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STUDY ON INDOOR LOCALIZATION USING SMARTPHONE-BASED IEEE 802.11MC

Weid Abdulsalam Jawad AL- RUBAYE

Master's Thesis

Supervisor

Prof. Dr. Osman Nuri UÇAN

Istanbul, 2023

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PREFACE

I would like to thank my supervisor Prof. Dr. Osman Nuri UÇAN for all support during my study. It’s great pleasure to express my deepest gratitude to my friends who have shared with me best moments during my study for the master's degree.

DEDICATION

First, I would like to thank allah almighty for the power of the mind, health, strength, guidance, knowledge, and skills to complete this study.

This thesis is wholeheartedly dedicated to my parents. There are no words to describe what you mean to me; there is nothing that I can repay for what you have done to me. I will continue to do my best to achieve your expectations.

Lastly, I dedicated this to the family, relatives, and friends who have been encouraging me during this study.

ABSTRACT

STUDY ON INDOOR LOCALIZATIONS USING SMARTPHONE BASED IEEE 802.11MC

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Indoor navigation has received much attention in recent years. This field isn't only for building interiors; it's used when GNSS can't be used. The topic interest experts from various fields, and there are numerous ways to approach it. Physicists, programmers, surveyors, and cartographers frequently need to work together. Wikipedia defines navigation as monitoring and managing a ship or vehicle's passage. "Localization" refers to identifying a place based on other places or patterns. The navigator must always know his or her location. Even though localization is an element of navigation, the term "navigation" is commonly used as a totum pro parte.in the design phase of modern constructions, indoor navigation may be considered. This would provide more exact location and navigation. This isn't always the case with existing buildings; in these circumstances, there is typically some infrastructure already, and a new one demands additional resources. in these cases, a positioning and navigation system may be added to existing infrastructure. Another alternative for existing buildings is building a navigation system, whose infrastructure presents no obstacles or significant expenses. This thesis evaluates technologies to see whether they can be used in an indoor positioning and navigation system. We performed research and testing to compare the accuracy and precision of different positioning and navigation systems.

Keyworks: Localization, Indoor Position, MSE, WIFI, Bluetooth.

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ABBREVIATIONS

RNN	:	Recurrent Neural Network
DBN	:	Deep Belief Network
DL	:	Deep Learning

1. INTRODUCTION

in recent years, indoor navigation has been a subject that has generated a lot of attention and discussion. This field does not concentrate just on the interiors of buildings; rather, it is used in situations in which the usual GNSS approach cannot be utilized. the subject at hand is of interest to specialists from a wide variety of areas, and there are many different approaches to addressing it. their collaboration is often highly vital, regardless of whether they are physicists, programmers, surveyors, or cartographers.

Navigation is "the act of monitoring and regulating the passage of a ship or vehicle from one location to another," according to Wikipedia. However, the term "localization" refers to the process of determining a place in relation to several other reference locations or patterns. it is essential for the navigator to be aware of his or her own position during the whole of the navigational processes. Even though localization is simply a component of the navigation process as a whole, the word "navigation" is often employed as if it were a totum pro parte when referring to the activity of navigation.

the Latin term navigation is derived from two words: navis, which means "ship," and agere, which means "act." these two words were combined to produce the modern English word navigation. People have been trying to figure out how to discover their position, show the surface of the planet on maps, and establish direction since the beginning of time. these activities make orientation and navigation much simpler. there are various meanings of the word "navigation" that can be found in professional literature. these definitions often have somewhat different conceptions of the term, but they all have certain characteristics. a person, thing, motor vehicle, or contemporary device can only be navigated to its intended location if its origin and final resting places are known. This holds true whether you're directing a person, an item, or a car. also, using both the right and the available tech, you must gather the information needed to figure out which route, or routes, between the two sites is the best. Given these foundational presumptions, we are now in a position to realize the goals we set out to achieve. [1] [2]

During the design phase of the construction process of contemporary structures, the necessity for an effective method of interior navigation may be taken into consideration. This would make it possible to use methods of positioning and navigation that are not only more intricate but also more precise. on the other hand, this is not always the case with structures that already exist; in these cases, there is often some form of infrastructure already, and the construction of a new one requires extra resources. in situations like these, a positioning and navigation system is required, the likes of which might be implemented on top of infrastructure that is already in place. Another option for the structures that are already in place is the construction of a navigation system, the infrastructure of which does not present any challenges or high costs.

1.1 THESIS AIM

The primary objective of this thesis is to assess a variety of technologies in order to determine whether or not they may be included into the development of an indoor positioning and navigation system. in order to achieve this objective, we conducted research and tests to assess and contrast the various positioning and navigation systems in terms of their accuracy and precision.

2. BACKGROUND

2.1 INDOOR LOCALIZATION

Localization is defined as "to discover or identify the position of anything" (such as an item or person) by Merriam-Webster (an Encyclopedia Britannica Company) [6]. [Note: Merriam-Webster is a subsidiary of Encyclopedia Britannica.] in addition to the other location-aware services, the localization may be considered the beginning of the navigation process. at this point in time, the procedure for finding the location of an item is an outdated issue. in order to find a solution to this issue, a wide variety of strategies and methods were devised. the present state of technology has made it possible for humans to localize their surroundings and navigate with the assistance of a variety of tools and applications. Some of them include the astrolabe, reflecting circle, traverse board, back staff, sextant, and compass. the aforementioned tools were first developed to aid in the navigation and positioning of ships while they were at sea. today, however, many of these tools are also put to use on land for a variety of purposes, including navigation and positioning. When seen from the perspective of more recent times, monitoring the position and location of vehicles may be viewed in a manner that is analogous to that of ships. the Global Positioning System (GPS) is the first gadget that was built specifically for this problem. the proliferation of digital technology and its increasing pervasiveness in our everyday lives necessitate the need for localization solutions that are not limited to vehicles such as ships and automobiles solely. the advent of smartphone technology has resulted in a rewrite of the guidelines for playing this game. at the moment, the GPS system is pre-installed on the majority of our smartphones, and we make frequent use of these devices in our day-to-day lives. Personalization of context- and location-aware apps is now possible because to the availability of sophisticated mobile digital devices, which may be held in one's hand. Figure 2.1 is a flowchart that explains the different methods of localization.

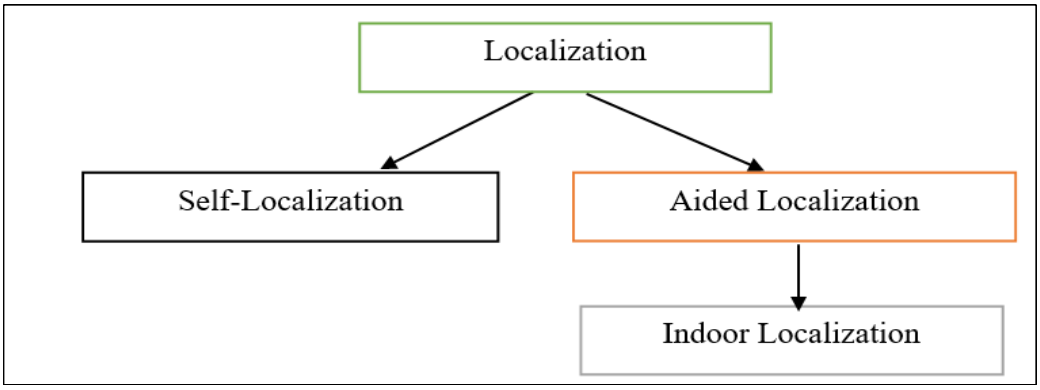

Figure 2.1: Localization Kinds.

a system that determines the location of an item in an interior environment constantly and in real-time is referred to as an indoor positioning system (IPS) [6]. the process or practice of precisely establishing one's location and arranging and following a path, according to the Oxford Dictionary's definition [7].

Therefore, the indoor positioning system (IPS) may be thought of as an extension of the indoor navigation system (INS). an extension that, in addition to the positioning capabilities supplied by the IPS, adds navigational capabilities.

Effective indoor positioning has various applications outside of navigation, including but not limited to the following: Tracking cargo in warehouses [8] and monitoring patients in hospitals [6] are two examples of possible applications for indoor positioning. Even in highly specialized applications, such as for first responders [11], the INS may be used in settings like as shopping malls [9] and other publicly accessible locations.

This chapter gives a classification of existing INSs along with an explanation of each category, as well as examples of navigation systems that are examples of systems that correspond to those categories.

2.2 BLUETOOTH TECHO

Bluetooth has quickly become one of the most well-known and widely utilized wireless communication technologies in recent years. Bluetooth is a kind of wireless technology that enables devices to transfer data to one another and communicate with one another across relatively short distances. the replacement of physical connections with wireless communication was the primary motivation for the development of Bluetooth. With the use of Bluetooth devices, the user may set up their own Personal area Network (PaN). the data transmission rate for Bluetooth is currently set at 5 the most recent version of Bluetooth is 5.1, and compared to its earlier predecessor, Bluetooth 4, it has a longer battery life, a greater message capacity, and a wider distance range. 2. the Bluetooth Special interest Group (SIG), which is in charge of Bluetooth's improvement, development, and the certification of Bluetooth devices, is in charge of Bluetooth. in today's world, Bluetooth is most often used on the internet of Things (IoT), for example, in smart homes, which enable electronic gadgets to have two-way conversations with one another to improve the overall quality of the user experience. [6, 7]

the frequency band known as the industrial, Scientific, and Medical (ISM) radio band is where Bluetooth technology functions. This band's frequency range is from 2.4 to 2.48 GHz. Frequency Hopping is used by Bluetooth devices in order to minimize interference with other Bluetooth devices that are in close proximity. When a link is formed between two devices, those devices will frequently switch communication channels many times per second. the time that frequency-hopping devices spend on a given channel is limited, which helps to lessen the likelihood that they may cause interference. Frequency Hopping in Bluetooth Revision 1.2 has been modified so that it will avoid channels that are already being used. a piconet is a collection of electronic devices that may communicate with one another via Bluetooth. within a piconet network, one of the devices acts as a master, exercising authority over the other connected devices, and may have up to seven slaves linked to it.

Every Bluetooth device has the capability of performing either the master or slave role. the link is often established by the Master. on the other hand, it is possible for the roles to switch throughout the course of the conversation. for instance, at the beginning, headphones play the function of master; but, once a connection is made to a mobile device, that mobile device takes control of the situation and becomes the master.

2.3 BLUETOOTH LOW ENERGY (BLE)

Bluetooth low energy is a technology that is being developed by the Bluetooth Special interest Group. it is a subset of Bluetooth, and [8, 9] may be found in the aforementioned references. Since the release of the Bluetooth 4.0 specification, BLE technology has begun to be included. it offers a reduction in the amount of energy that is used as well as an ease of integration into compact form factors like BLE Beacons. the fact that these devices have a compact form factor and a low energy consumption, however, makes it difficult for developers to provide security. BLE is not a secure technology since it relies on wireless channels with a low bandwidth and has limited storage space.

the transmission of discovery packets over three different discovery channels is the foundation of the BLE discovery detection system. these channels are utilized to prevent overlapping as much as possible. Frequency Hopping is used by data channels in order to lessen the effects of interference and propagation faults such as fading. it is possible for a device to connect to a sender device after it has received an advertising packet. there are two types of people involved in a BLE connection: slaves and masters. only one master at a time may establish a connection with a slave. as a result, they establish a network that is made up of masters and slaves and that conforms to the initial network architecture. in order to reduce the amount of power being used by the slaves, they are now sleeping. they do so at regular intervals and keep an ear out for packets sent by the master.

the time at which master packets are marketed to neighboring slave devices is referred as as the advertising interval. This might happen at regular intervals. Generally speaking, the range of the connection is more than a few tens of meters. the connection range between the slaves and the master is impacted by the presence of obstacles in the route between the two. Reflection off obstacles may also contribute to problems with multipath propagation.

2.4 BLE BEACON PROFILES

Bluetooth low energy beacons provide their data packets to adjacent devices in order to communicate with them. it is necessary for there to be a general specification or standards of the advertising packet in order for end devices to be able to comprehend information that is communicated to them by a beacon. apple's iBeacon was the first widely used standard for advertising packets. it was given this moniker by the company. after a period of two years, Google introduced its BLE advertising packet standard under the name Ed–dystone. This standard is open source. altBeacon is the name of the third most well-known BLE packet standard. the iBeacon, Eddystone, and altBeacon methods and message formats are broken out in further depth further on in this article.

apple is responsible for the development of the Bluetooth low energy beacon profile known as iBeacon[10, 11]. apple first presented the beacon profile at the apple Worldwide developer conference in 2013. it is a standard for communication that governs how information is sent between the BLE transmitter and receiver. Since the introduction of iOS 7, when support for the iBeacon profile first became available, the iOS mobile platform's CoreLocation library has been home to this feature. a communication beacon device that supports iBeacon will broadcast its packets to other devices in the vicinity while the conversation is taking place. it is not just supported for mobile devices that are based on iOS, but iBeacon may be utilized on android devices as long as Bluetooth 4.0 is supported by such devices. Using the iBeacon protocol, a developer is able to manage events that occur whenever a user visits a specified site or moves within a particular zone.

the structure of an iBeacon packet stores certain pieces of information. the iBeacon prefix, the major field, the minor field, and the TX power make up the five primary fields that make up the packet. the UUID field is a block of size 16 bytes that identifies the beacon as well as the area it resides in. Multiple beacons might share the same UUID. the UUID field is responsible for transmitting the beacon ID and is mostly connected to a single application. the UUID's primary function is to differentiate beacons under your control from those belonging to other applications' beacons. Within your beacon network, there are main and minor fields that work together to offer a higher level of identifying precision. the major and minor fields each consist of an unsigned integer that is two bytes long, and it is mandatory that they be assigned in the packet. for example, you may use the same UUID for a complicated structure that consists of several blocks, even if those blocks can be further subdivided into individual things. You will utilize the main field values to identify the blocks, and the minor field value will be used to identify the single items. the last field stores the TX power, which specifies the signal intensity at a distance of one meter from a beacon device. TX power is used to approximate the distance between a mobile device and the beacon. This distance is then used to compute the exact distance. the construction of an iBeacon packet is seen in image number 2.1 of this gallery.

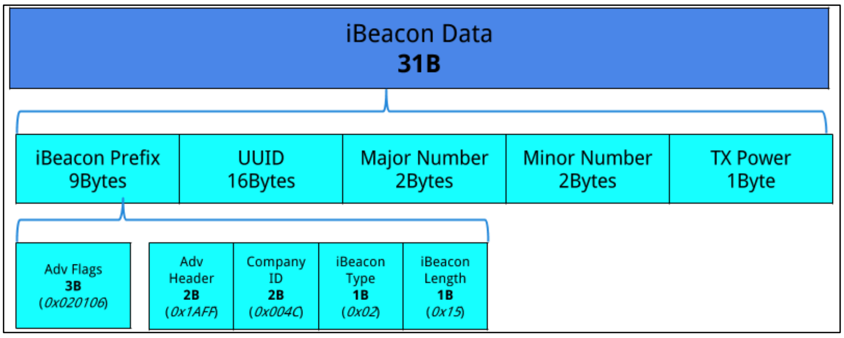

Figure 2.2: I Beacon Packet Structure [12].

the format of a message packet is defined by the Eddystone[13] protocol, which is an open-source Bluetooth low energy standard. 2015 was the year that Google first launched the standard, and it is compatible with any android devices that have android aPI 21 or later. Data from the prefix as well as data from the frame make up the packet. the values in a packet may be secured and controlled via the use of prefixed data. the UUID, which serves as the header of the frame, takes up four bytes, while the frame itself takes up twenty bytes. Eddystone-UID frames, Eddystone-TLM frames, Eddystone-URL frames, and Eddystone-EID frames are the four different kinds of frames. Following is a description of each of these four categories, and an illustration of an Eddystone packet can be seen in image number 2.

i. Eddystone-UID

the Eddystone UID consists of a frame that is 20 bytes long and is used to identify beacons. it is made up of its type, which takes up one byte, as well as range data, which is the calibrated Tx power at 0 meters (1 byte). in the iBeacon protocol, there is also a namespace that is 10 bytes long and serves the same purpose as UUID. it is possible to use it to filter Eddystone beacons so that only those that belong to the user's application are seen. it gives the beacon ID. a namespace's instance component, which is six bytes in length and serves as a unique identifier, is analogous to the Major value of an iBeacon.

the URL of a website, after being compressed using the appropriate encoding scheme, is stored in an Eddystone-URL URL frame. the encoded URL, as well as the frame's type (1 byte), are both included inside the frame. additionally, the frame contains the Tx power, which is the averaged signal strength power at 0 meters from a beacon (1 byte) (17 bytes)

Eddystone-TLM the Eddystone-TLM frame offers more information about the beacon device condition. it may contain the temperature of the device, the voltage of the battery, or the number of packets that have been broadcast.

ii. Eddystone-EID

the ephemeral ID is a frame that allows encrypted configuration of the beacon to broadcast information that authorized entities can only access. This information can only be read by the beacon. additionally, it facilitates the transmission of TLM frames in a manner that is cryptographically protected. If the developer makes use of EID, he or she may assure that only their program is able to access data from an Eddystone beacon.

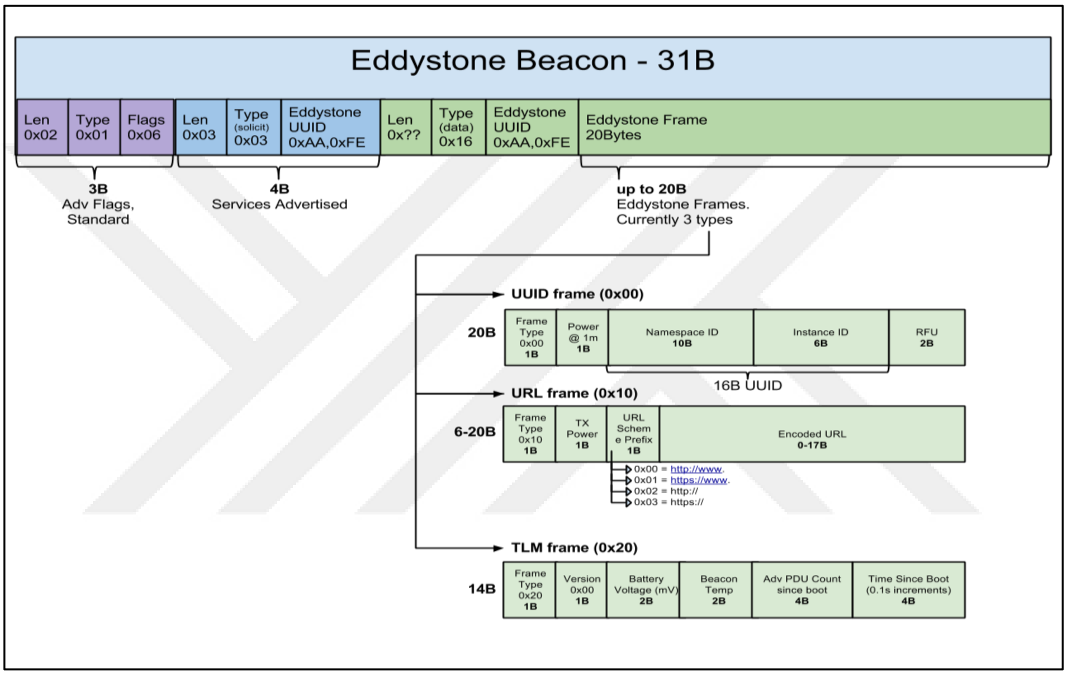

Figure 2.3: Eddystone Packet Structure [14].

2.5 BEACON DEVICES

Beacon [16] is a tiny gadget that broadcasts its globally unique identification (UUID) inside a packet to nearby receivers. This information is sent to receivers in close proximity. the data are written within the beacon and are included in the packet. Within beacon, the user may alter settings such the broadcast packet interval (in milliseconds) and the transmit power (in decibels/milliwatts) (dBm). as an extension of the Bluetooth 4.1 standard, it is compatible with Bluetooth low energy. Beacon devices are able to be powered by relatively tiny lithium coin batteries, which allows them to have a lifespan that is more than two years. the amount of time a charge will last is dependent on the broadcasting frequency as well as the power of the Bluetooth signal coming from the device. the device's mobility is reduced when powered by USB, which is another method of power delivery; nonetheless, this option is available.

Communication protocols describe both the manner in which a packet from the beacon is transmitted and the manner in which a receiving device interprets the packet once it has been received. the iBeacon, Eddystone, and altBeacon protocols may all be supported by the beacon. the following is a list of companies that make BLE beacons, as well as a table that provides a brief comparison of the products offered by these companies.

there is a firm called Kontakt.io that specializes in the production of BLE beacons [17]. they provide a wide variety of beacons that may be used in a variety of settings. they supply software libraries for the purpose of implementing localizations or beacon settings with each and every beacon that they manufacture. in addition, they provide a range of services in conjunction with their product, which include the ability to monitor utilized devices, establish safety guidelines for the connection, configure beacons, and organize the product for use in retail. they provide tags that may be used to label items in large warehouses so that they can be found more quickly. This company's Smart Beacon SB16-2 is a stationary beacon that may be used for positioning. If there are no obstructions in the way of the signal, the beacon may reach a maximum distance of 70 meters. it is compatible with both iBeacon and Eddystone, and its user-replaceable batteries have a lifespan that is more than 5 years.

Estimate is a firm with its headquarters in Poland [18], and it has been available on the market from the year 2012. they have developed the very first beacon that is iBeacon compatible. their software is designed to work in conjunction with beacons to carry out proximity marketing, automation, or localization inside a building. they provide seven distinct beacon kinds that come in a variety of form factors. for instance, their Proximity beacon is compatible with version 5.0, which results in an increased signal range of up to 100 meters and an improved battery life of up to 5 years of continuous use. the beacon comes with NFC functionality built in, which may be used for pairing purposes. the software that comes with the proximity beacon allows for complete customization of the device. the gadget is capable of supporting both the iBeacon and the Eddystone beacon profiles.

Em Microelectronic is a firm with its headquarters in Switzerland that operates as a semi-conductor manufacturer and focuses on the research, development, and design of low-power integrated circuits [19]. additionally, they provide three distinct varieties of beacons: EMBC22, EMBC02, and EMBP0. these beacons are compatible with all three BLE beacon profiles—Eddystone, iBeacon, and altBeacon. EMBC22 has a potential lifespan of more than four years. it is indicated in the documentation that the maximum power output of the device may result in a signal that can travel a distance of up to 200 meters. in addition, the device enables the user to customize several aspects of its operation, including the packet kinds, the device name, the address UUID, the beacon interval, the transmitter power, and the accelerometer functionality.

Every device that can use the BLE protocol and has the ability to handle multiple broadcasts is able to send or receive BLE data. a mobile device's functionality may be made to replicate the capabilities and features of a beacon via the usage of this capability. it is a fantastic choice for developers to learn how to connect with the data from beacons and construct applications without the need of any additional devices. there is an application called android simulator4 for the android operating system that can imitate beacon. it is possible to configure a variety of beacon profiles, including iBeacon, Eddystone, and altBeacon, amongst others. You can specify the TxPower, the frequency of packet sending, the major and minor values, and the UUID for each profile. Beacon Sim5 is another another program that may be used for the simulation of beacon. the Beacon Sim app is only available for use on iOS-based smartphones. therefore, it is only compatible with iBeacon, and the most significant drawback is that the user is unable to customize anything, which results in a less accurate calculation of the device's distance from the user.

Table 2.1: Comparison Between Different Beacon Devices.

Name	**BT Version**	**Battery**	**Range**	**Support**
SB16-2	4.2	5 years	75m	iBeacon
Proximality Beacon	5.0	5 years	110m	iBeacon
EMBC22	5.0	4 years	210m	iBeacon, altBeacon

a beacon is a very tiny device that could generate PaN and provide end devices with information that is helpful to them. it discovers a variety of choices across a variety of market categories. Some of them are as follows:

Beacons are used in retail establishments to enhance the overall shopping experience for consumers. Beacons, by providing services such as new product discounts or sales, may contribute to a rise in the retail establishment's overall profit.

Because tourism beacons can save data in relation to specific physical places, they provide a fantastic opportunity for cities, museums, and restaurants to deliver pertinent information to consumers as they get closer to a certain destination. Beacons may be used to construct a virtual tour that can be shown to visitors of museums or towns. This guide can include information about local attractions, such as a monument.it is simple to get disoriented in large, complicated buildings like airports or shopping malls.

Beacons provide a solution to this issue by transmitting signals that are compatible with Bluetooth Low Energy (BLE) in place of the Global Positioning System (GPS). it is possible to position using a variety of positioning systems, such as GPS; however, the precision is somewhat lower than that of GPS. on the other hand, it is accurate enough to indicate a user his probable location inside a structure.

3. LOCATION TECHNOLOGIES

it is common in today's world to use a mobile phone as a device for determining one's location. Users are able to verify their exact position on a map using this helpful function of a phone, as well as determine the best routes, follow navigation in real-time, or locate the nearby sites such as restaurants, petrol stations, and other such establishments. in addition, research is currently being done to investigate the potential applications of localization technology in mobile phones. This technology has applications not just in the realm of practical usage, such as tracing a misplaced phone or sharing one's position with pals through chat, but also in the realm of the entertainment business. This includes things like mobile games that use the player's present location and movement in the real world to control the movement of a gaming character in a virtual environment, for example. Even if the objective of this thesis is to create a mobile application that makes use of Bluetooth Low Energy and beacon technology, there are still a variety of other approaches that may be used to get and determine the position of a user. We will just discuss and compare a small number of them.

3.1 GPS

the phrase "global positioning system" may also be abbreviated as "GPS." it is a navigation system that is based on satellites and makes use of numerous satellites that orbit the planet in a circle. the Global Positioning System (GPS), which has been around for more than twenty years, is now widely used for navigation globally. This indicates that GPS modules are often used in contemporary navigational systems, including those utilized in automobiles, boats, field surveying equipment, and aircraft. in addition, GPS is influencing a great deal of our daily life in a variety of ways since this technology is present in a wide variety of devices, ranging from mobile phones to automated teller machines [16].
the Global Positioning System (GPS) is a component of the Global Navigation Satellite System (GNSS), which also includes GLONaSS, Galileo, Beidou, and other regional navigation satellite systems. to improve the reliability and accessibility of satellite signals, it is feasible to equip devices with navigation chips that can receive signals from many satellite networks and even combine them. Since navigation systems are not the topic of this thesis and won't be employed in any future practical applications, we'll keep this

chapter focused on the development of GPS and the methods it uses. the United States Department of Defense (DOD) initiated development of the Navstar Global Positioning System (GPS) in the early 1970s as a new navigation technology to succeed the first-generation satellite navigation system known as Transit. GPS stands for "Global Positioning System." This navigation system's initial mission was to assist in directing nuclear missiles launched from submarines toward their intended targets. Because they employed more electronic systems, which were usually used in certain regions for specialized jobs, the Navstar was also designed to establish a single navigation system that could be used all over the world [17]. 1978 was the year that saw the launch of the first four satellites. However, complete functionality of the GPS system was not achieved until July 1995. This is because a minimum of twenty-four satellites were required to ensure proper operation.

in the beginning, the Department of Defense offered not one but two distinct types of services to its customers. the Precise Positioning Service (PPS) came first, followed by the Standard Positioning Service. Both services were provided by the same company (SPS). the precision with which each one measured was what set them apart from one another. PPS was more accurate, although it was exclusively used by the United States military. on the other hand, SPS was designed with civilian applications in mind, although it did include a purposeful flaw that resulted in a measuring inaccuracy of up to one hundred meters. the Department of Defense made the decision to withdraw in order to safeguard the interests of the United States by preventing potential adversaries from abusing this technology to their advantage. However, in the year 2000, President Bill Clinton issued an order to correct the SPS to eliminate this purposeful flaw, which resulted in a fivefold increase in the reliability of this public service.

How GPS works the premise of the Global Positioning System is trilateration, a technique for estimating distances (GPS). the idea is that if we know the distance between two locations and the position of the first one, then the second point must be located on the circle whose radius is equal to the distance separating those two places. Since we know the location of the first point and its distance from the others, we can deduce that the second point must be located on the circle. to get a precise three-dimensional location, however, we need to know the distances between the five known locations and the four we're still missing. as was just discussed, the Global Positioning System (GPS) makes use of satellites in orbit around the planet as points that have a known position. Every satellite function as a transmitter and routinely transmits digital radio signals that include information about the current time as well as the precise location of the satellite. This radio signal travels at the same speed as light, which is the speed of light. Receiving such signals and then decoding them to retrieve the time that was sent by satellite requires a device that is equipped with a GPS module. With the help of the following equation, the receiver can determine the distance between itself and the satellite by subtracting its own time from the time that was transmitted from the satellite:

Distance equals Rate multiplied by Time [18]. the pace at which a radio signal is delivered by GPS satellites in orbit is referred to as the rate. it is proportional to the velocity of light (299,792,458 meters per second). the time that is included into the equation is the amount of time that elapses between the transmission of the signal from the satellite and its reception by the GPS receiver located on earth. When users calculate the distance between at least four satellites, they are provided with a precision of around 7.8 meters anywhere near the surface of the planet [19]. This accuracy is achieved in nearly 95 percent of all cases.

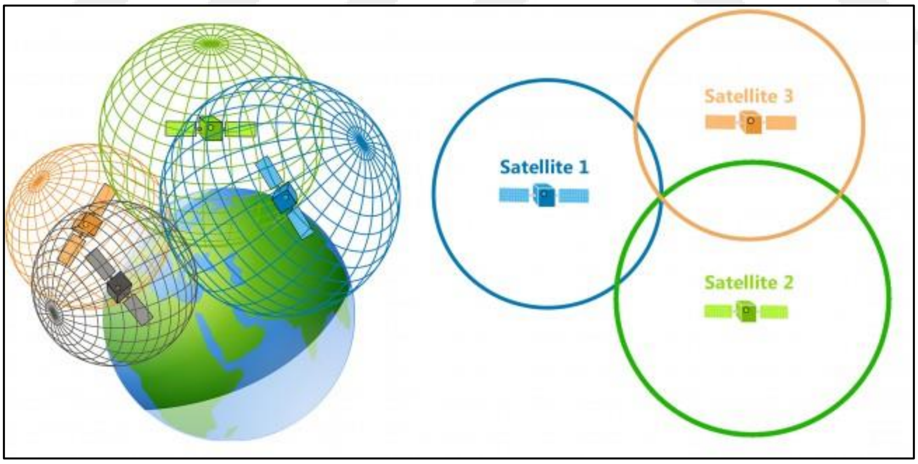

Figure 3.1: On the Right is a Depiction of Trilateration Using Three Satellites and a Single Circle Intersection, while on the Left is an Example Using Four Satellites to Pinpoint a Spot in a Tree Structure [20].

There is a good chance that every current phone comes equipped with a GPS module. This indicates that the phone has the capability of functioning as a receiver for radio signals sent by satellites. However, the technology that is used in mobile phones is not as precise as the GPS equipment that is utilized in professional settings. This gear, which is mostly used by the military but is also made accessible to people [21], combines the functions of two different GPS frequencies to provide a higher level of precision.

therefore, utilizing a cell phone as a localization device results in measurement mistakes induced by a range of circumstances, such as the imprecision related with space weather [22] or the device's close surroundings. an example is the research conducted by Krista Merry and Pete Bettinger, who found that "the overall average horizontal position error of the iPhone 6 is in the 7-13 m range, depending on conditions," which is "consistent with the general accuracy levels observed of recreation-grade GPS receivers in potential high multipath environments." [23]." When the gadget in question is housed indoors, meaning that it does not have a direct line of sight to any satellites, we have reason to believe that the inaccuracy will be much more pronounced. it is possible for this to be a concern since establishing exact position inside of structures is often more desired than doing so outside.

the position of a mobile phone may be determined using a variety of methods in addition to GPS, which is perhaps the technology that is the most well-known among the public.

3.2 WI-FI SYSTEMS

in recent years, Wi-Fi has emerged as an integral part of our daily life. Wi-Fi allows us to connect to wireless networks anywhere from our private homes and offices to public spaces like cafes, restaurants, airports, and trains. Everywhere we travel, we can connect to a wireless network. Wi-Fi placement utilizes a vast infrastructure of Wi-Fi hotspots and other wireless access points to precisely locate a mobile device, making it a kind of geolocation system. Due to the high potential for mistakes when using GPS inside, Wi-Fi positioning systems may find usage and application in the field of indoor navigation. Microsoft's RaDaR project, which started in 2001 and used a technique based on a Wi-Fi signal, was one of the first instances of a wireless fidelity positioning system. Since RaDaR is "the first Wi-Fi signal-strength based indoor locating system [24],"as stated on the company's official website. Despite this, various methods of discovering and localizing devices via the use of hotspot signals have been developed throughout the years.

Ekahau fabricated a simple gadget with the use of one of these technologies. it had lights, a button, and motion sensors. This piece of hardware may be worn by a person, and when the person walks, it will periodically send out Wi-Fi packets [25]. after some time, when there was a proliferation of mobile phones that were able to connect to wireless networks, programmers began using mobile phones as devices to receive or broadcast Wi-Fi packets. This was made possible by the quick spread of mobile phones with this capability. Smartphones have higher applications for any indoor positioning system that uses Wi-Fi because of their high penetration rate, cheap cost, and availability. Smartphones also have a low cost. This opened the door for the exploration of even more avenues leading to the use of hotspots for the purpose of localization.

as was discussed earlier, a Wi-Fi positioning system determines the location of a device by using wireless access points. as a result, this form of positioning system is one of the most cost-efficient types of positioning systems. currently, we have more than one option available to us when it comes to putting a Wi-Fi positioning system into action. active placement and passive positioning are the two strategies that we may differentiate between based on whether or not the user has a certain gadget.

active placement is used when the user is required to actively seek for nearby access points as well as carry a mobile phone to gather signals from nearby access points. the information that is available from the access points is collected and sent to the server. the location of the user may be determined by the system thanks to several positioning algorithms.

on the other hand, while using the passive placement approach, the user is not required to transport any equipment at any point throughout the process. Having said that, both a signal transmitter and a signal receiver must be set up. the passive positioning approach utilizes shifts in the signal to determine location. the receiver will get various signals depending on where the user is standing, and the system will be able to interpret these variations to come up with an estimate of where the user is standing [26].

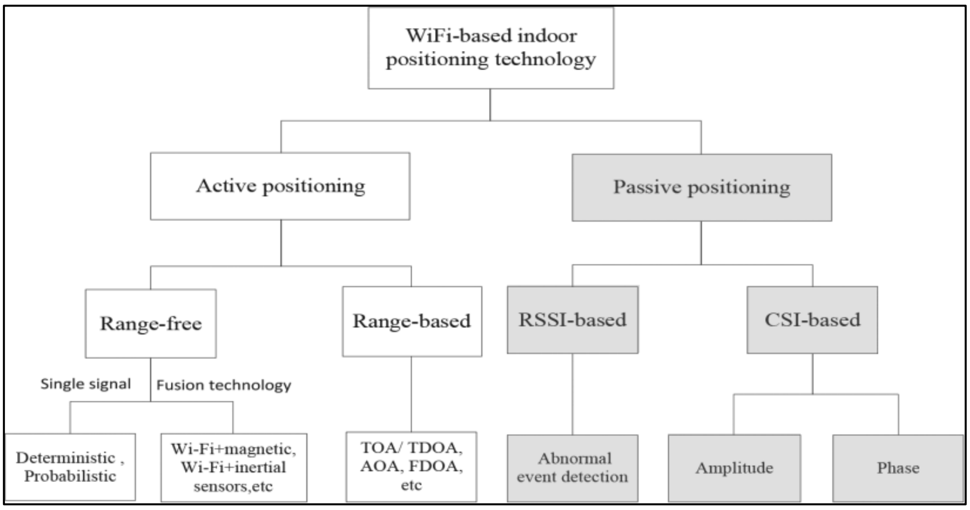

Figure 3.2: Wi-Fi Positioning System [26].

in most cases, the procedure for putting into action the active positioning approach is broken down into two stages: the offline phase and the online phase. Measurements of the signal's intensity and analysis based on a fingerprint are components of both stages.

When creating a radio map, the offline phase is required because it sections the environment into a dense grid of places. at these sites, the signal strength is collected from neighboring access points to generate a statistical model of the propagation environment at each spot [27]. Because physical obstacles might throw off measurements, it is important to make an estimate of the probability of the distribution of signal intensity in multiple directions and integrate those estimates during the offline phase of the practice. This is necessary because of the practice. This issue has the potential to become considerably more important in the locations where the things being monitored are sometimes relocated.

During the online phase, the goal is to locate the user by determining the signal intensities of nearby identified access points. This is done in order to do so. these readings are compared with the radio map to get an estimate of the user's position as well as their trajectory.

although a new measurement may help overcome the issue of a non-stable environment, it is important to keep in mind that the user's body also functions as a signal barrier. therefore, in busy settings, there is a greater potential for measurement mistakes, many of which are difficult to resolve [28].

Received signal strength (RSS), time-of-arrival (TOa), and angle-of-arrival (aoa) are only a few examples of the geometric methodologies used by this group of positioning techniques (aOa). the source of the signal may have been an anchor, a unique node, or an access point whose location in the network is totally known. Using these geometrical methods in conjunction with the received signals, the user's location may be calculated. However, if the received signal is distorted by noise, if the signal does not originate from an anchor in line of sight, or if the functionality of the technique varies depending on the model of the mobile phone, a range-based technique can produce errors in measuring location that are not insignificant [29].

3.3 BLE POSITIONING

BLE is an abbreviation for Bluetooth Low Energy, which is a component of the Bluetooth technology allowing wire-free communication. it is possible to employ beacons, which are tiny radio transmitters that use Bluetooth, to compute the position of a user. Bluetooth was developed specifically for the purpose of data transfer over relatively short distances and the creation of wire-free communication between two devices [25]. the majority of mobile phones manufactured in this day and age have support for Bluetooth technology, which is used on a daily basis to link our smartphones to accessories such as wireless headphones or speakers, smartwatches, and printers. in addition, even the most basic models of current automobiles come standard with an in-vehicle entertainment system that can wirelessly connect to a user's phone through Bluetooth to stream music, receive phone calls, or reflect the display of the user's phone.

in 2009 [30], Bluetooth Low Energy, which is also known as Bluetooth Smart, was revealed as a component of Bluetooth 4.0. When compared to the original Bluetooth, Bluetooth Low Energy was developed to be a wireless communication technology that uses the least amount of power possible while still being able to communicate a modest quantity of data. because of this, BLE devices are able to function on regular batteries for more than a few months, and in some cases even for years. Because of these qualities, this technology is well-suited for use in devices such as sensors, wearable devices, and the internet of Things in general [31]. a beacon is one example of this kind of equipment. During apple's Worldwide Developers Conference in 2013, the company demonstrated its first beacons to the public for the first time. they showed the transmission of data using their proprietary protocol, which is known as iBeacon, between a beacon and a receiver. Two years later, in 2015, Google responded to apple's move by releasing a new protocol known as Eddystone BLE beacon. This was done in 2015. it was very similar to iBeacon, except the protocol was designed specifically for usage on mobile devices operating on the android OS [32]. the rise of Bluetooth Low Energy may be seen as shown by the fact that more than fifty of the top one hundred merchants in the United States began testing beacons in their shops by the year 2014 [33]. This increase was caused by the implementation of Bluetooth Low Energy into mobile phones.

BLE beacons are tiny devices that are powered by a battery and provide data via a Bluetooth Low Energy communication channel. as was noted before, these beacons are also known as BLE tags. This information is accessible to all Bluetooth 4.0 devices. an article written by alexander Yohan and others provides the following summary: "the data that is sent by a Bluetooth beacon is condensed and organized in a straightforward fashion. This data includes the Universally Unique Identifier (UID) of the device, in addition to telemetry and a URL. in the Bluetooth ecosystem, Bluetooth beacons are often responsible for playing the job of the broadcaster [31]."

When a user gets a signal from a beacon, specified activities may be launched on their mobile phone. This is even though beacons are unable to communicate with other devices. it is possible to make an educated guess about the location of the user based on the information that has been received. Beacons, on the other hand, are incapable of carrying out any activities on their own in order to continue with the information or compute the distance. therefore, all computations have to be done either on the server side or on a mobile phone using an application that is appropriate [34].

as is the case with Wi-Fi positioning, there are other approaches that might be used to determine the location of the user based on the received signal.

Beacon proximity is a method that uses the Received Signal Strength indicator (RSSI) of a single beacon to determine the distance between a device and a beacon. This method is used to compute the distance between a device and a beacon. there are a great number of different applications for it. a beacon that is located at a certain distance away is known to send out a particular intensity of received signal strength. the calibration process and the measurement of the distance between a device and a given beacon based on the received signal strength value both make use of this information. the gadget is situated on the edge of a circle that is created because of the distance being measured.

the success of trilateration may be attributed to the closeness of the beacon, exactly as the success of a select few active Wi-Fi locating methods, both range-free and range-based, that make use of RSSI. it is one of the approaches that is utilized the most often for determining one's location within [31]. the RSSI readings from at least three beacons are used in the computation used to determine an approximate position. as was just discussed, received values may be translated to distances, which results in the creation of geometric forms similar to those produced by trilateration in GPS systems, but with circles being employed instead. the place determined by the result is the intersection of these two circles. according to ChinKun Ke and coworkers [35], however, the BLE beacon signal relies on a radio frequency operating at 2.4 GHz, making it susceptible to attenuation from multipath and shadowing from nearby objects. Rather than being a single point, which is what the user's actual location is, the estimated intersection is the whole area generated by errors in the received signal. This indicates that there is no way to precisely locate the predicted junction.

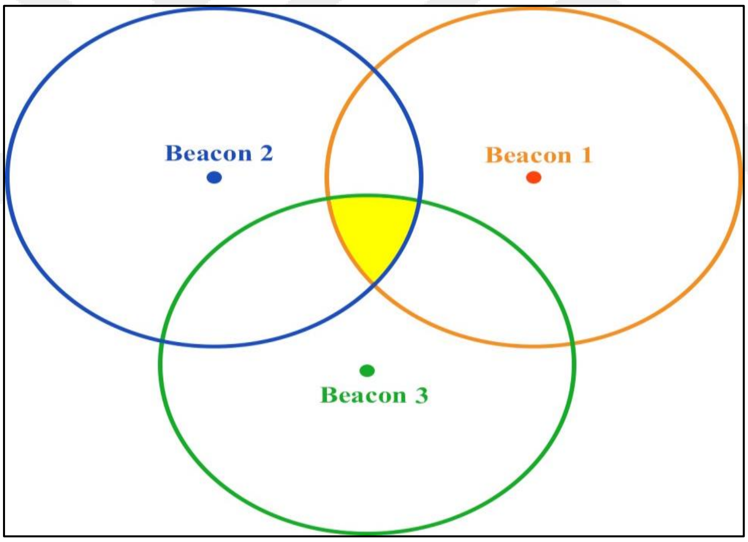

Figure 3.3: Trilateration Error Creates a Yellow Area.

3.4 FINGERPRINT METHOD

A fingerprint is another another method that may be used in conjunction with BLE beacons to locate an individual. This approach is very similar to the range-free active positioning fingerprint method that is used with Wi-Fi access points; the main difference is that a database is produced using the RSSI measurements of Bluetooth beacons rather than using the Wi-Fi method. the use of fingerprints in conjunction with trilateration may lead to more accurate findings [34]. the range-free active positioning methodology that is employed with Wi-Fi access points has the same challenges, and so does our method. in addition, the batteries that power beacons might run out. as a result, the database is no longer accurate, which results in further measurement inaccuracies.

Comparative analysis about several positioning systems when it comes to location precision for indoor positioning, BLE Positioning unquestionably provides a superior alternative to GPS. according to Tables 1 and 2 in the Survey on WiFi-based indoor locating approaches [26], we may attain an accuracy of around 2 meters using BLE, but GPS may have an accuracy of 10 meters. according to the data shown in the same tables, it is possible for basic Wi-Fi locating systems to provide results that are somewhat less precise than those produced by BLE.

When it comes to deployment, the GPS technique is the simplest option since it does not need any specialized hardware; all that is required is a standard mobile phone equipped with a GPS module. on the other hand, specialized hardware could be required for the BLE and Wi-Fi location systems. Both Bluetooth Low Energy (BLE) and Wi-Fi may need specialized access points to function properly.

why the purpose of this thesis is to create an android application, a comparison of how a mobile phone uses its battery is another essential component. according to the research conducted by Shu Liu and aaron Striegel [36], Bluetooth Low Energy (BLE) is much more power efficient than GPS and significantly more power efficient than Wi-Fi. This is since BLE was intended to be the most power effective technology.

3.5 THE ROUND-TRIP TIME FOR WIFI

WiFi the Round-trip-time (RTT) technology makes use of the Fine timing measurement (FTM) methodology to get accurate measurements of time down to the picosecond level. the IEEE 802.11mc standard, which was approved in 2016 (also known as 802.11-2016), includes the FTM protocol as one of its components [15]. During a session of FTM, the RTT measurement will be carried out. an instance of the FTM protocol is referred to as an FTM session, and it takes place between two communication devices known as an initiator and a responder. in most cases, a cell phone serves as the instigator. it is responsible for sending the FTM request frame and is also responsible for receiving the FTM frame. on the other side, the responder is often the access point in the situation. the FTM frame is sent by the aP, and it is also the recipient of the FTM request frame [37].

Figure 3.1 illustrates a session that is very typical of FTM. the person who started the conversation is on the left, and the one who responded to it is on the right. the initiator is the one responsible for making a request in order to start an FTM session. the aCK frame is the response sent by the responder. it then transmits the frame M while simultaneously marking time unit 1 (t1), which is the toD(M) of the FTM frame M. as t2, the initiator indicates the arrival of frame M, and this is denoted as toa. (M). Moreover, it provides a response in the form of an aCK frame and flags t3, the toD(aCK) indication. after receiving the second FTM frame, the responder adds the new timestamps t1 and t4 to indicate that it has arrived at the time of acknowledgement (toa(aCK)). after receiving the message, the sender will finally reply with an aCK.

the initiator may now compute the time-of-flight, also known as the round-trip time, by using the four individual timings (in seconds) (RTT). to do this, just subtract 1 from (t4-t1) to get the answer (t3-t2). once the initiator has received the tof data, they will be able to calculate the distance to the responder. (Time-of-Flight * c) / 2, where c is the speed of light, is the formula for determining the distance.

Whereas in [22] the author suggests marking timings t2 and t3 at a later point in time, our approach marks them at the same moment they are received over WiFi RTT.

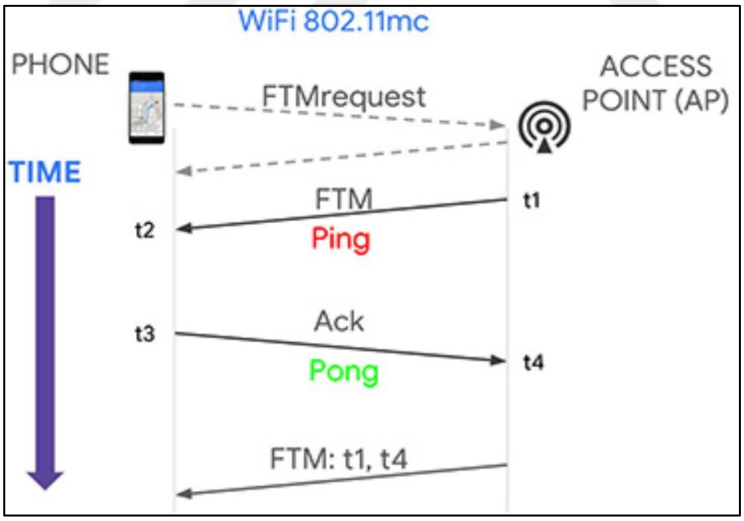

Figure 3.4: FTM Source [15].

4. PRACTICAL PART AND ANALYSIS

This chapter presents the results of an experimental investigation on the Round-trip time of WiFi (RTT). a experimental comparison of several technologies that may be used for indoor navigation, such as Bluetooth Low Energy (BLE) and WiFi Received signal strength indication, is also included in this chapter (RSSI). in terms of accuracy and precision, these technologies are evaluated in comparison to WiFi RTT.

the first section of the chapter provides a description of the testing conditions and the apparatus used in the experiment. in addition to that, it offers a description of the instruments that are used throughout the measuring process. the technique of measurement for each setting and method that was picked is going to be discussed in the next section. the last part gives the findings of the experiments as well as the comparative result based on the findings of the measurements.

4.1 EXPERIMENTS SETUP

for the purpose of the tests, two different testing conditions were prepared. Environment 1 consisted of a three-room apartment located inside of a multi-family dwelling and was shown in Figure 4.1a. the reference access points (aPs) and BLE beacons were placed at a height of roughly one meter in one of the apartment's corners (shown as a red circle labeled "aP"). the diagram presents an illustration of the sites of measurements. these places are shown as green circles and are identified according to their distance from the aPs and beacon. the first setting was created in order to assess the performance of technologies in locations where the multipath effect is possible to take place.

Environment 2 was a modest office space comprised of a few rooms of varying dimensions (shown in Figure 4.1b). the diagram depicts the door as having many glass panels using lines of a gray tint. the walls that include aluminum struts and frames as well as glass panels in between them are represented by dashed lines that are gray and black in color. a red circle represents the area where the reference aPs or beacon are situated on the map. at a height of 120 centimeters, the aPs and beacons were positioned directly next to the concrete wall. the site that is adjacent to the wall was picked to take use of the reflection that is produced by the wall, which may result in an increase in the range (inspired by the metal reflectors in [11]). the measurement points are shown by green circles that are labeled with the distance away from the aP. a location that has many wirelessly connected devices, including PCs, tablets, smartphones, Bluetooth printers, and WiFi access points, is represented by the red ellipse in the middle of the figure. Finally, the blue symbols of persons depict the areas during the measurement when the individuals in question were either walking or sitting. This setting was built up in order to evaluate the behavior of the technologies in an area that is "polluted" by the wireless signal and where people move about, both of which have the potential to cause interference with the signal.

the Google Pixel 2 was chosen as the receiver for each of the three technologies that were evaluated. the gadget that was chosen was a mid-range model with 4 gigabytes of random-access memory (RaM) and 64 gigabytes of storage space. it was powered by a Qualcomm MSM8998 Snapdragon 835 processor. in preparation for the test, the operating system on the gadget was upgraded to version 9. This the device was chosen since it is the only one known to support the IEEE 802.11mc standard and, as a result, WiFi RTT.

an I2 Max iBeacon BLE beacon manufactured by Social Retail was decided upon to serve as the transmitter for the Bluetooth Low Energy measurement. the specific beacon was chosen as the best option owing to its inexpensive cost (11 euros when purchased from amazon.com) and its small footprint (7x7x2cm).

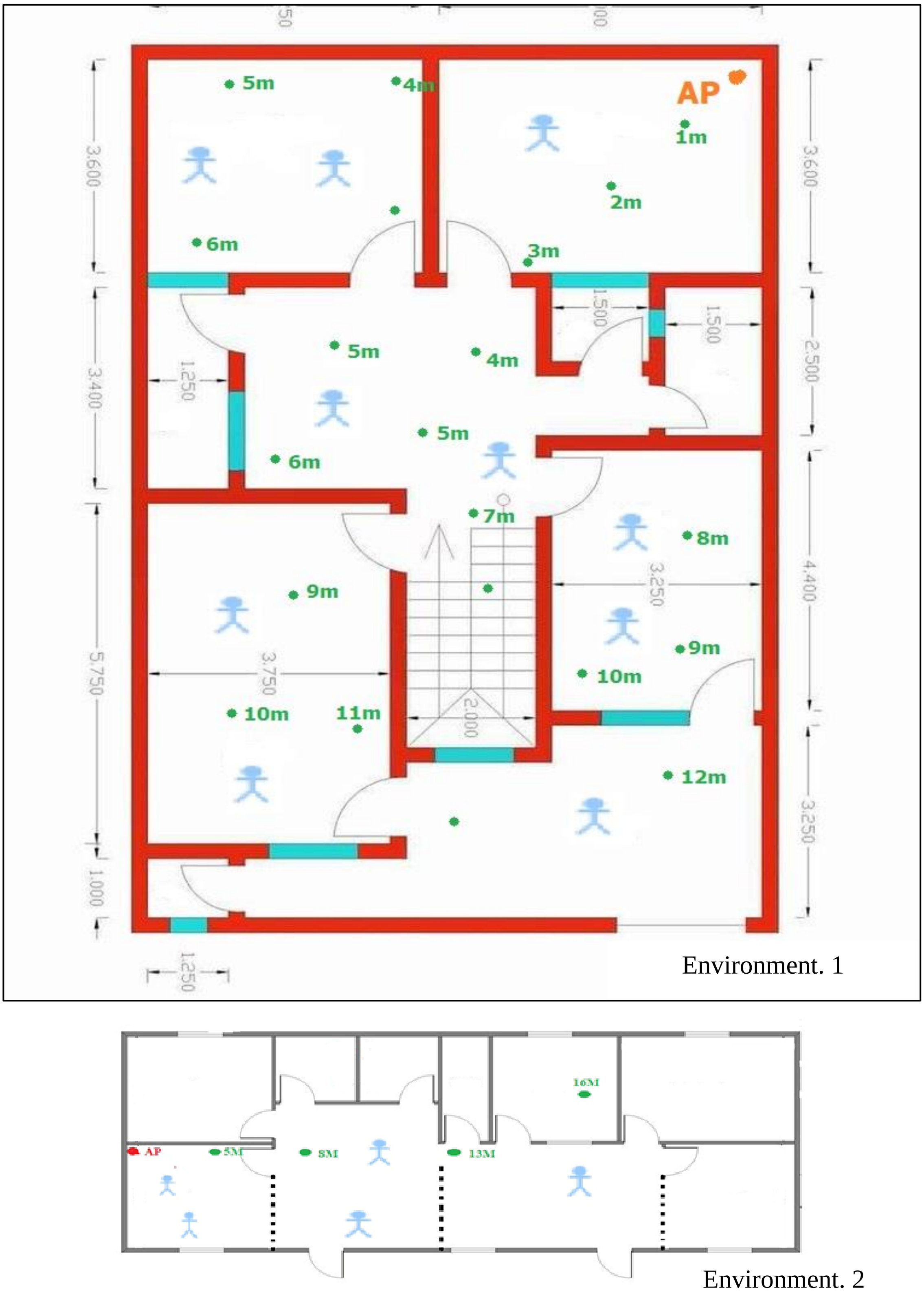

Figure 4.1: Both Environments we had 1 & 2 for Testing Environments Our Practical Work.

the program allows for the configuration of several of the beacon's transmission characteristics, and the beacon itself is compatible with the iBeacon protocol. in contrast, for the purposes of testing, those parameters were left in their default states; the transmission power was increased to its maximum level; the reference distance (txPower) was increased to 59 dBm; and the broadcasting interval was increased to 300 milliseconds.

access station was used so that the WiFi RSSI measurements could be taken. The access point is compatible with the 802.11n standard and broadcasts on the frequency of 2.4GHz. Measurements of the signal strength were carried out using the WiFi network that had previously been setup. Before we began the studies, there were no changes made to the transmission settings.

in conclusion, to put the WiFi RTT technology to the test, it was necessary to acquire a Compulab Wifi indoor Location Device (WILD). the first access point that has RTT functionality [41] is the computer. they used model had a CPU by intel named Celeron-J3455, 4 gigabytes of RaM, and a solid-state drive with a capacity of 32 gigabytes. according to [40], the computing device makes use of the intel Wireless-aC 8260 SoC, which is recognized as one of the WiFi Certified access points. WILD was using GNU/Linux Debian as its operating system (OS), and Compulab was responsible for supplying RTT tools. in order to prepare WILD for testing, a fresh image of the operating system needed to be flashed into it. the wild software was made available in the newest edition. This program is responsible for processing RTTs and configuring the system to operate in either the responder or the initiator mode, depending on the situation.

although it was the first access point (aP) to offer WiFi RTT, it has a few drawbacks or issues. the configuration itself is the source of the first of its many flaws. only by utilizing the terminal is it possible to setup the aP. Setting up Linux for a user who has no prior knowledge with the operating system would be very difficult. in addition, the procedure for updating the operating system has weak documentation, and it had to be carried out manually by installing the operating system from a removable media. the second drawback is that the access point (aP) does not let wireless clients to connect if there is no LaN connection present. Even though this is a known problem and has been mentioned in the wiki, dealing with it may be frustrating. Since of this problem, WILD was unable to be used for the WiFi RSS testing because the smartphone was unable to establish a connection to the network that WILD was using.

4.2 THE PROCESSES OF MEASUREMENTS

Before beginning the testing in the new setting, the floor was marked with a series of markers that indicated the actual distance from the aP. these markers were put there before the tests began. in all, eight marks were assigned to the Environment 1 category. the majority of the marks for Environment 1 were positioned along Marks for Environment 1 were concentrated in one area, with the bulk of them lying along an imaginary line from the aP (shown in Figure 4.1a's lower right corner) to the mark in the upper left corner of the flat. the starting point for this line was the upper left corner of the living quarters. the context in which the markers are located was taken into consideration while determining their placement. one mark, for instance, was placed in the upper left corner, close to the wall, to test whether or not the reflection from the wall affected the results. another tally was randomly distributed over the floor of the room. in the second setting shown in Figure 4.1b, most of the markings were made along the line perpendicular to the base wall in the area indicated by aP (red circle). Marks were positioned every 1, 2, 3, 5, 8, 10, and 13 meters along this line to serve as seven separate reference points.

an outlier was positioned farthest from the aP so that we could compare each technology's reach and precision across a larger area and with more obstructions in the way. This was performed so that the effectiveness of each technology could be evaluated. the location of this mark is roughly 17 meters away from the starting point.

the evaluating tool was held by hand at the average height of the tester. the height at which the smartphone may have been used without causing discomfort is referred to as the "natural height." the application that is described in appendix a was utilized for the measurement that was performed. Table 4.1 provides an overview of the sample rates that were used and may be seen here. Because it was anticipated that the value being measured using BLE would be dispersed, the sample rate for this measurement was set to 50 milliseconds.

Table 4.1: Rates That Used for the Thesis Measurement.

Technologies	Sample rates in (ms)
LE	55
WIFI RSS Tcho	510
WIFI RTT	850

the measurements were carried out in precisely the same sequence across all of the different settings. the Bluetooth LE measurement came first, then the WiFi RSS measurement, and lastly the WiFi RTT measurement. it was determined to carry out the measurement. a single measurement was comprised of many value readings at various points in time.

in the beginning of the process of measuring the distance using WiFi RTT, the values of distance that were being measured came out to be negative. for instance, the distance measurements were anywhere about 4 meters whereas the true distance from WILD was 3 meters. altering the transmitter's bandwidth may be helpful, as Horn found out in [16]; this possibility was brought to light by him. it was discovered that altering the bandwidth had the following effects: with the default bandwidth setting of 80MHz, the distance readings at a 3m actual distance reached 4m.

Negative values were recorded for distances in the immediate vicinity while using a 20MHz bandwidth (for example, at 1m, WiFi RTT reported the measured distance of 2m in average).
for larger actual distances, though (about 5 m and beyond), the reported values were very close to the actual distance. With a bandwidth of 40MHz, the distance measurements performed well at both short and long actual distances.

as a result of negative results that occurred within close proximity to a band-width of 20MHz, a bandwidth value of 40MHz was selected for the testing. Following the collection of the measurements, the application's measurement data were then exported to CSV files. Google Sheets was used to do the processing on the output files. the spreadsheets that were generated are in the.xlsx format, and they are included as an attachment to this thesis in digital form.

4.3 THE EVALUATIONS PROCESS

Because the output was already in millimeters, there was not necessary to do any post-processing on the observed values when it came to the WiFi RTT measurements. the root-mean-square-deviation (RMSD) was computed for each of the measurements in order to provide an expression of the inaccuracy in the measurements. the root-mean-squared deviation, or RMSD, is a version of the standard deviation. in contrast to the standard deviation (SD), the root mean squared deviation (RMSD) takes its cues from the reference value, also known as the anticipated value. the root mean square deviation (RMSD) is the square root of the mean-squared error (MSE), which is in turn the variation of variance. However, while calculating the RMSD, the reference value is used rather than the mean of the measured values. it is possible to calculate both the MSE and the RMSD for the measurement X by using the following equations:

$$MSE(X) = \frac{1}{n}\sum_{i=1}^{n}(x_i - x_0) \tag{4.1}$$

$$R\ MSD(x) = \sqrt{MSE(X)} \tag{4.2}$$

where n is the total number of values in the measurement X and x0 is the standard deviation.

the ME was determined for each measurement in each setting using this procedure. the aggregate measurement error was calculated by adding together the individual errors in each measurement:

$$ME = \frac{1}{m}\sum_{i=1}^{m} RMSD(X_i) \tag{4.3}$$

Measuring errors for both WiFi RSS and Bluetooth Low Energy may be computed using Equations 4.1, 4.2, and 4.3.

WiFi and Bluetooth Low Energy (LE) readings are reported in decibels relative to 1mW. (dBm). these numbers represent the quality of the signal picked up by the receiver device (RSSI). Finding an appropriate propagation formula to map RSSI to distance was a necessary step. the generic Free-space- path-loss (FSPL) function is one option. Because it does not account for obstructions (often walls), this propagation function is primarily useful in open space and may provide erroneous results in more common interior settings.

an empirical propagation model from [21] was selected as an alternative to the FSPL.

$$RSSI[dBm] = txPower[dBm] - 10.n.\log d - l.WAF \tag{4.4}$$

the received signal intensity is denoted by the RSSI, which is measured in dBm. the signal intensity at the reference distance, which is 1 meter in this example, is denoted by the txPower value, which is likewise expressed in dBm.

the value of the exponent is given by the parameter "n." the rate at which a signal decays through time and distance is determined by the value of the exponent. the value of the parameter d indicates the range over which the RSSI was collected. Within the logarithm, the value d is divided by one meter, which acts as the reference distance. there are l barriers between the transmitter and the receiver, and this value describes how many there are. Because of each of these obstacles, the received signal is attenuated by a number called as the wall attenuation factor (WaF) (WaF). the WaF is determined experimentally as the difference between the RSSI value measured when the receiver is in direct line of sight (LOS) with the transmitter and the RSSI measured when the receiver is in an environment with no direct line of sight (NLOS):

$$WaF = RSSI_{LOS} - RSSI_{NLOS}. \tag{4.5}$$

there must be consistency in distance between the two measurements taken from the transmitter.
We assessed WaF empirically to account for the barrier impact of walls. WaF for Bluetooth Low Energy was 10dBm and WaF for WiFi RSS was 8dBm. Following this, we have to compute the parameter n to get the separation between the observed and received RSSI values. adjustments were made to Equation 4.4 in order to calculate n:

$$n = \frac{RSSI - TX\ Power + l \cdot WaF}{-10 \log d} \tag{4.6}$$

for starters, the n-value appropriate to each measurement was determined (a measurement is defined as a collection of value measurements carried out at the same distance from the transmitter). then, the average of the first half of the test done with that technology in that environment was used to determine n for the given technology/environment combination, simulating the real deployment and calibration of a navigation system based on BLE and/or WiFi RSS. This was done in order to ensure that the simulation was accurate. in

Environment 1, n was determined by taking the average of the readings taken at 2 meters, 3 meters, 4 meters, and 5 meters. in Environment 2, n was determined by taking the average of the readings taken at 2 meters, 3 meters, 5 meters, and 8 meters. Because the reference values were also obtained at 1 meter from the transmitter, it was decided not to take into consideration the measurements made at 1 meter because doing so would result in the logarithm being equal to zero, which in turn would lead to division by zero. Table 4.2 provides the values of n for every possible combination of technological advancement and natural setting. as the table makes clear, Environment 1 had a larger rate of the signal fading than the other environments.

Table 4.2: the Exponent Value in Each Technology / Environment Combination.

	Environment 1	Environment 2
BLE	3.4483	1.1619
WiFi RSS	2.7454	0.6280

as compared to Environment 2, where testing were conducted in a wall-less, linear corridor (except for the last value).

after determining n, the model was complete. the modified version of Equation 4.4 was used to convert the received signal intensity to the distance:

$$d = 10^{\frac{\mathrm{RSSI}-\mathrm{txPower}+\mathrm{l}\cdot\mathrm{WaF}}{-10.n}} \qquad (4.7)$$

for each value in each measurement, the estimated distance was determined using this equation (columns designated d approx in the spreadsheets). Next, we used these numbers for each measurement to get its RMSD. Measurement error (ME) was determined by averaging the RMSDs, as previously described. the outcomes of these computations are shown in the next section.

4.4 RESULTS

This section will offer a summary of the outcomes that were identified. the average measurement error, which can be found in Table 4.5 at the very bottom of this article, is used to provide a description of the accuracy of each technique. the faults are broken down into categories based on the environment and the technology used.

4.4.1 Environment 1

The purpose of the testing that was done in Environment 1 was to investigate how the technologies performed in confined spaces that had a high concentration of walls. The inaccuracies in the measurements taken in Environment 1 are shown in table 4.3, and the results are arranged in accordance with the actual distance and the method that was used.

Table 4.3: Measurement Errors (in Meters) for Environment 1.

	1M	**2M**	**3M**	**5M**	**8M**	**9M**	**10M**	**12M**
BLE	1.120	1.650	1.930	6.850	9.736	26.130	29.330	32.210
RSS	1.425	1.694	2.788	5.573	6.842	42.254	33.645	34.351
RTT	0.475	0.850	0.973	0.963	1.822	2.452	2.693	2.633

only over very short distances do the selected propagation model seem to be appropriate for use with Wi-Fi RSS and Bluetooth LE.

the measurements at distances of one, two, and three meters were carried out in the same room as the aP or beacon, which meant that there was no wall between them. the measurements at 4m and 5m were taken outside of the room, with precisely one wall separating them from the aP or beacon in the center of the room. Last but not least, the distances of 6 meters, 8 meters, and 9 meters were all measured in the same room, with two walls separating them from the aP or beacon. the proportional rise in measurement error is observable when looking at the measurement that was taken at 6 meters, which was carried out just behind the second wall.

When compared to the previous measurement, the error in the BLE readings grew by a factor of three, while the inaccuracy in the WiFi RSS readings climbed by a factor of roughly seven (for WiFi RSS, the error calculated at 6m is the largest of errors calculated in Environment 1). Even in the case of WiFi RTT, the larger measurement error may be shown to be present. Nevertheless, the inaccuracy is not nearly as serious as it is with the other two methods.

4.4.2 Environment 2

the test carried out in Environment2 yielded findings that were more fascinating. in the case of BLE, the errors that were computed at 15m and 18m for WiFi RSS reached millions of meters, and in the case of WiFi RSS, they even reached billions of meters. because of this, some findings did not make it into the table. However, it is essential to consider that at a distance of 17 meters, the signal of the BLE device was rather weak, the signal from the BLE device was very weak, which resulted in longer gaps of time between the value readings and also resulted in a huge variation in the measurement. the intriguing finding is that at a location with a lot of devices that interfere with WiFi signals, the measurement errors that are computed for WiFi RSS are several times larger than the ones that are calculated for Bluetooth LE.

it was reasonable to anticipate high error values for the region, but not at this size. the 5-meter mark was situated near the interference zone, which can be identified by the significant rise in the amount of measurement error produced by WiFi RSS. Because many of the devices in the interference zone had Bluetooth or 2.4GHz WiFi enabled, it was reasonable to anticipate that the interference would be the most important factor influencing the testing findings. in addition, the RSS testing was carried out using the 2.4GHz WiFi network, as was mentioned in Section 4.1. Table 4.5 reveals that the significant average errors of BLE and WiFi RSS were mostly brought on by the high variation (and the standard deviation) of observed signal strengths. for instance, the WiFi RSS measurement at a distance of 8 meters recorded an RSSI variation of 41 dBm, but the measurement at a distance of 13 meters revealed an RSSI variance of 13 dBm. in every measurement, Bluetooth Low Energy demonstrated a substantial degree of variation. at 1 meter, the variance was measured to be at its lowest, 7 dBm, while at 10 meters, the variance was measured to be at its largest, 33 dBm. on the other hand, WiFi RTT performed as predicted, delivering accuracy of less than one meter most of the time. an important peak is found at 17 meters, where the computed inaccuracy is 3.342 meters. However, since there were five solid walls in the path between the aP and the reception device, it is acceptable for this mistake to occur.

Table 4.4: Measurement Errors in Meters for Environment 2 Setup.

	1M	2M	3M	5M	8M	10M	13M	17M
BLE	0.880	1.632	3.983	5.012	6.992	42.649	36.303	–
RSS	1.301	0.948	4.543	20.124	23.398	125.253	127.04	–
RTT	1.132	0.899	1.324	0.954	1.132	0.895	0.697	3.994

Table 4.5: Mean Measurement Errors by Environment and Technology has Been Used.

	Environment 1	Environment 2
BLE	9.453	780412
RSS	10.659	410628040.8
RTT	1.76	1.350

First, in [1], Sadowski and Spachos noted that although Bluetooth's accuracy error was documented as being 1.1143 meters, WiFi RSS location accuracy error was just 0.5183 meters. a similar approach was used by Sadowski and Spachos, whereby measured values were utilized as the basis for determining the model's parameters. Unfortunately, they did not provide any details on the model's parameters. their research revealed that compared to Bluetooth LE, WiFi RSS showed higher levels of accuracy. However, each company's testing conditions were unique. they conducted their experiments in silence and with as few distractions as possible.

Lanzisera, Zats, and Piste contrasted the RSS approach with a novel implementation of time-of-flight (TOF) measurement they developed themselves. Because of the device's built-in 2.4GHz antenna, they were able to transmit the signal [24]. Since WiFi RSS measurements were performed in opposition to the 2.4GHz WiFi aP, this approach is analogous to the testing environment employed for this thesis. Researchers found that although the RSS method had an accuracy error of around 8 meters, the TOF implementation only had an inaccuracy of about 1 and a third meters. their RSS suggested a significantly bigger error rate than the research presented by Sadowski and Spachos, but its results do not agree with the conclusions of this thesis. However, it seems that their TOF implementation's accuracy error is somewhat on par with the results of the WiFi RTT presented in this thesis.

Next, we'll look at Schauer, Dorfmeister, and Maie's study. an inaccuracy of 1.33 meters was shown using their suggested round-trip-time-of-flight (RTOF) approach [22], which is similarly close to the least average error obtained with WiFi RTT (1.231m).

This thesis's conclusions are consistent with those shown in [42] and reported in [16] by Horn, therefore the three bodies of work may be considered complementary. for reference, Horn estimated an accuracy of "about meter or two," whereas the Cobbs recorded a standard deviation of 0.83 mm. there is harmony between this conclusion and the thesis's observations.

5. CONCLUSION

The purpose of this thesis was to examine the new IEEE 802.11mc WiFi standard in relation to the various methods of indoor positioning and navigation that are already in use. the evidence presented in support of the thesis demonstrated that WiFi RTT had the lowest amount of measurement error when compared to the other technologies under consideration. WiFi RTT has also been shown to be acceptable for usage in areas with significant levels of interference, which may be created either by the signals of other devices or by the movement of humans across the testing space. the technology was able to achieve a measurement error of 3.342 meters when there were five solid walls placed between the transmitter and the receiver. However, the technology was able to achieve an error of approximately 2.5 meters when there were only two solid walls placed between the transmitter and the receiver. This thesis demonstrated that the navigation systems on android devices can achieve the sub-meter precision referred to in [15] by taking advantage of WiFi RTT.

5.1 FUTURE WORK

one of the many potential developments of further research based on this concept is an increase in accuracy. the least-squares method, gradient descent, or a particle filter may all be used to smooth the received information and improve the accuracy of an indoor positioning and navigation system [16]. Similarly, a particle filter may be used to clean up the data.

another strategy that may be utilized to enhance positioning precision is to combine WiFi RTT with other navigation methods. the next step may be researching whether existing approaches work best when combined with WiFi RTT, or it could inspire the creation of an entirely new technology.

Among the many avenues that may be explored in the course of future research is the introduction of the intelligent scanning approach discussed in Section 3.

in the past, this section has suggested a workaround for some of android's limitations. once the RTT is enhanced with details about the aP's precise position (including latitude, longitude, and altitude), it might lead to exciting new research that, in turn, could inspire the creation of a universal, self-sufficient indoor navigation system for everyone. [37] adding the aP's precise position details to the RTT might lead to some fascinating studies. This indoor navigation system will function autonomously since the locations of aPs will not need to be entered by hand. the system's robustness and adaptability will be improved as a result of this.

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