	4.252058	-61.7354
4.252058	-61.7547	4.525483	-62.3895	4.252058	-61.717	3.959798	-61.0373
4.560702	-62.4716	4.816638	-63.0702	4	-61.0991	3.687818	-60.3876
4.882622	-63.2193	5.122499	-63.7853	3.773592	-60.544	3.44093	-59.7979
5.215362	-63.9922	5.440588	-64.529	3.577709	-60.0638	3.224903	-59.2819
5.556978	-64.7856	5.768882	-65.2965	3.417601	-59.6713	3.046309	-58.8553
5.905929	-65.5961	6.105735	-66.0841	3.298485	-59.3793	2.912044	-58.5346
6.26099	-66.4208	6.449806	-66.8885	3.224903	-59.1989	2.828427	-58.3348
3.224903	-59.3689	2.828427	-58.4218	6.26099	-66.6421	6.449806	-66.9851
3.298485	-59.5398	2.912044	-58.6173	5.905929	-65.7717	6.105735	-66.1632
3.417601	-59.8165	3.046309	-58.9312	5.556978	-64.9162	5.768882	-65.3586
3.577709	-60.1884	3.224903	-59.3488	5.215362	-64.0787	5.440588	-64.5744
3.773592	-60.6434	3.44093	-59.8538	4.882622	-63.2629	5.122499	-63.8146
4	-61.1692	3.687818	-60.431	4.560702	-62.4737	4.816638	-63.084
4.252058	-61.7547	3.959798	-61.0669	4.252058	-61.717	4.525483	-62.3885
4.525483	-62.3898	4.252058	-61.7502	3.959798	-61.0005	4.252058	-61.7354
4.816638	-63.066	4.560702	-62.4718	3.687818	-60.3337	4	-61.1333
5.122499	-63.7765	4.882622	-63.2245	3.44093	-59.7285	3.773592	-60.5925
5.440588	-64.5153	5.215362	-64.0024	3.224903	-59.1989	3.577709	-60.1246
5.768882	-65.2778	5.556978	-64.8011	3.046309	-58.761	3.417601	-59.7422
6.105735	-66.0602	5.905929	-65.6169	2.912044	-58.4319	3.298485	-59.4576
6.449806	-66.8594	6.26099	-66.4471	2.828427	-58.2269	3.224903	-59.2819
3.622154	-60.2916	2.433105	-57.4976	6.092618	-66.2293	6.657327	-67.4808
3.687818	-60.4441	2.529822	-57.7237	5.727128	-65.3333	6.324555	-66.6859
3.794733	-60.6925	2.683282	-58.0825	5.366563	-64.4493	6	-65.9107
3.939543	-61.0288	2.884441	-58.5528	5.011986	-63.5801	5.685068	-65.1584
4.118252	-61.4439	3.1241	-59.1131	4.664762	-62.7288	5.38145	-64.4332
4.326662	-61.928	3.394113	-59.7444	4.326662	-61.8999	5.091169	-63.7398
4.560702	-62.4716	3.687818	-60.431	4	-61.0991	4.816638	-63.084
4.816638	-63.066	4	-61.1609	3.687818	-60.3337	4.560702	-62.4727
5.091169	-63.7037	4.326662	-61.9246	3.394113	-59.6137	4.326662	-61.9136
5.38145	-64.3779	4.664762	-62.7151	3.1241	-58.9517	4.118252	-61.4158
5.685068	-65.0831	5.011986	-63.5269	2.884441	-58.3642	3.939543	-60.9889
6	-65.8146	5.366563	-64.3559	2.683282	-57.871	3.794733	-60.643
6.324555	-66.5685	5.727128	-65.1989	2.529822	-57.4948	3.687818	-60.3876
6.657327	-67.3414	6.092618	-66.0534	2.433105	-57.2577	3.622154	-60.2308
4.01995	-61.2156	2.039608	-56.5776	5.946427	-65.8709	6.88186	-68.0171
4.079216	-61.3532	2.154066	-56.8452	5.571355	-64.9514	6.560488	-67.2495
4.176123	-61.5783	2.332381	-57.2621	5.2	-64.041	6.2482	-66.5035
4.308132	-61.8849	2.56125	-57.7972	4.833218	-63.1418	5.946427	-65.7827
4.472136	-62.2659	2.828427	-58.4218	4.472136	-62.2566	5.656854	-65.091
4.664762	-62.7133	3.1241	-59.1131	4.118252	-61.389	5.38145	-64.4332
4.882622	-63.2193	3.44093	-59.8538	3.773592	-60.544	5.122499	-63.8146
5.122499	-63.7765	3.773592	-60.6316	3.44093	-59.7285	4.882622	-63.2416
5.38145	-64.3779	4.118252	-61.4374	3.1241	-58.9517	4.664762	-62.7212
5.656854	-65.0176	4.472136	-62.2648	2.828427	-58.2269	4.472136	-62.2611
5.946427	-65.6902	4.833218	-63.109	2.56125	-57.5718	4.308132	-61.8694
6.2482	-66.3911	5.2	-63.9665	2.332381	-57.0108	4.176123	-61.554

6.560488	-67.1165	5.571355	-64.8347	2.154066	-56.5736	4.079216	-61.3226
6.88186	-67.8629	5.946427	-65.7116	2.039608	-56.293	4.01995	-61.181
4.418144	-62.1405	1.649242	-55.6649	5.824088	-65.571	7.121798	-68.5903
4.472136	-62.2659	1.788854	-55.9913	5.440588	-64.6308	6.811755	-67.8497
4.560702	-62.4716	2	-56.485	5.059644	-63.6969	6.511528	-67.1325
4.68188	-62.753	2.262742	-57.0993	4.68188	-62.7708	6.22254	-66.4422
4.833218	-63.1046	2.56125	-57.7972	4.308132	-61.8545	5.946427	-65.7827
5.011986	-63.5198	2.884441	-58.5528	3.939543	-60.9509	5.685068	-65.1584
5.215362	-63.9922	3.224903	-59.3488	3.577709	-60.0638	5.440588	-64.5744
5.440588	-64.5153	3.577709	-60.1736	3.224903	-59.1989	5.215362	-64.0364
5.685068	-65.0831	3.939543	-61.0196	2.884441	-58.3642	5.011986	-63.5506
5.946427	-65.6902	4.308132	-61.8813	2.56125	-57.5718	4.833218	-63.1236
6.22254	-66.3315	4.68188	-62.7551	2.262742	-56.84	4.68188	-62.7621
6.511528	-67.0028	5.059644	-63.6383	2	-56.1959	4.560702	-62.4727
6.811755	-67.7001	5.440588	-64.529	1.788854	-55.6782	4.472136	-62.2611
7.121798	-68.4202	5.824088	-65.4256	1.649242	-55.336	4.418144	-62.1321
4.816638	-63.066	1.264911	-54.7664	5.727128	-65.3333	7.375636	-69.1966
4.86621	-63.1812	1.442221	-55.1809	5.336666	-64.3761	7.076722	-68.4826
4.947727	-63.3705	1.697056	-55.7767	4.947727	-63.4225	6.788225	-67.7935
5.059644	-63.6305	2	-56.485	4.560702	-62.4737	6.511528	-67.1325
5.2	-63.9565	2.332381	-57.2621	4.176123	-61.5309	6.2482	-66.5035
5.366563	-64.3433	2.683282	-58.0825	3.794733	-60.5959	6	-65.9107
5.556978	-64.7856	3.046309	-58.9312	3.417601	-59.6713	5.768882	-65.3586
5.768882	-65.2778	3.417601	-59.7993	3.046309	-58.761	5.556978	-64.8524
6	-65.8146	3.794733	-60.681	2.683282	-57.871	5.366563	-64.3976
6.2482	-66.3911	4.176123	-61.5727	2.332381	-57.0108	5.2	-63.9997
6.511528	-67.0028	4.560702	-62.4718	2	-56.1959	5.059644	-63.6645
6.788225	-67.6454	4.947727	-63.3767	1.697056	-55.4532	4.947727	-63.3971
7.076722	-68.3155	5.336666	-64.286	1.442221	-54.8284	4.86621	-63.2024
7.375636	-69.0098	5.727128	-65.1989	1.264911	-54.3937	4.816638	-63.084
5.215362	-63.9922	0.894427	-53.9002	5.656854	-65.161	7.641989	-69.8328
5.261179	-64.0986	1.131371	-54.4541	5.261179	-64.191	7.353911	-69.1447
5.336666	-64.2739	1.442221	-55.1809	4.86621	-63.2227	7.076722	-68.4826
5.440588	-64.5153	1.788854	-55.9913	4.472136	-62.2566	6.811755	-67.8497
5.571355	-64.819	2.154066	-56.8452	4.079216	-61.2933	6.560488	-67.2495
5.727128	-65.1808	2.529822	-57.7237	3.687818	-60.3337	6.324555	-66.6859
5.905929	-65.5961	2.912044	-58.6173	3.298485	-59.3793	6.105735	-66.1632
6.105735	-66.0602	3.298485	-59.5208	2.912044	-58.4319	5.905929	-65.686
6.324555	-66.5685	3.687818	-60.431	2.529822	-57.4948	5.727128	-65.2589
6.560488	-67.1165	4.079216	-61.3461	2.154066	-56.5736	5.571355	-64.8868
6.811755	-67.7001	4.472136	-62.2648	1.788854	-55.6782	5.440588	-64.5744
7.076722	-68.3155	4.86621	-63.1861	1.442221	-54.8284	5.336666	-64.3262
7.353911	-68.9594	5.261179	-64.1095	1.131371	-54.0664	5.261179	-64.1459
7.641989	-69.6285	5.656854	-65.0346	0.894427	-53.4855	5.215362	-64.0364
5.614268	-64.9187	0.565685	-53.1316	5.614268	-65.0566	7.919596	-70.4959
5.656854	-65.0176	0.894427	-53.9002	5.215362	-64.0787	7.641989	-69.8328
5.727128	-65.1808	1.264911	-54.7664	4.816638	-63.1012	7.375636	-69.1966
5.824088	-65.406	1.649242	-55.6649	4.418144	-62.1242	7.121798	-68.5903
5.946427	-65.6902	2.039608	-56.5776	4.01995	-61.148	6.88186	-68.0171

6.092618	-66.0298	2.433105	-57.4976	3.622154	-60.1728	6.657327	-67.4808
6.26099	-66.4208	2.828427	-58.4218	3.224903	-59.1989	6.449806	-66.9851
6.449806	-66.8594	3.224903	-59.3488	2.828427	-58.2269	6.26099	-66.5341
6.657327	-67.3414	3.622154	-60.2775	2.433105	-57.2577	6.092618	-66.1319
6.88186	-67.8629	4.01995	-61.2076	2.039608	-56.293	5.946427	-65.7827
7.121798	-68.4202	4.418144	-62.1385	1.649242	-55.336	5.824088	-65.4905
7.375636	-69.0098	4.816638	-63.0702	1.264911	-54.3937	5.727128	-65.2589
7.641989	-69.6285	5.215362	-64.0024	0.894427	-53.4855	5.656854	-65.091
7.919596	-70.2733	5.614268	-64.935	0.565685	-52.6795	5.614268	-64.9893

A.2 Estimated RSS Values for Room Size 6*6 With 60 Cm Grid Size

Distance	RSS for AP1	Distance	RSS for AP2	Distance	RSS for AP3	Distance	RSS for AP4
0.848528	-53.6177	5.433231	-64.4987	7.636753	-69.3559	5.433231	-64.3181
1.341641	-54.7797	5.531727	-64.7391	7.224957	-68.4196	4.837355	-62.9814
1.897367	-56.0892	5.6921	-65.1306	6.841053	-67.5467	4.242641	-61.6472
2.473863	-57.4477	5.909315	-65.6609	6.489992	-66.7485	3.649658	-60.317
3.059412	-58.8275	6.177378	-66.3153	6.177378	-66.0378	3.059412	-58.9929
3.649658	-60.2184	6.489992	-67.0785	5.909315	-65.4283	2.473863	-57.6793
4.242641	-61.6158	6.841053	-67.9355	5.6921	-64.9344	1.897367	-56.3861
4.837355	-63.0172	7.224957	-68.8727	5.531727	-64.5698	1.341641	-55.1394
5.433231	-64.4214	7.636753	-69.878	5.433231	-64.3458	0.848528	-54.0332
1.341641	-54.7797	4.837355	-63.044	7.224957	-68.4196	5.531727	-64.5391
1.697056	-55.6172	4.947727	-63.3135	6.788225	-67.4266	4.947727	-63.229
2.163331	-56.716	5.126402	-63.7497	6.378087	-66.4941	4.368066	-61.9286
2.683282	-57.9412	5.366563	-64.3359	6	-65.6345	3.794733	-60.6425
3.231099	-59.2321	5.660389	-65.0532	5.660389	-64.8623	3.231099	-59.378
3.794733	-60.5603	6	-65.8823	5.366563	-64.1942	2.683282	-58.1491
4.368066	-61.9113	6.378087	-66.8053	5.126402	-63.6482	2.163331	-56.9827
4.947727	-63.2773	6.788225	-67.8065	4.947727	-63.2419	1.697056	-55.9367
5.531727	-64.6535	7.224957	-68.8727	4.837355	-62.991	1.341641	-55.1394
1.897367	-56.0892	4.242641	-61.5922	6.841053	-67.5467	5.6921	-64.8988
2.163331	-56.716	4.368066	-61.8984	6.378087	-66.4941	5.126402	-63.6298
2.545584	-57.6167	4.569464	-62.39	5.939697	-65.4974	4.569464	-62.3804
3	-58.6875	4.837355	-63.044	5.531727	-64.5698	4.024922	-61.1588
3.498571	-59.8624	5.161395	-63.8351	5.161395	-63.7278	3.498571	-59.9781
4.024922	-61.1027	5.531727	-64.7391	4.837355	-62.991	3	-58.8596
4.569464	-62.3859	5.939697	-65.7351	4.569464	-62.3819	2.545584	-57.8402
5.126402	-63.6983	6.378087	-66.8053	4.368066	-61.924	2.163331	-56.9827
5.6921	-65.0314	6.841053	-67.9355	4.242641	-61.6388	1.897367	-56.3861
2.473863	-57.4477	3.649658	-60.1446	6.489992	-66.7485	5.909315	-65.3861
2.683282	-57.9412	3.794733	-60.4988	6	-65.6345	5.366563	-64.1686
3	-58.6875	4.024922	-61.0607	5.531727	-64.5698	4.837355	-62.9814
3.394113	-59.6163	4.326662	-61.7973	5.091169	-63.5681	4.326662	-61.8357
3.841875	-60.6714	4.68615	-62.6749	4.68615	-62.6472	3.841875	-60.7482
4.326662	-61.8138	5.091169	-63.6636	4.326662	-61.8298	3.394113	-59.7437
4.837355	-63.0172	5.531727	-64.7391	4.024922	-61.1438	3	-58.8596

5.366563	-64.2643	6	-65.8823	3.794733	-60.6204	2.683282	-58.1491
5.909315	-65.5432	6.489992	-67.0785	3.649658	-60.2906	2.473863	-57.6793
3.059412	-58.8275	3.059412	-58.7037	6.177378	-66.0378	6.177378	-65.9875
3.231099	-59.2321	3.231099	-59.1228	5.660389	-64.8623	5.660389	-64.8277
3.498571	-59.8624	3.498571	-59.7758	5.161395	-63.7278	5.161395	-63.7083
3.841875	-60.6714	3.841875	-60.6138	4.68615	-62.6472	4.68615	-62.6422
4.242641	-61.6158	4.242641	-61.5922	4.242641	-61.6388	4.242641	-61.6472
4.68615	-62.6609	4.68615	-62.6749	3.841875	-60.7276	3.841875	-60.7482
5.161395	-63.7808	5.161395	-63.8351	3.498571	-59.947	3.498571	-59.9781
5.660389	-64.9566	5.660389	-65.0532	3.231099	-59.3389	3.231099	-59.378
6.177378	-66.1749	6.177378	-66.3153	3.059412	-58.9485	3.059412	-58.9929
3.649658	-60.2184	2.473863	-57.2742	5.909315	-65.4283	6.489992	-66.6888
3.794733	-60.5603	2.683282	-57.7855	5.366563	-64.1942	6	-65.5896
4.024922	-61.1027	3	-58.5587	4.837355	-62.991	5.531727	-64.5391
4.326662	-61.8138	3.394113	-59.5208	4.326662	-61.8298	5.091169	-63.5508
4.68615	-62.6609	3.841875	-60.6138	3.841875	-60.7276	4.68615	-62.6422
5.091169	-63.6153	4.326662	-61.7973	3.394113	-59.7095	4.326662	-61.8357
5.531727	-64.6535	4.837355	-63.044	3	-58.8134	4.024922	-61.1588
6	-65.7569	5.366563	-64.3359	2.683282	-58.0933	3.794733	-60.6425
6.489992	-66.9116	5.909315	-65.6609	2.473863	-57.6172	3.649658	-60.317
4.242641	-61.6158	1.897367	-55.8669	5.6921	-64.9344	6.841053	-67.4763
4.368066	-61.9113	2.163331	-56.5162	5.126402	-63.6482	6.378087	-66.4377
4.569464	-62.3859	2.545584	-57.4493	4.569464	-62.3819	5.939697	-65.4543
4.837355	-63.0172	3	-58.5587	4.024922	-61.1438	5.531727	-64.5391
5.161395	-63.7808	3.498571	-59.7758	3.498571	-59.947	5.161395	-63.7083
5.531727	-64.6535	4.024922	-61.0607	3	-58.8134	4.837355	-62.9814
5.939697	-65.6148	4.569464	-62.39	2.545584	-57.7803	4.569464	-62.3804
6.378087	-66.6479	5.126402	-63.7497	2.163331	-56.9111	4.368066	-61.9286
6.841053	-67.7388	5.6921	-65.1306	1.897367	-56.3064	4.242641	-61.6472
4.837355	-63.0172	1.341641	-54.5102	5.531727	-64.5698	7.224957	-68.3375
4.947727	-63.2773	1.697056	-55.3779	4.947727	-63.2419	6.788225	-67.3578
5.126402	-63.6983	2.163331	-56.5162	4.368066	-61.924	6.378087	-66.4377
5.366563	-64.2643	2.683282	-57.7855	3.794733	-60.6204	6	-65.5896
5.660389	-64.9566	3.231099	-59.1228	3.231099	-59.3389	5.660389	-64.8277
6	-65.7569	3.794733	-60.4988	2.683282	-58.0933	5.366563	-64.1686
6.378087	-66.6479	4.368066	-61.8984	2.163331	-56.9111	5.126402	-63.6298
6.788225	-67.6143	4.947727	-63.3135	1.697056	-55.851	4.947727	-63.229
7.224957	-68.6435	5.531727	-64.7391	1.341641	-55.0429	4.837355	-62.9814
5.433231	-64.4214	0.848528	-53.3064	5.433231	-64.3458	7.636753	-69.2613
5.531727	-64.6535	1.341641	-54.5102	4.837355	-62.991	7.224957	-68.3375
5.6921	-65.0314	1.897367	-55.8669	4.242641	-61.6388	6.841053	-67.4763
5.909315	-65.5432	2.473863	-57.2742	3.649658	-60.2906	6.489992	-66.6888
6.177378	-66.1749	3.059412	-58.7037	3.059412	-58.9485	6.177378	-65.9875
6.489992	-66.9116	3.649658	-60.1446	2.473863	-57.6172	5.909315	-65.3861
6.841053	-67.7388	4.242641	-61.5922	1.897367	-56.3064	5.6921	-64.8988
7.224957	-68.6435	4.837355	-63.044	1.341641	-55.0429	5.531727	-64.5391
7.636753	-69.6139	5.433231	-64.4987	0.848528	-53.9217	5.433231	-64.3181

A.3 Estimated RSS Values for Room Size 6*6 With 100 Cm Grid Size

Distance	RSS for AP1	Distance	RSS for AP2	Distance	RSS for AP3	Distance	RSS for AP4
1.414214	-55.6153	5.09902	-63.8547	7.071068	-68.0599	5.09902	-63.8451
2.236068	-57.4433	5.385165	-64.5111	6.403124	-66.6096	4.123106	-61.6212
3.162278	-59.5033	5.830952	-65.5338	5.830952	-65.3672	3.162278	-59.4317
4.123106	-61.6404	6.403124	-66.8464	5.385165	-64.3993	2.236068	-57.3211
5.09902	-63.811	7.071068	-68.3787	5.09902	-63.7779	1.414214	-55.4483
2.236068	-57.4433	4.123106	-61.6158	6.403124	-66.6096	5.385165	-64.4971
2.828427	-58.7608	4.472136	-62.4165	5.656854	-64.9892	4.472136	-62.4166
3.605551	-60.4892	5	-63.6275	5	-63.5629	3.605551	-60.4418
4.472136	-62.4167	5.656854	-65.1344	4.472136	-62.4168	2.828427	-58.671
5.385165	-64.4474	6.403124	-66.8464	4.123106	-61.6589	2.236068	-57.3211
3.162278	-59.5033	3.162278	-59.4116	5.830952	-65.3672	5.830952	-65.513
3.605551	-60.4892	3.605551	-60.4285	5	-63.5629	5	-63.6194
4.242641	-61.9062	4.242641	-61.8901	4.242641	-61.9184	4.242641	-61.8936
5	-63.5907	5	-63.6275	3.605551	-60.5351	3.605551	-60.4418
5.830952	-65.4389	5.830952	-65.5338	3.162278	-59.5726	3.162278	-59.4317
4.123106	-61.6404	2.236068	-57.2868	5.385165	-64.3993	6.403124	-66.8168
4.472136	-62.4167	2.828427	-58.6457	4.472136	-62.4168	5.656854	-65.1163
5	-63.5907	3.605551	-60.4285	3.605551	-60.5351	5	-63.6194
5.656854	-65.0517	4.472136	-62.4165	2.828427	-58.8477	4.472136	-62.4166
6.403124	-66.7115	5.385165	-64.5111	2.236068	-57.5615	4.123106	-61.6212
5.09902	-63.811	1.414214	-55.4014	5.09902	-63.7779	7.071068	-68.3389
5.385165	-64.4474	2.236068	-57.2868	4.123106	-61.6589	6.403124	-66.8168
5.830952	-65.4389	3.162278	-59.4116	3.162278	-59.5726	5.830952	-65.513
6.403124	-66.7115	4.123106	-61.6158	2.236068	-57.5615	5.385165	-64.4971
7.071068	-68.1971	5.09902	-63.8547	1.414214	-55.777	5.09902	-63.8451

A.4 Estimated RSS Values for Room Size 12*12 With 100 Cm Grid Size

Distance	RSS for AP1	Distance	RSS for AP2	Distance	RSS for AP3	Distance	RSS for AP4
1.414214	-59.7782	11.04536	-70.9626	15.55635	-76.1768	11.04536	-71.0662
2.236068	-60.7345	11.18034	-71.1181	14.86607	-75.3797	10.04988	-69.8671
3.162278	-61.8123	11.40175	-71.3732	14.21267	-74.6252	9.055385	-68.6692
4.123106	-62.9303	11.7047	-71.7223	13.60147	-73.9194	8.062258	-67.4729
5.09902	-64.0659	12.08305	-72.1582	13.0384	-73.2692	7.071068	-66.279
6.082763	-65.2106	12.52996	-72.6732	12.52996	-72.682	6.082763	-65.0885
7.071068	-66.3606	13.0384	-73.259	12.08305	-72.166	5.09902	-63.9036
8.062258	-67.514	13.60147	-73.9078	11.7047	-71.729	4.123106	-62.728
9.055385	-68.6696	14.21267	-74.612	11.40175	-71.3792	3.162278	-61.5707
10.04988	-69.8268	14.86607	-75.3649	11.18034	-71.1235	2.236068	-60.455
11.04536	-70.9852	15.55635	-76.1602	11.04536	-70.9677	1.414214	-59.4651
2.236068	-60.7345	10.04988	-69.8156	14.86607	-75.3797	11.18034	-71.2288
2.828427	-61.4238	10.19804	-69.9863	14.14214	-74.5437	10.19804	-70.0456

3.605551	-62.3281	10.44031	-70.2654	13.45362	-73.7487	9.219544	-68.867
4.472136	-63.3364	10.77033	-70.6457	12.80625	-73.0011	8.246211	-67.6945
5.385165	-64.3989	11.18034	-71.1181	12.20656	-72.3086	7.28011	-66.5308
6.324555	-65.492	11.6619	-71.673	11.6619	-71.6796	6.324555	-65.3798
7.28011	-66.6039	12.20656	-72.3005	11.18034	-71.1235	5.385165	-64.2483
8.246211	-67.728	12.80625	-72.9915	10.77033	-70.6501	4.472136	-63.1485
9.219544	-68.8606	13.45362	-73.7374	10.44031	-70.269	3.605551	-62.1046
10.19804	-69.9992	14.14214	-74.5307	10.19804	-69.9892	2.828427	-61.1685
11.18034	-71.1423	14.86607	-75.3649	10.04988	-69.8181	2.236068	-60.455
3.162278	-61.8123	9.055385	-68.6697	14.21267	-74.6252	11.40175	-71.4955
3.605551	-62.3281	9.219544	-68.8589	13.45362	-73.7487	10.44031	-70.3374
4.242641	-63.0694	9.486833	-69.1668	12.72792	-72.9106	9.486833	-69.1889
5	-63.9507	9.848858	-69.584	12.04159	-72.1181	8.544004	-68.0532
5.830952	-64.9176	10.29563	-70.0987	11.40175	-71.3792	7.615773	-66.9351
6.708204	-65.9384	10.81665	-70.6991	10.81665	-70.7036	6.708204	-65.8419
7.615773	-66.9944	11.40175	-71.3732	10.29563	-70.1019	5.830952	-64.7852
8.544004	-68.0746	12.04159	-72.1105	9.848858	-69.586	5	-63.7843
9.486833	-69.1716	12.72792	-72.9013	9.486833	-69.1679	4.242641	-62.872
10.44031	-70.2811	13.45362	-73.7374	9.219544	-68.8593	3.605551	-62.1046
11.40175	-71.3999	14.21267	-74.612	9.055385	-68.6697	3.162278	-61.5707
4.123106	-62.9303	8.062258	-67.5254	13.60147	-73.9194	11.7047	-71.8604
4.472136	-63.3364	8.246211	-67.7374	12.80625	-73.0011	10.77033	-70.7349
5	-63.9507	8.544004	-68.0805	12.04159	-72.1181	9.848858	-69.625
5.656854	-64.715	8.944272	-68.5417	11.31371	-71.2775	8.944272	-68.5354
6.403124	-65.5834	9.433981	-69.1059	10.63015	-70.4882	8.062258	-67.4729
7.211103	-66.5236	10	-69.7581	10	-69.7605	7.211103	-66.4477
8.062258	-67.514	10.63015	-70.4842	9.433981	-69.1069	6.403124	-65.4744
8.944272	-68.5403	11.31371	-71.2718	8.944272	-68.5414	5.656854	-64.5755
9.848858	-69.5929	12.04159	-72.1105	8.544004	-68.0792	5	-63.7843
10.77033	-70.6652	12.80625	-72.9915	8.246211	-67.7353	4.472136	-63.1485
11.7047	-71.7524	13.60147	-73.9078	8.062258	-67.5229	4.123106	-62.728
5.09902	-64.0659	7.071068	-66.3834	13.0384	-73.2692	12.08305	-72.3162
5.385165	-64.3989	7.28011	-66.6242	12.20656	-72.3086	11.18034	-71.2288
5.830952	-64.9176	7.615773	-67.011	11.40175	-71.3792	10.29563	-70.1631
6.403124	-65.5834	8.062258	-67.5254	10.63015	-70.4882	9.433981	-69.1253
7.071068	-66.3606	8.602325	-68.1477	9.899495	-69.6444	8.602325	-68.1235
7.81025	-67.2207	9.219544	-68.8589	9.219544	-68.8593	7.81025	-67.1694
8.602325	-68.1424	9.899495	-69.6423	8.602325	-68.1465	7.071068	-66.279
9.433981	-69.1102	10.63015	-70.4842	8.062258	-67.5229	6.403124	-65.4744
10.29563	-70.1128	11.40175	-71.3732	7.615773	-67.0073	5.830952	-64.7852
11.18034	-71.1423	12.20656	-72.3005	7.28011	-66.6197	5.385165	-64.2483
12.08305	-72.1927	13.0384	-73.259	7.071068	-66.3783	5.09902	-63.9036
6.082763	-65.2106	6.082763	-65.2446	12.52996	-72.682	12.52996	-72.8545
6.324555	-65.492	6.324555	-65.5232	11.6619	-71.6796	11.6619	-71.8089
6.708204	-65.9384	6.708204	-65.9653	10.81665	-70.7036	10.81665	-70.7907
7.211103	-66.5236	7.211103	-66.5447	10	-69.7605	10	-69.807
7.81025	-67.2207	7.81025	-67.2351	9.219544	-68.8593	9.219544	-68.867
8.485281	-68.0062	8.485281	-68.0128	8.485281	-68.0114	8.485281	-67.9825
9.219544	-68.8606	9.219544	-68.8589	7.81025	-67.2318	7.81025	-67.1694

10	-69.7688	10	-69.7581	7.211103	-66.54	7.211103	-66.4477
10.81665	-70.7191	10.81665	-70.6991	6.708204	-65.9592	6.708204	-65.8419
11.6619	-71.7026	11.6619	-71.673	6.324555	-65.5162	6.324555	-65.3798
12.52996	-72.7127	12.52996	-72.6732	6.082763	-65.237	6.082763	-65.0885
7.071068	-66.3606	5.09902	-64.1111	12.08305	-72.166	13.0384	-73.467
7.28011	-66.6039	5.385165	-64.4408	11.18034	-71.1235	12.20656	-72.465
7.615773	-66.9944	5.830952	-64.9545	10.29563	-70.1019	11.40175	-71.4955
8.062258	-67.514	6.403124	-65.6137	9.433981	-69.1069	10.63015	-70.5661
8.602325	-68.1424	7.071068	-66.3834	8.602325	-68.1465	9.899495	-69.686
9.219544	-68.8606	7.81025	-67.2351	7.81025	-67.2318	9.219544	-68.867
9.899495	-69.6518	8.602325	-68.1477	7.071068	-66.3783	8.602325	-68.1235
10.63015	-70.502	9.433981	-69.1059	6.403124	-65.6069	8.062258	-67.4729
11.40175	-71.3999	10.29563	-70.0987	5.830952	-64.9462	7.615773	-66.9351
12.20656	-72.3364	11.18034	-71.1181	5.385165	-64.4314	7.28011	-66.5308
13.0384	-73.3043	12.08305	-72.1582	5.09902	-64.101	7.071068	-66.279
8.062258	-67.514	4.123106	-62.9867	11.7047	-71.729	13.60147	-74.1452
8.246211	-67.728	4.472136	-63.3888	10.77033	-70.6501	12.80625	-73.1873
8.544004	-68.0746	5	-63.997	9.848858	-69.586	12.04159	-72.2662
8.944272	-68.5403	5.656854	-64.7539	8.944272	-68.5414	11.31371	-71.3895
9.433981	-69.1102	6.403124	-65.6137	8.062258	-67.5229	10.63015	-70.5661
10	-69.7688	7.211103	-66.5447	7.211103	-66.54	10	-69.807
10.63015	-70.502	8.062258	-67.5254	6.403124	-65.6069	9.433981	-69.1253
11.31371	-71.2974	8.944272	-68.5417	5.656854	-64.7452	8.944272	-68.5354
12.04159	-72.1444	9.848858	-69.584	5	-63.9866	8.544004	-68.0532
12.80625	-73.0342	10.77033	-70.6457	4.472136	-63.3771	8.246211	-67.6945
13.60147	-73.9595	11.7047	-71.7223	4.123106	-62.974	8.062258	-67.4729
9.055385	-68.6696	3.162278	-61.8796	11.40175	-71.3792	14.21267	-74.8814
9.219544	-68.8606	3.605551	-62.3903	10.44031	-70.269	13.45362	-73.9671
9.486833	-69.1716	4.242641	-63.1244	9.486833	-69.1679	12.72792	-73.093
9.848858	-69.5929	5	-63.997	8.544004	-68.0792	12.04159	-72.2662
10.29563	-70.1128	5.830952	-64.9545	7.615773	-67.0073	11.40175	-71.4955
10.81665	-70.7191	6.708204	-65.9653	6.708204	-65.9592	10.81665	-70.7907
11.40175	-71.3999	7.615773	-67.011	5.830952	-64.9462	10.29563	-70.1631
12.04159	-72.1444	8.544004	-68.0805	5	-63.9866	9.848858	-69.625
12.72792	-72.9431	9.486833	-69.1668	4.242641	-63.1121	9.486833	-69.1889
13.45362	-73.7875	10.44031	-70.2654	3.605551	-62.3764	9.219544	-68.867
14.21267	-74.6707	11.40175	-71.3732	3.162278	-61.8645	9.055385	-68.6692
10.04988	-69.8268	2.236068	-60.8124	11.18034	-71.1235	14.86607	-75.6685
10.19804	-69.9992	2.828427	-61.4949	10.19804	-69.9892	14.14214	-74.7965
10.44031	-70.2811	3.605551	-62.3903	9.219544	-68.8593	13.45362	-73.9671
10.77033	-70.6652	4.472136	-63.3888	8.246211	-67.7353	12.80625	-73.1873
11.18034	-71.1423	5.385165	-64.4408	7.28011	-66.6197	12.20656	-72.465
11.6619	-71.7026	6.324555	-65.5232	6.324555	-65.5162	11.6619	-71.8089
12.20656	-72.3364	7.28011	-66.6242	5.385165	-64.4314	11.18034	-71.2288
12.80625	-73.0342	8.246211	-67.7374	4.472136	-63.3771	10.77033	-70.7349
13.45362	-73.7875	9.219544	-68.8589	3.605551	-62.3764	10.44031	-70.3374
14.14214	-74.5887	10.19804	-69.9863	2.828427	-61.479	10.19804	-70.0456
14.86607	-75.4311	11.18034	-71.1181	2.236068	-60.7949	10.04988	-69.8671
11.04536	-70.9852	1.414214	-59.8654	11.04536	-70.9677	15.55635	-76.4999

11.18034	-71.1423	2.236068	-60.8124	10.04988	-69.8181	14.86607	-75.6685
11.40175	-71.3999	3.162278	-61.8796	9.055385	-68.6697	14.21267	-74.8814
11.7047	-71.7524	4.123106	-62.9867	8.062258	-67.5229	13.60147	-74.1452
12.08305	-72.1927	5.09902	-64.1111	7.071068	-66.3783	13.0384	-73.467
12.52996	-72.7127	6.082763	-65.2446	6.082763	-65.237	12.52996	-72.8545
13.0384	-73.3043	7.071068	-66.3834	5.09902	-64.101	12.08305	-72.3162
13.60147	-73.9595	8.062258	-67.5254	4.123106	-62.974	11.7047	-71.8604
14.21267	-74.6707	9.055385	-68.6697	3.162278	-61.8645	11.40175	-71.4955
14.86607	-75.4311	10.04988	-69.8156	2.236068	-60.7949	11.18034	-71.2288
15.55635	-76.2343	11.04536	-70.9626	1.414214	-59.8459	11.04536	-71.0662

A.5 Estimated RSS Values for Room Size 18*18 With 100 Cm Grid Size

Distance	RSS for AP1	Distance	RSS for AP2	Distance	RSS for AP3	Distance	RSS for AP4
1.414214	-62.562	17.02939	-74.6521	24.04163	-80.4181	17.02939	-74.6911
2.236068	-63.1968	17.11724	-74.7207	23.34524	-79.8549	16.03122	-73.9003
3.162278	-63.9123	17.26268	-74.8342	22.67157	-79.31	15.0333	-73.1096
4.123106	-64.6545	17.46425	-74.9916	22.02272	-78.7852	14.03567	-72.3192
5.09902	-65.4084	17.72005	-75.1913	21.40093	-78.2824	13.0384	-71.5291
6.082763	-66.1683	18.02776	-75.4316	20.80865	-77.8033	12.04159	-70.7393
7.071068	-66.9317	18.38478	-75.7103	20.24846	-77.3502	11.04536	-69.95
8.062258	-67.6974	18.78829	-76.0253	19.72308	-76.9253	10.04988	-69.1612
9.055385	-68.4645	19.23538	-76.3744	19.23538	-76.5309	9.055385	-68.3733
10.04988	-69.2328	19.72308	-76.7552	18.78829	-76.1693	8.062258	-67.5864
11.04536	-70.0017	20.24846	-77.1653	18.38478	-75.8429	7.071068	-66.8011
12.04159	-70.7713	20.80865	-77.6027	18.02776	-75.5542	6.082763	-66.0181
13.0384	-71.5413	21.40093	-78.0651	17.72005	-75.3053	5.09902	-65.2387
14.03567	-72.3117	22.02272	-78.5506	17.46425	-75.0984	4.123106	-64.4654
15.0333	-73.0823	22.67157	-79.0571	17.26268	-74.9354	3.162278	-63.7042
16.03122	-73.8532	23.34524	-79.5831	17.11724	-74.8178	2.236068	-62.9703
17.02939	-74.6242	24.04163	-80.1268	17.02939	-74.7467	1.414214	-62.3192
2.236068	-63.1968	16.03122	-73.8728	23.34524	-79.8549	17.11724	-74.7607
2.828427	-63.6544	16.12452	-73.9456	22.62742	-79.2743	16.12452	-73.9742
3.605551	-64.2547	16.27882	-74.0661	21.93171	-78.7116	15.13275	-73.1884
4.472136	-64.9241	16.49242	-74.2329	21.26029	-78.1686	14.14214	-72.4036
5.385165	-65.6294	16.76305	-74.4442	20.61553	-77.6471	13.15295	-71.6198
6.324555	-66.3551	17.08801	-74.6979	20	-77.1493	12.16553	-70.8375
7.28011	-67.0932	17.46425	-74.9916	19.41649	-76.6774	11.18034	-70.0569
8.246211	-67.8395	17.88854	-75.3229	18.86796	-76.2337	10.19804	-69.2786
9.219544	-68.5914	18.35756	-75.6891	18.35756	-75.8209	9.219544	-68.5034
10.19804	-69.3472	18.86796	-76.0875	17.88854	-75.4416	8.246211	-67.7322
11.18034	-70.106	19.41649	-76.5158	17.46425	-75.0984	7.28011	-66.9667
12.16553	-70.867	20	-76.9714	17.08801	-74.7941	6.324555	-66.2097
13.15295	-71.6298	20.61553	-77.4519	16.76305	-74.5313	5.385165	-65.4654
14.14214	-72.3939	21.26029	-77.9553	16.49242	-74.3124	4.472136	-64.742
15.13275	-73.1591	21.93171	-78.4795	16.27882	-74.1397	3.605551	-64.0554
16.12452	-73.9252	22.62742	-79.0227	16.12452	-74.0149	2.828427	-63.4397

17.11724	-74.6921	23.34524	-79.5831	16.03122	-73.9394	2.236068	-62.9703
3.162278	-63.9123	15.0333	-73.0937	22.67157	-79.31	17.26268	-74.876
3.605551	-64.2547	15.13275	-73.1713	21.93171	-78.7116	16.27882	-74.0965
4.242641	-64.7468	15.29706	-73.2996	21.2132	-78.1305	15.29706	-73.3186
5	-65.3319	15.52417	-73.4769	20.51828	-77.5685	14.31782	-72.5428
5.830952	-65.9738	15.81139	-73.7012	19.84943	-77.0275	13.34166	-71.7693
6.708204	-66.6514	16.15549	-73.9698	19.20937	-76.5099	12.36932	-70.9989
7.615773	-67.3525	16.55295	-74.2801	18.60108	-76.0179	11.40175	-70.2323
8.544004	-68.0695	17	-74.6292	18.02776	-75.5542	10.44031	-69.4706
9.486833	-68.7978	17.49286	-75.014	17.49286	-75.1216	9.486833	-68.7151
10.44031	-69.5344	18.02776	-75.4316	17	-74.723	8.544004	-67.9681
11.40175	-70.2771	18.60108	-75.8792	16.55295	-74.3614	7.615773	-67.2327
12.36932	-71.0245	19.20937	-76.3541	16.15549	-74.0399	6.708204	-66.5136
13.34166	-71.7756	19.84943	-76.8538	15.81139	-73.7616	5.830952	-65.8186
14.31782	-72.5296	20.51828	-77.376	15.52417	-73.5293	5	-65.1602
15.29706	-73.2861	21.2132	-77.9185	15.29706	-73.3456	4.242641	-64.5601
16.27882	-74.0444	21.93171	-78.4795	15.13275	-73.2128	3.605551	-64.0554
17.26268	-74.8044	22.67157	-79.0571	15.0333	-73.1323	3.162278	-63.7042
4.123106	-64.6545	14.03567	-72.3148	22.02272	-78.7852	17.46425	-75.0357
4.472136	-64.9241	14.14214	-72.3979	21.26029	-78.1686	16.49242	-74.2657
5	-65.3319	14.31782	-72.5351	20.51828	-77.5685	15.52417	-73.4985
5.656854	-65.8393	14.56022	-72.7243	19.79899	-76.9867	14.56022	-72.7348
6.403124	-66.4158	14.86607	-72.9631	19.10497	-76.4254	13.60147	-71.9752
7.211103	-67.0399	15.23155	-73.2485	18.43909	-75.8869	12.64911	-71.2206
8.062258	-67.6974	15.65248	-73.5771	17.80449	-75.3736	11.7047	-70.4724
8.944272	-68.3787	16.12452	-73.9456	17.20465	-74.8885	10.77033	-69.7321
9.848858	-69.0775	16.64332	-74.3507	16.64332	-74.4345	9.848858	-69.002
10.77033	-69.7893	17.20465	-74.7889	16.12452	-74.0149	8.944272	-68.2853
11.7047	-70.5111	17.80449	-75.2573	15.65248	-73.6331	8.062258	-67.5864
12.64911	-71.2406	18.43909	-75.7527	15.23155	-73.2927	7.211103	-66.9121
13.60147	-71.9763	19.10497	-76.2726	14.86607	-72.9971	6.403124	-66.2719
14.56022	-72.7169	19.79899	-76.8144	14.56022	-72.7497	5.656854	-65.6806
15.52417	-73.4615	20.51828	-77.376	14.31782	-72.5537	5	-65.1602
16.49242	-74.2094	21.26029	-77.9553	14.14214	-72.4116	4.472136	-64.742
17.46425	-74.9602	22.02272	-78.5506	14.03567	-72.3255	4.123106	-64.4654
5.09902	-65.4084	13.0384	-71.5362	21.40093	-78.2824	17.72005	-75.2383
5.385165	-65.6294	13.15295	-71.6256	20.61553	-77.6471	16.76305	-74.4801
5.830952	-65.9738	13.34166	-71.773	19.84943	-77.0275	15.81139	-73.7261
6.403124	-66.4158	13.60147	-71.9758	19.10497	-76.4254	14.86607	-72.9771
7.071068	-66.9317	13.92839	-72.2311	18.38478	-75.8429	13.92839	-72.2342
7.81025	-67.5027	14.31782	-72.5351	17.69181	-75.2825	13	-71.4986
8.602325	-68.1146	14.76482	-72.8841	17.02939	-74.7467	12.08305	-70.7721
9.433981	-68.757	15.26434	-73.2741	16.40122	-74.2387	11.18034	-70.0569
10.29563	-69.4226	15.81139	-73.7012	15.81139	-73.7616	10.29563	-69.356
11.18034	-70.106	16.40122	-74.1617	15.26434	-73.3192	9.433981	-68.6733
12.08305	-70.8033	17.02939	-74.6521	14.76482	-72.9152	8.602325	-68.0143
13	-71.5116	17.69181	-75.1693	14.31782	-72.5537	7.81025	-67.3868
13.92839	-72.2288	18.38478	-75.7103	13.92839	-72.2387	7.071068	-66.8011
14.86607	-72.9531	19.10497	-76.2726	13.60147	-71.9743	6.403124	-66.2719

15.81139	-73.6834	19.84943	-76.8538	13.34166	-71.7642	5.830952	-65.8186
16.76305	-74.4185	20.61553	-77.4519	13.15295	-71.6115	5.385165	-65.4654
17.72005	-75.1577	21.40093	-78.0651	13.0384	-71.5189	5.09902	-65.2387
6.082763	-66.1683	12.04159	-70.758	20.80865	-77.8033	18.02776	-75.4821
6.324555	-66.3551	12.16553	-70.8547	20	-77.1493	17.08801	-74.7376
6.708204	-66.6514	12.36932	-71.0138	19.20937	-76.5099	16.15549	-73.9987
7.211103	-67.0399	12.64911	-71.2323	18.43909	-75.8869	15.23155	-73.2667
7.81025	-67.5027	13	-71.5062	17.69181	-75.2825	14.31782	-72.5428
8.485281	-68.0242	13.41641	-71.8313	16.97056	-74.6991	13.41641	-71.8286
9.219544	-68.5914	13.89244	-72.203	16.27882	-74.1397	12.52996	-71.1262
10	-69.1942	14.42221	-72.6166	15.6205	-73.6072	11.6619	-70.4385
10.81665	-69.8251	15	-73.0677	15	-73.1054	10.81665	-69.7688
11.6619	-70.478	15.6205	-73.5521	14.42221	-72.6381	10	-69.1217
12.52996	-71.1486	16.27882	-74.0661	13.89244	-72.2096	9.219544	-68.5034
13.41641	-71.8333	16.97056	-74.6062	13.41641	-71.8246	8.485281	-67.9216
14.31782	-72.5296	17.69181	-75.1693	13	-71.4878	7.81025	-67.3868
15.23155	-73.2355	18.43909	-75.7527	12.64911	-71.204	7.211103	-66.9121
16.15549	-73.9492	19.20937	-76.3541	12.36932	-70.9777	6.708204	-66.5136
17.08801	-74.6695	20	-76.9714	12.16553	-70.8129	6.324555	-66.2097
18.02776	-75.3954	20.80865	-77.6027	12.04159	-70.7127	6.082763	-66.0181
7.071068	-66.9317	11.04536	-69.9802	20.24846	-77.3502	18.38478	-75.765
7.28011	-67.0932	11.18034	-70.0856	19.41649	-76.6774	17.46425	-75.0357
7.615773	-67.3525	11.40175	-70.2584	18.60108	-76.0179	16.55295	-74.3136
8.062258	-67.6974	11.7047	-70.4949	17.80449	-75.3736	15.65248	-73.6002
8.602325	-68.1146	12.08305	-70.7903	17.02939	-74.7467	14.76482	-72.8969
9.219544	-68.5914	12.52996	-71.1393	16.27882	-74.1397	13.89244	-72.2057
9.899495	-69.1166	13.0384	-71.5362	15.55635	-73.5554	13.0384	-71.5291
10.63015	-69.681	13.60147	-71.9758	14.86607	-72.9971	12.20656	-70.87
11.40175	-70.2771	14.21267	-72.453	14.21267	-72.4686	11.40175	-70.2323
12.20656	-70.8987	14.86607	-72.9631	13.60147	-71.9743	10.63015	-69.621
13.0384	-71.5413	15.55635	-73.5021	13.0384	-71.5189	9.899495	-69.0421
13.89244	-72.201	16.27882	-74.0661	12.52996	-71.1077	9.219544	-68.5034
14.76482	-72.8749	17.02939	-74.6521	12.08305	-70.7462	8.602325	-68.0143
15.65248	-73.5606	17.80449	-75.2573	11.7047	-70.4402	8.062258	-67.5864
16.55295	-74.2562	18.60108	-75.8792	11.40175	-70.1952	7.615773	-67.2327
17.46425	-74.9602	19.41649	-76.5158	11.18034	-70.0161	7.28011	-66.9667
18.38478	-75.6712	20.24846	-77.1653	11.04536	-69.9069	7.071068	-66.8011
8.062258	-67.6974	10.04988	-69.203	19.72308	-76.9253	18.78829	-76.0847
8.246211	-67.8395	10.19804	-69.3186	18.86796	-76.2337	17.88854	-75.3718
8.544004	-68.0695	10.44031	-69.5078	18.02776	-75.5542	17	-74.6679
8.944272	-68.3787	10.77033	-69.7655	17.20465	-74.8885	16.12452	-73.9742
9.433981	-68.757	11.18034	-70.0856	16.40122	-74.2387	15.26434	-73.2927
10	-69.1942	11.6619	-70.4615	15.6205	-73.6072	14.42221	-72.6255
10.63015	-69.681	12.20656	-70.8868	14.86607	-72.9971	13.60147	-71.9752
11.31371	-70.209	12.80625	-71.355	14.14214	-72.4116	12.80625	-71.3451
12.04159	-70.7713	13.45362	-71.8604	13.45362	-71.8547	12.04159	-70.7393
12.80625	-71.362	14.14214	-72.3979	12.80625	-71.3311	11.31371	-70.1626
13.60147	-71.9763	14.86607	-72.9631	12.20656	-70.8461	10.63015	-69.621
14.42221	-72.6103	15.6205	-73.5521	11.6619	-70.4056	10	-69.1217

15.26434	-73.2608	16.40122	-74.1617	11.18034	-70.0161	9.433981	-68.6733
16.12452	-73.9252	17.20465	-74.7889	10.77033	-69.6845	8.944272	-68.2853
17	-74.6015	18.02776	-75.4316	10.44031	-69.4176	8.544004	-67.9681
17.88854	-75.2879	18.86796	-76.0875	10.19804	-69.2216	8.246211	-67.7322
18.78829	-75.9829	19.72308	-76.7552	10.04988	-69.1018	8.062258	-67.5864
9.055385	-68.4645	9.055385	-68.4265	19.23538	-76.5309	19.23538	-76.439
9.219544	-68.5914	9.219544	-68.5547	18.35756	-75.8209	18.35756	-75.7435
9.486833	-68.7978	9.486833	-68.7634	17.49286	-75.1216	17.49286	-75.0583
9.848858	-69.0775	9.848858	-69.046	16.64332	-74.4345	16.64332	-74.3853
10.29563	-69.4226	10.29563	-69.3948	15.81139	-73.7616	15.81139	-73.7261
10.81665	-69.8251	10.81665	-69.8016	15	-73.1054	15	-73.0832
11.40175	-70.2771	11.40175	-70.2584	14.21267	-72.4686	14.21267	-72.4594
12.04159	-70.7713	12.04159	-70.758	13.45362	-71.8547	13.45362	-71.858
12.72792	-71.3015	12.72792	-71.2938	12.72792	-71.2678	12.72792	-71.2831
13.45362	-71.8621	13.45362	-71.8604	12.04159	-70.7127	12.04159	-70.7393
14.21267	-72.4484	14.21267	-72.453	11.40175	-70.1952	11.40175	-70.2323
15	-73.0566	15	-73.0677	10.81665	-69.722	10.81665	-69.7688
15.81139	-73.6834	15.81139	-73.7012	10.29563	-69.3006	10.29563	-69.356
16.64332	-74.326	16.64332	-74.3507	9.848858	-68.9392	9.848858	-69.002
17.49286	-74.9822	17.49286	-75.014	9.486833	-68.6464	9.486833	-68.7151
18.35756	-75.6502	18.35756	-75.6891	9.219544	-68.4303	9.219544	-68.5034
19.23538	-76.3283	19.23538	-76.3744	9.055385	-68.2975	9.055385	-68.3733
10.04988	-69.2328	8.062258	-67.6512	18.78829	-76.1693	19.72308	-76.8254
10.19804	-69.3472	8.246211	-67.7948	17.88854	-75.4416	18.86796	-76.1478
10.44031	-69.5344	8.544004	-68.0273	17	-74.723	18.02776	-75.4821
10.77033	-69.7893	8.944272	-68.3398	16.12452	-74.0149	17.20465	-74.83
11.18034	-70.106	9.433981	-68.7221	15.26434	-73.3192	16.40122	-74.1934
11.6619	-70.478	10	-69.164	14.42221	-72.6381	15.6205	-73.5749
12.20656	-70.8987	10.63015	-69.656	13.60147	-71.9743	14.86607	-72.9771
12.80625	-71.362	11.31371	-70.1897	12.80625	-71.3311	14.14214	-72.4036
13.45362	-71.8621	12.04159	-70.758	12.04159	-70.7127	13.45362	-71.858
14.14214	-72.3939	12.80625	-71.355	11.31371	-70.124	12.80625	-71.3451
14.86607	-72.9531	13.60147	-71.9758	10.63015	-69.5711	12.20656	-70.87
15.6205	-73.5359	14.42221	-72.6166	10	-69.0615	11.6619	-70.4385
16.40122	-74.139	15.26434	-73.2741	9.433981	-68.6037	11.18034	-70.0569
17.20465	-74.7596	16.12452	-73.9456	8.944272	-68.2076	10.77033	-69.7321
18.02776	-75.3954	17	-74.6292	8.544004	-67.8839	10.44031	-69.4706
18.86796	-76.0445	17.88854	-75.3229	8.246211	-67.643	10.19804	-69.2786
19.72308	-76.705	18.78829	-76.0253	8.062258	-67.4943	10.04988	-69.1612
11.04536	-70.0017	7.071068	-66.8773	18.38478	-75.8429	20.24846	-77.2416
11.18034	-70.106	7.28011	-67.0405	17.46425	-75.0984	19.41649	-76.5824
11.40175	-70.2771	7.615773	-67.3026	16.55295	-74.3614	18.60108	-75.9364
11.7047	-70.5111	8.062258	-67.6512	15.65248	-73.6331	17.80449	-75.3053
12.08305	-70.8033	8.602325	-68.0728	14.76482	-72.9152	17.02939	-74.6911
12.52996	-71.1486	9.219544	-68.5547	13.89244	-72.2096	16.27882	-74.0965
13.0384	-71.5413	9.899495	-69.0856	13.0384	-71.5189	15.55635	-73.524
13.60147	-71.9763	10.63015	-69.656	12.20656	-70.8461	14.86607	-72.9771
14.21267	-72.4484	11.40175	-70.2584	11.40175	-70.1952	14.21267	-72.4594
14.86607	-72.9531	12.20656	-70.8868	10.63015	-69.5711	13.60147	-71.9752

15.55635	-73.4864	13.0384	-71.5362	9.899495	-68.9802	13.0384	-71.5291
16.27882	-74.0444	13.89244	-72.203	9.219544	-68.4303	12.52996	-71.1262
17.02939	-74.6242	14.76482	-72.8841	8.602325	-67.9311	12.08305	-70.7721
17.80449	-75.223	15.65248	-73.5771	8.062258	-67.4943	11.7047	-70.4724
18.60108	-75.8383	16.55295	-74.2801	7.615773	-67.1332	11.40175	-70.2323
19.41649	-76.4682	17.46425	-74.9916	7.28011	-66.8617	11.18034	-70.0569
20.24846	-77.1109	18.38478	-75.7103	7.071068	-66.6926	11.04536	-69.95
12.04159	-70.7713	6.082763	-66.1057	18.02776	-75.5542	20.80865	-77.6855
12.16553	-70.867	6.324555	-66.2945	17.08801	-74.7941	20	-77.0448
12.36932	-71.0245	6.708204	-66.594	16.15549	-74.0399	19.20937	-76.4183
12.64911	-71.2406	7.211103	-66.9866	15.23155	-73.2927	18.43909	-75.808
13	-71.5116	7.81025	-67.4544	14.31782	-72.5537	17.69181	-75.216
13.41641	-71.8333	8.485281	-67.9814	13.41641	-71.8246	16.97056	-74.6445
13.89244	-72.201	9.219544	-68.5547	12.52996	-71.1077	16.27882	-74.0965
14.42221	-72.6103	10	-69.164	11.6619	-70.4056	15.6205	-73.5749
15	-73.0566	10.81665	-69.8016	10.81665	-69.722	15	-73.0832
15.6205	-73.5359	11.6619	-70.4615	10	-69.0615	14.42221	-72.6255
16.27882	-74.0444	12.52996	-71.1393	9.219544	-68.4303	13.89244	-72.2057
16.97056	-74.5788	13.41641	-71.8313	8.485281	-67.8364	13.41641	-71.8286
17.69181	-75.1359	14.31782	-72.5351	7.81025	-67.2904	13	-71.4986
18.43909	-75.7132	15.23155	-73.2485	7.211103	-66.8059	12.64911	-71.2206
19.20937	-76.3082	16.15549	-73.9698	6.708204	-66.3991	12.36932	-70.9989
20	-76.9189	17.08801	-74.6979	6.324555	-66.0888	12.16553	-70.8375
20.80865	-77.5436	18.02776	-75.4316	6.082763	-65.8933	12.04159	-70.7393
13.0384	-71.5413	5.09902	-65.3377	17.72005	-75.3053	21.40093	-78.1547
13.15295	-71.6298	5.385165	-65.5611	16.76305	-74.5313	20.61553	-77.5324
13.34166	-71.7756	5.830952	-65.9091	15.81139	-73.7616	19.84943	-76.9255
13.60147	-71.9763	6.403124	-66.3558	14.86607	-72.9971	19.10497	-76.3356
13.92839	-72.2288	7.071068	-66.8773	13.92839	-72.2387	18.38478	-75.765
14.31782	-72.5296	7.81025	-67.4544	13	-71.4878	17.69181	-75.216
14.76482	-72.8749	8.602325	-68.0728	12.08305	-70.7462	17.02939	-74.6911
15.26434	-73.2608	9.433981	-68.7221	11.18034	-70.0161	16.40122	-74.1934
15.81139	-73.6834	10.29563	-69.3948	10.29563	-69.3006	15.81139	-73.7261
16.40122	-74.139	11.18034	-70.0856	9.433981	-68.6037	15.26434	-73.2927
17.02939	-74.6242	12.08305	-70.7903	8.602325	-67.9311	14.76482	-72.8969
17.69181	-75.1359	13	-71.5062	7.81025	-67.2904	14.31782	-72.5428
18.38478	-75.6712	13.92839	-72.2311	7.071068	-66.6926	13.92839	-72.2342
19.10497	-76.2276	14.86607	-72.9631	6.403124	-66.1524	13.60147	-71.9752
19.84943	-76.8026	15.81139	-73.7012	5.830952	-65.6896	13.34166	-71.7693
20.61553	-77.3944	16.76305	-74.4442	5.385165	-65.3291	13.15295	-71.6198
21.40093	-78.0011	17.72005	-75.1913	5.09902	-65.0977	13.0384	-71.5291
14.03567	-72.3117	4.123106	-64.5757	17.46425	-75.0984	22.02272	-78.6474
14.14214	-72.3939	4.472136	-64.8482	16.49242	-74.3124	21.26029	-78.0433
14.31782	-72.5296	5	-65.2604	15.52417	-73.5293	20.51828	-77.4554
14.56022	-72.7169	5.656854	-65.7732	14.56022	-72.7497	19.79899	-76.8855
14.86607	-72.9531	6.403124	-66.3558	13.60147	-71.9743	19.10497	-76.3356
15.23155	-73.2355	7.211103	-66.9866	12.64911	-71.204	18.43909	-75.808
15.65248	-73.5606	8.062258	-67.6512	11.7047	-70.4402	17.80449	-75.3053
16.12452	-73.9252	8.944272	-68.3398	10.77033	-69.6845	17.20465	-74.83

16.64332	-74.326	9.848858	-69.046	9.848858	-68.9392	16.64332	-74.3853
17.20465	-74.7596	10.77033	-69.7655	8.944272	-68.2076	16.12452	-73.9742
17.80449	-75.223	11.7047	-70.4949	8.062258	-67.4943	15.65248	-73.6002
18.43909	-75.7132	12.64911	-71.2323	7.211103	-66.8059	15.23155	-73.2667
19.10497	-76.2276	13.60147	-71.9758	6.403124	-66.1524	14.86607	-72.9771
19.79899	-76.7637	14.56022	-72.7243	5.656854	-65.5488	14.56022	-72.7348
20.51828	-77.3193	15.52417	-73.4769	5	-65.0176	14.31782	-72.5428
21.26029	-77.8925	16.49242	-74.2329	4.472136	-64.5906	14.14214	-72.4036
22.02272	-78.4814	17.46425	-74.9916	4.123106	-64.3084	14.03567	-72.3192
15.0333	-73.0823	3.162278	-63.8256	17.26268	-74.9354	22.67157	-79.1615
15.13275	-73.1591	3.605551	-64.1717	16.27882	-74.1397	21.93171	-78.5753
15.29706	-73.2861	4.242641	-64.6691	15.29706	-73.3456	21.2132	-78.006
15.52417	-73.4615	5	-65.2604	14.31782	-72.5537	20.51828	-77.4554
15.81139	-73.6834	5.830952	-65.9091	13.34166	-71.7642	19.84943	-76.9255
16.15549	-73.9492	6.708204	-66.594	12.36932	-70.9777	19.20937	-76.4183
16.55295	-74.2562	7.615773	-67.3026	11.40175	-70.1952	18.60108	-75.9364
17	-74.6015	8.544004	-68.0273	10.44031	-69.4176	18.02776	-75.4821
17.49286	-74.9822	9.486833	-68.7634	9.486833	-68.6464	17.49286	-75.0583
18.02776	-75.3954	10.44031	-69.5078	8.544004	-67.8839	17	-74.6679
18.60108	-75.8383	11.40175	-70.2584	7.615773	-67.1332	16.55295	-74.3136
19.20937	-76.3082	12.36932	-71.0138	6.708204	-66.3991	16.15549	-73.9987
19.84943	-76.8026	13.34166	-71.773	5.830952	-65.6896	15.81139	-73.7261
20.51828	-77.3193	14.31782	-72.5351	5	-65.0176	15.52417	-73.4985
21.2132	-77.8561	15.29706	-73.2996	4.242641	-64.405	15.29706	-73.3186
21.93171	-78.4111	16.27882	-74.0661	3.605551	-63.8898	15.13275	-73.1884
22.67157	-78.9827	17.26268	-74.8342	3.162278	-63.5312	15.0333	-73.1096
16.03122	-73.8532	2.236068	-63.1025	17.11724	-74.8178	23.34524	-79.6952
16.12452	-73.9252	2.828427	-63.5649	16.12452	-74.0149	22.62742	-79.1265
16.27882	-74.0444	3.605551	-64.1717	15.13275	-73.2128	21.93171	-78.5753
16.49242	-74.2094	4.472136	-64.8482	14.14214	-72.4116	21.26029	-78.0433
16.76305	-74.4185	5.385165	-65.5611	13.15295	-71.6115	20.61553	-77.5324
17.08801	-74.6695	6.324555	-66.2945	12.16553	-70.8129	20	-77.0448
17.46425	-74.9602	7.28011	-67.0405	11.18034	-70.0161	19.41649	-76.5824
17.88854	-75.2879	8.246211	-67.7948	10.19804	-69.2216	18.86796	-76.1478
18.35756	-75.6502	9.219544	-68.5547	9.219544	-68.4303	18.35756	-75.7435
18.86796	-76.0445	10.19804	-69.3186	8.246211	-67.643	17.88854	-75.3718
19.41649	-76.4682	11.18034	-70.0856	7.28011	-66.8617	17.46425	-75.0357
20	-76.9189	12.16553	-70.8547	6.324555	-66.0888	17.08801	-74.7376
20.61553	-77.3944	13.15295	-71.6256	5.385165	-65.3291	16.76305	-74.4801
21.26029	-77.8925	14.14214	-72.3979	4.472136	-64.5906	16.49242	-74.2657
21.93171	-78.4111	15.13275	-73.1713	3.605551	-63.8898	16.27882	-74.0965
22.62742	-78.9485	16.12452	-73.9456	2.828427	-63.2612	16.12452	-73.9742
23.34524	-79.503	17.11724	-74.7207	2.236068	-62.7821	16.03122	-73.9003
17.02939	-74.6242	1.414214	-62.4608	17.02939	-74.7467	24.04163	-80.247
17.11724	-74.6921	2.236068	-63.1025	16.03122	-73.9394	23.34524	-79.6952
17.26268	-74.8044	3.162278	-63.8256	15.0333	-73.1323	22.67157	-79.1615
17.46425	-74.9602	4.123106	-64.5757	14.03567	-72.3255	22.02272	-78.6474
17.72005	-75.1577	5.09902	-65.3377	13.0384	-71.5189	21.40093	-78.1547
18.02776	-75.3954	6.082763	-66.1057	12.04159	-70.7127	20.80865	-77.6855

18.38478	-75.6712	7.071068	-66.8773	11.04536	-69.9069	20.24846	-77.2416
18.78829	-75.9829	8.062258	-67.6512	10.04988	-69.1018	19.72308	-76.8254
19.23538	-76.3283	9.055385	-68.4265	9.055385	-68.2975	19.23538	-76.439
19.72308	-76.705	10.04988	-69.203	8.062258	-67.4943	18.78829	-76.0847
20.24846	-77.1109	11.04536	-69.9802	7.071068	-66.6926	18.38478	-75.765
20.80865	-77.5436	12.04159	-70.758	6.082763	-65.8933	18.02776	-75.4821
21.40093	-78.0011	13.0384	-71.5362	5.09902	-65.0977	17.72005	-75.2383
22.02272	-78.4814	14.03567	-72.3148	4.123106	-64.3084	17.46425	-75.0357
22.67157	-78.9827	15.0333	-73.0937	3.162278	-63.5312	17.26268	-74.876
23.34524	-79.503	16.03122	-73.8728	2.236068	-62.7821	17.11724	-74.7607
24.04163	-80.041	17.02939	-74.6521	1.414214	-62.1174	17.02939	-74.6911