A Cost-Efficient Bluetooth Low Energy Based Indoor Positioning System for IoT Applications

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Abstract

The indoor positioning system is a series of networking systems used to monitor/locate objects at indoor area as opposed that of GPS which does the same at outdoor. The increase in the popularity of the Internet of Things made the demand for Bluetooth Low Energy technology more and more essential due to their compatibility in the smartphones which makes it to access easier. The BLE’s reliable signal and accuracy in calculating the distance has a cutting edge on others in IPS. In this thesis, the Bluetooth Low Energy indoor positioning system was designed and implemented in the office area, and the position of IoT devices were monitored. On the IoT devices, the beacons were placed. And these beacons were covering the office area. The receiver, smartphone in our case, recorded the Received Signal Strength Indication of the transmitted signals from the beacons within the range of the signal and stored the collected data in a database. Two experiments have been conducted. One is for beacons that are stationary and one that is moving. To evaluate these experiments, a few tests were performed to predict the position of beacons based on the recorded received signal strength’s. In the case of stationary beacons, it offers accuracy range from 1 m to 5 m, and 3 m to 9.5 m in anticipating the position of each beacon in the case of moving beacon. This methodology was a mixture of fingerprinting and an algorithm of multilateration. Finally, the experiments show that the algorithm used provides the most accurate indoor position using BLE beacons that can be monitored through an Android-based application in real-time.

Keywords: Indoor positioning system, Internet of Things, Bluetooth Low Energy technology, RSSI, fingerprinting, multilateration.
Acknowledgments

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Sanjana Vupparige Vijaykumar
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List of Abbreviations

AP                Access Point
BLE               Bluetooth Low Energy
B2C               Business to Consumer
CDF               Cumulative Distribution Function
CoAP              Constrained Application Protocol
dBm               deciBell-milliwatt
E2E               End to End
GPS               Global Positioning System
GHz               GigaHertz
ICN               Information centric networking
IoT               Internet of Things
IPS               Indoor Positioning System
ISM               Industrial, Scientific and Medical
mW                milliwatt
MAC               Media Access Control
MHz               MegaHertz
MySQL             My Structured Query Language
M2M               Man to Machine
OS                Operating System
PAN               Personal Area Network
PDR               Pedestrian Dead Reckoning
RFID              Radio-frequency identification
RSSI              Received Signal Strength Indicator
SWOT              Strengths, Weaknesses Opportunities and Threats
TDoA              Time Difference Of Arrival
Tx                Transmit power
UAV               Unmanned Aerial Vehicles
URL               Uniform Resource Locator
UUID              Universally Unique Identifier
UWB               Ultra Wide Band
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<tr>
<td>VLC</td>
<td>Visual Light Communication</td>
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<tr>
<td>WLAN</td>
<td>Wireless Local Area Networking</td>
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1 Introduction

In this chapter, background and motivation to this master thesis is explained. It also presents the aim and research questions of this thesis in section 1.2 and section 1.3 respectively. Section 1.4 explains the research methodology and section 1.5 gives the purpose behind this thesis. Whereas the Sections 1.6 describe the delimitation and section 1.7 provides the remaining layout of this thesis work.

1.1 Background

Over the past decade, demand for indoor positioning services has risen rapidly as many fields depend on positioning and location. Some of the main examples of these location-aware applications would be navigation of civilians inside buildings, navigation of customers inside malls, health care center and product localization in supermarkets [1].

The motivation for IPS researching and developing stems from excellence of GPS-based outdoor positioning system. Sadly, GPS is not accessible inside the buildings as well as in the urban areas where signals are low and the visual conditions are not met [2]. This result in alternate means to detect location and position at the indoor, without depending on GPS satellite. IPS uses techniques such as Wi-Fi, RFID and Bluetooth signals as well as effective positioning algorithms to to locate objects at indoors [3]. The WiFi method is limited to parameters including climate as well as power supply, RFID method is limited to the customers with different requirements for positioning equipment. Meanwhile, BLE technology is strong enough to maintain the signals energy reliable and establishing a network necessary for indoor positioning [4].

Currently, there has been an increasing deployment of BLE beacons by many individuals and organizations inside their homes, offices, buildings, and campuses. The popularity of BLEs opens a new opportunity for location and positioning at indoors. The beacons can be applied to provide indoor location service without deploying additional equipment. They are cheap, small, have an extended battery life which do not need any external source. Bluetooth-based smartphones or laptops detect incoming beacon signals and then determine the distance to beacons and predict the position [5].

IoT is able to connect to different networks utilizing clouds and media to find the precise position of an object and to transfer the data among them. The rise in IoT’s popularity has rendered this BLE device’s requirement increasingly important owing to its compatibility
in smartphones, making it simpler to access. In the distance estimation, the BLE’s accurate signal and precision has a significant advantage over others in IPS.

1.2 Aim

The main aim of this study is to define an effective positioning algorithm for the indoor positioning of IoT devices employing BLE beacons that take into account the received signal strength, distance and other parameters in order to locate them accurately at low cost as well as to be energy efficient and user-friendly.

1.3 Research questions

The aim of the study is to answer the following questions:

1. Why BLE beacons are chosen for indoor positioning?
2. How to obtain measurements from the nearby BLE beacons?
3. What is the accuracy of the position of an IoT device inside a building using BLE beacons?
4. What are the requirements and challenges faced while using BLE beacons?
5. How many number of beacons used for indoor positioning can impact the accuracy of the location estimation?
6. What are the main use-cases in which BLE positioning would become beneficial?

1.4 Research Methodology

The methodologies of both qualitative and quantitative analysis are used in this study. Qualitative analysis was carried out to learn the BLE beacons’ criteria and requirements, while quantitative analysis is carried out to determine the efficiency of a model of the proposed scheme, based on the metrics outlined in section 3.9.

1.5 Purpose

The purpose of this research topic about BLE beacon for Indoor Positioning System is because the next decade is all about the IoT and the normal life in the future will be very much dependent on it. As a 90’s kid going through the rapid changes in technology had always amused me about the new technologies and their effect on the life of the people. The interaction between a man and machine was very much beyond the imagination of a commoner in the last few decades, but with the IoT the M2M, B2C interactions have increased the efficiency of the products. GPS has made tremendous improvement in connecting the outside with much greater accuracy but it’s still a challenge as far as it is concerned indoor navigation and positioning. Taking advantage of BLE beacon which is cost and energy effective, the indoor navigation accuracy can be improved in terms of positioning.

1.6 Delimitations

The project is carried at the NavAlarm company, LEAD, Linköping.
1.7 Structure of the thesis

The rest of this thesis will be structured as follows: Chapter 2 offers important theoretical data on the terminology and techniques used in this study followed by related works. The procedure used to solve the problem outlined in Section 1.3 is discussed in Chapter 3. Chapter 4 explains how the research problem posed in section 1.3 is applied and the outcomes. Chapter 5 summarizes the study and proposes potential future directions for positioning systems study.
2 Theory

The following chapter covers the different technologies involved in this thesis. It also focuses on different positioning methods, filters and positioning optimization techniques followed by the related work.

2.1 Indoor Positioning System - Wireless Technology

There are many wireless technologies used for IPS. The one which is found most interesting related to this thesis has been reviewed.

2.1.1 Wi-Fi

From the past 20 years, Wi-Fi has become the most popular wireless network protocol. It is commonly used for WLAN at home, workplaces or public areas [6].

Figure 2.1: Wifi based indoor positioning
Wi-Fi hotspot are the keys, which is also known as the access point. These are used to establish a connection between the different devices over the network. Every access point for Wi-Fi transmits data. Using the RSSI and MAC from the data transmitted, may measure the end-user device’s current location [7]. This is known as client-based positioning. Figure 2.1 represent the IPS using Wi-Fi.

Wi-Fi based indoor positioning fairly gives high-level accuracy about 5-15 meters. Accuracy depends on multiple factors such as walls, ceiling, our own body, reflections, and available networks. But the use of a smartphone sensor, known as sensor fusion, can help in improving accuracy [7].

2.1.2 Bluetooth

Bluetooth is another wireless technology specification for the shorter distance sharing of information. It was designed for continuous, streaming data applications which means with the help of it, a lot of data exchange can be done over the close range [8]. That’s why portable headphones use it, also hands-free communication through your car, and wireless data transfer. It has a low power consumption and works within the ISM 2.4 GHz frequency band of 2400-2483.5 MHz range [8]. It has low interference and is a standardized protocol.

Below table 2.1 represents the different versions of Bluetooth and their respective range.

<table>
<thead>
<tr>
<th>Version</th>
<th>Year</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>1999</td>
<td>10m</td>
</tr>
<tr>
<td>2.0</td>
<td>2004</td>
<td>10m</td>
</tr>
<tr>
<td>3.0</td>
<td>2009</td>
<td>10m</td>
</tr>
<tr>
<td>4.0</td>
<td>2010</td>
<td>60m</td>
</tr>
<tr>
<td>5.0</td>
<td>2016</td>
<td>240m</td>
</tr>
</tbody>
</table>

Table 2.1: Versions of Bluetooth

Bluetooth is again classified into four classes based on power. Each class has a certain power allowed along with a certain range. This is shown in table 2.2. Among those classes, class 1 and class 2 is most commonly used in industries.

<table>
<thead>
<tr>
<th>Class</th>
<th>Power allowed</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20 dBm</td>
<td>~100m</td>
</tr>
<tr>
<td>2</td>
<td>4 dBm</td>
<td>~10m</td>
</tr>
<tr>
<td>3</td>
<td>0 dBm</td>
<td>~1m</td>
</tr>
<tr>
<td>4</td>
<td>-3 dBm</td>
<td>~0.5m</td>
</tr>
</tbody>
</table>

Table 2.2: Classes based on power [9]

The deployment of this Bluetooth technology is less of a cost. Along with wireless connectivity, it also establishes PAN immediately where there is no mobile network available. Not only that, Bluetooth typically ranges from 0-30 meters which can be increased by amplifying the power beyond one mW. [10]

Bluetooth is not exactly used for location but instead, it is all about proximity. It is known for geo-fence or micro-fence, it is not aimed to locate as GPS or Wi-Fi. So, it is used for indoor proximity solutions. In recent years, Bluetooth usage has expanded rapidly. When IoT was introduced to the market, there was a need for low power consumption technology which uses less power from the belonging devices. Thus, a new product Bluetooth 4.0 was launched in the market, also known as Bluetooth Low energy which has low power consumption.
2.1.3 Bluetooth Low Energy

BLE is a wireless PAN technology specification designed by Bluetooth Interest Group. It is very useful when it comes to M2M communication. BLE’s key advantage over earlier Bluetooth models is minimal power usage across the same scope, but lower bandwidth. It is targeted for systems that just have to regularly transfer limited amounts of data, improving life of the battery over months or years. [11]

Depending on the purpose of what needs to be accomplished, the usage of Bluetooth or BLE is decided. Bluetooth can manage most data, but the main disadvantage is it consumes a lot of battery life and is expensive too. On the other hand, BLE is being used for systems which don’t need to share large data and can therefore operate at battery power at a lower cost for years. [8]

BLE is a Bluetooth application-friendly version optimized for IoT devices [12]. The two main components of BLE communication are Advertising and Connecting. Advertising are the devices which want them to be listened and hence, transmit a packet of the data in a set of interval. On the other hand, devices which listens to the advertised device and possibly can read/write the services. These devices are known as connecting [12]. Figure 2.2 shows how the BLE communication is established.

![BLE Communication](image)

The advertising device is called a Bluetooth Peripheral and the one scanning is called a Bluetooth Central device. BLE is therefore a fairly well-established tool for indoor monitoring, but it is still quite recent and uncertain indoor positioning technology. [13]

2.1.4 Ultra Wide Band

UWB is a technology used for transmitting much information over a short distance and wide frequency spectrum. It also consumes less power.

Three or more readers transmit wide pulse over the GHz spectrum and listen for chirps reflected back by ultra-wide bags. Tags have an exciter in the spark-gap style that triggers a very little pulse in them, generating a fast, encrypted, very large, almost instant burst [14]. Readers use this to determine accurate time measurements and report to the server.

The accuracy of the location information given while using UWB technology is very good because the signals of UWB is very wide. It almost gives about 10-30 cm accuracy and also gives the most accurate result. But this technology also has a major drawback, that is, UWB is a very expensive system when it comes to installation. Regardless of UWB tags being inexpensive, the range of the tags is limited. So, every location should have at least three readers [14].
2.2. iBeacon

Table 2.3 shows the comparison between all the above technology [15].

<table>
<thead>
<tr>
<th>Technology</th>
<th>Accuracy</th>
<th>Power Consumption</th>
<th>Range [m]</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wi-Fi</td>
<td>m</td>
<td>High</td>
<td>1 - 15</td>
<td>Interference</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>m</td>
<td>Low</td>
<td>1 - 20</td>
<td>Interference, Low Range</td>
</tr>
<tr>
<td>Bluetooth Low Energy</td>
<td>m</td>
<td>Low</td>
<td>1 - 30</td>
<td>Additional hardware, Client-based application require app</td>
</tr>
<tr>
<td>Ultra wideband</td>
<td>cm - dm</td>
<td>Low</td>
<td>1</td>
<td>Expensive, Large metallic object blocks the signals</td>
</tr>
</tbody>
</table>

Table 2.3: Comparison between the technologies

From the table 2.3, it is clear that each positioning technology has its own drawbacks. Now it’s customer who decides which kind of positioning technology to go with for their application. Regardless of some limitations, BLE technology provides decent positioning range which can be quite useful in several applications.

2.2 iBeacon

The word iBeacon is indeed the term given to Apple’s BLE communication technology standard. An iBeacon is a protocol that helps to transmit data. It has opened opportunities for location-data and proximity marketing [16]. iBeacon typically act as a lighthouse. They only advertise, not the connecting component from BLE communication. It is always advertising “I’m here, and my ID is...” [17]. They send entire information related to the beacon in the advertising packet. The packet structure is shown in figure 2.3 [9].

![Packet structure of iBeacon protocol](image)

Figure 2.3: Packet structure of iBeacon protocol

The following information is provided by an iBeacon advertising packet:
1. **Preamble**: It is the first field of the packet and has 9-byte string length.

2. **UUID**: This is 16-byte string and developers must identify an application-specific UUID and use case for deployment [18].

3. **Major Value**: This is 2-byte string and it specified a sub-part of the larger part defined by UUID [18].

4. **Minor Value**: This is also 2-byte string and allows further sub-division of the part [18].

5. **Tx Power**: This is a string length of 1 byte and is used to determine distance from the beacon. The signal strength is described as the RSSI value at 1 meter from the device. [19]

Consider a grocery store, where a network of beacons are maintained for each product. One particular product say milk bottles will share the same UUID. This will ensure that from which milk bottles owned beacon, the advertisement has come on the app. If the bottles of milk are maintained by four beacons in a specific store, the major value would be equal for all the four beacons. And minor value will be by the beacon at the front of the store, which is unique. Thus, this will allow us to know where the product is in the store with the help of the app.

For instance any gadget that receives this packet will recognize its from the beacon of the milk bottle (UUID) in front of grocery store (Minor) on a 1st level (Major). This is how iBeacons interacts with the Bluetooth owner.

iBeacon technology is employed across different applications. It is used for object/person tracking, indoor navigation, digital scavenger hunts and many more. Figure 2.5 shows the indoor positioning system using iBeacons.

The position of an object/person is recorded with the help of the Bluetooth signals from beacons installed in the building, received by smartphone and uses the signal strength measurement for localization. The accuracy of indoor positioning is 1-3 meters, but it ranges up to 30 meters.
2.2. iBeacon

Figure 2.5: Indoor Positioning using iBeacons

2.2.1 Beacon Locator

Beacon Locator is an android application for scanning, tracking and managing of beacons [20]. It was developed by SameBits. It was implemented using Mvvv pattern and data binding. The application will scan and locate beacons (Eddystone, iBeacons or AltBeacons) and present detailed information about beacons properties which is explained in section 2.2. Along with that, this application also gives the information of distance between the beacon and smartphone in which this application is installed. Figure 2.6 [21] shows the screenshot of an app showing the features of it.

![Beacon Locator app](image)

Figure 2.6: Beacon Locator app

This application will support the events when beacon enters the region, when beacon leaves the region and when the beacon is near you [21]. It enables you to set up action types such as opening a URL, broadcasting an Android purpose, launching an app, modifying the sound profile and performing tasks using Tasker to detect or lose a beacon signal [22].
2.3 Positioning Method

A number of IPS’s are suggested, introduced and examined. Based on the utilization approaches, these systems can be divided into three categories: beacon-based systems, PDR based systems, and vision-based systems.

In the beacon-based systems, a device that is carried by the user is made to listen to the optical or radio frequency signals that are sent by the beacons from the surroundings. Thus, this (Wi-Fi, Bluetooth, infrared) signals which contain the information such as strength, steps, and time-of-exursion are assessed and used to identify the user’s location. In PDR-based system, previously determined starting position of the user is used to calculate the next position. It also uses the user’s orientation and step’s number to evaluate the location. In vision-based system, cameras are used in order to assess the user’s position. The user is made to wear the camera and capture the images from it. These images are studied and analyzed to perceive the user’s position.

In this thesis, a beacon-based system using Bluetooth technology is implemented, as a result of it’s simple to access the received signal strength in today’s smartphones because it is supplied with Bluetooth interfaces. PDR, on the other hand, was not considered as it does not provide very precise information because of the cheap sensors introduced in smartphones. This can lead to a big increase in errors. Even due to its difficulty, the analysis of the vision-based system was not considered. In a standard system based on vision, such as [23], an image database and location model, consisting of places and paths between places of an indoor environment, must be pre-constructed to acknowledge a location. A portable mobile device captures and transmits images to a server for position detection. It is avoided due to the difficulty and cost of building the large image database, and the need for real-time interaction.

Given that the ones most used today will be discussed in the following subsections.

2.3.1 Distance calculation

The distance calculation between two peers, in our case, between a smartphone and a beacon, is necessary to be expressed and resolved with an equation. The following equation may be used to calculate the distance which is used by the Android Beacon Library [24].

\[
D = S_1 \cdot \left( \frac{\text{RSSI}}{\text{TxPower}} \right)^{S_2} + S_3
\]  
(2.1)

where:
- RSSI is the received signal strength of the beacon which is read by the smartphone.
- TxPower is the value of RSSI at one meter.
- \( S_1, S_2, S_3 \) are constants.

The constants mentioned in equation 2.1 can be calculated for a specific device using [25]. It is calculated on the Bluetooth chip and antenna of smartphones.

Euclidean distance calculation

Euclidean distance is indeed the linear fashion distance in an Euclidean space between certain two positions. It is the most obvious way of measuring distance between two points. The Euclidean formula can be used to find the distance between two points to nth dimension. It is generally indicated by,

\[
d(x, y) = \sqrt{(y_1 - x_1)^2 + (y_2 - x_2)^2 + \ldots + (y_n - x_n)^2}
\]  
(2.2)

\[
d(x, y) = \sum_{i=1}^{n} (y_i - x_i)^2
\]
2.3. Positioning Method

The above formula gives the distance between the line segment x and y in any dimension. Where x and y are two positions in Euclidean space, thus, the distance between them is calculated by the Pythagorean formula 2.2.

![Figure 2.7: Euclidean distance calculation in 2D](image)

Also, Euclidean distance can be found in polar coordinates with points \( x = (r_1, \theta_1) \) and \( y = (r_2, \theta_2) \) then the distance between them is calculated by,

\[
d(x, y) = \sqrt{r_1^2 + r_2^2 + 2r_1r_2 \cos(\theta_1 - \theta_2)}
\]

In this thesis, I have considered the 2-dimensional Euclidean distance equation to find the distance between the IoT device attached to beacon and smartphone. In the Euclidean plane (Cartesian system) if \( x = (x_1, x_2) \) and \( y = (y_1, y_2) \) then the distance can be found out by and can be represented as shown in figure 2.7,

\[
d(x, y) = d(y, x) = \sqrt{(y_1 - x_1)^2 + (y_2 - x_2)^2}
\]  

(2.3)

2.3.2 Triangulation

Triangulation is the oldest technique used to find out the unknown position. For instance, this was the same method that the Greeks used to calculate the Earth’s orbit radius around the sun [26].

The idea behind this method to determine the unknown position is carried out by calculating the distance between two devices and their respective angles. And it is illustrated in figure 2.8. This method operates to discover the device’s position by using the angle-side-angle triangle congruency theorem [27].

\[
d = L \frac{\sin(\alpha) \sin(\beta)}{\sin(\alpha + \beta)}
\]  

(2.4)

Thus, with the help of equation 2.2 which is the combination of side L and two known angles \( \alpha \) and \( \beta \), we are able to calculate the distance d [26].
2.3.3 Trilateration

Trilateration is also a positioning method used, similar to triangulation, to calculate a position. This is the most common method which is used by GPS as well [28]. It utilizes the known distance for calculating an object’s position from at least three APs in 2D space and four APs in 3D space, and operates by discovering a sequence of circles junction [27]. The distance between the object position can be measured with the help of RSSI value or Time of Flight (ToF) algorithm. Thus, the unknown position of the device can be calculated with the help of the position and distance [29, 30, 31].

However, with more or fewer APs, this method can be applied. But with more number of APs, we can find the position more accurately compared to less number of APs, which is illustrated in figure 2.9.

Let us consider three following cases, to show how this method works:

In case one, only the AP A is used, the definite position can’t be resolved. It is discovered some spot on the drift with center A and radius being the length from A to the device. This is generally called proximity-based positioning. This case can be formulated using the equation below:

\[
d_a^2 = (x - x_a)^2 + (y - y_a)^2
\]  

(2.5)

Where \(d\) is the distance, \(\{x_a, y_a\}\) is the A coordinates and \(\{x, y\}\) is the unknown device coordinates.
In the second case, let’s add AP B to the existing AP A. This will result in excluding all except two positions as shown in figure 2.10. With the help of distances to the searched devices from the APs A and B, it is feasible to find out the two points, especially the two circle intersections. It is commonly referred to as bilateration and the equation is given below:

\[
d_a^2 = (x - x_a)^2 + (y - y_a)^2
\]
\[
d_b^2 = (x - x_b)^2 + (y - y_b)^2
\]

(2.6)

Where \(d_a, d_b\) are the distance, \((x_a, y_a)\) and \((x_b, y_b)\) are the A and B coordinates respectively. Thus, the coordinates \((x, y)\) is from an unknown device.

In the last case, the third AP C is added as shown in figure 2.11. This will give the exact position of the device to be searched. After adding the third AP, it will eliminate one of the intersecting points and thus will give the exact position. This can be achieved by solving the below three equations:
2.3 Positioning Method

Figure 2.11: Trilateration method for three transmitters

\[
d_a^2 = (x - x_a)^2 + (y - y_a)^2 \\
d_b^2 = (x - x_b)^2 + (y - y_b)^2 \\
d_c^2 = (x - x_c)^2 + (y - y_c)^2
\]  

(2.7)

Where the first two equations are the same as in equation 2.6, with reference to A and B, and the third with reference to C. A distinctive point with \(x, y\) coordinates should be evaluated.

But in few cases, there is a chance that equation 2.7 becomes difficult to be solved. Such as in the case where the distance is not appropriate which may lead to a non-intersecting circle and in a situation where APs are placed in such a way that circles get overlapped without intersecting each other [9]. Hypothetically, this suggests that it is difficult to compute the position. There are a few techniques to explain this issue which is explained in section 2.5.

2.3.4 Fingerprinting

Fingerprinting is one of the simplest and most widely used in the IPS environment. In this positioning method, the computation of one’s position is done by using signal measurements across the building. This stems from the assumption that for each position there are more or less almost exclusive signals that can be recorded. Then, the comparison is made with the existing record to find out one’s current position [32]. Thus, this method can be very precise and require excellent coverage of the region [33, 34].

The advantages of fingerprints over others is mainly because of its high accuracy and low hardware systems. This does not include measurements of the AP’s line of sight, Has minimal complexity and is highly applicable in the challenging indoor environment [35]. It comprises of two phases namely training (offline) and testing (online) phase.

This technique is also used in the outdoors. The outdoor fingerprint technology uses three types of fingerprint. The first type is a visual fingerprint, the second type is the motion fingerprint and the last type is based on the signal called RSSI. Whereas for indoor fingerprint positioning technology the signal type is mainly used. The fingerprint database contains previously collected data at a reference point. The location is calculated by calculating the fingerprints collected by the device (online) and the reference present in the database (offline) [33].
But this method has some limitation. It will work only in motion with a steady signal for a certain prolonged duration. This approach can be used independently or to enhance the accuracy of different positioning systems, for instance, those based on trilateration [32].

### 2.3.5 Clustering

Clustering is a method where the area is divided into small clusters, which helps the computation cost to get reduced. The idea behind this method is to form a cluster which is the location that has similar characteristics of received signals. Then, these clusters are spotted which has an unknown sample and further the position of the sample is located within that cluster [36].

### 2.3.6 Proximity

Positioning based on proximity is about finding a device to another device, depending on its range. The entire protocol of iBeacon itself is about proximity [18]. It works using received signal strength. The proximity method only indicates if the device being searched is within the range of another device and is unable to provide a precise position. Figure 2.12, explains how proximity works inside a building.

![Figure 2.12: Proximity](image)

Most of the time, it is used on the client-side except for Wi-Fi that has detection capabilities on the server-side [32].

### 2.4 Filters

Filtering is phenomenon where the unwanted components are segregated from the signal. The main feature of the filter is that a signal gets suppressed partially or completely to need of the purpose. There are different types of filters [37] and some of them are as follows:

- Non-linear or linear
- Time variant or time-invariant
2.4. Filters

- Analog or digital
- Discrete-time or continuous-time

In this thesis, we are considering linear filter and some of the linear filters are Kalman filter, Bessel filter, Butterworth filter, and Fraser filter. Due to its advantages over others linear filters, Kalman filter is used as it filters and smoothens the signal by removing the noise in the signals; and checks that the RSSI is received from all k-BLE devices in each sample.

We are considering the Kalman filter for this thesis.

Kalman filter

Kalman filter is an algorithm that uses linear quadratic equation which considers continuous measurements of the past and present including the noise and inaccuracies to predict the unknown variable from the available measurement. The variable of interest can be measured indirectly. Since it is an optical estimator it reduces the estimated measurement error in normal disturbance condition [38].

The application of Kalman filters extends to Autopilot, Brain-Computer interface, Inertial guidance system, Radar tracker, a Satellite navigation system, weather forecasting, and others.

The Kalman filter can be processed in accordance with the following two equations:

\[ x_k = P_{x_{k-1}} + Q y_k + n_{k-1} \]  \hspace{1cm} (2.8)

\[ z_k = R x_k + m_k \]  \hspace{1cm} (2.9)

Where \( x_k \) is a true state vector at time \( k \) and \( y_k \) being the control signal. The estimated value is the sum of control signal with process noise denoted by \( n_{k-1} \) and previous estimated value \( x_{k-1} \), which is a linear combination.

\( z_k \) is the measured value which is the sum of true state in a linear combination, \( x_k \), and noise measurement \( m_k \), \( P \), \( Q \) and \( R \) are matrices and represented by state transition model, control input model and observation model respectively. [36]

Using equations 2.8 and 2.9 we can obtain the true state by the Gaussian distribution of the predicted and measured result. When multiplying this both distribution with the probability density function (PDF), we get a new Gaussian distribution that being the best-estimated result.

Figure 2.13: Example of a car passing through a tunnel where GPS signals become weak before applying Kalman filter
2.5. Positioning Optimization

For example, let us consider a car passing through a long tunnel and where the GPS signal is very weak (in figure 2.13). To find the location we can use the Inertial Measurement Unit (IMU) and odometer of the car which measures the relative position of the car which updates frequently but signals prone to drift whereas GPS measures the exact position of the car but due to its weak signal the frequency of update is very low and it may be noise. In this case, all three parameters can be used to get the absolute position of the car by applying the Kalman filter to it has been demonstrated in figure 2.14 [39].

![Figure 2.14: Illustration of a car after Kalman filter usage](image)

2.5 Positioning Optimization

There is always a possibility that the values may be miscalculated when using positioning algorithms depending on whether the signal is disrupted somehow. Fortunately, techniques of optimization are accessible to prevent these and similar issues. Two of them are shown below.

2.5.1 Multilateration

Multilateration, also known as hyperbolic positioning, depends on the time difference when the signals arrive at different base stations or APs [40]. This is one of the most common methods in confined areas for indoor and outdoor positioning. One of the most common methodologies for positioning known as TDoA utilizes multilateration, in order to synchronize the APs, shown in figure 2.15.

The concept behind multilateration is comparable to trilateration except that in this case there is no circle or sphere; in the case of 2D it is hyperbola and in the event of 3D positioning it is hyperboloids. At least 4 APs or transmitters are also required here to correctly place the tag [28].

With extra APs, the equation system 2.7 can be further created. For 1 to n APs, the equation system contains a set of known distances d1 ... dn and known coordinates \( x_1, y_1 \) ... \( x_n, y_n \). The only remaining unknown is the \( x, y \) point. It is possible to write the equation...
2.5. Positioning Optimization

Figure 2.15: Multilateration in TDoA

scheme as:

\[ d_1^2 = (x - x_1)^2 + (y - y_1)^2 \]
\[ \vdots \]
\[ d_n^2 = (x - x_n)^2 + (y - y_n)^2 \]

For 3D positioning, the equation system contains known coordinates \( (x_1, y_1, z_1) \) \( \ldots \) \( (x_n, y_n, z_n) \). The only remaining unknown is the \( (x, y, z) \) point. The equation 2.7 can be written as:

\[ d_1^2 = (x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2 \]
\[ \vdots \]
\[ d_n^2 = (x - x_n)^2 + (y - y_n)^2 + (z - z_n)^2 \]

As you can see from equation 2.10 and equation 2.11, more equations are available than the unknown. It is said that the equation system is over-determined, leading either in a distinctive solution where all distances and AP positions are completely matched or no solution at all.

2.5.2 Least Squares

If the measurements are not appropriate for finding an accurate solution to the equation system 2.10, it is possible to calculate approximate solutions and find the best solution using the least square approach [41]. Figure 2.16 illustrates the schematic diagram for the least square method to locate the target node. The equation system 2.10 can be rewritten in matrix form as:
2.5. Positioning Optimization

\[ AX = B \]  \hspace{1cm} (2.12)

where \( X = \begin{bmatrix} x \\ y \end{bmatrix} \) is the vector of the search device’s unknown coordinates, \( A = \begin{bmatrix} a_{x1} & a_{y1} \\ . & . \\ . & . \\ a_{xn} & a_{yn} \end{bmatrix} \) is a \( n \times 2 \) distribution matrix containing \( x \) and \( y \) coefficients and \( B = \begin{bmatrix} b_1 \\ . \\ . \\ b_n \end{bmatrix} \) is the vector that holds all the constant equation values. To satisfy \( X \), the distinctive solution to this scheme is discovered:

\[ AX - B = 0 \]  \hspace{1cm} (2.13)

Sometimes the solution cannot be discovered to the above equation, definitely because of AP measurement errors. So to minimize this error, least-square approximation is used to find the best approximate value \( \hat{X} \), The new equation is:

\[ A\hat{X} = B \]  \hspace{1cm} (2.14)

Because \( X \) is an approximation, it generates a vector of residual mistakes \( R_e \):

\[ A\hat{X} - B = R_e \]  \hspace{1cm} (2.15)

When the amount of \( R_e \) is the lowest possible value, the best approximation of \( \hat{X} \) is then. Therefore, minimizing \( \| R_e \| \) is essential.

A formula to solve this issue is the least square [42]:

\[ A^T \cdot A\hat{X} = A^T \cdot B \]  \hspace{1cm} (2.16)

Figure 2.16: Schematic diagram for least square method to locate the target node

\[ A^T \cdot A\hat{X} = A^T \cdot B \]  \hspace{1cm} (2.16)
which is achieved by multiplying $A^T$, the transpose of $A$ on both side of equation 2.14. To calculate the best approximation value for the least square problem, we need to isolate $\hat{X}$, which then can be solved.

2.6 Internet of Things

IoT is defined as an idea of connecting everyday real objects to the internet and being able to identify themselves with other devices [43]. The transmission of information does not involve human-to-human or computer-to-human communication over the network as it is provided with unique identifiers [44]. It also includes technologies such as sensor technologies, wireless technologies and QR codes.

The communication between the objects is established through standardized communication protocols. It has been discovered recently, the Bluetooth is going to place the platform as the ‘main communication protocol’ for IoT [10]. IoT’s architecture is made up of hardware, networking, software system, and application layers, for example, with Bluetooth serving as the networking layer. The networking layer is used bridge between different layers and consists of a multi-layer stack. Bluetooth or BLE is part of the multi-layer stack which links either device to device or device to the gateway, and thus establishes contact between them. [10]

With the introduction of Bluetooth 5.0, the new features of this technology can be applied to a diverse range of potential IoT devices, the speed of establishing the connection between the objects is fast and the range of the connection is also being elongated [45].

2.7 Android Operating System

Android is a mobile OS initially created by Android Inc., which was then bought by Open Handset Alliance. It was mainly developed for the touchscreen mobile devices such as smartphones and tablets. It is easily available in the market as it is open and free to use which satisfies both application users and software developers. This platform is a Linux kernel-based and other open-source software-based operating system.

The Linux kernel handles the center framework which benefits and works as the layer between the physical equipment and the Android OS. Inside the Linux kernel, there are drivers for various purpose like display, camera, Bluetooth, keypad, WiFi. These drivers work on threading and hardware interactions, such as accessing the Bluetooth sensor. The hardware is abstracted by the drivers and software present on the phone, making the manipulation, for example, Bluetooth for developers. The drivers assemble with other different components such as the View System and the Resource Manager which could be essential for manipulating the user interface of the application [46]. It also takes care of most essential services like security, memory management, and networking.

2.8 Related Work

This section introduces early research done in this area.

2.8.1 Indoor Positioning System

Many scientific papers have been written about different technologies of IPS. L. Batistić et al. presents the technical overview and identification of the most applicable IPS technology used for the smartphone applications. Comparison is focused on quality, accuracy efficiency and complexity is made [47]. The variety of approaches have been investigated that can be valuable to overcome the limitations of specific IPS technologies.
Papers about specific technologies are presented and reviewed in the following sections. First are papers about Bluetooth, the technology used in this thesis. Later on, works about other technology used within IPS are reviewed.

2.8.2 Indoor Positioning System with Bluetooth

Bluetooth based IPS is done with the help of Bluetooth enabled smartphones. This works by using the RSSI value of Bluetooth signals to track the location of the object \[48\]. The application of this technology is not only tracking an object but also to monitor the human movement in an indoor environment. Y.F. Tsang et al provides a method to design an IPS for IoT applications \[49\].

Bluetooth Low Energy is an advancement in this technology. Ankush A. Kalbandhe et al uses BLE tag RSSI and transmission power to estimate the BLE tag role for indoor location \[50\]. Hence, it is believed that BLE is an effective technology for indoor positioning.

But, as the technology is real and available to use, it still has plenty of challenges in terms of RSSI fluctuation which leads to poor precision. Cantón Paterna et al, proposed and introduced a real BLE IPS that increases accuracy although reducing power usage and costs \[51\].

BLE for IoT

IoT uses the cloud medium to transfer the data from the BLE through the gateways which can be used as the communication between both. Pawani Porambage et al, in their research, has proposed a solution where the BLE based sensors can transfer the data to the cloud without any gateways in between \[52\] which makes E2E connection more secure.

The CoAP which is used for constrained network and devices. A complete CoAP applications may require more capacity, capability, and power in IoT devices. To reduce this complexity Andrei Gurtov and others have used an ICN networks to provide transparent CoAP services to IoT endpoints which results in the overall management of the CoAP servers \[53\].

IoT and UAV are the two most advanced and trending topics in the fields of communication and Aerospace respectively. So to connect BLE powered IoT devices with UAV through an E2E secure connection, data processing becomes a very tedious work and to process this task the heterogeneous wireless network has been considered. Archana Rajakaruna with others, has implemented this work in their research and showed that the distance between the two sensor nodes is the most important factor determining the performance of this research which provides the information about the importance of distance between the sensors \[54\].

2.8.3 Other approaches to IPS

Apart from using Bluetooth, other technologies can be used to calculate the positions. Some of such approaches are presented below.

2.8.3.1 Wi-Fi

Wi-Fi based positioning is among the most widely used IPS technology. Arash Habibi Lashkari et al. proposes a mobile application using such a technology to estimate the position of a user within a building \[55\]. Gints Jekabsons et al, also used Wi-Fi technology to examine the aspects of location fingerprinting based indoor positioning \[56\].

2.8.3.2 Geomagnetic Technology

Geomagnetic fields supports both indoor positioning and navigation which has attracted considerable interest from the researchers because this technology has no infrastructure needs.
2.8. Related Work

But geometric field technology alone has difficulties. So, it usually integrate with other technology like Wi-Fi or BLE beacons to estimate position [57]. Using this technology, Seong Eun Kim et al, proposed an indoor positioning using smartphone to localize the position of pedestrian in indoors [58]. An IPS company called IndoorAtlas uses the earth’s magnetic field to calculate the position [59].

There is one major disadvantage of this technology, the presence of large steel components in a building may affect and distort the geomagnetic field. So, Bimal Bhattarai et al, present a magnetic sensor-based IPS in a smartphone to identify the position of the user [60].

2.8.3.3 Ultra-wide band

UWB is another one of the technology in the field of IPS. It is mainly used in the high accuracy indoor wireless positioning. Guowei Shi et al gave an overview of IPS based on UWB technology [61].

It has been proven that it shows better performance compared to other technology. Abdulrahman Alarifi et al, provides a survey including a detailed analysis of UWB technologies in their research. They do provide an analysis of SWOT in order to determine the current role of UWB technology [62].

2.8.3.4 Image Based Localisation

Smartphone camera can also be used for IPS. Buti Al Delail et al, evaluated an indoor image-based positioning system using smartphone augmented reality. This kind of IPS uses the concept of the comparison made between pictures taken in the camera and sample pictures stored in the database [63].

VLC can also be done by camera. Junhai et al analyzed the accuracy of VLC based IPS and found out that this technique gives a very good accuracy and also free from the radio frequencies [64].
The description of the methodology used for the thesis will be explained in this chapter. Section 3.1 explains the experiment scenario used in this thesis. And then I explain the research paradigm, research process in section 3.2 and section 3.3 respectively. Section 3.4 explains the operation procedure of both fingerprinting and multilateration approach. Data collection technique and experimental design are explained in section 3.5 and section 3.6 respectively. Section 3.7 tells you about data reliability and its validity. And then section 3.8 and section 3.9 describes the method used to analyze data and framework chosen for performance evaluation respectively.

3.1 Experiment Scenario

This section introduces two experiment scenarios that are relevant for this thesis work. Each beacon is attached to an IoT device. First is a case where the beacons are kept at the stationary position whereas the receiver is constantly in movement. The second one is an experiment where the receiver is kept stationary and the beacon is moved constantly.

3.1.1 Experiment A

The first scenario is about keeping IoT devices attached with beacons at the stationary known position and the receiver which is a smartphone is our case is moving constantly. Consider the previous example of a grocery store from section 2.2. Assume that milk bottles are attached by the beacon which is kept stationary and the customer can navigate them self towards the product with the help of his/her smartphone (receiver). One of the reasons why this is done is to help customers to find the products easily and quickly.

Similarly, this scenario was carried out in the office for the thesis work. Figure 3.1 demonstrates the office floor plan. For the implementation, seven beacons attached to seven different IoT devices and one receiver (smartphone) were used. Firstly, beacons were placed at a different known positions as shown in figure 3.1. And then a person holding the receiver is made to walk around the beacons in an irregular fashion.
3.1. Experiment Scenario

Figure 3.1: Floor plan of office having stationary beacons

3.1.2 Experiment B

In the second scheme, moving beacons, i.e., receivers are kept at the stationary known position. It could regard finding a patient’s behavior, for example in a hospital. They are usually many patients in a hospital and it is difficult to keep track of each one at the same time. For instance, if the beacons are attached to medicine devices or patients. This helps doctors to monitor where his/her patients or medical devices are while they are moving around.

This set up was also constructed in the office. In this case, receivers were kept stationary at the known position and beacon attached to an IoT device was moved constantly. As shown in figure 3.2, two receivers are placed, and a single beacon was used. A person holding this beacon was made to walk in an irregular fashion.
3.2 Research paradigm

When researching the quantitative output (precision, accuracy, etc.) of IPS, I follow the realism paradigm because the device efficiency does not rely on an observer. I gather information from experiments and use this information to create understanding.

3.3 Research process

Figure 3.3 demonstrates the steps taken to conduct this research.
The similar steps are carried out for the moving beacons (which is explained in section 3.1.2). Instead of deploying beacons in an area, the receiver (smartphone) is deployed.

### 3.4 Operation procedure

The process of localization comprises of two different approach to estimate the positions: fingerprinting and multilateration approach. During the fingerprinting approach, the RSSI collected from all the BLE devices are used to estimate the coordinates at various radio maps. Likewise, an multilateration approach consists of three steps: data collection, data filtrating, and data analysis. Through the mobile application, data collection is done on the mobile-side and sent to the server-side. Here, the x and y coordinates, of receiver position in experiment A and beacon position in experiment B at various location is calculated. The server estimates the location and the data is stored in the database. In the following subsection, a brief explanation of two approaches is given:

#### 3.4.1 Fingerprinting approach

This approach involves following steps collection of data, the development of a radio map, estimating coordinates and storing them in a database. This is done when the indoor field is first divided into small areas, with a dimension of (1m×1m). These small areas is called a radio-map or sub-map. This is achieved with the application of a grid as shown in figure 3.4.
3.4. Operation procedure

The grid represents the radio-maps. However, the same idea follows for the experiment B. This technique is called fingerprinting.

A total of n samples of RSSI are collected from each BLE device at each radio map location and the data collected is used to estimate the coordinates. For example, below are shown the RSSI samples \((\text{map}_{1\text{RSSI}})\) collected on the radio map \((\text{map}_1)\), where \(b_{1\text{RSSI1,R1}}\) represents the first RSSI value from beacon b1 received by receiver R1.

\[
(\text{map}_1, \text{map}_{1\text{RSSI}})_A = \begin{bmatrix}
 b_{1\text{RSSI1,R1}} & b_{2\text{RSSI1,R1}} & \cdots & b_{7\text{RSSI1,R1}} \\
 b_{1\text{RSSI2,R1}} & b_{2\text{RSSI2,R1}} & \cdots & b_{7\text{RSSI2,R1}} \\
 \vdots & \vdots & \ddots & \vdots \\
 b_{1\text{RSSI}_n,R1} & b_{2\text{RSSI}_n,R1} & \cdots & b_{7\text{RSSI}_n,R1}
\end{bmatrix}
\]

In experiment B, the RSSI samples \((\text{map}_{1\text{RSSI}})\) collected on the radio map \((\text{map}_1)\), where \(b_{1\text{RSSI1,R1}}\) represents the first RSSI value from beacon b1 received by receiver R1. \(b_{1\text{RSSI1,R2}}\) represents the first RSSI value from beacon b1 received by receiver R2 is shown below.

\[
(\text{map}_1, \text{map}_{1\text{RSSI}})_B = \begin{bmatrix}
 b_{1\text{RSSI1,R1}} & b_{1\text{RSSI1,R2}} \\
 b_{1\text{RSSI2,R1}} & b_{1\text{RSSI2,R2}} \\
 \vdots & \vdots \\
 b_{1\text{RSSI}_n,R1} & b_{1\text{RSSI}_n,R2}
\end{bmatrix}
\]
The grid is represented in the form of a graph having x-axis and y-axis. With the help of coordinate system, each position of the receiver in case of experiment A and beacon position in case of experiment B \((x_{\text{fingerprint}}, y_{\text{fingerprint}})\) coordinate is calculated. And it is shown as \((R_{\text{map}_x}, R_{\text{map}_y})\). Table 3.1 and table 3.2 illustrate coordinates of each radio maps and collected RSSI values at that particular coordinate for experiment A and experiment B respectively, which consist of RSSI of all devices, and its corresponding coordinates.

<table>
<thead>
<tr>
<th>Coordinate ([x,y])</th>
<th>Device1</th>
<th>Device2</th>
<th>\ldots</th>
<th>Device7</th>
</tr>
</thead>
<tbody>
<tr>
<td>((R_{\text{map}<em>1x}, R</em>{\text{map}_2y}))</td>
<td>rss1</td>
<td>rss2</td>
<td>\ldots</td>
<td>rss7</td>
</tr>
<tr>
<td>((R_{\text{map}<em>2x}, R</em>{\text{map}_3y}))</td>
<td>rss1</td>
<td>rss2</td>
<td>\ldots</td>
<td>rss7</td>
</tr>
<tr>
<td>\ldots</td>
<td>\ldots</td>
<td>\ldots</td>
<td>\ldots</td>
<td>\ldots</td>
</tr>
<tr>
<td>((R_{\text{map}<em>ix}, R</em>{\text{map}_iy}))</td>
<td>rss1</td>
<td>rss2</td>
<td>\ldots</td>
<td>rss7</td>
</tr>
</tbody>
</table>

Table 3.1: Radio maps for experiment A

<table>
<thead>
<tr>
<th>Coordinate ([x,y])</th>
<th>Device1</th>
<th>Device2</th>
</tr>
</thead>
<tbody>
<tr>
<td>((R_{\text{map}<em>1x}, R</em>{\text{map}_2y}))</td>
<td>rss1</td>
<td>rss2</td>
</tr>
<tr>
<td>((R_{\text{map}<em>2x}, R</em>{\text{map}_3y}))</td>
<td>rss1</td>
<td>rss2</td>
</tr>
<tr>
<td>\ldots</td>
<td>\ldots</td>
<td>\ldots</td>
</tr>
<tr>
<td>((R_{\text{map}<em>ix}, R</em>{\text{map}_iy}))</td>
<td>rss1</td>
<td>rss2</td>
</tr>
</tbody>
</table>

Table 3.2: Radio maps for experiment B

3.4.2 Multilateration approach

The multilateration approach consists of two phases: data collection, filtrating and position estimation:

3.4.2.1 Data Collection

An android app (section 2.2.1) on a mobile device gathers the following distance samples from the k closest devices (seven in experiment A case). Below are shown the distance samples \((d_{\text{sample}})\) collected by app, where \(b_{1_{d1,R1}}\) represents the first distance value \(d_1\) from beacon \(b_1\) received by receiver \(R_1\).

\[
(d_{\text{sample}})_A = \begin{bmatrix}
    b_{1_{d1,R1}} & b_{2_{d1,R1}} & \ldots & b_{7_{d1,R1}} \\
    b_{1_{d2,R1}} & b_{2_{d2,R1}} & \ldots & b_{7_{d2,R1}} \\
    \vdots & \vdots & \ldots & \vdots \\
    b_{1_{dn,R1}} & b_{2_{dn,R1}} & \ldots & b_{7_{dn,R1}}
\end{bmatrix}
\]

In experiment B the distance samples \((d_{\text{sample}})\) are collected by an app (section 2.2.1), where \(b_{1_{d1,R1}}\) represents the first RSSI value from beacon \(b_1\) received by receiver \(R_1\) and \(b_{1_{d1,R2}}\) represents the first RSSI value from beacon \(b_1\) received by receiver \(R_2\) is shown below.

\[
(d_{\text{sample}})_B = \begin{bmatrix}
    b_{1_{d1,R1}} & b_{1_{d1,R2}} \\
    b_{1_{d2,R1}} & b_{1_{d2,R2}} \\
    \vdots & \vdots \\
    b_{1_{dn,R1}} & b_{1_{dn,R2}}
\end{bmatrix}
\]
3.5. Data collection

3.4.2.2 Data Filtrating

Using the filtrating algorithm (explained in section 2.4), the $dist_{sample}$ and RSSI value collected from the beacons at each location is filtered. The reason why this is done because it filters and smoothen the signal and checks that the RSSI is received from all $k$ BLE devices in each sample. It is then sent to the server-side of the system. The server inputs the $RSSI_{sample}$ to the positioning algorithms and gives the estimated result as an $(x_{multilateral}, y_{multilateral})$ coordinate.

3.4.2.3 Position Estimation

This section explains the estimation of the coordinates using the algorithms. Let us suppose we have a total of $m$ radio maps $\{map_1, map_2, \ldots, map_m\}$. Consider $dist_{sample}$ from the previous section 3.4.2.1. When this is given as input to the multilateration algorithm, it returns the coordinates of the location of the receiver in case of experiment A. It is as shown below:

$$\{d_1, d_2, \ldots, d_m\} \Rightarrow \text{Multilateration} \Rightarrow \{x_{multilateral}, y_{multilateral}\}$$

where $d_i$ represents the distance of being on the $map_i^{th}$ radio map, $(x_{multilateral}, y_{multilateral})$ coordinates of the location.

Similar steps are repeated for experiment B, to estimate the location but Euclidean distance equation is used instead of using multilateration algorithm.

3.5 Data collection

I collected data from two experiments to assess the system’s quantitative performance.

3.5.1 Sampling

To evaluate the performance of this scheme, in experiment A, 7 reference points were selected on the map where beacons are placed, as shown in figure 3.1. And in experiment B, 2 reference point are selected where the receivers are positioned as shown in figure 3.2. The user is made to walk around the map in an irregular pattern.

The reference point’s density in the corridor is much effective than in the rooms. The explanation for this is that the destination of the user is actually located in a particular room in a real user situation, rather than a specific location within a room. The positioning performance in the corridor should, therefore, have a greater weight when assessing this scheme.

3.5.2 Sample size

In the case of experiment A, a person holding the receiver in his/her hand is made to walk 7 times having different patterns where the starting and the ending point and the number of steps covered differs from the other pattern. The group of data collected from each pattern is called data-set. Thus, the data-set’s sample size is 1900.

Similarly, in the case of experiment B, there is only one data-set containing total of 100 sample sizes of data as shown in figure 3.5.
3.6 Experiment design

This section explains the conditions of the test used for the experiments and the hardware and software used.

3.6.1 Test Environment model

I collected data in one environment for both of the experiments. Environment is an office space on the 3rd floor, that consist of three rooms, one seminar room and a corridor. This space’s dimensions are 1400 cm × 1000 cm. The rooms are numbered as 301-304. There are very few furniture inside this room, but there were no people. Such a space is not really representative of space. Experimenting at such an environment, however, helps us to learn the upper bound of system stability, as having several furniture and people inside the space will obstruct the transmission of the line of sight, lead to more thought, and thus probably reduce the performance [36].

3.6.2 Hardware / Software used

A Lenovo Vibe Notebook phone was used to collect RSSI values with the help of Beacon Locator android application. NavAlarm provided the Bluetooth ibeacons developed by Apple company, which were used in the experiments. Every Bluetooth beacon is powered by 4 AA batteries. The battery supply for these beacons are about 2-3 years of energy. The hardware used to carry out this experiment is shown in Table 3.3.
3.7 Data reliability and validity

This section addresses how to check the reliability and validity of the information collected.

3.7.1 Reliability

For each data-set in the experiments, I conducted identical tests at least twice and checked for consistent and stable outcomes from these tests. I repeated these tests until a reasonable and acceptable variation occurred in the observed results. Here the acceptable variation is defined as: if all findings are x on average, then all findings must fall within the limit [0.9x, 1.1x]. Similar work has also been done for experiment B.

3.7.2 Validity

In this study, four variables are measured directly: beacon’s positions, receiver’s positions estimated by the system, RSSI of beacon and distance from each beacon to receiver. These four variables were measured for both the experiments as follows:

- The beacon’s position is measured, differs in both the experiments. In experiment A, the beacons are fixed at the position. So the grid is plotted to take the actual measurement. With the help of the coordinate system, the coordinates (x, y) are calculated.
  
  While in experiment B, beacons are moving. The distance between both the beacon and the receiver is measured first and then the coordinates are determined via Euclidean distance equation.

- The calculation of position of the receiver also differs in both of the experiment. In experiment A, receiver is moving. With the help of distance value and multilateration algorithm, the coordinates of receiver position is estimated.
  
  The beacons are set at certain location in experiment A. So to estimate the position, the grid is drawn. The coordinates (x, y) are determined using the coordinate system.

- The RSSI value of each beacon was measured by the smartphone Lenovo Vibe Notebook. I used the android application called Beacon Locator to read the RSSI value of each beacon.
  
  As in this experiment B, the RSSI value of a beacon was measured by the two smartphones (receivers) Lenovo Vibe Notebook and One Plus 6T. In both the smartphone beacon locator android application was installed to read the RSSI value of each beacon.

- After getting the RSSI value, then using the same application we get the distance between beacon and smartphone (receiver) in which the application is installed.

3.8 Data analysis

The below subsections describe the techniques and software I have chosen for data analysis.
3.9. Evaluation framework

3.9.1 Accuracy

Accuracy is usually defined as mean distance error, that is the average euclidean distance between both the predicted position and to real location [65].

Then accuracy can be given as:

\[
\text{Accuracy}(m) = \frac{1}{N} \sum_{k=0}^{N} \| P_{\text{real,}k} - P_{\text{estimated,}k} \| \tag{3.1}
\]

where \( N \) is positioning attempts, \( P_{\text{real,}k} \) is the real position and \( P_{\text{estimated,}k} \) is the estimated position.

And then,

\[
\text{Accuracy}() = \frac{\text{Accuracy}}{\text{TotalNumberofInstances}} \times 100 \tag{3.2}
\]

3.9.2 Precision

Only the mean of the distance error is considered while measuring the accuracy metric. We therefore have to consider a different metric to show the range of errors in positioning over several tests. Therefore, this is called precision.

There are multiple definitions for precision. The CDF of the general positioning error defines precision, according to some literature. Precision is described in some other literature as the standard deviation in position error or precision geometric dilution. Even though there are multiple distinct definitions, all of them offer a general image of the positioning error variation. In this study, I used the second definition: precision is the standard position error deviation because of its simplicity.

It is given by:

\[
\text{Precision}_() = \frac{\text{Average}_\text{deviation} - \text{Actual}_\text{instances}}{\text{Totalnumberofinstances}} \times 100 \tag{3.3}
\]

3.9.3 Rate of failure

Every time the system attempts to calculate the position of the user. The system does not, however, determine the position at times. The reason for this is that multilateration
3.9. Evaluation framework

uses the hyperbola intersection to determine a position. So, if neither of hyperbolas overlap, the user’s location can not be determined by the process. As stated in section 3.5.2, in case of experiment A, the total data sample collected is 1900 and in the case of experiment B is 100. The rate of failure of determining a position can be defined as follows:

\[ R = \frac{f}{s} \times 100 \]  (3.4)

where R indicates the rate of failure (in percentage), whereas f denotes the times when a position was not determined by the system and s denotes total number of data sample.

3.9.4 Performance

This metric is used for real-time testing of the system. Consider a mobile device gathered a total of \( r \) samples and was sent for processing to the server. Fingerprinting and multilateration approach estimated positions were sent to the database by the server.

The estimation error was calculated as follows concerning the fingerprinting approach:

\[ Error_f = \sqrt{(x - x_{fingerprint})^2 + (y - y_{fingerprint})^2} \]  (3.5)

with respect to multilateration approach:

\[ Error_m = \sqrt{(x - x_{multilateral})^2 + (y - y_{multilateral})^2} \]  (3.6)

where, \((x, y)\) are the real coordinates which were calculated using the android application called ruler, \((x_{fingerprint}, y_{fingerprint})\) are estimated coordinates of the fingerprinting approach and \((x_{multilateral}, y_{multilateral})\) which are obtained from an multilateration approach. The obtained errors are plotted on the map.

3.9.5 Beacon identity-based

In this thesis, accuracy range is calculated using cell identity-based (CID) method or in my case beacon identity-based (BID) method. It is a proximity-based technique, as it returns the location or the geographic coordinates of the strongest RSSI connected with the serving beacon (which is supposed to be nearest to the receiver) [66]. And the result is plotted in the CDF graph.

In order to better evaluate the accuracy range, we compare the location of the moving devices on the map, with its Beacon-Id approximate location (highest RSSI).

3.9.6 Complexity

Complexity is implemented as another metric in the literature that can be used when benchmarking a system. Complexity can be calculated as to the time needed to calculate a device’s position. Nonetheless, current smartphones have enough computing capability to make the calculation time shorter than 0.1 seconds while using the algorithm included in this study; thus, time usage is not an important aspect in our assessment of this method. Nevertheless, this metric has not been used in this study.

3.9.7 Navigation time

Measuring precision and accuracy needs the true position of the user. While this kind of positioning is accessible for stationary positions wherein the user is standing still; but that’s not the situation dynamic positions because the person can move continually. This is the reason why this metric was introduced so that it makes easy to measure the navigation efficiency of
the system. The proposed metric is indeed the time it takes for all the user to travel from a starting point to their final destination. Thus, in this thesis, this metric was not used as the purpose is not to navigate the user.
This chapter presents the solution provided beginning with the architecture and implementation of the system. Then the segment of the result and discussion is proceeded.

4.1 System Architecture

I have installed BLE beacons attached to an IoT device in the office corridor and rooms. At a regular interval, the BLE devices broadcast beacon’s information (explained in section 2.2). To estimate the beacon position (i.e., coordinates), beacons RSSI and distance from the receiver are used. Figure 4.1 illustrates our proposed system architecture.
The architecture is made up of two sides, the server and the mobile side. On the mobile side, data collection is carried out. The information gathered will be sent to the server, where all the calculation is performed to estimate the device’s and user position i.e., x and y coordinates and thus result is stored in server-side. Finally, the outcome is held by the database.

On the mobile side, to collect the RSSI value, an android app has been installed on a smartphone, while on the server-side, the algorithms are written to analyze the data and compute the locations.

4.2 Mobile side

The mobile-side deals with data on three multiple layers, regardless if it is in the fingerprinting approach or perhaps the multilateration approach. This system includes an object of BLE beacons, location module and Android application in order to determine the position of the receiver and beacon in case of experiment B, which is shown in figure 4.2.

![Figure 4.2: Mobile-side flow chart for fingerprinting and multilateration approach](image)

4.2.1 BLE Beacon object

The object BeaconObj is used when viewing to store the data about a beacon.

```java
public class BeaconObj {
    public String uuid;
    public String TxPower;
    public String RSSI;
    public double major;
    public double minor;
    public String beaconName;
    public HashMap<String, BeaconObj> positioningMethod;
}
```

Listing 4.1: The Beacon Info Object

As seen in Listing 5.1, this object contains important data to place a beacon. The uuid is the unique identification number given to every beacon. The TxPower and RSSI value are the signal measurement from the beacon. The major and minor value is read as well to distinguish from room and specific beacon in a room respectively. The beaconName field is used to differentiate a beacon from another. The positioningMethod field is a hashmap used to store
observations done every time. Later on, these fields are used by the positioning algorithm to compute coordinates with the multilateration technique in experiment A and Euclidean distance to compute coordinates in case of experiment B. The constructor of a BeaconObj object needs RSSI, TxPower and the position (Major and Minor value) from the beacon.

4.2.2 Location Module

This module uses beacon information from the BLE Beacon block to estimate the location. The location value is calculated from the beacon’s RSSI, Major, Minor value and TxPower which is read from the beacon. This gives the distance which is used to calculate the measurement between the beacon and the user in meters. This is given to the android application which displays the distance value to the user.

During the fingerprinting approach, the RSSI value of a beacon is given as an input for the positioning algorithm which will calculate coordinates (position) using the coordinate system. It is carried out by dividing the map into smaller radio-maps, and the RSSI is collected from all these radio-maps.

4.2.3 Android application

I chose to use the Android platform for my thesis because of the wide range of devices and sensors are available on the market, ease of use and widespread use of the platform.

In this thesis, due to lack of time, I have used the Android application from the Google Play Store, while a proper approach could have been to develop an application which allowed the users to get the beacon information such as RSSI value, UUID, distance and the current time, and saving it in a cloud server for further post processing.

Beacon Locator is an android application used for scanning and tracking the beacons. It gives the beacon information like beacon name, its UUID, RSSI value, TxPower, major and minor value. In addition to that, it also gives the distance from the beacon to the user and information whether the beacon is far or near the user. This is explained in detail in section 2.2.1 and figure 2.6 shows the screenshot of the application.

4.3 Server Side

The measurements produced by the mobile-side consists of Bluetooth strength readings and the distance, which are filtered and processed using the Kalman filter to allow the server to conduct the calculations under the correct circumstances.

The server side is implemented consist of algorithms and databases to store the result. This carries out all the calculations on the data from those of the devices connected. Figure 4.3 shows briefly how it works and communicates with a device and server.
4.3. Server Side

It has two different layers positioning algorithm and database.

4.3.1 Positioning algorithm

This block operates differently in the fingerprinting and multilateration approach with data from the mobile side. This is explained in the following section:

Fingerprinting approach

The fingerprinting approach is illustrated in figure 4.4. As seen, the mobile-side sends RSSI value to the server. Then this is given as an input to the positioning algorithm block. In this block, with the help of map which were divided into radio-maps and coordinate system, the coordinates for the devices are calculated. The coordinate system is a technique of estimating the x and y axis of a map. The map is represented in the form of a grid and each position of the grid is represented in the form of $(X_{\text{fingerprint}}, Y_{\text{fingerprint}})$ axis.
4.3. Server Side

**Multilateration approach**

The flowchart of the server in the multilateration approach is presented in figure 4.5, where it all starts with a smartphone sending the distance of all the position from beacon to device through an android application.

The reference point of beacons in experiment A and experiment B the receiver locations is estimated previously in the fingerprinting approach. These data are also used in this approach as well. Along with this data and the distance calculated by an android application, the position of the other device (which is in movement) is calculated. The position is calculated with the help of multilateration algorithm in case of experiment A and in case of experiment B Euclidean distance formula is used.

**4.3.2 Database**

The database, as shown in Figure 4.6, is a MySQL database containing all the fingerprints collected from the fingerprinting approach, reference points and position coordinates calculated by multilateration (by Euclidean distance in experiment B) from the multilateration

---

**Figure 4.4: Server flow diagram during the fingerprinting approach**

**Figure 4.5: Server flow diagram during the multilateration approach**

---

39
4.4 Fingerprints

The office area was broken up into multiple radio maps to begin with. Bluetooth proximity was used to classify the different maps. Some of the radio map includes a BLE beacon that smartphones in the surrounding area must identify for experiment A. While for experiment B, a receiver is placed at some radio maps that will recognize when the beacon comes near to it. The search position for fingerprints is narrowed down by identifying the coordinates i.e., x-axis and y-axis of the known BLE beacon getting the highest signal strength.

The key idea behind finding the x and y coordinates is that the process compares the coordinates with the previous measurement in the floor plan, so that the new measurement does not end up being given current measurement. This means that when the map is divided into radio-maps, the leftmost bottom corner is our origin (0,0), for example. Then adjacent radio-map will have by one with regards to coordinate x and y. This is how the coordinate system works and gives the position of every radio map in terms of x and y coordinates.

4.5 Multilateration

In this section, I am going to explain how multilateration can be used for indoor localization. This method of positioning helps to improve position accuracy. So, I implement a multilateration positioning scheme with a Kalman filter. Algorithm 1 uses the multilateration method to describe the general steps of the developed application which has been explained below:
4.5.1 Algorithm

If a user wishes to find a device position, a few operations need to be performed before displaying their position on the map. Firstly, the information on the beacon explained in section 4.2.1.1 needs to be downloaded. This data is then used as an input to the algorithm shown in algorithm 1. A fresh thread begins each time a new RSSI is measured. It is necessary to check the measured RSSI and the corresponding distances if it belongs to one of the seven BLE modules registered in experiment A and one in experiment B. The Kalman filter will be implemented if the RSSI is approved. A Kalman filter was introduced to achieve better estimates of the position of a device. Then, the coordinates are calculated and stored in the database. Multilateration method must be applied for at least four distances. Consequently, the algorithm loops in the RSSI reading procedure until the limit is achieved $y_1 = 4$. But in the case of experiment B, $y_1$ is decreased to 2, as it contains only two distance values because it has only two receivers.

**Algorithm 1 Multilateration algorithm to estimate the coordinates**

1: while approved distances $i \geq$ Threshold $\tau_1$ do  
2: Collect RSSI readings from $k$ BLE beacon and $d_i$ distance  
3: if the RSSI and $d_i$ are recorded then  
4: use the Kalman filter  
5: end if  
6: if $d_i >$ Threshold $\tau_2$ then  
7: discard $d_i$  
8: get to the second step  
9: end if  
10: end while  
11: implement the positioning algorithms to all $i$ distances  
12: save the coordinates

Until applying multilateration to determine the location, it is important to determine distance between both the mobile node and that at least four reference nodes. The calculations are based on the distance to the RSSI relationship. With the distance of nodes, the RSSI reduces, particularly regarding the longer the distance, the smaller the RSSI becomes. Keeping this principle in mind while performing the tests, I found that the best result is obtained when the distance between BLE beacon and receiver was less than 3 m. The specification of distances of below 3 m throughout the RSSI model is therefore pretty reliable. Thus, the algorithm checks to all stored distances below or equal to 3 m, then implement the positioning algorithms. Distances are overlooked, greater than thresholds ($\tau_2 = 3$ m). Then the method of multilateration is successfully applied in the case of experiment A, while in experiment B Euclidean distance formula is used and a new coordinates are recorded.

4.6 Results

I will first show the results of the two experiments in this section. Next, I analyzed these results based on the BID method.

4.6.1 Stationary beacon result

Table 4.1 outlines the result of the positioning of both the fingerprinting and multilateration approach under the two different conditions. Comparing all the tests carried out for this experiment (from tests 1 and 7, shown in table 4.2), I can draw the conclusion that using first four strongest beacon reading improves the accuracy. The reason for this is that subjected to reflection and multi-path impact, RSSI does not always represent the distance properly, so using fewer beacons prevents introducing erroneous data into the environment. The use of 4
4.6. Results

Strongest beacons greatly enhances performance when the hyperbolas are often not intersecting.

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Number of beacons</th>
<th>Steps</th>
<th>Accuracy (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Multilateration approach</td>
</tr>
<tr>
<td>1</td>
<td>No</td>
<td>1900</td>
<td>2.46</td>
</tr>
<tr>
<td>2</td>
<td>Yes</td>
<td></td>
<td>3.89</td>
</tr>
</tbody>
</table>

Table 4.1: Summary of experiment A results

Table 4.2 outlines the result of each test carried out considering the 4 strongest beacon. I can also draw the conclusion that a few measurements achieves lower accuracy compared to a large number of measurements. But this is not always true because even a few measurements are applied under the right requirement and still achieve adequate accuracy with a suitable algorithm.

<table>
<thead>
<tr>
<th>Test Number</th>
<th>4 strongest beacons</th>
<th>Steps</th>
<th>Accuracy (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Multilateration approach</td>
</tr>
<tr>
<td>1</td>
<td>Yes</td>
<td>84</td>
<td>3.6</td>
</tr>
<tr>
<td>2</td>
<td>Yes</td>
<td>90</td>
<td>2.12</td>
</tr>
<tr>
<td>3</td>
<td>Yes</td>
<td>127</td>
<td>2.89</td>
</tr>
<tr>
<td>4</td>
<td>Yes</td>
<td>148</td>
<td>3.11</td>
</tr>
<tr>
<td>5</td>
<td>Yes</td>
<td>438</td>
<td>1.83</td>
</tr>
<tr>
<td>6</td>
<td>Yes</td>
<td>499</td>
<td>2.6</td>
</tr>
<tr>
<td>7</td>
<td>Yes</td>
<td>514</td>
<td>1.12</td>
</tr>
</tbody>
</table>

Table 4.2: Result of each test considering 4 strongest beacons

Table 4.3 compares the system’s performance with both fingerprinting and multilateration approach. The multilateration approach accuracy improved by 5.5% compared to the fingerprinting approach. Even the precision increases by 5.2%. This might be caused by using the coordinate system method as while calculating the coordinate of the receiver ignores the small decimal number. However, the failure rate is null because every time four hyperbolas intersect each other.
4.6. Results

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Accuracy (%)</th>
<th>Precision (%)</th>
<th>Rate of failure (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multilateration approach</td>
<td>94.2</td>
<td>86.5</td>
<td>0</td>
</tr>
<tr>
<td>Fingerprinting approach</td>
<td>88.7</td>
<td>81.3</td>
<td>0</td>
</tr>
<tr>
<td>Comparison</td>
<td>5.5</td>
<td>5.2</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4.3: Comparison of positioning result

4.6.2 Moving beacon result

Table 4.4 summarizes the positioning result of both the fingerprinting and multilateration approach under a single condition. In this experiment, Euclidean distance formulae are used to estimate the coordinates of the moving beacon. Here the method of multilateration or trilateration positioning was not used because, respectively, hyperbolas and circles do not intersect as there is only two possible readings from the receivers, which led to the difficulty of estimating the coordinates or some time it intersect at two different points giving the possibility of outcomes. It therefore, decreases the system’s performance.

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Condition</th>
<th>Steps</th>
<th>Accuracy (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 receiver, 1 beacon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Yes</td>
<td>100</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Table 4.4: Summary of experiment B result

Table 4.5 compares the output of the system in experiment B with both fingerprinting and multilateration approach. The multilateration approach formula, enhanced accuracy by 3.4% compared to the fingerprinting approach. However, the precision degraded by 5.2%. And the failure rate is also null here, as in this experiment they are no notion of intersection.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Accuracy (%)</th>
<th>Precision (%)</th>
<th>Rate of failure (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multilateration approach</td>
<td>88.7</td>
<td>76.3</td>
<td>0</td>
</tr>
<tr>
<td>Fingerprinting approach</td>
<td>85.3</td>
<td>81.5</td>
<td>0</td>
</tr>
<tr>
<td>Comparison</td>
<td>3.4</td>
<td>-5.2</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4.5: Comparison of positioning algorithm
4.6.3 Beacon-ID method

I will first show the results of the experiments on Beacon-ID’s performance performed both in stationary and moving beacon case. Studying Beacon-ID’s performance by simulation requires information on beacon’s signal strength. In addition, the performance of Beacon-ID is highly determined by unexpected factors such as noise, propagation of multi-paths, etc. These factors make it difficult to define an appropriate simulation environment. So with the aid of Kalman filter, I have tried to remove most of the noise from the signals.

4.6.3.1 Stationary beacon

In this section, the results of some simulations performed to better estimate the accuracy range in case of stationary beacon is formulated.

As the outcome of the four strongest beacons has the better result, we consider that to measure the range of accuracy. To estimate this, firstly a CDF of BID measurements (geographic coordinates of the strongest RSSI connected with a particular beacon) with respect to fingerprinting and multilateration approach in order to evaluate the performance of it.

Figure 4.7: Distribution of highest RSSI for the BID measurements

Figure 4.7 illustrates the curves showing the distribution of highest RSSI for the BID measurements. This means that each curve represent the strongest to weakest beacon RSSI for each measurements. We can see that certain instances such as instance from 120 to 180, instance from 290 to 300 and instance from 410 to 435 has the highest signal strength which can be said good signals. Whereas from the instance 220 to 240, all the beacons have bad performance as the signal strength is low. When these instances are indicate on the map, it shows that distance close to beacon have good accuracy compared to far on. This is illustrated in figure 4.8.

Multilateration approach and BID method are applied for the good signal measurements. Then thresholds are set, that is, it takes into account signals above -55dB, -60dB and -65dB and the respective coordinates.
Results are shown in Figure 4.9. The accuracy ranges from 1 m to 5 m in case of stationary beacons.

4.6.3.2 Moving beacon

In this section, the results of some simulations performed to better estimate the accuracy range in case of stationary beacon is formulated.
4.6. Results

Similar steps are carried out in order to estimate accuracy range, firstly a CDF of BID measurements (geographic coordinates of the strongest RSSI connected with a particular beacon) with respect to fingerprinting and multilateration approach in order to evaluate the performance of it.

Figure 4.10: Distribution of highest RSSI for the BID measurements

Figure 4.10 illustrates the curves showing the distribution of highest RSSI for the BID measurements. We can see that certain instances such as instance from 50 to 60, provides us the good signals. Whereas from the instance 30 to 40, all the beacons have bad performance as the signal strength is low. These instances are indicate on the map, illustrated in figure 4.11.

Figure 4.11: Map indicating the position of good and bad signal instance
4.7 Discussion

Signals of -55dB, -60dB and -65dB are also taken into consideration here. Figure 4.12 displays the CDF of these measurements along with measurements that are obtained from multilateration and the BID method.

![Empirical CDF graph]

**Figure 4.12: Accuracy range of moving beacon**

The accuracy ranges from 3 m to 9.5 m in case of moving beacon. This experiment was lacking data collection to provide any valuable conclusion.

4.7 Discussion

In the stationary beacon experiment, the result of the multilateration approach was much better than the fingerprinting approach in many ways as shown in figure 4.13. In the fingerprinting approach, I was not able to estimate the actual coordinates of the user steps due to which accuracy was dropped. However, in the multilateration approach, the distance was calculated by an android application which gives an accurate distance between beacon and the receiver. This is the reason that improved the result. But if the application receives four incorrect values, it is difficult to calculate the resulting multilateration location.

Another experiment was done, moving along a determined route with the beacon in hand. The accuracy was somewhat uncertain between the two approaches as shown in figure 4.14. This is because of the uncertain estimates of the coordinates of the beacon position. If the system gets the required beacon distance value incorrect, it is difficult to calculate the resulting location of the beacon using a positioning algorithm.

Instead of displaying a position on the map that could be misplaced, the application could indicate an area where the beacon could be positioned. The user can search an area rather than just going to a wrong position with the help of a graphical aid. Thus, to measure this area instead of a single coordinate, the positioning algorithm would have to be rewritten.
4.7. Discussion

Figure 4.13: Comparison between accuracy of fingerprinting and multilateration approach in experiment A

Figure 4.14: Comparison between accuracy of fingerprinting and multilateration approach in experiment B
This chapter summarizes this thesis by looking back at the research questions as well as defining the limitation of the result. There are also some suggestions for future work being addressed.

5.1 Research Questions

Research question 1

*Why BLE beacons are chosen for indoor positioning?*

There are several indoor positioning technologies like BLE, WiFi, Magnetic field detection, UWB, and others. If you consider WiFi which requires an external power source and it’s not cost-effective, whereas Magnetic field detection technology requires a stable magnetic field which is very difficult to achieve in all the places. As far as UWB is considered which requires installation of sensors/antennas at very high number to get a great accuracy. Whereas BLE beacons is easy, cheap, low battery consumption, no external power source needed, but on the other hand it is not that accurate and reliable, however, for many IoT use-cases it is one of the best options for indoor positioning. Comparing all technologies I found that all of them have one or the other drawbacks but in the case of BLE the drawbacks are minimal and moreover, all the smartphones are pre-equipped with the Bluetooth which makes it the most available technology which is the main reason for choosing BLE for indoor positioning.

Research question 2

*How to obtain measurements from the nearby BLE beacons?*

BLE beacons are one-way communicating device. These devices can be configured using smartphone and applications installed on the it. The beacons transmits a unique ID that is recognized by these smartphones. The Application program interface (API) in the smartphone estimates the distance. The accuracy of these distance values mainly depends on the received signal strength. The received estimation is then combined with the RSSI, this provides a distance measurement between the device and the beacon taking environmental factors into account and neglecting them.
5.1. Research Questions

Research question 3
What is the accuracy of the position of an IoT device inside a building using BLE beacons?

After measuring the performance of the positioning system and assessing the outcome, several observations were made. One of them was the accuracy is very different from stationary beacon to that of moving beacon. The accuracy depends on many different parameters, for example how much dense we have the deployment, and how close we are to the beacons. Also whether the beacon is stationary or moving would impact the accuracy. While in the case of stationary beacons, it offers accuracy range from 1 m to 5 m, and accuracy range from 3 m to 9.5 m in predicting the position of each beacon in the case of moving beacons.

Research question 4
What are the requirements and challenges faced while using BLE beacons?

Requirement:
• BLE receiver, there is a need to have a receiver to collect RSSI measurements from each beacon. I simply used my mobile device which supports BLE technology and an android app. However, this could also be done by programming a Raspberry Pi as a BLE receiver.
• Location services (This is a type of service that is accessible for mobile devices through its networks and uses information about the mobile device’s geographical position) should always be on and running at all times.
• Connection to the Internet should always be on.
• In mobile devices, Bluetooth should always be on.
• Beacon locator app should always be running on a mobile device.

Challenges:
• One important challenge is the fact that in this study as the deployment was very dense the BID result was better than both fingerprinting and multilateration approach, that means that for all these methods the accuracy can’t be better than few meters.
• If the internet is disconnected for a fraction of a second, the android application will not respond and the IoT device record will not be updated. Once the internet connection is restored, the app will start running again and send the information to the server only to represent the location of the device.
• Understanding the placement of the beacon was very important because even if the beacon range is good and there is some barrier between the beacon and the mobile device, it can be a challenge to locate the mobile device. I often saw this while carrying out the tests.

Research question 5
How many number of beacons used for indoor positioning can impact the accuracy of the location estimation?

According to the result in this thesis, for stationary beacons experiment using first four strongest beacon reading improves the accuracy. The reason is that RSSI doesn’t always portray the distance subject to reflection and multi-path impact correctly, therefore with use of fewer beacons, prevents the incorrect data from entering the environment. Thus use of 4
strongest beacons greatly enhances performance compared to considering all seven beacon’s readings.

But for the moving beacon experiment, only one beacon was used.

**Research question 6**

_What are the main use-cases in which BLE positioning would become beneficial?_

Since with rapid increase in the technology, the uses can be found in many places,

- According to my thesis, it can be used in an office environment with an indoor positioning system for IoT applications. It also is used to monitor employees at the office.
- The biggest benefit goes to the logistics and transportation industry as it would help in tracking and packaging of the items in the indoor warehouses.
- It can also be used to track patients and doctors during emergencies in hospitals.
- Airports are usually very complex building structures and it’s very difficult to keep track of everything. Indoor navigation assists people from their arrival to departure and the correct security planning can be done for passengers considering the current flight information which in turn reduces the stress.

And there are many more places where it can be beneficial.

**5.2 Limitations**

This research may have certain potential limitations.

The primary limitation is the lack of data. The sample size for stationary beacons experiment is 1900 and 100 for moving beacon. To infer a valid research result, it is necessary to have enough sample size when conducting a thesis. The larger the sample the more reliable will be the results. If the sample size is too small, significant data relationships will be hard to identify.

Secondly, the method used here is accurate for a research aim, but it also includes limitations. The procedure used in the fingerprinting approach to calculate the coordinates is not handled in a systematic manner. Because of this the exact position of the devices was not accurately measured.

**5.3 Future work**

There is always room to improve the accuracy by doing further post processing of the data. Future work can focus on expanding the work by using more advanced algorithms like neural network or machine learning, and will enhance our result.

Furthermore, in a relatively small space, I checked the system with few IoT devices, few network barriers. If the device is implemented in a big, crowded area, with many IoT applications being deployed in such a place where large metal barriers are deployed, shopping malls or airports, the accuracy could be decreased, and it would be more challenging to improve the route planning systematically.
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