INDOOR POSITIONING USING WIRELESS
ACCESS SIGNALS

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INDOOR POSITIONING USING WIRELESS
ACCESS SIGNALS

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Submitted by **Merve ALTINBAŞ**

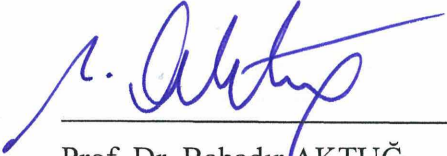Approval of the Graduate School of Natural and Applied Sciences, Çankaya University.

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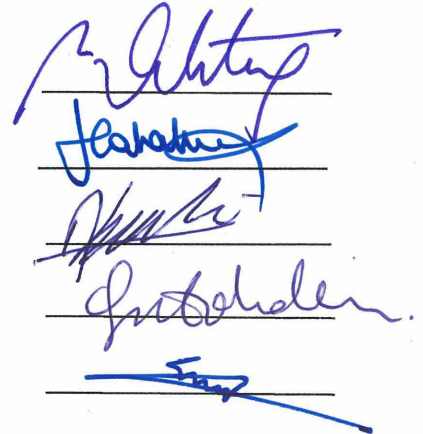
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ABSTRACT

INDOOR POSITIONING USING WIRELESS ACCESS SIGNALS

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Indoor positioning is one of the most popular topics searched in recent years, but it is not a precise and clear solution. This thesis study discusses different solutions for indoor positioning in abstract form and compares various methods. From these comparisons, Wi-Fi access points (APs) were determined to be the best method for indoor positioning. In the first phase, assuming that the locations of the APs are unknown, measurements are made at several points and information is taken, such as Wi-Fi AP signal level and mac-id. All information is saved into the database. With this information, the coordinates of the Wi-Fi APs are found using MATLAB programming language. The second phase finds the location of the person indoors using these coordinates. The aim of thesis is to achieve a position coordinate accuracy between 0 and 5 meters.

Keywords: Wi-Fi, multilateration, MATLAB, mac-id, RSSI, fingerprinting, access points (APs)

ÖZ

KABLOSUZ ERİŞİM SİNYALLERİNİ KULLANARAK İÇ MEKAN KONUMLANDIRMASI

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Yükseklisans, Bilgisayar Mühendisliği Anabilim Dalı

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İç mekan konumlandırması son yıllarda araştırılan en popüler konulardan biri oldu. Bu konunun kesin ve net çözümü olmadığından herkes tarafından en iyi çözüm tartışılır durumda. Bu tez çalışmasında iç mekan konumlandırmanın farklı çözüm yollarından özet şeklinde bahsedildikten sonra çözümler arasında bir kıyaslama yapıldı. Bu kıyaslamalar sonucunda en iyi yöntem olunduğu düşünülen Wi-Fi erişim noktaları kullanılarak iç mekan konumlandırma yönteminden bahsedildi ve bu yöntem ile geliştirilen uygulamanın ayrıntılarından bahsedildi. Bizim uygulamamız iki aşamadan oluşmaktadır. İlk olarak Wi-Fi erişim noktalarının yerini bilmediğimizi varsayarak birkaç farklı noktada ölçüm yapılarak veri tabanına kaydedilen ölçüm bilgileri (sinyal seviyeleri, benzersiz id) ile Wi-Fi erişim noktalarının koordinatlarını MATLAB çalışmaları ile bulmak, ikinci aşama ise bu koordinatları kullanarak iç mekanda kişi konumunu bulmaktır. Bu çalışmanın amacı 0 ile 5 metre arasında doğrulukla konum bulmaktır..

Anahtar kelimeler : Wi-Fi, multilaterasyon, MATLAB, mac-id, Sinyal Seviyesi , Yer İşaretleme, Erişim noktaları

ACKNOWLEDGMENTS

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CHAPTER 1

INTRODUCTION

1.1. Problem and Solution Statement

Indoor positioning systems have become very popular in recent years. The necessity of these systems has emerged in the real world, such as location determination of rooms and restaurant in large hotels, location determination of medical staff or equipment in a hospital, and classroom identification in universities. Numerous solutions have been considered for indoor positioning systems, which are becoming increasingly widespread in use. Particularly in the last 10 years, many academicians have researched this issue. There are many solutions for indoor positioning, such as global positioning system (GPS)-based, RFID, cellular based, UWB, and WLAN. There are advantages and disadvantages for each solution, as detailed in Table 1.1.

Table 1.1: Comparing solutions to indoor positioning [1]

Method	Advantages	Disadvantages	Accuracy
Ultrasound	• Simple and inexpensive equipment • Precise measurement	• Need to install receivers in each room • Negative effect of high intensity voices • Need to transmitter and receiver directly	When installed frequently enough, a few centimeters
Radio Frequency Identification (RFID)	• Receiver and transmitter do not need to see each other directly • Possible to work in any kind of environment • Rapid interaction • Passive receivers are cheaper, smaller, and do not need a clip compared to the active ones	• Passive carriers are more low precision than active carriers • RFID readers are expensive	Depending on the distribution of RFID readers and carriers, from 1 cm to 2 m
Bluetooth	• Any type of Bluetooth device can be monitored (laptop, mobile phone, mp3 player) • Variable reading distance (1 m) • Small-scale installations cheaper	• Costly in large-scale installations • Limited bandwidth • Up to seven sub connection possibilities for main connection • Delay in transmission	2–15 m
WLAN (Wi-Fi)	• The possibility to use the IEEE 802.11 infrastructure • Low cost	• Performance degradation in multistorey and very dense areas • Variable signal strength due to signal reflection and dynamic network structure	1–3 m (within 50 m range)
Pseudo-GPS		• Need to build small suites similar to GPS satellites in the building • GPS-enabled mobile devices. • Cost is high	Around 1 m
Infrared	• Compact • Low power consumption	• Sensitive to daylight • Need to see transmitter and receiver directly • Facility and maintenance are costly	5–10 m

Table 1.1 provides the advantages, disadvantages, and accuracy levels of the technologies that can be used for indoor positioning. In this respect, WLAN technology, which is thought to be the best method for the thesis, has been preferred, and the application has been developed through this solution. The most important reason for this choice is that Wi-Fi has a very common usage area and does not require an extra cost. The purpose of this thesis is to create an application that applies Wi-Fi trilateration method for indoor positioning using Android-based mobile devices.

A system with two functions in the thesis will be developed. The first function is to find the location of Wi-Fi access points (APs) with MATLAB programming language, assuming the location of the Wi-Fi APs are not known. The aim of the first function is to make more precise positioning using the signal strength of the added or displaced Wi-Fi APs. Before calculations in MATLAB, the measurements should be done in the environment and then record the signal strength levels (RSSI) and unique IDs (mac-id) of the received Wi-Fi APs in the database to develop an Android-based application that provides these measurements. The location of APs is found with data saved into the database of the Android application. The second function is to find the location of the mobile phone or tablet using the location and signal strength of APs in an indoor environment.

The location information of APs found in the first function gives an answer to different questions. Is the Wi-Fi AP located at the right spot? Are there obstacles in front of the APs? Where should the APs have been placed to receive more effective signals? The answer to these questions can provide the basis for a separate study; however, indoor positioning is the basis for this thesis.

In practice, the accuracy problem is solved by using the trilateration algorithm and by summing the lengths of the received signal powers. Over the past few years, mobile phones have become compulsory to achieve good accuracy using a variety of technologies. The problem is the creation of ground plans based on maps, the selection of effective positioning technology and algorithm in interior space, and the finding of

suitable devices within buildings. This technology estimates the distance between the user and the transmitter using Wi-Fi signals.

Distances are used to produce circles around each transmitter; then the intersection of the three circles is marked.

If the information given is correct, a unique result will be produced. However, blocks (e.g., walls and equipment in a building) and other factors (e.g., the number of people in the vicinity) can affect the signal strength. This thesis investigates the closed localization method based on Wi-Fi signal strength trilateration technique. The communication between the machines used for indoor positioning is shown in Figure 1.1.
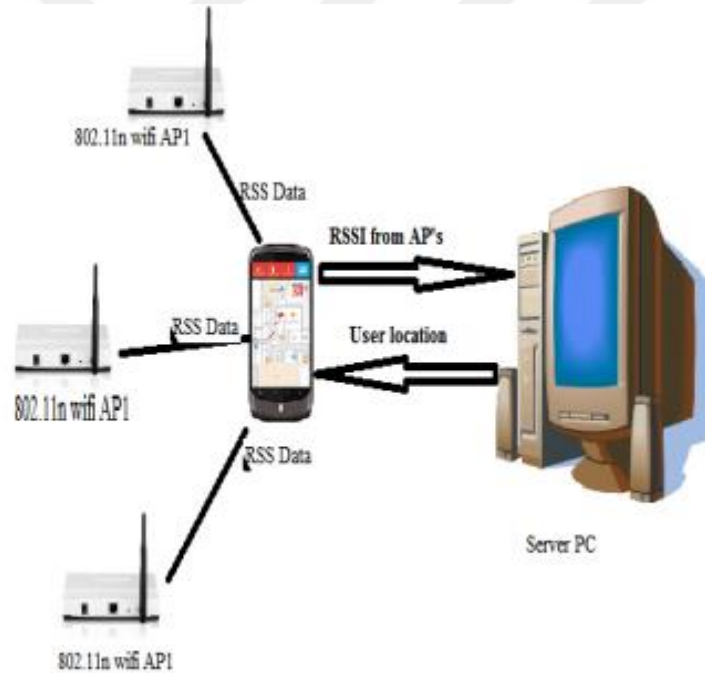
Figure 1.1: The communication between Wi-Fi APs and a mobile phone [1]

1.2. Related Works

Özyeğin University developed an application called "Pergel" [2], which offers services based on indoor location. Pergel users and objects are positioned within the

building, and they enhance the visitor experience with location-based, value-added services (see Figure 1.2). The offered services are orientation/navigation, searching people/place, push content, and gathering statistical user information. Usage areas of this application are shopping centers, museums, exhibitions, airports, and hospitals.

The system consists of a server and a mobile user application. Using the data in the environment, mobile users are positioned on the map, which determines the user's location by communicating with the server. The maps saves the content of the place and the user information. Navigation and searching a place is offered to the user with a mobile interface. This increases the interaction between the user and place management. In addition, it creates new and interactive channels. It optimizes place evaluating the behavior of visitors the most effectively. The Pergel application makes indoor positioning using Wi-Fi signals.

Antalya Rixos Hotel developed a similar project with an augmented reality system for the hotel [3]. Rixos customers can access the information they want to learn and can reach the point in the facility with Android or iOS smartphones in three dimensions. This system works as navigation. QR codes installed in different places of hotel are read using Android or iOS smartphones. The system directs guests with arrows. When the guest goes to a targeted point, she or he takes information on all areas on the itinerary. When the guest goes out of the hotel, the system starts to work with GPS signals. The system became active after installing a small program on any smartphone. Avea's 3G technology is used in the system; however, it runs on the Rixos server at the background.
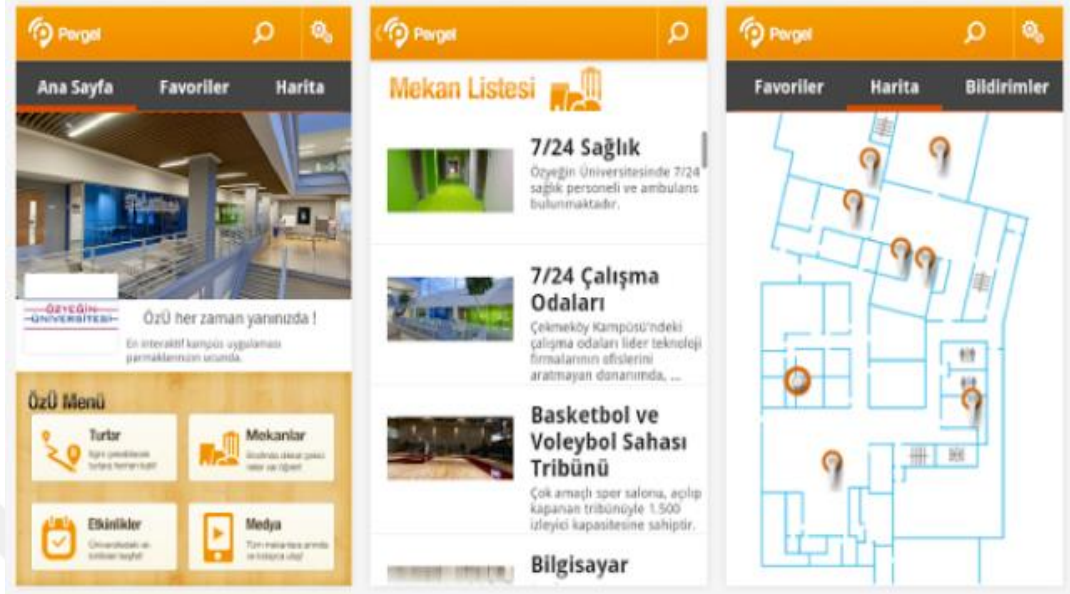
Figure 1.2: Özyeğin University Pergel application

The methods used for the Rixos hotel application are not clearly described. These two applications (Pergel and Rixos) also have navigation features.

A study at the University of Transylvania is similar to my thesis study. The accuracy of this application for Android-based devices using the trilateration method is between 2 and 2.5 meters [4].

1.3. Rationale for Selecting the Android Operating System

The smartphone operating system deemed suitable for the application is Android. Most importantly, there are not enough resources for indoor positioning using Wi-Fi APs on the iOS.

First, beacons that use Bluetooth technology have been preferred for indoor positioning in previous work done with iOS because Apple has its own iBeacon protocol. Beacons can also work with Android devices, but these devices are not integrated with beacons at the operating system level like iOS. Android devices should specifically search Bluetooth signals. Apple owners want to develop a similar protocol using Wi-Fi signals so they are not sharing information with the outside.

In addition, Android has prefabricated functions that can take Wi-Fi signal

strength and other necessary information.

With these services, it is possible to access Wi-Fi features with a small application.

Second, there is a serious difference between Android and iOS user counts. While the number of iOS users is 1 billion, the number of Android users is 2 billion [5]. The Android operating system is chosen because it reaches more people.

1.4. **Organization of the Thesis**

This thesis contains seven chapters. The methods used for indoor positioning, along with their advantages, disadvantages, accuracy levels, and performance criteria for determining the best method, are mentioned. After the best method has been identified, the application developed by this method is mentioned and the results obtained in the test environment are explained.

The thesis is organized as follows. Chapter 1 includes the methods used for indoor positioning, as well as the advantages, disadvantages, and accuracy levels of these methods. It includes similar work done earlier. Chapter 2 includes performance criteria to determine the best method. Chapter 3 explains the details of the methods used for indoor positioning. Chapter 4 contains the technical details of the developed application. Chapter 5 reviews the results obtained in test environments. Chapter 6 includes the conclusion part. Chapter 7 concludes the thesis and discusses future works.

CHAPTER 2

PERFORMANCE CRITERIA

The performance of a positioning technique is not solved only by its correctness. There are multiple metrics for indoor positioning: accuracy, precision, complexity, robustness, scalability, and cost.

2.1. Accuracy

Accuracy is the most important metric in the use of positioning systems. The performance metric is usually set as the average distance error, which is the Euclidean distance between the actual distance and the estimated distance [1]. High accuracy refers to a good system, but there must be a balance between other performance metrics and accuracy. Reconciliation must be between appropriate accuracy and other features.

2.2. Precision

Precision determines how consistently the positioning technique works as a result of several measurements. In some studies, sensitivity is defined as the standard deviation in position error and geometric dilution. The most accurate definition is the dispersion error of the distance between the actual position and the estimated position. Generally, cumulative probability functions are used to find precision. If the two positioning techniques are compared and if the accuracy is the same, the technique with the greatest value as a result of this function may be better because the distance error is concentrated in small values [1].

2.3. Complexity

The complexity of a positioning system depends on software, hardware, and processing factors [1]. The factor to consider for the thesis is mostly the software. If algorithmic calculations are made on the central server side, the positioning process can be done quickly, thanks to the powerful processor capacity [1]. If it is run on the

mobile side, the complexity is greater.

Because mobile device operating systems are not very powerful, algorithms with low complexity are preferred. Generally, it is difficult to derive the complexity formula of different positioning techniques, so the computation time can be considered as complexity [1]. Position ratio is an important criterion for complexity; it is the rate of delay between location launching and locating the mobile device on the system.

2.4. Robustness

In some methods during locating, robustness depends on environmental conditions. If some signals are not present or some received signal strength (RSS) values are not visible, a high endurance positioning technique can be created. Sometimes all signals coming from a transmitter are blocked, so no signal is obtained from some measurement units. The signals from the other units are the only criteria for estimating the position. Sometimes some measurement units do not work or are damaged in a hard area. Positioning techniques must use this incomplete information, but such information should be based on robustness [1].

2.5. Scalability

When the positioning area is large, the scalable character of a system provides the normal positioning function. Usually the distance between the receiver and the transmitter increases when the positioning performance drops. Two axes should scale a location system: geography and density. Geographical scale means the area or volume is covered. Density refers to the number of units located per unit of geographic area/space per time period [1].

When more space is occupied or units are concentrated on a field, wireless signal channels may become jammed, more computation may be required, or more communication infrastructure may need to be implemented. Another criterion of scalability is the metric of the system. Some systems can do 2-D positioning, some 3-D positioning, and some systems support both.

2.6. Cost

The cost of a positioning system can depend on multiple criteria, though important factors include time, money, and energy [1].

Time refers to the time allocated for the installation and maintenance of the system is the explanation. Hardware costs are important for money. For example, it can be assumed that the positioning system over the wireless network does not have the hardware costs. Energy can be considered the most important cost criterion of a system. In some mobile units the energy is completely passive. These units only have an unlimited consumption life because they react to external fields. The battery-operated mobile phone has only a few hours of battery life.

When all of this is taken into consideration, indoor positioning is achieved using the signal strength of Wi-Fi APs that have the best results, cheap cost, high accuracy, and low complexity.

CHAPTER 3

INDOOR POSITIONING METHODS AND COMPARISON

While global navigation satellite system (GNSS) have very high accuracy in open areas, GNSS signals decrease in largely indoor environment because of roofs, walls, etc. Therefore, various solutions have been developed using existing infrastructures, such as wireless APs and wireless routers.

3.1. Indoor Positioning Using GNSS Signals

Although GNSS has achieved success outdoors, it cannot perform the same indoors. In an indoor environment, the forces of the signals coming from the satellites fail because of walls and buildings; GNSS buyers cannot resolve these low-power signals [6]. GNSS signals need strengthening and direction to the interior for location determination in indoor spaces. These modifications concern the strength and direction of the signal (see Figure 3.1).
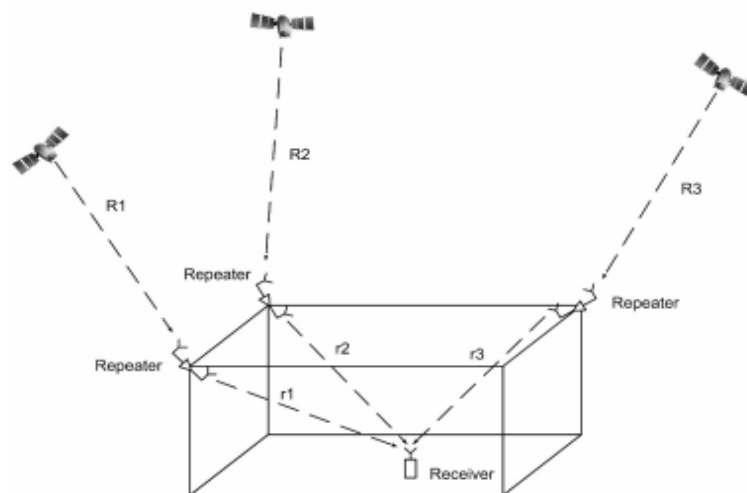
Figure 3.1: Indoor positioning with GNSS signals [7]

Repeaters that increase the decreasing GNSS signal strength should be set on certain points for system operation. The repeaters consist of a signal amplifier and a steered antenna. The antennas on these repeaters are different from the conventional GNSS antennas because they are designed to receive satellite signals from a certain direction. In this way, the signal that a repeater receives from any satellite and transmits to the interior is not transmitted to the same place a second time by another repeater. This situation is a very important point in terms of the functioning of the system [6]. The steered antenna comprises a combined ordinary GNSS receiver and conical reflector. This antenna receives satellite signals from a particular direction, filters out signals from the satellites, and prevents them from reaching the GNSS receiver. The working principle of this method is shown in Figure 3.2.
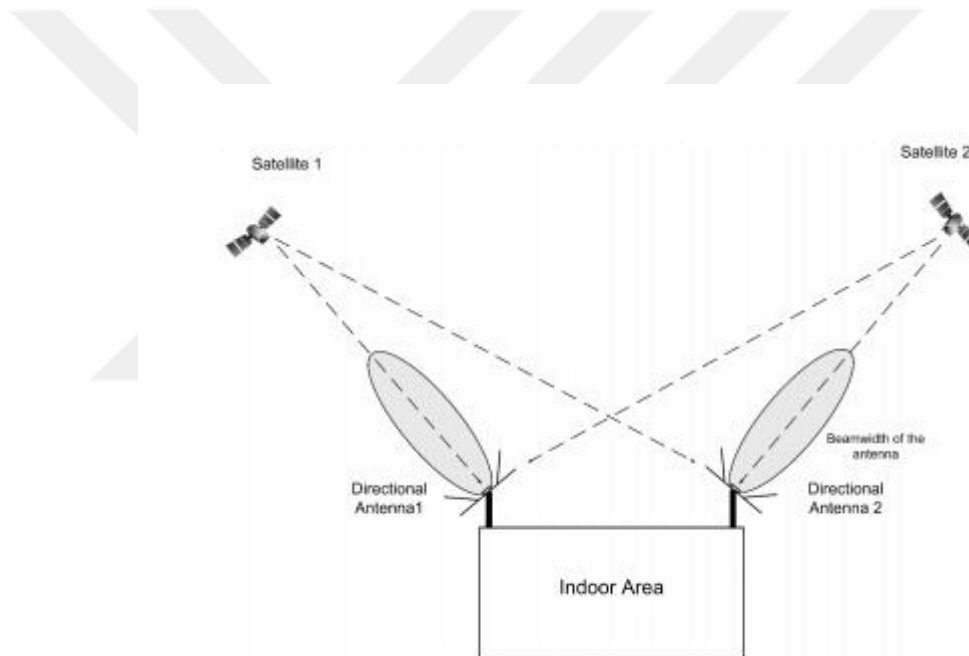
Figure 3.2: Antenna–satellite scenario [7]

It is necessary to develop and produce a sufficient number of antennas in a suitable position for all of the system. In addition, a low noise amplifier should be designed. This system can provide accuracy of up to 5 meters for location determinations in indoor spaces using the GNSS infrastructure.

In addition, there are many options available as a receiver because existing GNSS signals are used; the user does not need to acquire new hardware. The application is therefore simple and cheap.

3.2. Indoor Positioning with Wi-Fi Signals

Wi-Fi (Wireless Fidelity) is a common name for the IEEE 802.11 standard. Devices such as computers, game consoles, smartphones, or tablets can be connected wirelessly to an existing internet network with Wi-Fi technology. Communication over a wireless network is like a two-way radio. The wireless adapter of a device converts radio signals into data bits and transmits them via an antenna. The wireless router receives the signal and decodes it, then sends information to the Internet using a physical wired Ethernet connection.

The process works the same way in reverse. Each wireless router (distributor) broadcasts a signal received by devices in a specific area. These devices have the ability to measure signal strength.

There are several different methods for location technique and algorithm. Position trimming methods can be divided into three main categories: proximity, triangulation, and scene analysis (Figure 3.3).
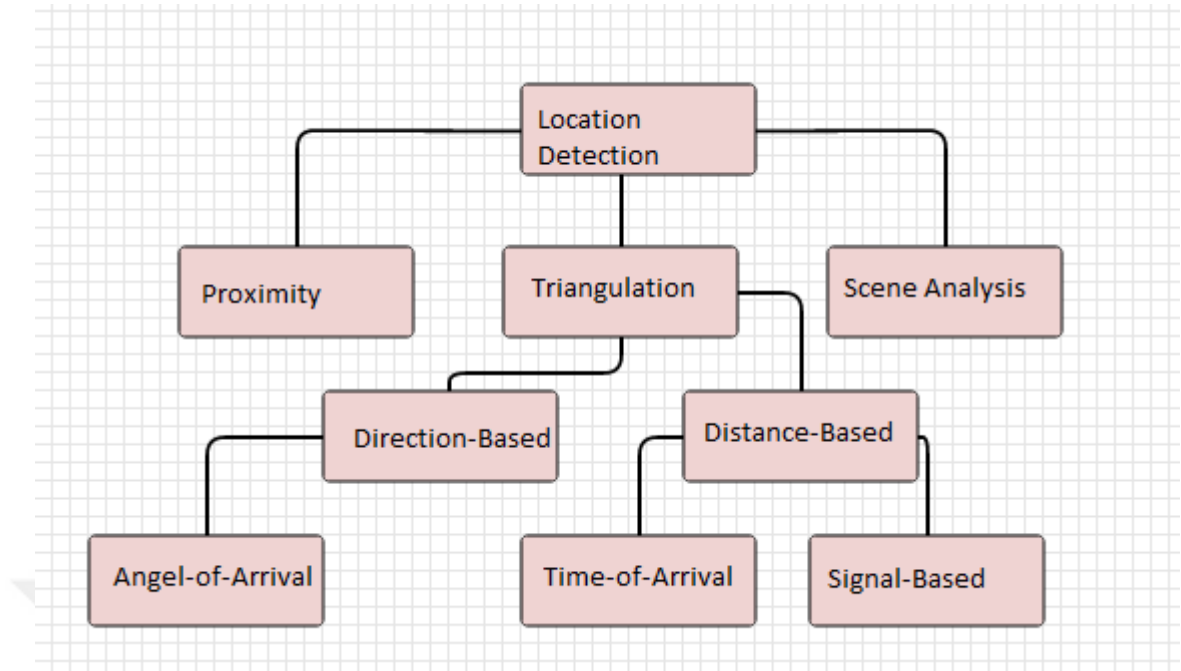
Figure 3.3: Location detection-based classification [6]

3.2.1. Proximity method

Proximity detection is the easiest method to implement, and it provides symbolic relative position information. The location of the mobile user is found with the network to which it is connected, with the help of known coordinates and distance. If multiple transmitters detect the target user, then it simply transmits the position to the nearest point where the signal is strongest.

This method is implemented with several different wireless technologies, especially GSM (Cell-ID), Bluetooth, and Radio Frequency Identification (RFID).

3.2.2. Triangulation method

Triangulation utilizes the geometric properties of = triangles to determine the location of the target user.

3.2.2.1 Angle of arrival (AoA) method

This method calculates the angles of the signals that reach more than one receiver from a certain point with the receiver antennas. Two receivers are sufficient to obtain position information in a two-dimensional plane. To increase the accuracy, three or more receivers are used in the point estimation (triangulation) (Figure 3.4). Directional antenna or antennas are required to determine direction. Then, by taking advantage of the geometric properties, the position of the nodal point of the intersecting two lines can be estimated.

AoA methods also have own disadvantages. The AoA technique requires special antennas to measure angles, which increased the cost of the technique. It also is affected by multipath in closed areas. These effects can change the AoA of the signal, thus significantly reducing positional accuracy.
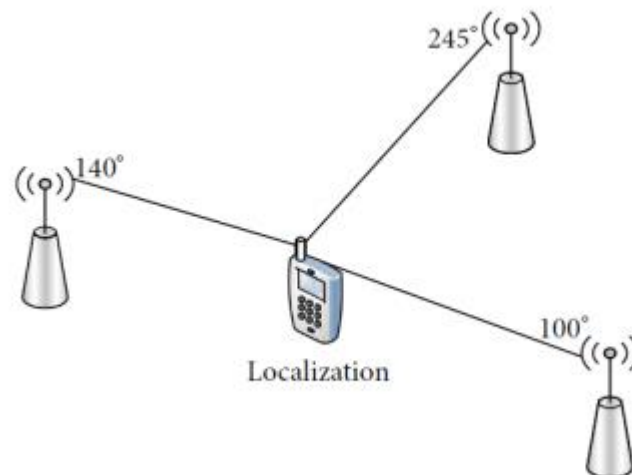
Figure 3.4: Angle of arrival [8]

3.2.2.2. Time-based method

Lateration / Trilateration / Multilateration refers to the determination of the location with the help of lengths. The lateration or trilateration method also determines the position of the object point by measuring distances to one or more reference points. This is called the range measurement technique. At least three reference points are needed to determine position.

3.2.2.1. Time of arrival (ToA) method

ToA methods are based on high accuracy synchronization of the arrival time of the transmitted signal from a mobile device to several reference points. The ToA method sends the time-stamped signal on the handset to several receivers. The distance between the mobile point and the receiver points is calculated with the aid of the signal transfer delay and the speed of the corresponding signal (Figure 3.5).
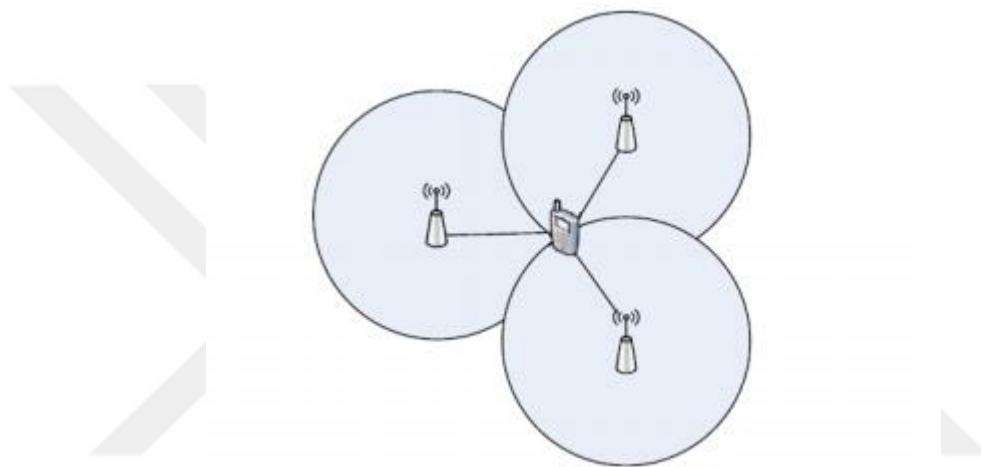
Figure 3.5: Location determination with time of arrival (ToA) method [8]

3.2.2.2.2. Time difference of arrival (TDoA) method

The relative position of the user is determined from the difference between the time when the signal transmitted from the mobile unit and when it reaches the multiple measurement units [6].

3.2.2.2.3. Round trip time (RTT) method

This method measures the RTT of the signal that travels from the transmitter to the measurement unit and returns. In the arrival time method, local clocks at both points measure the delay, whereas in RTT this operation is performed only on one side. The output and arrival times of the signal are recorded only in one spot. Thanks to this advantage, this technology also eliminates the synchronization problem.

3.2.2.3. Signal-based method

A large part of the wireless positioning technologies determine the coordinates of the positioning device, either with time information or angle information. In both scenarios, the results are under multipath effect. For this reason, position accuracy may be reduced. Instead, the signal strength weakening spread by a set of measures can be used to estimate the distance between the unknown point and known points. This method is only possible with radio signals.

3.2.3. Dead reckoning method

The dead reckoning method is a process for estimating the position of the end point with known or predicted speed information according to the latest known position. The dead reckoning method uses an internal navigation system that provides direction information at very high accuracy.

One disadvantage of this method is the accumulation of errors in the operations. Therefore, the positional deviation increases with time. The new points are calculated by taking advantage of the old points.

3.2.4. Map matching method

This method is based on template recognition theory. By combining a map with position information, the actual coordinates of the vehicle in a road network are found. Maps are an effective alternative to external hardware requirements.

3.2.5. Comparison of methods

Table 3.1 compares methods and their suitability. The fingerprinting method is determined to be best for this thesis.

Table 3.1: Comparison of Methods [6]

Method	Measurement Type	Accuracy	Inclusion	Effectiveness of Multipath	Cost
Dead Reckoning	Acceleration, speed	Low-Medium	Good	Yes	Low
Proximity	Signal type	Low-Medium	Good	No	Low
Angle of Arrival	Arrival angle of the received signal	Medium	Good (Multipath problems)	Yes	High
Map Matching	Template definition and projection based algorithms	Medium	Medium	Yes	Medium
Time of Arrival	Arrival time differences	High	Good (Multipath problems)	Yes	High
Fingerprinting	*Received signal strength*	*High*	*Good*	*No*	*Medium*

3.2.6. Fingerprinting method

The estimation of the distance over the signal power with the RSSI is reliable in the ideal environment that has no obstacles. In the real world, however, radio waves can pass through all kinds of obstacles and objects, reflecting and losing signal strength.

Therefore, it is necessary to minimize these problems to be able to reliably and consistently locate via RSSI.

A fingerprinting method has been developed to overcome these problems. This method has two steps: mapping and position estimation. The locations of the APs were determined on the map of the environment. The exact coordinates are determined with the first stage of the application and these coordinates are recorded into the database. These coordinates were used when performing positioning.

The second stage is the location estimation stage. In this phase, the device's instantaneous position is calculated. For this, the signals from all the APs that the mobile device can capture at the time of each location query are compared with all APs in the database. The unique name of the AP in the database and the unique names of APs of received signals are the same, the information of these signals are transferred into a list. By using the APs obtained after this step, the position of the device can be calculated by various algorithms. In this thesis, the multilateration function is used. When there are over three Wi-Fi AP information, multilateration function uses the trilateration method as many as the number of combinations of three.

When there is AP information, the combinations of three of n are sequentially calculated by trilateration function in a loop. For example, if there are four Wi-Fi APs as P_1, P_2, P_3, P_4, these points is send to trilateration function as "P_1,P_2,P_3", "P_1,P_2,P_4", "P_1,P_3,P_4", and "P_2,P_3,P_4". Coordinate result is available as much as the number of trilateration. The average of these results will give the nearest correct result.

The Wi-Fi trilateration uses the power of the signals to predict the distance of each of the three transmitters to the user. The employed method is the Global Tri-Side Detection Algorithm, which uses the parameters of known Wi-Fi networks, such as Wi-Fi signal frequency, signal strength, network MAC address, and the actual coordinates of the Wi-Fi APs in the location. The signal strength received by the mobile device can be used to estimate the distance between the AP and the mobile device [4]. The signal strength at these points decreases exponentially and depends on the distance between the transmitter, receiver and random noise factor so this dependence can be considered as a function of distance.

The distance estimated by the signal strength is presented as a circle with a radius around the AP.

The intersection of the three AP radius provides a point or receiver area. This model can be shown as a system of this equation. Distances are between $P_M(x,y,z)$ and P_{A1} (x_1,y_1,z_1), P_{A2} (x_2,y_2,z_2), P_{A3} (x_3,y_3,z_3):

P_M: The measurement point (MP),

P_{A1}, P_{A2}, P_{A3}: The APs

$$d1^2 = (x - x1)^2 + (y - y1)^2 + (z - z1)^2$$
$$d2^2 = (x - x2)^2 + (y - y2)^2 + (z - z2)^2 \qquad (3.1)$$
$$d3^2 = (x - x3)^2 + (y - y3)^2 + (z - z3)^2$$

The equation system in Eq. (3.1):

Here, x_1, x_2, x_3, y_1, y_2, y_3, z_1, z_2, z_3 are the coordinates of the APs, x,y,z are the coordinates of the MPs and d_1, d_2, d_3 are the estimated distances. The solution of these equations gives points at the intersection of the circles providing the closed localization domain (Figure 3.6).
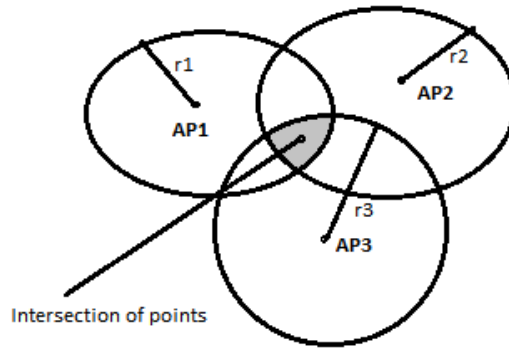
Figure 3.6: Trilateration method [7]

The system consists of three main modules. Network with at least three Wi-Fi APs, any device with the Android operating system, and the server. Using Android's

WifiManager API, the device scans all available connections it can detect. The resulting coordinate values (x, y, z) will be used on the server side. The server runs positioning algorithms that calculate the user's location coordinates.

The server runs two type algorithms. The first finds the exact location from the user's distance and calculates the distance of the user from the AP. The second is the trilateration function. Then, the server sends these position coordinates to the client device.
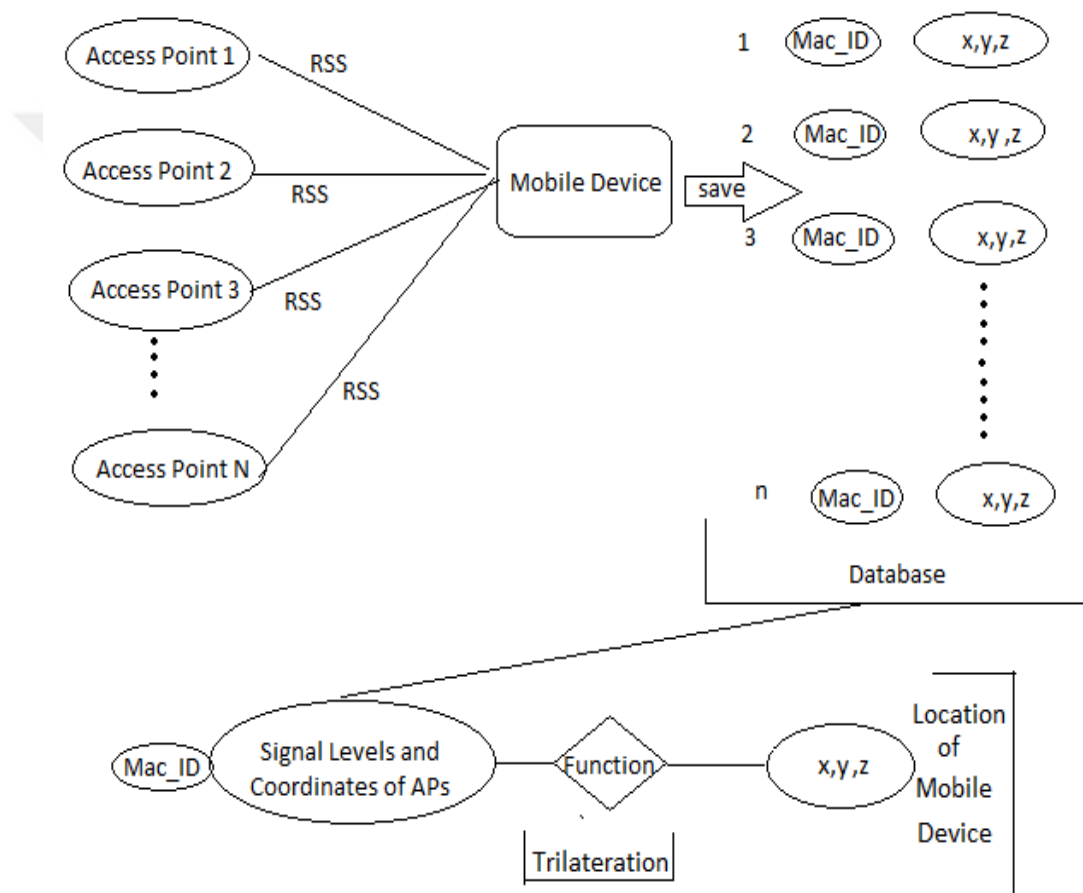
Figure 3.7: The working principle of application

Figure 3.7 shows the working principle of thesis application. According to this principle, the location of the mobile device is found with the multilaretation function.

CHAPTER 4

IMPLEMENTATION OF APPLICATION

There are two steps for indoor positioning application. The first step is to the find coordinates of Wi-Fi APs. The second step is to locate using the signal strengths and coordinates of the APs with multilateration function. Figure 4.1 summarizes the application.
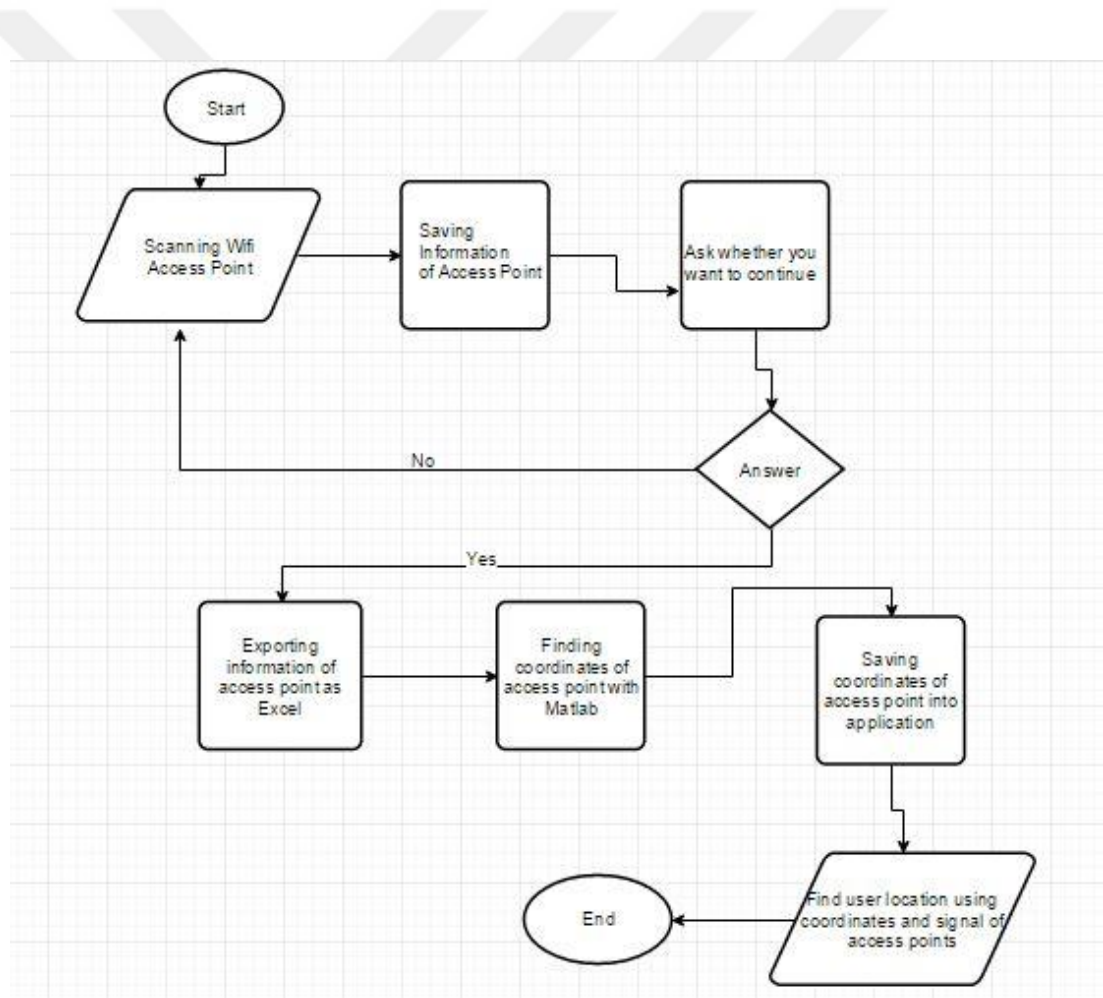
Figure 4.1: Flow chart of indoor positioning system

4.1. Finding Coordinates of Wi-Fi Access Points

The technologies used to locate the Wi-Fi APs are SQLite, MATLAB, and Java for the Android programming language. Android Studio is used as the program, but it can be used in Eclipse. There are advantages and disadvantages for each. However, Android Studio has more advantages than Eclipse, so it is preferred for the Android application. The coordinates of measuring points, taken signal strength and mac-id from these points are needed for MATLAB operations.

The choice of place for the application needs to be decided first. For this thesis, the three-storey section of Çankaya University, which is called the common area, was determined as the measurement area. First, the Wi-Fi APs have been scanned, and it was determined whether there was enough of an AP. Wi-Fi locations are marked and coordinates are set on the sketch (see Figure 4.2) to confirm after the application. The strategic points to be measured in this area have been determined. These points are defined as points in the middle of the building. With critical obstacles on the corner and obstacles in the front, Wi-Fi signals are less common .
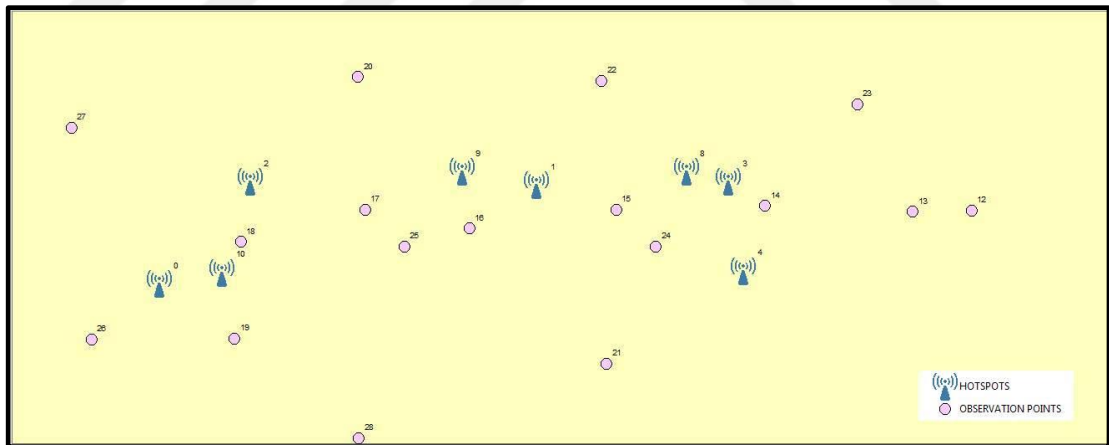
Figure 4.2: Observation points and visible Wi-Fi APs of environment

The common area of Çankaya University is illustrated in Figure 4.2. There are strategic points of measurement and visible Wi-Fi APs. When the Wi-Fi scan is done, it is understood that there are many more APs.

An Android application was developed that allows measurement results to be retrieved before in MATLAB calculations. This application is called "Thesis Application." SQLite is used as database. SQLite is a database library that is very simple to use and install. This database does not provide an outsourced service like the other databases; instead, it only records the information contained in the smart device being measured. The information of the same application loaded on another device is not visible by a second device. There is no installation or configuration steps as SQLite does not need any server for its operation. There are text, numeric, integer, and real and none data types supported by SQLite database. For this application, only the information of the MPs is needed, so that SQLite does not require extra cost and effort, which is preferred.

Figure 4.3: First page of application in first stage

Figure 4.3 is the first page of the application. The first step is to register the coordinates of the MPs when the application is installed. These coordinates can be seen on the application after they are entered, or they can be deleted from the tables if they are entered incorrectly. Each AP is given an ID. This ID is then used as the

primary key when saving the measurement results. The aim is to know from which Wi-Fi APs come information and provide convenience when calculations are made in MATLAB. After recording the coordinate information, the measurement is started. The information of coming all Wi-Fi APs from the MP is recorded. The signal strength is measured as decibel (dB). Wi-Fi signal strength is generally negative, because this value represents free space path loss. It means that as the signal level increases, the path loss decreases

The Wi-Fi APs used in the second stage are filtered according to the signal strength level, but the more precision coordinate value is obtained if there are more data to find the coordinates in the first step. Before signal strength measurement, if Wi-Fi is not enable, Wi-Fi is turned. Using Android's WifiManager API, the device will scan all available connections it can detect. The scanned information is saved in the database (Figure 4.4). The measurement results obtained are continued until the "End Measurement" command. If the measurement is made on more point, the more accurate coordinates are find.

Figure 4.4: Wi-Fi scan and save results

These measurement results can be seen in practice, or they can be deleted from the application for further measurement. The tables generated in the database are transferred to Excel and results are used in MATLAB. The sample spreadsheets from the Android app are provided in Tables 4.1 and 4.2. Figure 4.5 shows ER diagram of application.
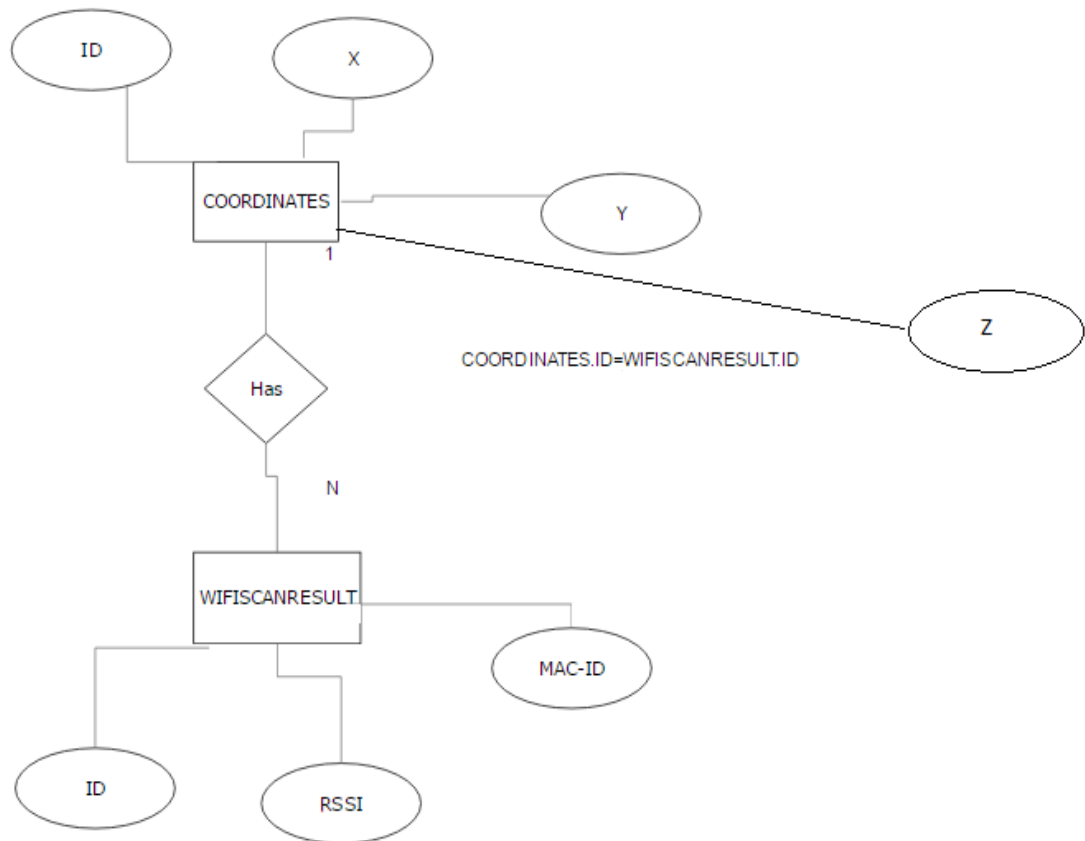
Figure 4.5: ER diagram of database

Table 4.1: Measuring Points and Access Point Information from those Points

ID	RSSI	MAC-ID
1	-53 dbm	2c:41:38:f1:04:60
1	-76 dbm	2c:76:8a:f6:dc:00
1	-68 dbm	00:0f:66:c9:c8:fb
2	-41 dbm	2c:41:38:f1:04:60
2	-73dbm	2c:76:8a:f6:dc:00

Table 4.2: Measuring Points Numbering and Coordinates

ID	X	Y	Z
1	1199,02	995,60	1,6
2	1191,30	995,39	1,2
3	1120,15	998,45	1,5

After this application was developed, it was compared with the previous Android-based Wi-Fi analysis program. This program is found at Google Play Store and is called "Wifi Analyzer (open-source)" [9]. Signals received at the same points were recorded in both applications. Similar results were obtained when signal strengths were compared (see Table 4.3).

Table 4.3: Signal Strengths on Wifi Scanner and Wifi Analyzer Software

Access Point	Software	Measurement Point 1	Measurement Point 2	Measurement Point 3
1	Wifi Analyzer	-52 dB	-53 dB	-57 dB
	Thesis Application	-52 dB	-55 dB	-55 dB
2	Wifi Analyzer	-50 dB	-49 dB	-52 dB
	Thesis Application	-50 dB	-49 dB	-55 dB
3	Wifi Analyzer	-51 dB	-60 dB	-62 dB
	Thesis Application	-55 dB	-60 dB	-64 dB
4	Wifi Analyzer	-49 dB	-47 dB	-56 dB
	Thesis Application	-47 dB	-48 dB	-54 dB

The same applications have been tried on different Android-based devices. These studies showed that there were differences between signal strengths even though measurements were made at the same spot (see Table 4.4).

In particular, the signal strength is lower in older android devices. A detailed table appears in Appendix A.

Table 4.4: Signal Strength for Different Android-based Devices

Access Point	Receiver	Software	Measurement Point 1	Measurement Point 2
1	GT-N5110	Wifi Analyzer	-61 dB	-56 dB
	Z3 Dual		-52 dB	-64 dB
	SM-T532		-52 dB	-53 dB
2	GT-N5110	Wifi Analyzer	-50 dB	-51 dB
	Z3 Dual		-51 dB	-62 dB
	SM-T532		-50 dB	-49 dB
3	GT-N5110	Wifi Analyzer	-60 dB	-58 dB
	Z3 Dual		-53 dB	-59 dB
	SM-T532		-51 dB	-60 dB

In addition to this work, signal measurements were taken from the same distances from hotspots of the same brand. Signals were received separately at distances of 5, 10, 15, 20, 25, and 30 meters. While the same signals are expected at the same distance for the same brand hotspots, different signal strengths came from each other. (Appendix B)

4.1.1. MATLAB calculations

The coordinates of measuring points, taken mac-id and signal strength leaves from measuring points are needed for MATLAB calculations. With the Android application, measurements were made at 17 different points and a total of 561 mac-id and signal strength values were drawn from these points. These results are transferred to Excel and this Excel file is read by MATLAB. Because the number of Wi-Fi APs at the end of the measurement is too large, filtering is required. After reading the Excel file, it is understood that 137 different unique mac-id.

To find a value very close to the true value of the location of the coordinates of the APs, it was deemed appropriate to have more than 5 points of information of the same AP, and the AP information of more than 5 points was recorded in an empty matrix. This matrix is called the unique ssid matrix. After this filtering, the data of 37 different APs are added to the unique ssid matrix. There are mathematical formulas that should be applied after all these data are recorded.

$$\begin{bmatrix} f(RSS_1) \\ f(RSS_2) \\ \vdots \\ f(RSS_n) \end{bmatrix} = \begin{bmatrix} 0 & d_{X1}d_{y1}d_{z1} & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & d_{zn} \end{bmatrix} \begin{bmatrix} x_{ssid1} \\ y_{ssid1} \\ z_{ssid1} \\ \vdots \\ z_{ssidn} \end{bmatrix} \tag{4.1}$$

$$L_{n,1} \qquad\qquad A_{n,3n} \qquad\qquad X_{3n,1}$$

Where n is the number of unique Wi-Fi APs referred to in 5 or more than 5 results from the end of the measurement in Eq. (4.1). The value of n is 37 for this application.

f(RSS) is the distance between Wi-Fi AP and MP [10]. The taken signal power from the Wi-Fi AP is converted to the distance in meters. RSS is received signal strength of Wi-Fi AP. $f(RSS_1)$ is to convert the taken first unique ssid signal level as dbm to the distance as meters in Eq. (4.2). The formula for this is as follows:

$$f(RSS) = 100 * 10^{\left(\frac{27.55-(20log_{10}(frequency)+|RSS|)}{20}\right)} \tag{4.2}$$

The frequency in this form is recorded while taking information of the Wi-Fi APs and is used during the distance finding function, but in general the frequency of most APs is 2412. For each unique ssid, this formula is applied and it is filled in the L matrix.

To fill the inside of matrix A, firstly, matrix B consisting of 0 is defined. The size of this matrix is 1,3n because there are three coordinate values as x, y, and z for an AP. B matrix will form the columns of the A matrix. The distance from the MPs to the coordinates of the APs is placed in the matrix B as approximate value.

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For this, the AP coordinate values are regarded "0" as approximate value and the formula of Taylor series is applied to find this value.

$$f_1 = \sqrt{(x_{ssid1} - x_P)^2 + (y_{ssid1} - y_P)^2 + (z_{ssid1} - z_P)^2} \qquad (4.3)$$

In Eq. (4.3):

x_{ssid1}, y_{ssid1}, z_{ssid1} = The x, y and z coordinates of Wi-Fi APs are assumed as 0.

x_P, y_P = They are the coordinates of the point P. The value of P is the value of the point at which the ssid1 value is obtained. A total of 17 measurements were made, P is a value between 1 and 17.

$$d_{X1} = (x_{ssid1} - x_P) \div f_1$$
$$d_{y1} = (y_{ssid1} - y_P) \div f_1 \qquad (4.4)$$
$$d_{z1} = (z_{ssid1} - z_P) \div f_1$$

In Eq. (4.4);

d_{x1}, d_{y1} and d_{z1} are the values obtained at the end of Taylor series expansion. The ssid values of all APs are compared to the unique ssid values. If the ssid value in the loop is one of the unique ssid values, then the index in the unique ssid matrix is found. If this index value is denoted as a, the index "3 * a-2" of the matrix B is set d_{x1}, the index "3 * a-1" of the matrix B is set d_{y1} and the index "3 * a" of the matrix B is set d_{z1}

$$B = \begin{bmatrix} 0000d_{X1}d_{y1}d_{z1}0000 \dots \dots \dots \dots \dots \dots 0 \end{bmatrix} \qquad (4.5)$$

The matrix B for a unique ssid looks like Eq. (4.5). Matrix B forms the columns of the matrix A. All of these operations are repeated for each unique ssid and in each case the matrix B is again defined as a matrix of 0's, the filled matrix B is added as the next column of the matrix A (see Eq. (4.6)).

The resultant matrix A in dimension n, 3n is:

$$A = \begin{bmatrix} 0 & d_{X1}d_{y1}d_{z1} & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & d_{zn} \end{bmatrix} \tag{4.6}$$

As a result of applying all these formulas, the L and A matrices are known values. The values of the matrix X can be found with these information and the values of the matrix A are the coordinates of Wi-Fi APs (see Eq. (4.7)).

$$L = A * X \tag{4.7}$$

To find the matrix X, use the Eq. (4.8):

$$X = (A^T A)^{-1} A^T L \tag{4.8}$$

The name of this function is the least squares method. A^T is transpose of matrix A. It is the matrix formed by the displacement of rows and columns of matrix A. This matrix can be found easily with the command " A' " in MATLAB. A^{-1} is the inverse of matrix A, which is easily found in MATLAB with the inv (A) command.

Finally, this function is applied to find the values in matrix X and the values in this matrix are used during the indoor positioning using the signal of the Wi-Fi APs.

4.2. Indoor Positioning Using Wi-Fi Signals

The second step of the application is to find the location of the device that is measured with the multilateration function using indoor Wi-Fi AP signals. At this stage, the information that needs to be known is the x, y, and z coordinates, mac-id and signal strength levels of the Wi-Fi APs, and the sketch of the environment. In the first stage, the coordinates of Wi-Fi APs and mac-id information were accessed in the direction of the results and recorded in the database. At this stage, instantaneous Wi-Fi scanning is performed with the measured device and the scan results are compared to the APs in the database.

The signal levels of matching Wi-Fi APs and the coordinate information retrieved from

the database are sent to the multilateration function.

At the end of these calculations, the x, y, and z coordinates of location of the measured device are found. Because the coordinates of the sketch are known, marking on the sketch completes the positioning operation.

4.2.1. Calculations for indoor positioning

The coordinates and mac-ids of the APs obtained from the MATLAB operations in the measurement environment are recorded via the application (see Figure 4.6). The purpose of recording through the application is to update or delete the wrong or incomplete information entered through the application. In addition, the coordinate information added for a single location only brings the application running in that environment, but if the information is entered through the application, it runs in all environments. The use of SQLite is also important in this respect.
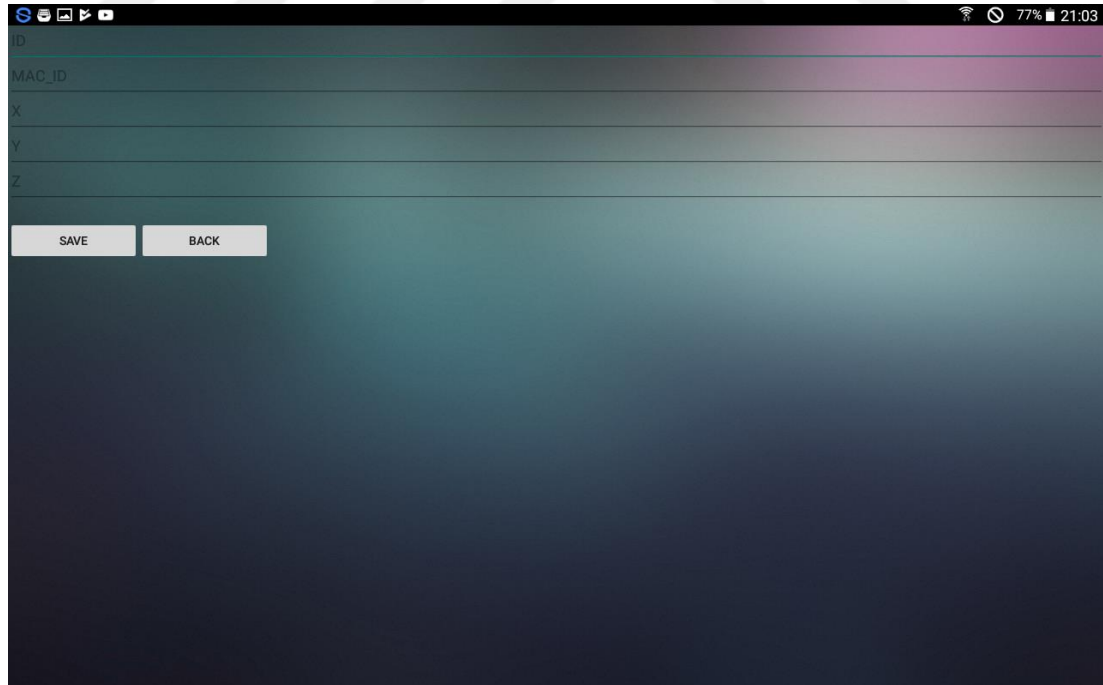
Figure 4.6: Screen of application for saving access point information

Table 4.5: Access Point Information Stored in the Database

ID	MAC-ID	X	Y	Z
1	2c:41:38:f1:cd:20	1092,26	985,96	5
2	00:0f:66:c9:c8:fb	1141,86	998,91	5
3	2c:41:38:f1:e2:40	1104,14	999,38	8,5
......	....	....	....	....

An example of the APs recorded in Table 4.5 is shown. After all of the Wi-Fi APs are registered in database, indoor positioning operation can be started. The sketch of the environment is installed on application.

To find a location, the first thing is to do an instant Wi-Fi hotspot. The mac-ids of the Wi-Fi APs obtained are compared with the mac-ids of the APs registered in the database.

Table 4.6: Access Point Information Obtained as a Result of Instant Scan

SSID	BSSID (MAC-ID)	LEVEL (RSSI)
CANKAYA	2c:41:38:f1:cd:20	-53
CANKAYA	2c:41:38:f1:e2:40	-68
CANKAYA	34:12:98:0c:c7:8a	-91
....	....	....

Mac-ids are compared in Tables 4.5 and 4.6. The signal levels obtained at the scan result of the same APs, and the stored coordinates as x, y, and z in the database

are dropped into an empty array.

After this step, multilateration function is applied together with the information in the array. The multilateration function is to apply trilateration function several times. Trilateration uses 3 different AP information to find the location. However, if the APs obtained are more than 3, trilateration method is applied separately for each. In doing so, the 3-point combination of Wi-Fi APs is sent to this method one by one. The result is returned from the trilateration method up to the 3-point combination of Wi-Fi APs.

For example, when Wi-Fi APs are scanned, if 5 of the APs obtained are considered to have matched with APs mac-ids in the database, then the trilateration method works as much as the combination of 3 of 5 (see Eq. (4.9)).

$$C(5,3) = 5! / (3!*2!) = 10 \qquad (4.9)$$

Assume there is an array of Wi-Fi APs named P. The type of this array is a method created in the algorithm section that contains the x, y, and z coordinates. The contents of the P array are sent to the trilateration method with a sequence in a loop. Firstly, P[0], P[1], P[2] are sent to trilateration method, then P[0], P[1], P[3] and continue, respectively. The results from this are stored in the result array, which is as large as the number of combinations. In the trilateration method, the x, y, and z coordinates of Wi-Fi APs and signal level strength at the MP are used. The signal strength is in dB and is converted to distances in centimeters or meters by formulas. The intersection of the circles providing indoor localization finds location of user with these distance. However, because the multilateration method is applied, more than one result will be returned. All results add an empty coordinate array as x, y, and z. Then, the average of these coordinates in coordinate array will give the location of the device. If this value is not invalid, the position finding process is completed by marking with the coordinate information of location of user on the environment sketch in the application.

Figure 4.7 shows the menu of application, while Figure 4.8 shows the MP on the sketch. Figure 4.9 shows the sequence diagram of the thesis application.
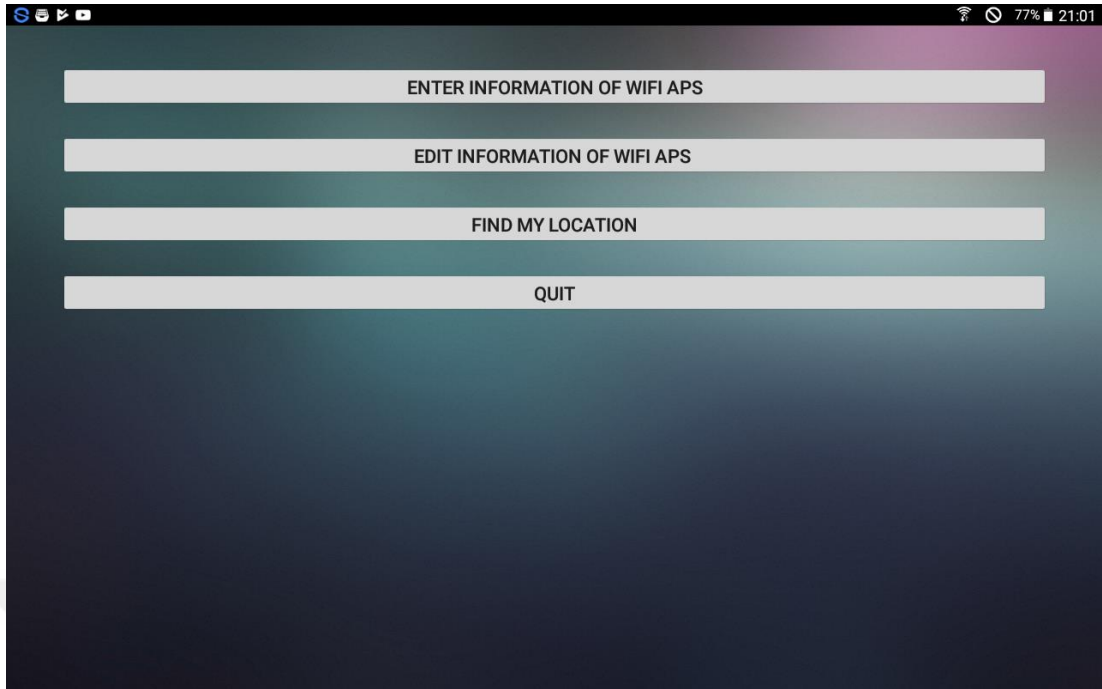
Figure 4.7: Application menu
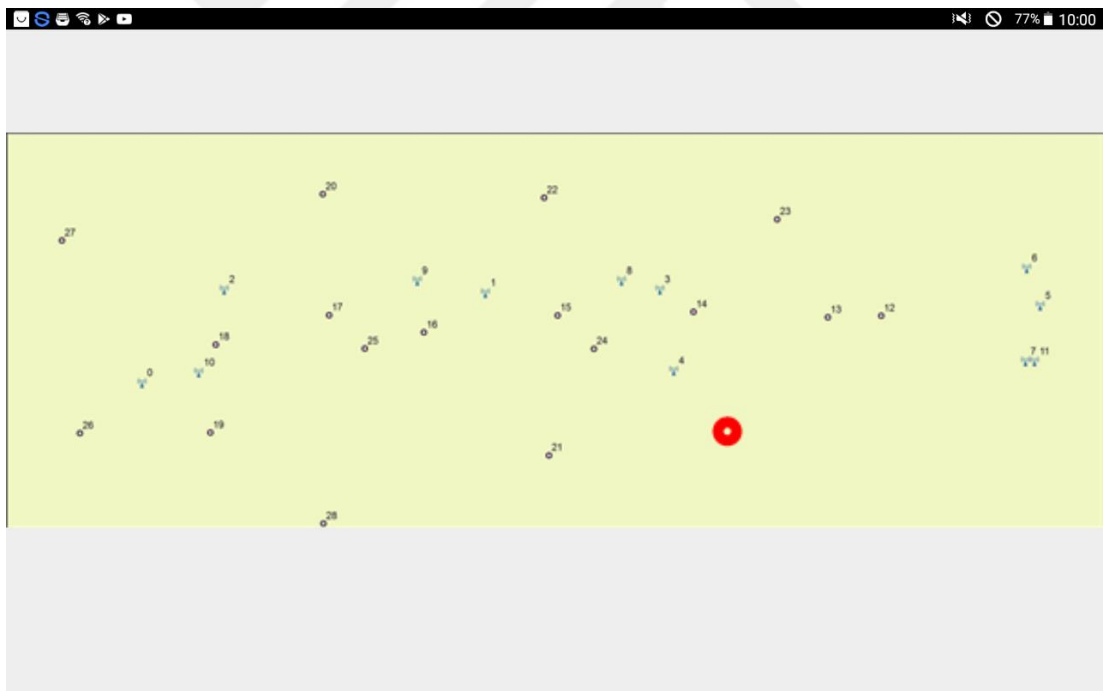
Figure 4.8: Indoor positioning using Wi-Fi signals
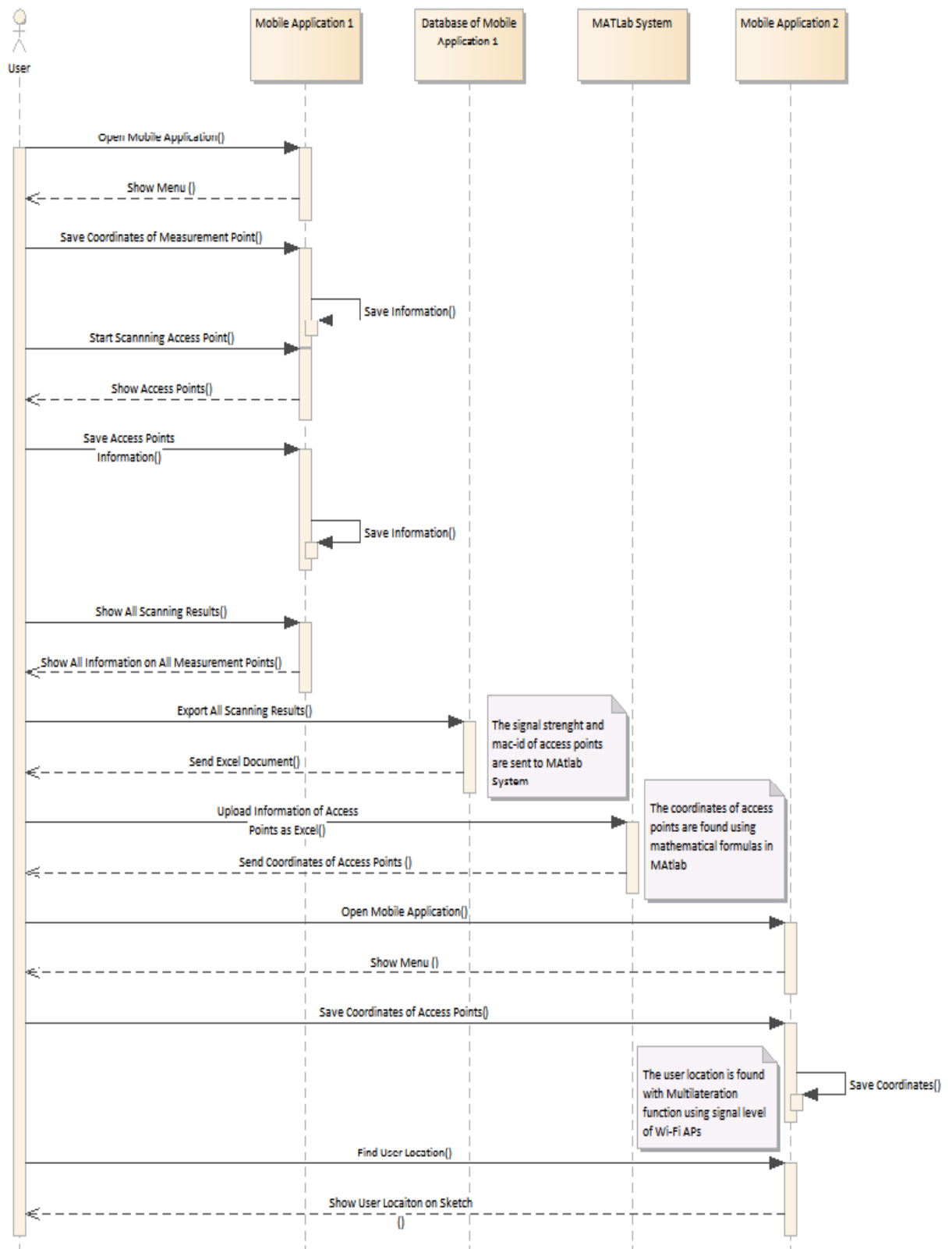
Figure 4.9: Sequence diagram of application

In addition to all of these, the indoor positioning algorithm again works in the background of the application as it walked. There are three methods to do this:

- Constant Time
- Constant Distance
- Consecutive

The Android program sometimes runs slow. The mixed calculations can occur because the work done in the background of application and can take longer than constant time. Much processing are required on the background of application for constant distance, and the application can slow down. For this reason sequential calculation was preferred. When an indoor positioning algorithm finishes, the new one runs.

CHAPTER 5

RESULTS

There are two functions for indoor positioning application. The first function is to find coordinates of Wi-Fi APs. The signal strengths of the APs obtained as a result of the Wi-Fi scanning and the coordinates of the places where the measurements are made are needed to determine this. Unique id and signal level of Wi-Fi APs with an Android application are recorded, and these values are also used in MATLAB to determine the coordinates of Wi-Fi APs.

These formulas are detailed above under the heading "*MATLAB Calculations*," according to these formulas, the results were found. In order to understand if these formulas work correctly, the coordinates of visible Wi-Fi APs in measurement environment were measured manually. There are a total of 12 visible Wi-Fi APs in the measurement environment. Eight out of these 12 points were shown, but others did not appear in the measurement results at 17 different points. Because there may be walls or other obstacles blocking the reception of these 4 signals, work has been done with only the remaining eight Wi-Fi APs. Some differences have come to the fore between the coordinates obtained by the manual measurement of these eight and the measurements obtained by the MATLAB calculations.

The distance between coordinates of known Wi-Fi APs and the coordinates of the MPs was calculated to find reason of differences with formula of finding the distance between the coordinates as in Eq. (5.1).

$$d_1 = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \qquad (5.1)$$

Where d_1 is distance, x_1, y_1 and z_1 are coordinates of MPs, x_2, y_2 and z_2 are coordinates of known Wi-Fi APs in Eq. (5.1).

Secondly, by using the signal levels of known Wi-Fi APs taken from the measuring points, the distance was calculated with finding distance formula (Eq. (5.2)) using signal level of Wi-Fi APs.

$$d_2 = 100 * 10^{\left(\frac{27.55 - (20log_{10}(frequency) + |RSS|)}{20}\right)} \qquad (5.2)$$

Where d_2 is distance, RSS is received signal strength from known Wi-Fi APs, frequency is frequency of known Wi-Fi APs, and general frequency is 2412. Under normal circumstances, d_1 and d_2 should have been very close together. d1 and d2 are the results in meters (see Table 5.1).

Table 5.1: Comparing Found Distances with Signal Strengths (SS) and Coordinates

Measurement	AP1		AP2		AP3	
Points (MP)	Coordinates (d1)	SS (d2)	Coordinates (d1)	SS (d2)	Coordinates (d1)	SS (d2)
MP1	110.1	107.2	99.1	104.6	80.4	74.3
MP2	57.6	24.9	49.1	22.5	30.2	15.3
MP3	95.5	96.1	29.6	19.2	15.1	19.4

If the distance calculated by the signal level is fur from the distance calculated by the coordinates, there may be a wall or barrier that affects the signal strength. If it is closer, it can be a condition that causes the reflection of the signals. Another and most important reason is that distances do not increase at the same rate as signal levels decrease. For example, when the signal level is between -60 dB and -61 dB, the distance is 2 meters, but when the signal level is between -80 dB and -81 dB, the distance is 13-14 meters. It is a very serious distance for the indoor environment. The Wi-Fi manager API is used for signal measurement in the Android-based app. The signals received at this API are sent in integer type. Therefore, full number is coming. All signal strengths were used if decimal numbers were sent.

The code used in API is as follows:

```
public static int calculateSignalLevel(int rssi, int numLevels) {
    if (rssi <= MIN_RSSI) {
        return 0;
    } else if (rssi >= MAX_RSSI) {
        return numLevels - 1;
    } else {
        float inputRange = (MAX_RSSI - MIN_RSSI);
        float outputRange = (numLevels - 1);
        return (int)((float)(rssi - MIN_RSSI) * outputRange / inputRange);
    }
}
```

It is a wrong approach to convert to the integers in the sending phase and the code should be developed. Because the code in the API is not touched, at most 3 meters can be overlooked for the indoor environment. Therefore, the signal levels that is smaller than -70 dB is unvalued.

The measurement was done with signal levels greater than -70 dB again, and the close results to calculated distances with coordinates were found. The formulas in MATLAB are more correct.

The second capability is to find the location of the device being measured, using the coordinate information of the found Wi-Fi APs with MATLAB functions. Wi-Fi scanning was done again, unique id of registered Wi-Fi APs was compared to unique id of scanned Wi-Fi APs, if the signal levels of matched Wi-Fi APs are greater than -70 dB, using coordinates of these APs, the location of device was found with Multilateration method. Because the previously measured points were marked on the used sketch (see Figure 4.2), it was more readily understood whether or not the correct position was found. The positions found were not close to the correct position and the accuracy the percentage was not good (Table 5.2).

Table 5.2: Comparing Actual and Found Coordinates

Measurement Point	Actual Coordinates		Found Coordinates	
	x	y	x	y
1	1199,02	995,60	990,85	881,45
2	1191,30	995,39	2125,45	932,32
3	1171,90	996,16	1100,1	895,87

The results of this study in the common area of Çankaya University were not close to the actual results, and it has been observed there are distant slips from the actual results at some points. The results were not very accurate. The reason for this was that there were no equal signal coming from the Wi-Fi APs in environment due to interference and signal reflections. Studies were conducted in different environment to test the validity of the methods used.

The gymnasium in Cankaya University Balgat Campus was chosen as the trial environment where signal reflections and obstacles are not much. The necessary equipment was installed here for measuring. Ten Wi-Fi APs were set (Figure 5.1).
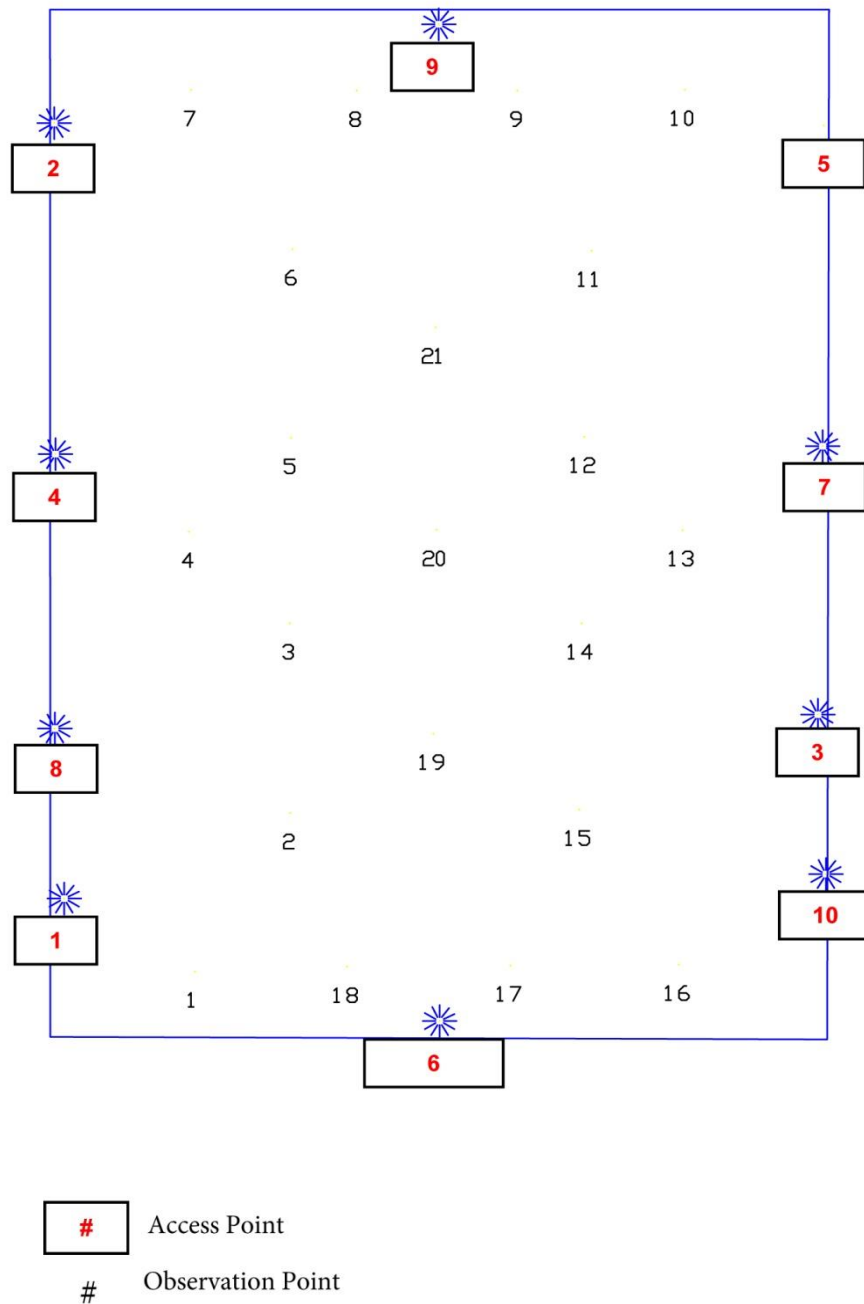
Figure 5.1: The Xystus of Cankaya University Balgat Campus

The placement locations of these Wi-Fi APs were found as x, y, and z coordinates. These coordinates were found to look at their conformity to the calculated coordinates in MATLAB. Measurements were made at specified points and recorded in the database of the application (Table 5.3). In addition, coordinates of APs and specified points were saved (Table 5.4). Measurements were made at 21 different points. Three

MPs and three APs are given as examples in the tables (Table 5.3 and Table 5.4). d1 and d2 were found using Eq. (5.1) and Eq. (5.2). The results are shown in Table 5.5.

Table 5.3: Signal Strengths of Access Points (APs) at Different Measurement Points in Gymnasium

Measurement Point	AP1	AP2	AP3	…….
1	-48 dB	-46 dB	-50 dB	....
2	-46 dB	-44 dB	-49 dB	....
3	-46 dB	-42 dB	-50 dB	....
…..	……	……	……	……

Table 5.4: Coordinates of APs and Measurement Points (MPs)

APs and MPs	x	y	z
MP1	4.372	2.081	0.8
MP2	7.248	7.113	0.8
MP3	7.227	13.141	0.8
AP1	0.421	4.401	3.24
AP2	0.119	29.041	3.43
AP3	23.176	10.246	3.28

Table 5.5: Comparing Found Distances with Signal Strengths (SS) and Coordinates Points in Gymnasium

Measurement Points (MP)	AP1		AP2		AP3	
	Coordinates (d1)	SS (d2)	Coordinates (d1)	SS (d2)	Coordinates (d1)	SS (d2)
MP1	5.19	2.48	7.74	1.97	11.3	3.12
MP2	27.4	1.97	23.20	1.56	17.61	2.68
MP3	119.1	1.93	115.99	1.2	116.01	3.06

The measurement made at point 3 is very different, the likelihood of reflections

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at this point is very high, but MATLAB calculations were done with the signals from the hotspots and the coordinates of all measuring points. Overall, more accurate results were obtained compared to measurements made in the common area of Çankaya University. In the second phase of the application, the Wi-Fi coordinates were recorded to application and the position of the device was found using the position finding algorithm. The locations here are more correct than the locations in the first trial environment. However, there were still shifts. Comparison of actual and found coordinates are shown in Table 5.6.

Table 5.6: Comparing Actual and Found Coordinates in Gymnasium

Measurement Point	Actual Coordinates		Found Coordinates	
	x	Y	x	y
1	4.372	2.081	14.23	17.41
2	7.248	7.113	12.04	17.73
3	7.23	13.142	11.95	14.68

The carpet field in the open area in Çankaya University was chosen as the trial area where the reflections would be even less to find the cause of this problem (Figure 5.2). After the necessary hardware installations, the same operations were repeated. The results are similar with the indoor sports hall. Measurements were made at 14 different points. Tables 5.7 and 5.8 show signal strengths and coordinates taken from the carpet field. In the carpet field, d1 and d2 were found using Eq. (5.1) and Eq. (5.2). The result are shown Table 5.9.
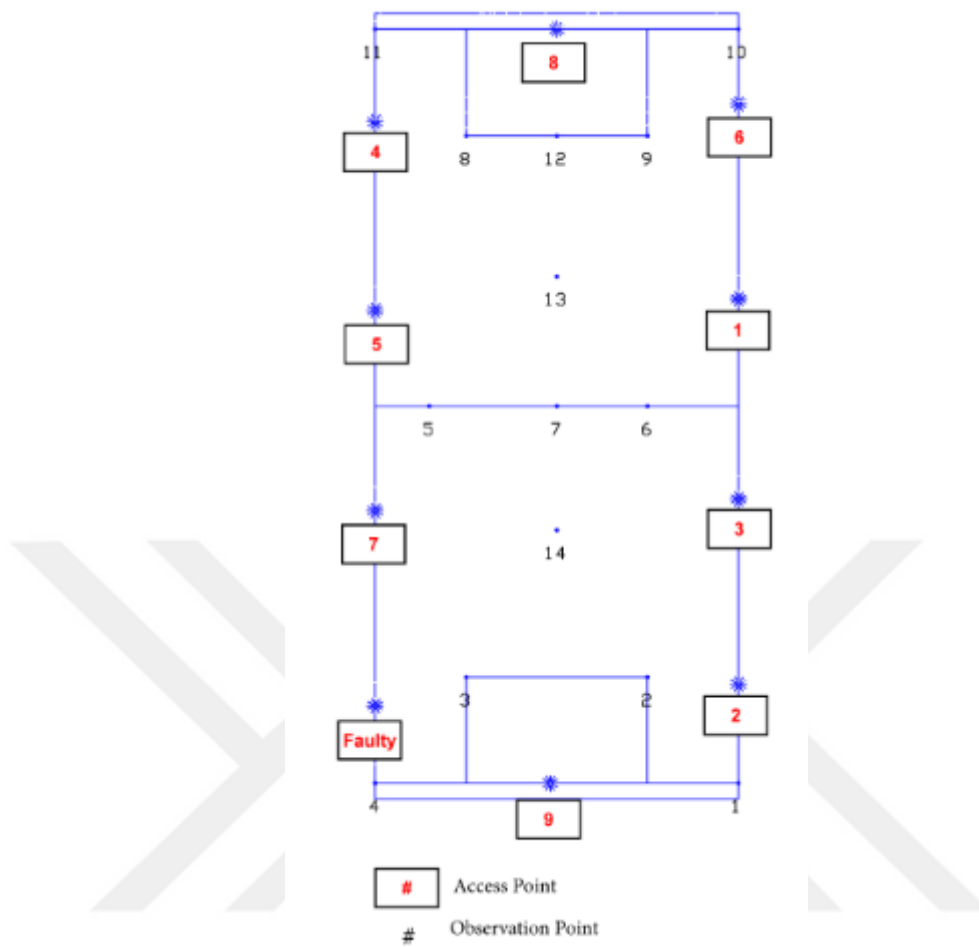
Figure 5.2: The carpet field on open area of Cankaya University Balgat Campus

Table 5.7: Signal Strengths of APs at Different Measurement Points in the Carpet Field

Measurement point	AP1	AP2	AP3	…….
1	-62 dB	-44 dB	-63 dB	....
2	-55 dB	-41 dB	-59 dB	....
3	-60 dB	-50 dB	-53 dB	....
…..	……	……	……	……

Table 5.8: Coordinates of APs and Measurement Points (MPs) of the Carpet Field

APs and MPs	x	y	z
MP1	23.15	1	0.9
MP2	17.35	7.75	0.9
MP3	5.8	7.75	0.9
AP1	23.15	31.83	2.45
AP2	23.15	7.43	2.45
AP3	23.15	19.08	2.45

Table 5.9: Comparing Found Distances with Signal Strengths (SS) and Coordinates Points in the Carpet Field

Measurement Points (MP)	AP1		AP2		AP3	
	Coordinates (d1)	SS (d2)	Coordinates (d1)	SS (d2)	Coordinates (d1)	SS (d2)
MP1	30.86	12.44	24.81	1.56	29.71	13.96
MP2	6.61	5.56	6.02	1.11	17.42	8.81
MP3	18.14	9.68	12.82	3.06	20.77	4.32

Table 5.10: Comparing Actual and Found Coordinates in the Carpet Field

Measurement Point	Actual Coordinates		Found Coordinates	
	x	Y	x	y
1	23.15	1.0	13.36	28.8
2	17.35	7.75	17.31	24.56
3	5.8	7.75	12.81	21.85

The detailed table of the signals received from the indoor sports hall and the carpet field are in Appendix C. Figures 5.3 and 5.4 show differences between real coordinates and calculated coordinates.

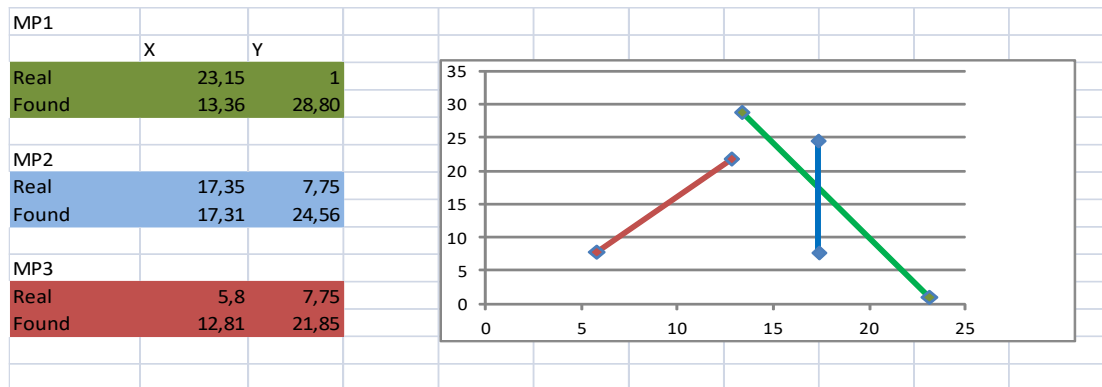| MP1		
	X	Y
Real	23,15	1
Found	13,36	28,80
MP2		
Real	17,35	7,75
Found	17,31	24,56
MP3		
Real	5,8	7,75
Found	12,81	21,85

Figure 5.3: Differences between real and found coordinates in carpet field

MP1		
	X	Y
Real	4,37	2,08
Found	14,23	17,41
MP2		
Real	7,248	7,11
Found	12,04	17,73
MP3		
Real	7,23	13,14
Found	11,95	14,68
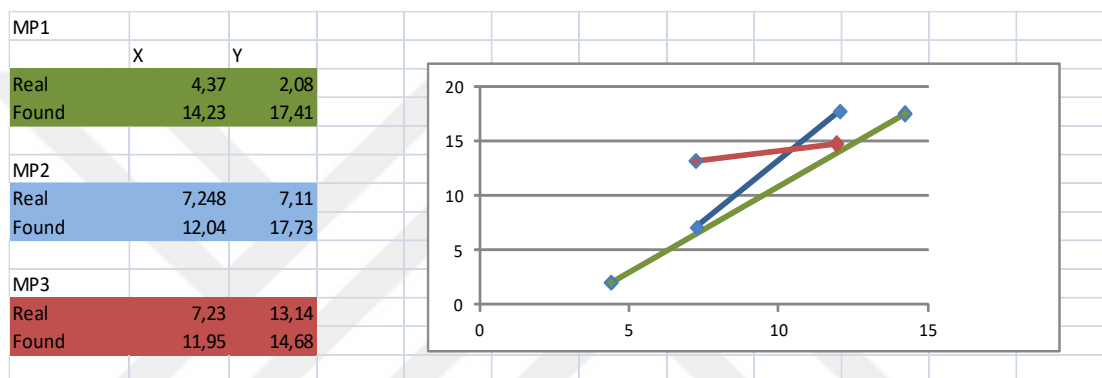
Figure 5.4: Differences between real and found coordinates in closed sport hall

When all of these results are examined, different results are obtained from the actual results. The environments chosen as the trial environment were mediums with a size of up to 50 square meters. When the previous studies were examined, it was observed that the selected environments were smaller environments. Because of the feature of the Wi-Fi module used, it is not possible to change the RSSI value when the distance is less than 2 meters and more than 12 meters [11]. However, indoor positioning should usually be a work to be used in large areas.

According to the results obtained from these trial environments, it is likely that a remote Wi-Fi APs may appear closer, because the signal strength from Wi-Fi will not change same rate for very large environments so the possibility of incorrect results increases. The correctness of the solution methods was seen in studies conducted in

trial environments, but the size of the trial environments was effective in generating the results. If this method is used in a bigger area and it is desired to increase the usage area, then new methods should be added to these methods, or Wi-Fi locations must be set with special strategies. Because of the different signals even from hotspots of the same brand, every hotspot in the environment must be added to formulas that use their own behavioral patterns.

In an empty field, the found meters with the signals (Appendix B) from the measurements made at 5, 10, 15, 20, 25, and 30 meters distance were compared with the actual meters. As a result, the polynomial coefficients for each AP were determined using the differences between these two meters, which were done with MATLAB using polyfit function. The name of this method is linear regression. At the same time, these actions included average of the measurements taken from different Android-based devices. In this case, the polynomial coefficients were determined by both the behavioral patterns of the APs and the behavior patterns of the Android-based devices.

To find the location on the device, these polynomial coefficients are added to the database with the coordinates of APs for each hotspot. These polynomial coefficients are also used in the formula that turns the signal to meter. Even if the brands of the hotspots are the same, arriving different signals at the same distances, the obligation of the finding polynomial coefficients was created. The fingerprints of each AP and different android-based devices were also added to the database. When a new hotspot is added to the environment again the calibration processes should be made for added hotspot. The polynomial coefficients are added to the distance calculated by the signal strength and real distances like Eq. (5.3).

$$d_3 = d_2 + d_1 * a_1 + a_0 \tag{5.3}$$

Where d_1 is real distance, x_1, y_1 and z_1 are coordinates of MPs, x_2, y_2 and z_2 are coordinates of known Wi-Fi APs in Eq. (5.1), d_2 is distance was calculated with finding distance formula (Eq. (5.2)) using signal level of Wi-Fi APs, and a_0 and a_1 are found polynomial coefficients from MATLAB using polyfit command. The locations are found using the distance information obtained from this Eq. (5.3) at the closed sports

hall and the carpet field with Trilateration method (Tables 5.11 and 5.12).

Table 5.11: Comparing Actual and Found Coordinates Using Polynomial Coefficients in Gymnasium

Measurement Point	Actual Coordinates		Found Coordinates	
	x	Y	x	y
1	4.372	2.081	7.32	2.64
6	7.31	25.03	8.62	18.72
11	16.35	24.98	12.72	17.74

Table 5.12: Comparing Actual and Found Coordinates Using Polynomial Coefficients in the Carpet Field

Measurement Point	Actual Coordinates		Found Coordinates	
	x	Y	x	y
1	23.15	1.0	11.03	11.35
6	17.35	25.0	18.41	28.54
7	11.58	25.0	15.31	32.41

Figures 5.1 and 5.2 show the MP of the indoor sports hall and the carpet scene. When Tables 5.11 and 5.12 are examined, the coordinates of the measurements made in the center of the environment are more accurate. For this reason, it is necessary to find a position within the environment. Measures made on the edge, in the corner may not give very accurate results. The accuracy rate is 0–10 meters according to the results obtained by fingerprinting method.
This ratio is a good for large environments.

The results in Tables 5.11 and 5.12 are shown in Figures 5.5 and 5.6 as images. The correctness of the coordinates is better understood in this picture.
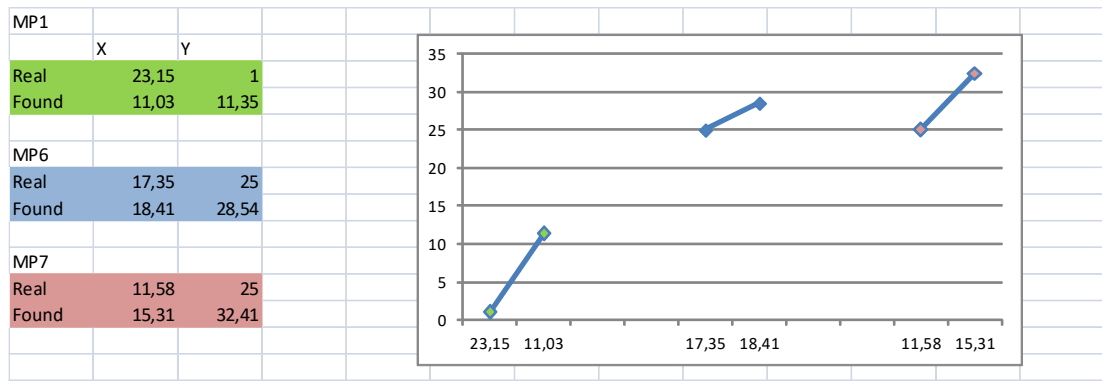
MP1				
	X	Y		
Real	23,15	1		
Found	11,03	11,35		
MP6				
Real	17,35	25		
Found	18,41	28,54		
MP7				
Real	11,58	25		
Found	15,31	32,41		

Figure 5.5: Closeness between real and found coordinates in carpet field

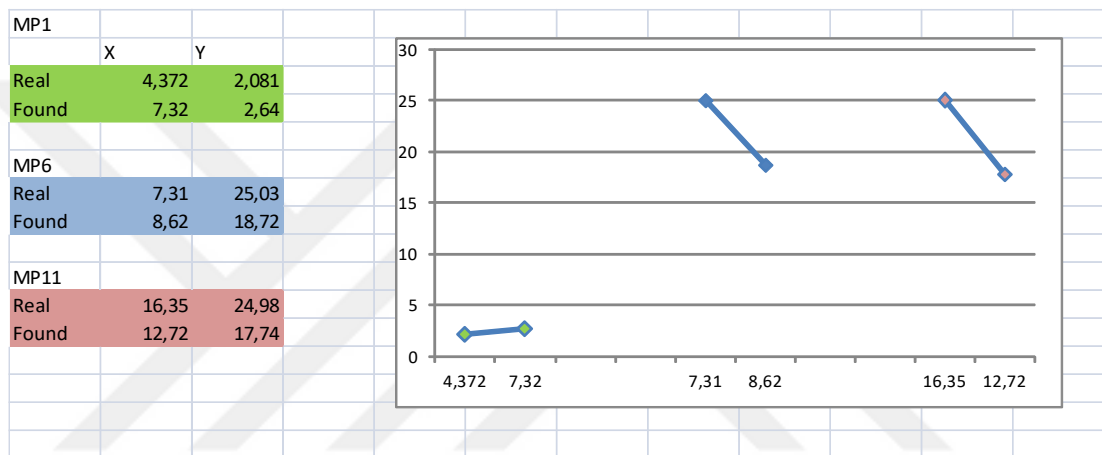| MP1				
	X	Y		
Real	4,372	2,081		
Found	7,32	2,64		
MP6				
Real	7,31	25,03		
Found	8,62	18,72		
MP11				
Real	16,35	24,98		
Found	12,72	17,74		

Figure 5.6: Closeness between real and found coordinates in closed sport hall

In addition, this thesis work has two applications, all of the screen displays of these applications are in Appendix D.

CHAPTER 6

CONCLUSION

In this thesis, the details of the indoor positioning technique using the signal strength of Wi-Fi APs and the application developed using this technique are mentioned. This thesis consists of two steps. The first step is to locate Wi-Fi APs in the room, and the second step is to make indoor positioning using the detected instantaneous signal levels and the coordinates of the Wi-Fi APs.

At the first stage, the points to be measured in the space have been determined and an application is improved for measurement. This application is an application that records the mac-id and signal level of the Wi-Fi APs received from the points to be measured until the measurement is completed. The Wi-Fi APs recorded in the database are exported in Excel format and are also read in MATLAB. How many unique points are there with the works done? At what points did these points reappear? The answers were found for these types of questions with MATLAB studies.

Filtering has to be done because there are too many unique Wi-Fi APs and some of them are difficult to reach coordinate information because they only appear in a few of the MPs. The Wi-Fi APs seen at 5 dots or over 5 dots were recorded again in an empty matrix and only the signal levels received from these Wi-Fi APs were used and the coordinates of these APs were obtained by calculations made in MATLAB. In addition, if the signal levels of Wi-Fi APs are smaller than -70 dB, the hotspots did not participate in the calculation.

In the second phase, a new application was developed and the database of this application was recorded with the mac-id and coordinate information of Wi-Fi APs

in the first stage. In addition, the sketch of the place is buried in the background.

In the background of the location discovery process, the instant Wi-Fi AP is scanned, the signal levels of those matching the APs stored in the database are converted to the distance in meters, then using the distance information and the coordinate information of the APs, the coordinates of device are found with trilateration method and fingerprinting and these coordinates are marked on the inserted sketch to give the user position information.

This is the general operating logic of the application. Three different test environments, two different software for Wi-Fi scanning, and five different Android-based devices have been used to obtain the results in the direction of this study logic. One Wi-Fi scanning software is an application developed for the thesis, while the other is a pre-existing application. It was observed that different results were obtained on different software with two different Wi-Fi scanning applications and the polynomial coefficients were determined with the average of the signals from this two software was taken. It has also been observed that the signals change according to devices using different android based devices. The obstacles and reflections in test environments are the factors that affect the signal.

An application has been developed to find locations on the map. However, it is necessary to add the fingerprints of the hotspots to the database before running the application, because different signals even from hotspots at the same distance are coming. Thus, it is necessary to carry out calibration work in free space to determine fingerprints specific to the hotspots in the environment. The polynomial coefficients of each hotspot are also determined by the polyfit command in the MATLAB. These coefficients are also added to the formula that is converted to meter from signal. The coordinates of APs and fingerprint information registered in the database were used for location discovery with the trilateration method. As a result of these operations, sensitivity ranges from 0–10 meters were obtained. Initially, it was stated that the aim of this study was to find a position with sensitivity between 0 and 5 meters. Because of the results of the tests, this result was close it.

CHAPTER 7

FUTURE WORKS

In this thesis, details of indoor positioning using the signal levels of Wi-Fi APs that do not require the extra hardware that is thought to be the best solution and a developed application with this method are described. This technique has low cost and the accuracy is good, but the accuracy level may decrease as the signal strength level decreases when the APs are obstructed. In addition, calibration work is necessary for each hotspot. By combining different technical methods for solving this problem, studies can be made to find the perfect indoor positioning technique in every direction.

Another study could be to navigate by saving the map information to the system in this method where you find your own location. Similar studies have been done but those applications are only specific to a place. If map information is entered through the application, adaptive studies will emerge in each case. Using shortest distance finding algorithms can also lead to good work that offers navigation features.

REFERENCES

[1] H. Liu *et al.*, "Survey of Wireless Indoor Positioning Techniques and Systems," *IEEE Trans. on Systems, Man, and Cybernetıcs—Part C: Applications and Reviews, vol. 37*, no. 6, pp. 1067–1079, Nov. 2007.

[2] Özyeğin University, *Konum bazlı servisleri kapalı alanlarda kullanabilme ayrıcalığı ilk kez Özyeğin Üniversitesi'nde*, Basın Bülteni, 2013.

[3] "Avea'dan Rixos'a Özel Navigasyon Sistemi, Turistler Artık Otelde Kaybolmayacak," 2011 [Online]. Available: https://www.haberler.com/avea-dan-rixos-a-ozel-navigasyon-sistemi-turistler-3200946-haberi/. Accessed on: Nov. 19, 2011.

[4] B. Bobescu and M. Alexandru, "Mobile Indoor Positioning Using Wi-Fi Localization," *Rev. of the Air Force Academy, vol. 1*, no. 28, pp. 119–122, 2015.

[5] "Android'in kullanıcı sayısı ne kadar?" [Online]. Available: https://shiftdelete.net/androidin-kullanici-sayisi-ne-kadar-82011. Accessed on: Apr. 17, 2017.

[6] B. N. Özdemir *et. al.*, "KAPALI MEKÂNLARDA UYGULANAN KONUM BELİRLEME YÖNTEMLERİ VE KARŞILAŞTIRILMASI," presented at Harita ve Kadastro Mühendisleri Odası, Mühendislik Ölçmeleri STB Komisyonu7. Mühendislik Ölçmeleri Sempozyumu, Hitit Üniversitesi – Çorum, Oct. 15–17, 2014.

[7] K. Özsoy, *An Indoor Positioning System Based on Global Positioning System: Design, Implementation and Analysis*, 2009.

[8] Z. Farid *et. al.*, "Recent Advances in Wireless Indoor Localization Techniques and System," *J. of Comput. Networks and Commun., vol. 2013*, Article ID 185138, 12 pages, 2013.

[9] Wifi Analyzer (open-source), VREM Software Development 1.8.8, Google Play Store.

[10] M. Kuo, "Free-space path loss," 2011. [Online]. Available: https://michaelkuo8088.wordpress.com/2011/04/08/system-equations/. Accessed on: Apr. 8, 2011.

[11] T. Türkoral *et. al.*, *Alınan İşaret Güç Göstergesi (RSSI) Metriği Kullanılarak Kapalı Alan Mesafe Kestirimi,* Dokuz Eylül Üniversitesi, İzmir Kâtip Çelebi Üniversitesi, pp. 397–401, 2016.

[12] C. Feng *et. al.*, "Received-Signal-Strength-Based Indoor Positioning Using Compressive Sensing," *IEEE Trans. on Mobile Computing, vol. 11*, no. 12, pp. 1983–1992, Dec. 2012.

[13] J. Kwon, "Hybrid Algorithm for Indoor Positioning Using Wireless LAN," Inst. of Transportation Studies University of California, Berkeley and Depart. of Statist. California State University Hayward, California, pp. 4625–4629, 2004.

[14] Y. Gu *et. al.*, "A Survey of Indoor Positioning Systems for Wireless Personal Networks," *IEEE Commun. Surveys & Tutorials, vol. 11*, no. 1, pp. 13–31, 1st Quarter 2009.

[15] T. Lin and P. C. Lin, "Performance comparison of indoor positioning techniques based on location fingerprinting in wireless networks," presented at the 2005 Int. Conf. on Wireless Networks, Commun. and Mobile Computing, Taiwan, pp. 1569–1574, 2005.

[16] A. D. Valesco and S. M. Delgado, *Indoor Positioning Using the Android Platform,* Blekinge Inst. of Technol., 2014.

[17] C. Tunca *et. al.*, **"**Yapay Sinir Ağları ile WiFi Tabanlı İç Mekan Konumlandırma," Boğaziçi Üniversitesi, Bilgisayar Mühendisliği Bölümü, NETLAB, İstanbul, 2014.

[18] E. Demiral *et. al.*, "RFID sistemleri ile konum belirleme uygulamaları," presented at TMMOB Harita ve Kadastro Mühendisleri Odası, 14. Türkiye Harita Bilimsel ve Teknik Kurultayı, Ankara, Turkey, May 14–17 2013.

[19] B. B. Peterson *et. al.*, "Spread spectrum indoor geolocation*," J. Inst. Navigat.,* *vol. 45*, no. 2, pp. 97–102, 1998.

[20] A. Goldsmith, *Wireless Communications*, 1st ed. Cambridge University, 2005

[21] M. A. Youssef *et. al.*, "*WLAN location determination via clustering and probability distributions,*" presented at Proc. First IEEE Int. Conf. Pervasive Computing and Commun., pp. 143–155, 2003.

[22] K. Kaemarungsi and P. Krishnamurthy, *Properties of indoor received signal strength for WLAN location fingerprinting*, Proceeding of the First Annual Int. Conf. on Mobile and Ubiquitous Syst.: Networking and Service, 2004.

[23] R. Ballazhi, *Wireless Indoor Positioning Techniques, Communication Systems Seminar*, 2012.

[24] J. Werb and C. Lanzi, "Designing a position system finding things and people indoors," *IEEE Spectr. vol. 35*, no. 9, pp. 71–78, 1998.

[25] G. Yanying *et. al.*, "A survey of indoor positioning systems for wireless personal networks," *IEEE Commun. Surveys & Tutorials, vol. 11*, no. 1, pp. 13–32, 2009.

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WORK EXPERIENCE

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HOBBIES

Tennis, Movies watching

# APPENDIX A: SIGNAL STRENGTHS FROM THE DIFFERENT SOFTWARE

| Access Point | Receiver | Software | 10 | 15 | 20 | 25 | 30 |
| | | | 5m. | 10m. | 15m. | 20m. | 25m. | 30m. |
			Strength (dBm)	Strength (dBm)	Strength (dBm)	Strength (dBm)	Strength (dBm)	Strength (dBm)
INS_01	SM-T532	WIFI Analyzer	-52	-53	-57	-63	-68	-65
		Thesis Application	-52	-55	-55	-63	-70	-66
INS_02	SM-T532	WIFI Analyzer	-50	-49	-52	-56	-58	-59
		Thesis Application	-50	-49	-55	-56	-57	-59
INS_03	SM-T532	WIFI Analyzer	-51	-60	-62	-64	-75	-66
		Thesis Application	-55	-60	-64	-64	-74	-68
INS_05	SM-T532	WIFI Analyzer	-49	-47	-56	-56	-56	-60
		Thesis Application	-47	-48	-54	-57	-57	-61
INS_06	SM-T532	WIFI Analyzer	-50	-49	-54	-56	-60	-62
		Thesis Application	-48	-51	-55	-58	-60	-63
INS_07	SM-T532	WIFI Analyzer	-53	-58	-64	-61	-67	-70
		Thesis Application	-50	-59	-60	-63	-70	-68
INS_08	SM-T532	WIFI Analyzer	-29	-39	-45	-49	-51	-57
		Thesis Application	-30	-39	-45	-50	-53	-56
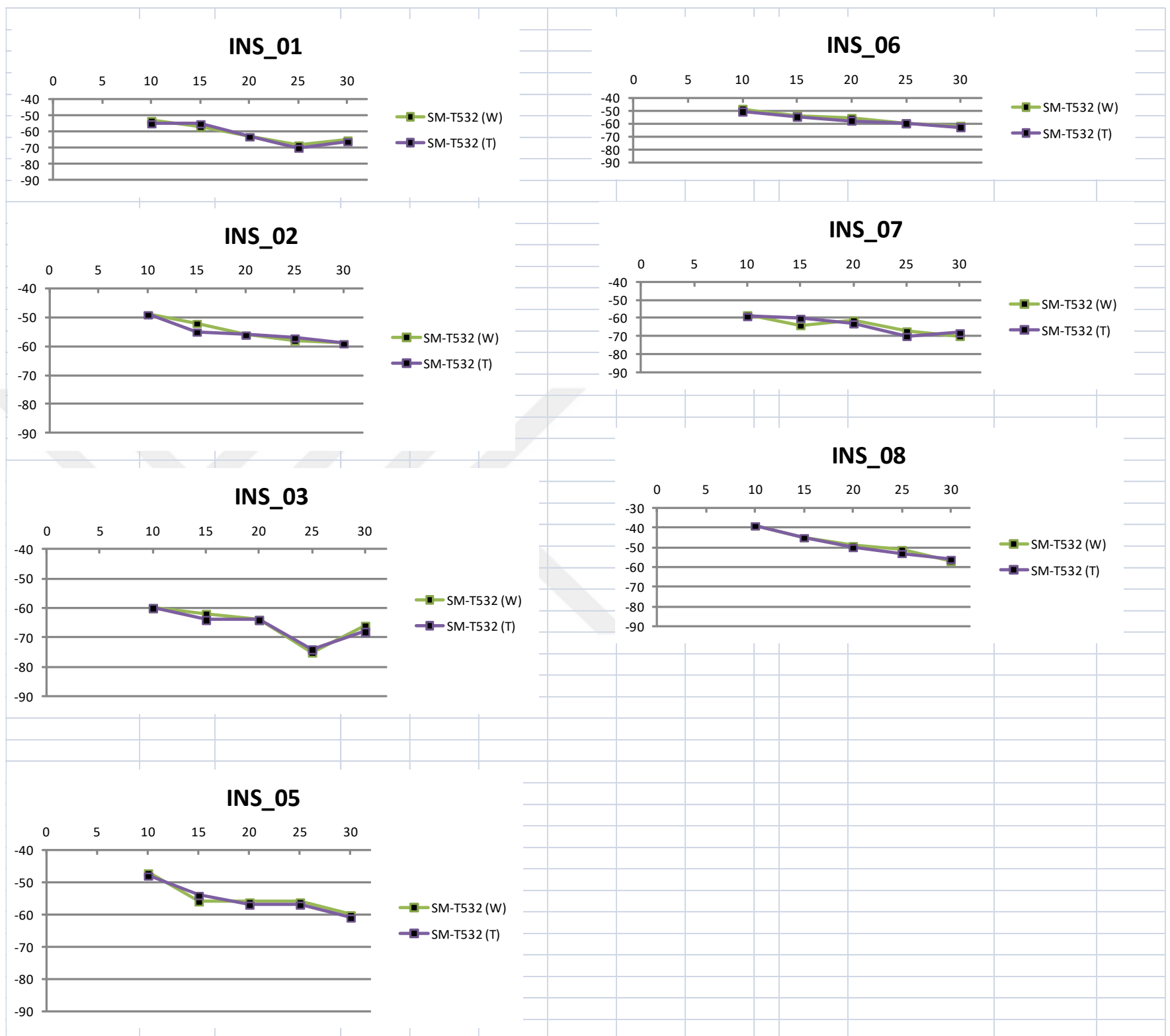
INS_01, INS_02 and others are names of the hotspots in the table displayed at the top of this page.

# APPENDIX B: SIGNAL STRENGTHS FROM THE SAME BRAND HOTSPOTS

Access Point	Receiver	Software	5m. Strength (dBm)	10m. Strength (dBm)	15m. Strength (dBm)	20m. Strength (dBm)	25m. Strength (dBm)	30m. Strength (dBm)
INS_01	GT-N5110	WIFI Analyzer	-61	-56	-60	-63	-71	-72
	Z3 Dual	WIFI Analyzer	-52	-64	-60	-68	-61	-63
	SM-T532	WIFI Analyzer	-52	-53	-57	-63	-68	-65
		Thesis Applicaton	-52	-55	-55	-63	-70	-66
	SM-T210	WIFI Analyzer	-66	-70	-82	-82	-76	-81
		Thesis Applicaton	-53	-57	-59	-61	-67	-63
INS_02	GT-N5110	WIFI Analyzer	-50	-51	-53	-59	-61	-63
	Z3 Dual	WIFI Analyzer	-51	-62	-63	-63	-61	-62
	SM-T532	WIFI Analyzer	-50	-49	-52	-56	-58	-59
		Thesis Applicaton	-50	-49	-55	-56	-57	-59
	SM-T210	WIFI Analyzer	-61	-72	-74	-76	-71	-74
		Thesis Applicaton	-49	-65	-58	-60	-64	-60
INS_03	GT-N5110	WIFI Analyzer	-60	-58	-60	-62	-70	-71
	Z3 Dual	WIFI Analyzer	-53	-59	-62	-66	-62	-63
	SM-T532	WIFI Analyzer	-51	-60	-62	-64	-75	-66
		Thesis Applicaton	-55	-60	-64	-64	-74	-68
	SM-T210	WIFI Analyzer	-68	-74	-83	-82	-78	-81
		Thesis Applicaton	-50	-52	-55	-60	-63	-61
INS_05	GT-N5110	WIFI Analyzer	-62	-54	-58	-61	-62	-66
	Z3 Dual	WIFI Analyzer	-51	-59	-59	-64	-61	-61
	SM-T532	WIFI Analyzer	-49	-47	-56	-56	-56	-60
		Thesis Applicaton	-47	-48	-54	-57	-57	-61
	SM-T210	WIFI Analyzer	-60	-62	-78	-79	-73	-79
		Thesis Applicaton	-53	-57	-58	-61	-64	-62
INS_06	GT-N5110	WIFI Analyzer	-60	-57	-59	-61	-68	-67
	Z3 Dual	WIFI Analyzer	-54	-57	-57	-63	-62	-62
	SM-T532	WIFI Analyzer	-50	-49	-54	-56	-60	-62
		Thesis Applicaton	-48	-51	-55	-58	-60	-63
	SM-T210	WIFI Analyzer	-60	-65	-78	-82	-78	-81
		Thesis Applicaton	-48	-51	-62	-57	-61	-60
INS_07	GT-N5110	WIFI Analyzer	-47	-48	-56	-56	-59	-60
	Z3 Dual	WIFI Analyzer	-46	-54	-63	-63	-64	-66
	SM-T532	WIFI Analyzer	-53	-58	-64	-61	-67	-70
		Thesis Applicaton	-50	-59	-60	-63	-70	-68
	SM-T210	WIFI Analyzer	-79	-70	-85	-88	-78	-87
		Thesis Applicaton	-56	-55	-60	-61	-61	-64
INS_08	GT-N5110	WIFI Analyzer	-53	-54	-58	-60	-61	-66
	Z3 Dual	WIFI Analyzer	-44	-52	-57	-61	-60	-62
	SM-T532	WIFI Analyzer	-29	-39	-45	-49	-51	-57
		Thesis Applicaton	-30	-39	-45	-50	-53	-56
	SM-T210	WIFI Analyzer	-76	-65	-77	-85	-72	-77
		Thesis Applicaton	-45	-65	-69	-70	-61	-71

INS_01

INS_06

INS_02

INS_07

INS_03

INS_08

INS_05
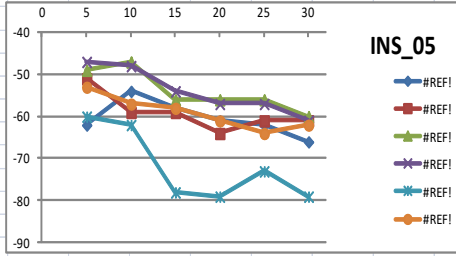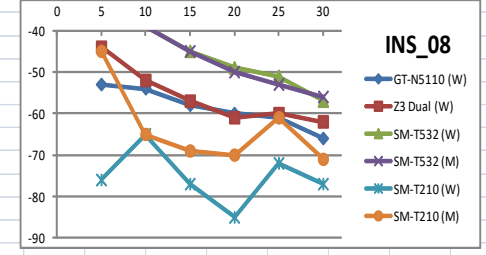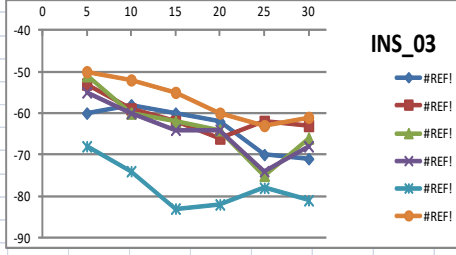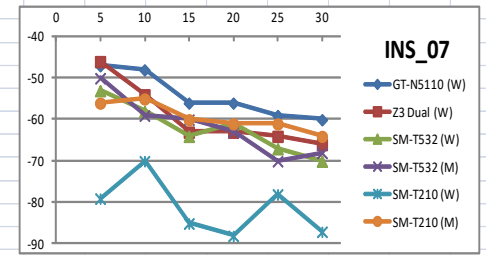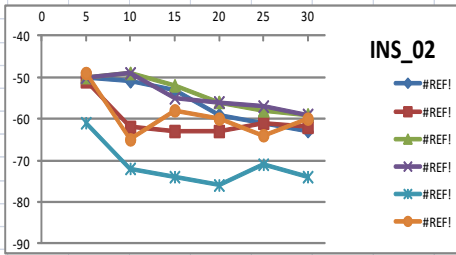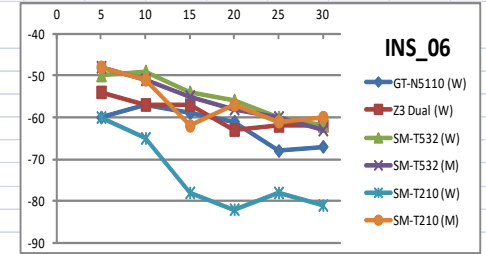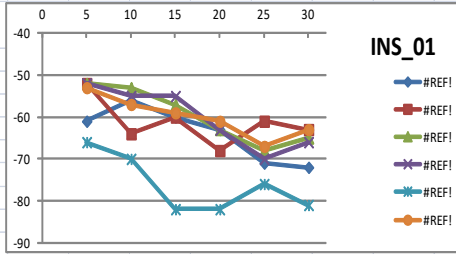
APPENDIX C: SIGNAL STRENGTHS AT INDOOR SPORT HALL AND CARPET FIELD

Indoor Sport Hall

Carpet Field
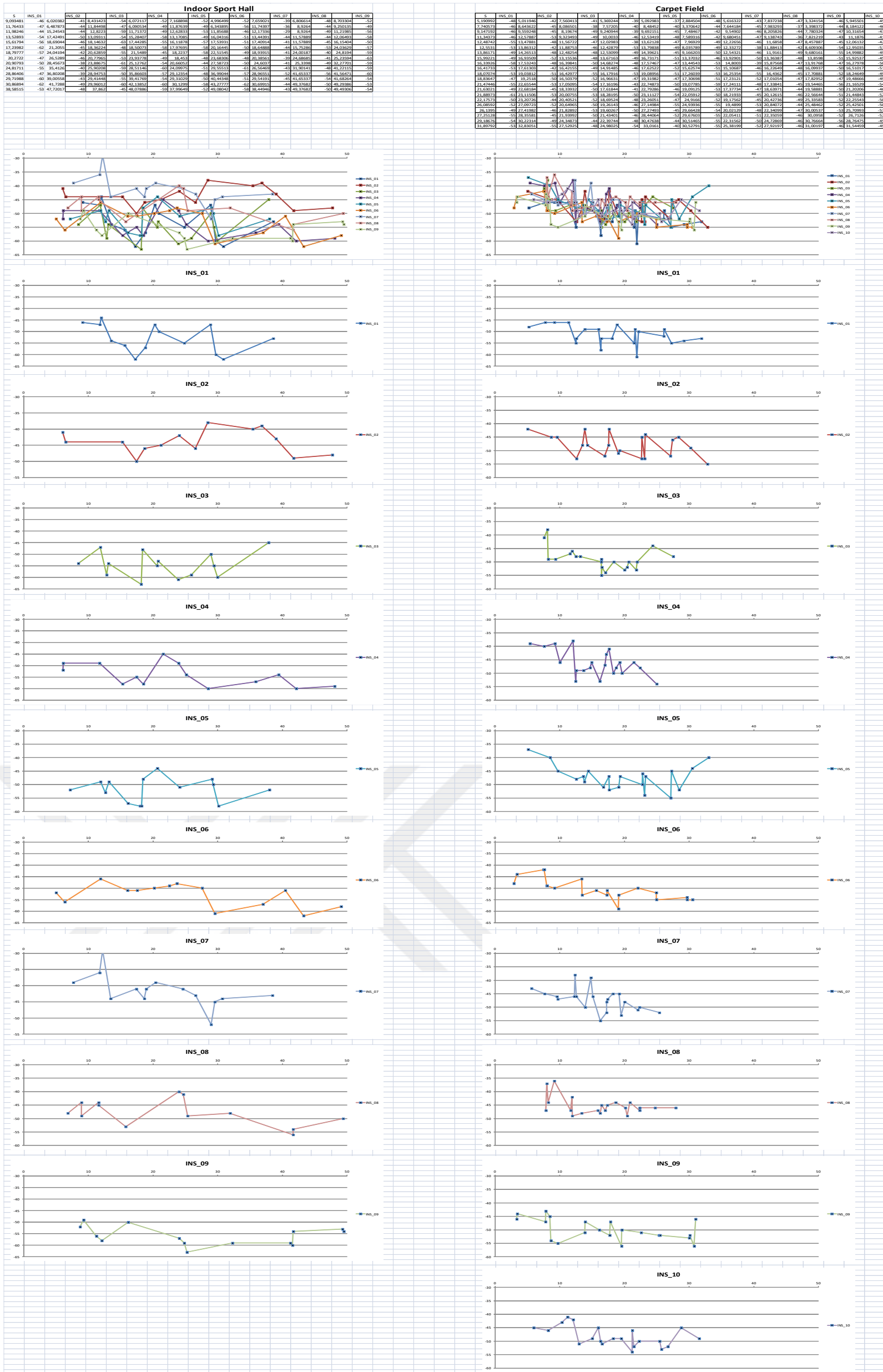
APPENDIX D: SCREENSHOTS OF APPLICATIONS
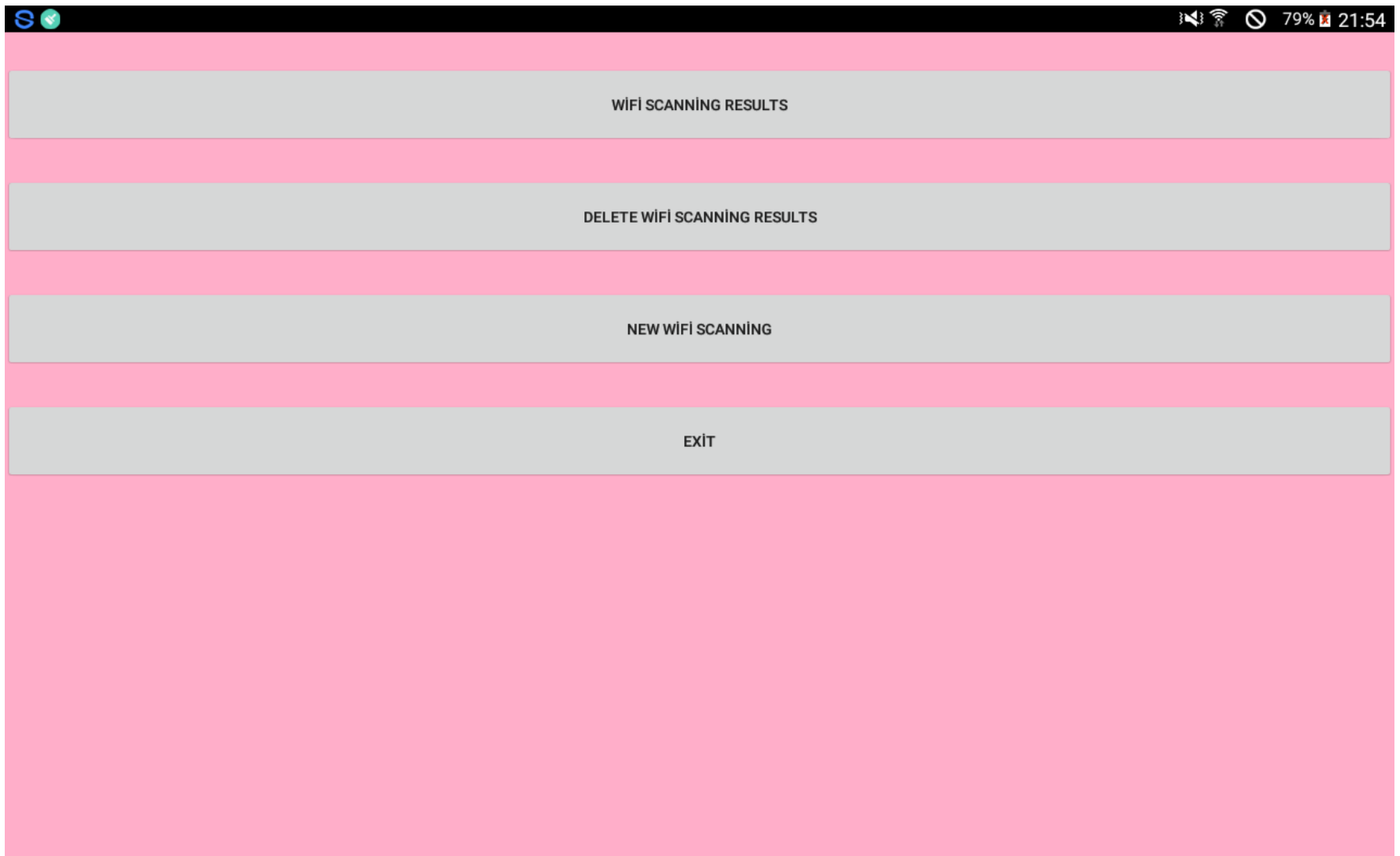
Wi-Fi Scanner Application:

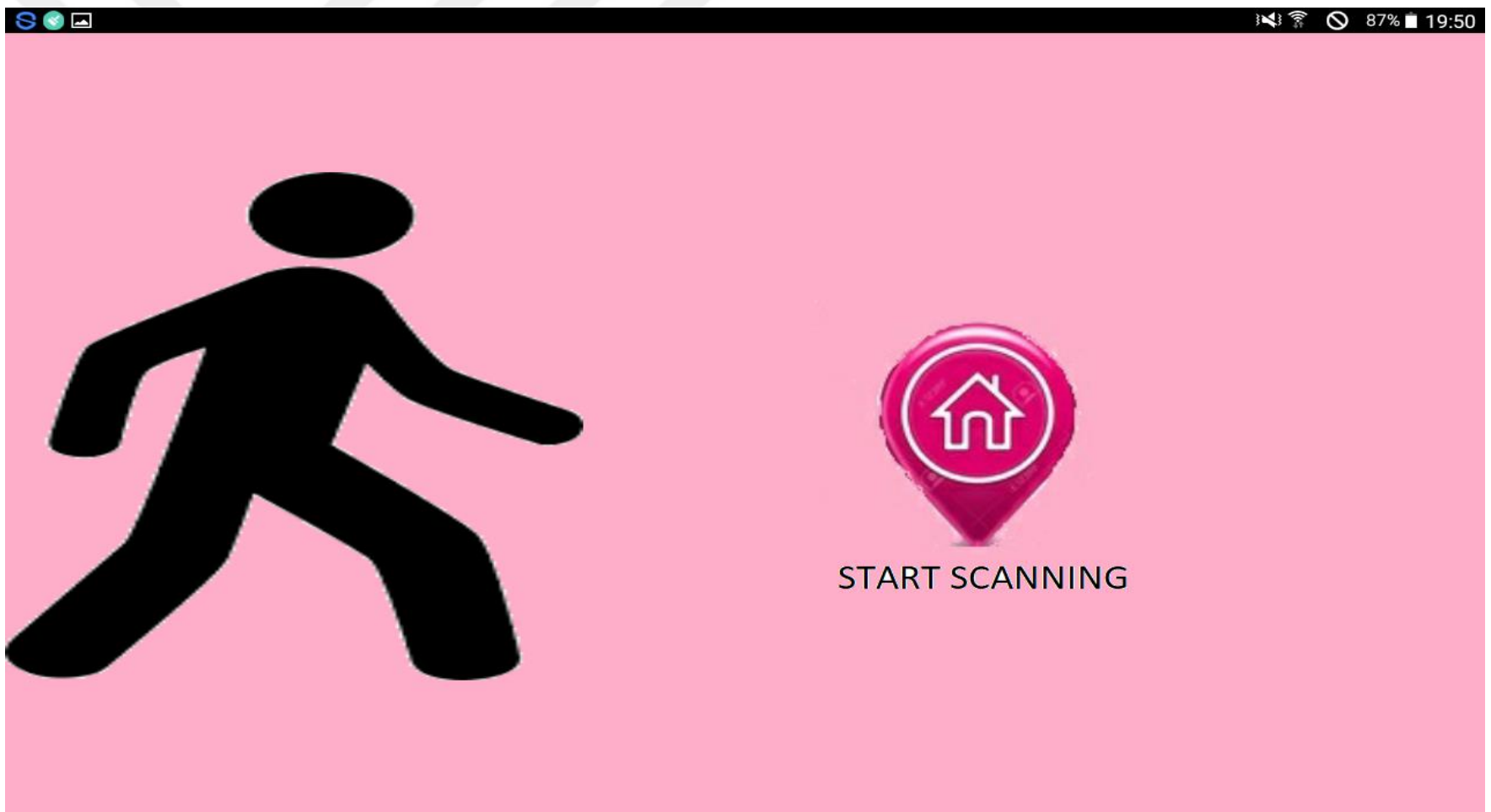Figure D.1: Main screen of Wi-Fi scanning application
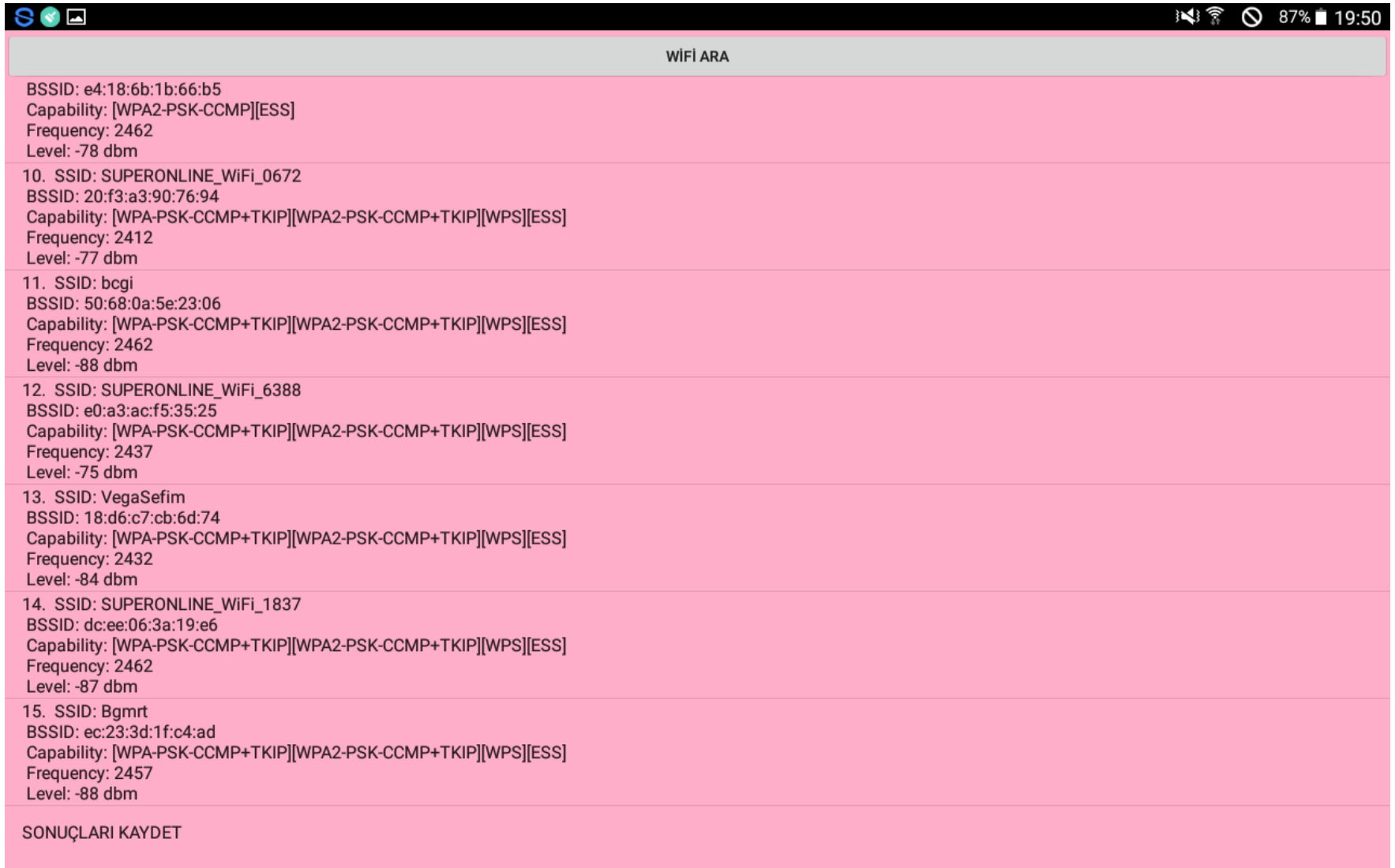

Figure D.2: Starting screen of scanning
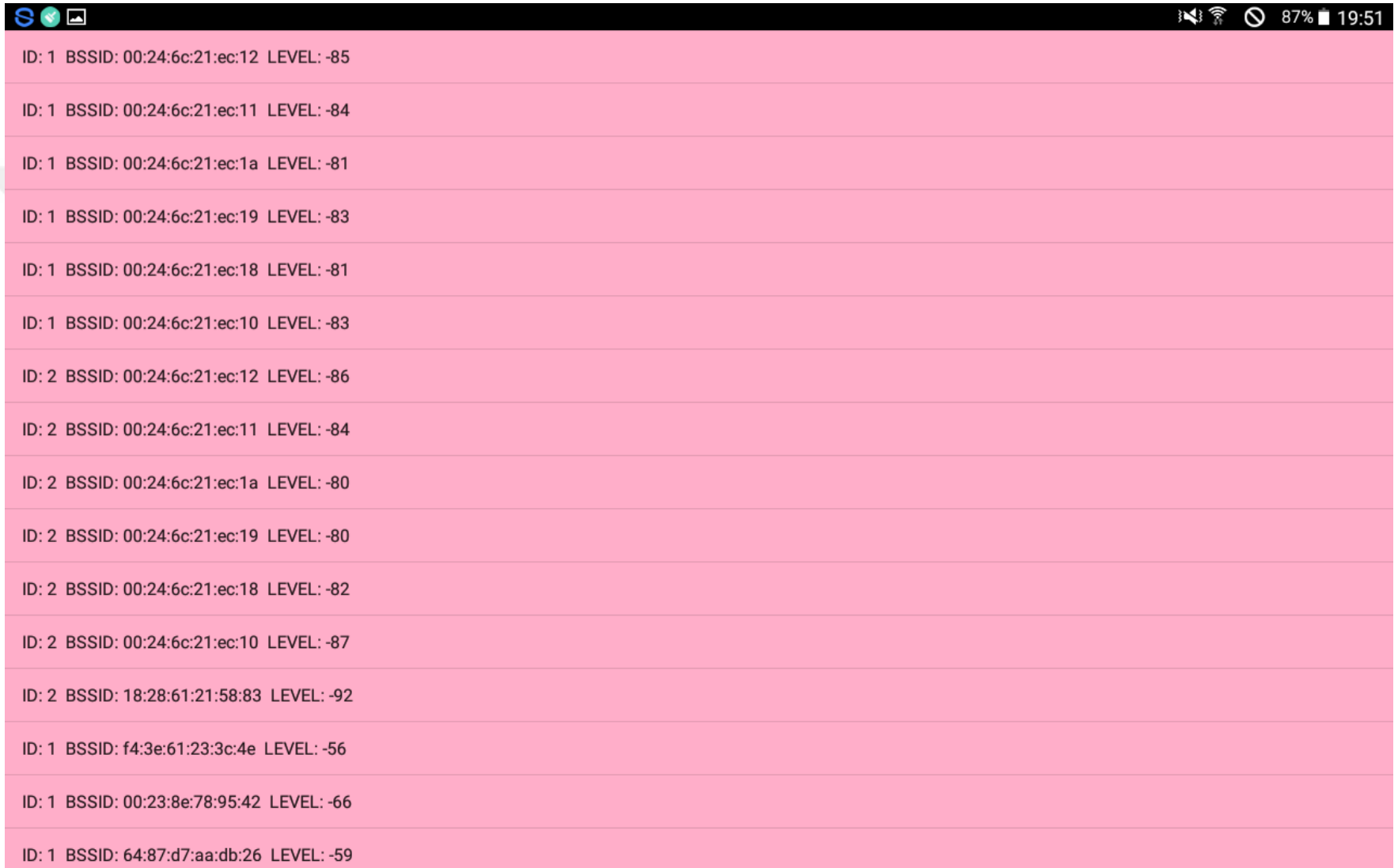
Figure D.3: Wi-Fi scanning results

Figure D.4: List of saved Wi-Fi access points
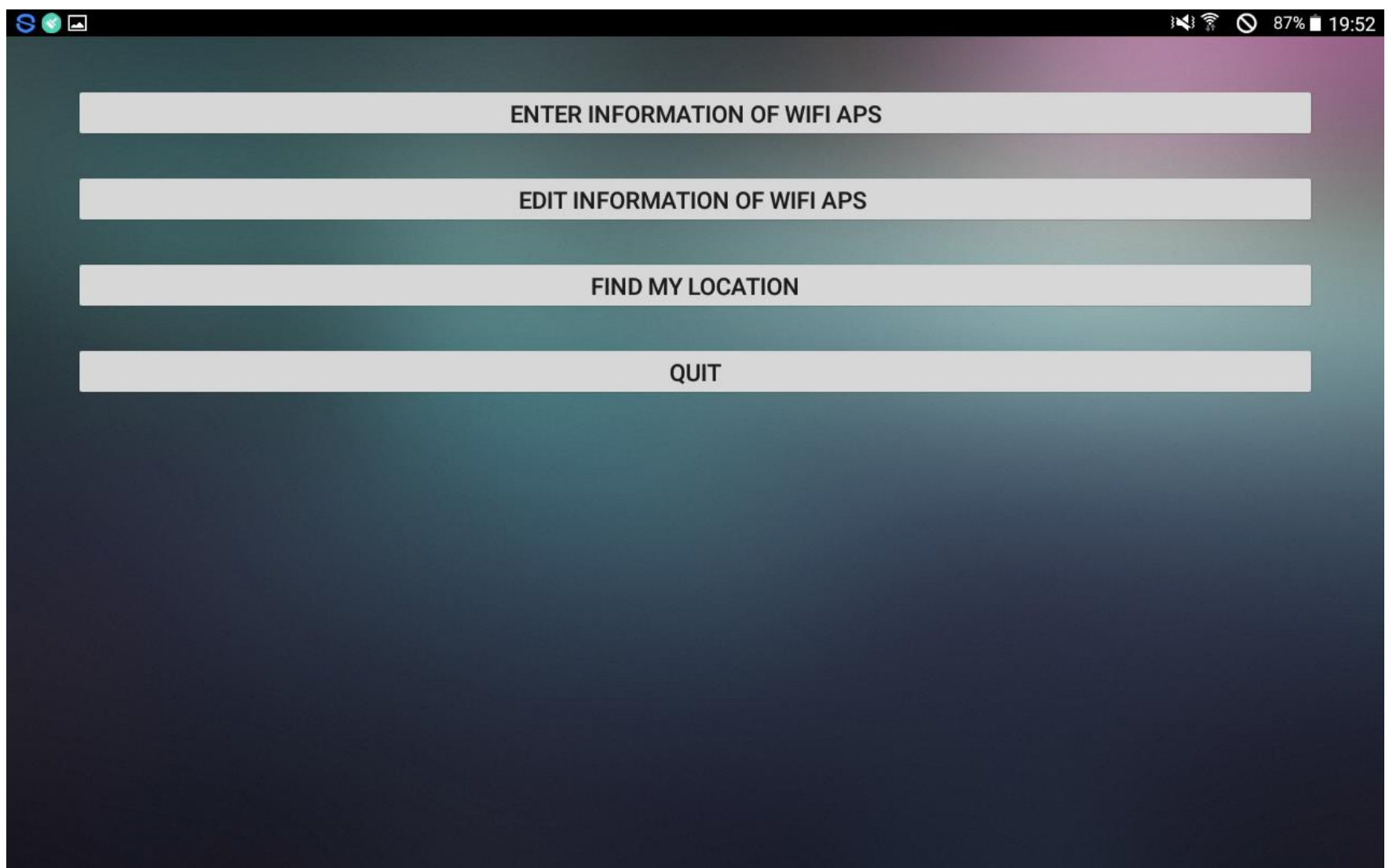
Indoor Positioning Application:

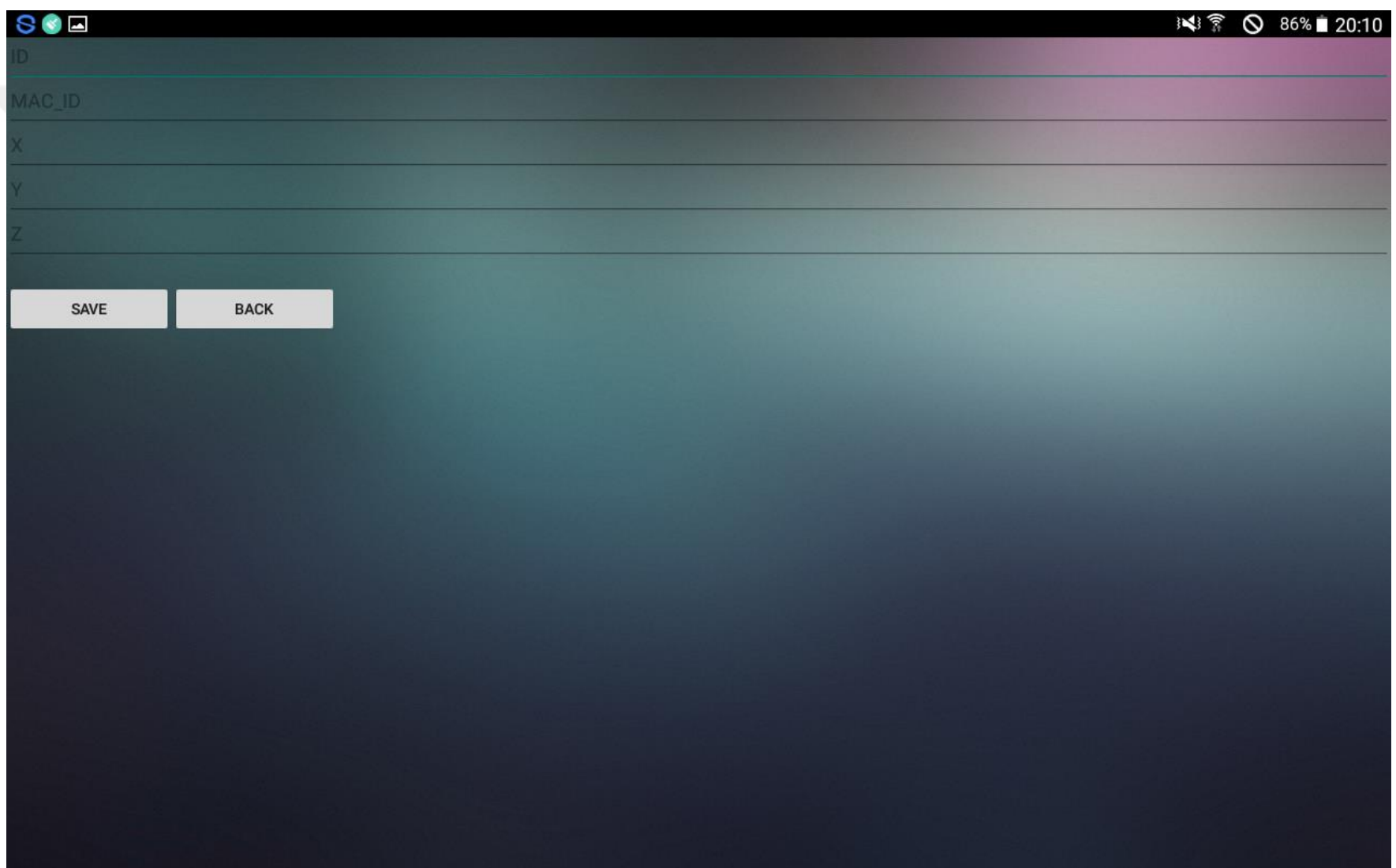Figure D.5: Main screen of indoor positioning application

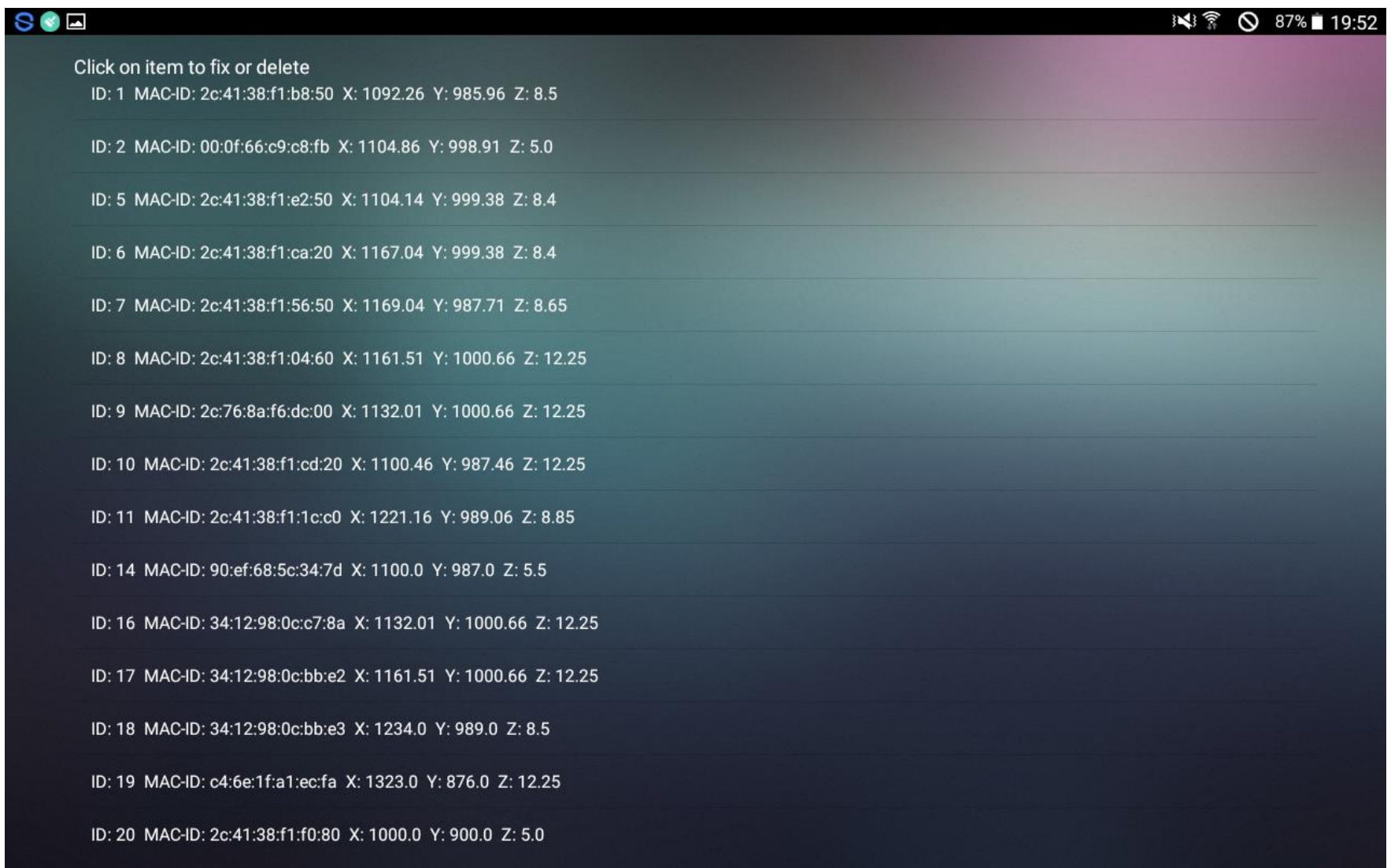Figure D.6: Screen of entering Wi-Fi access point's information

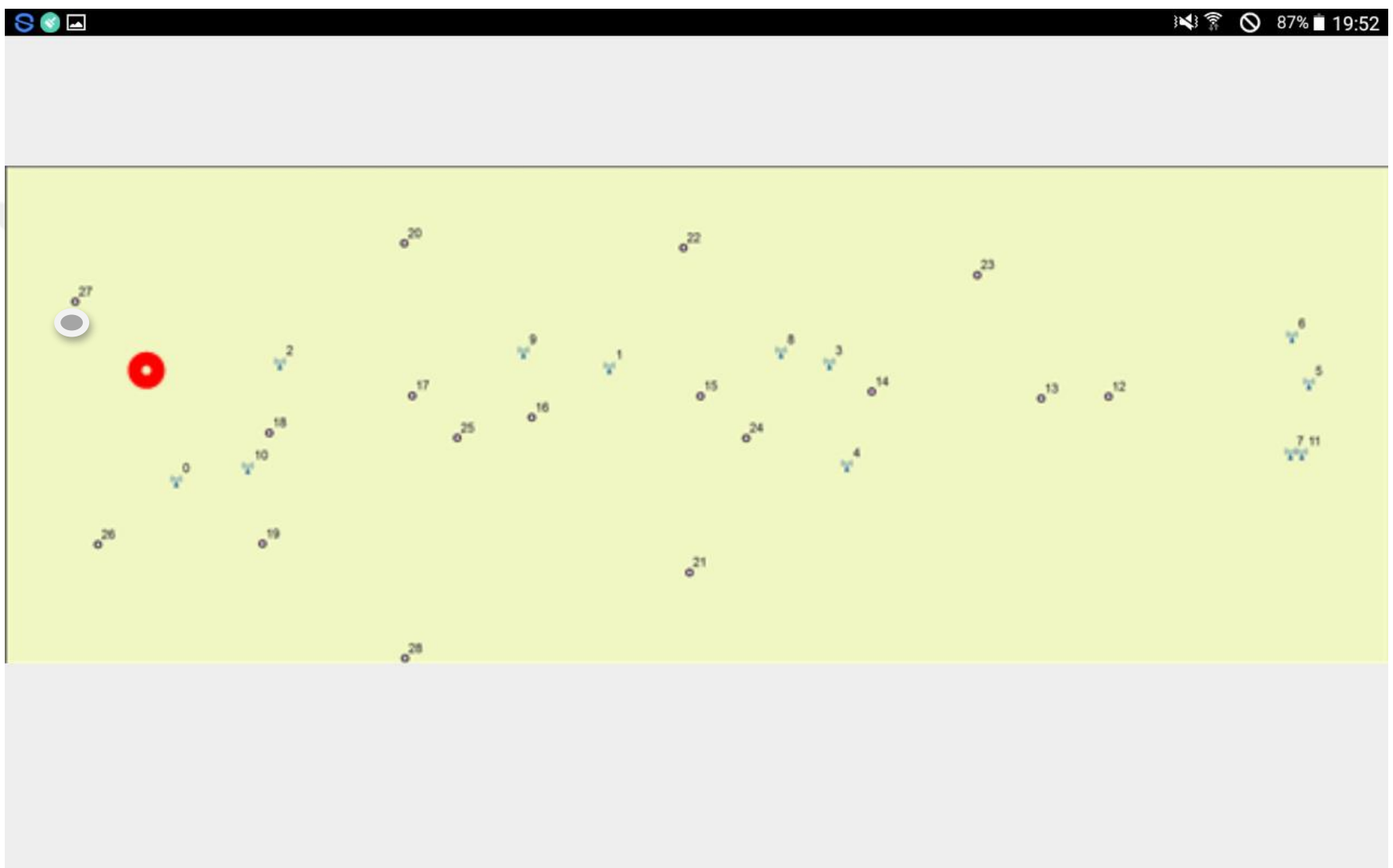Figure D.7: List of Wi-Fi access point's information

Figure D.8: Screen displaying location on sketch

The measurement was made at point 27 in Figure D.8. The application showed the position of the person, which is in red point.