Bachelor's Thesis

Geolocalization and routing in complex multi-floor hospital environments

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Thankssssssss

Abstract

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Acronyms

AP access point. 17–20, 22

API application programming interface. 9, 12

GPS global positioning system. 14

IPS indoor positioning technologies. 13, 14, 16, 23

IR infrared. 14

LBS location-based services. 13

MAC media access control. 18

MU mobile user. 15, 18, 21–23

PN personal network. 13

. 9

POI point of interest. 13

RF radio frequency. 18

RFID radio-frequency identification. 14

RSSI radio signal strength indicator. 19–22

Rx receiver. 14

SDK software development kit. 9, 12

SNR signal-to-noise ratio. 18

TDoA time difference of arrival. 15, 18

ToA time of arrival. 14, 15, 18

Tx transmitter. 14, 15

UML Unified Modelling Language. 12

UWB ultra wideband. 14

WLAN wireless local area network. 14, 22

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Chapter 1

Summary

Chapter 2

Context

2.1 Internship at IBM

This bachelor's thesis covers the concrete specification of the internship project, the company in which the internship took place, the research needed to complete the project and the practical implementation. The internship project was provided by IBM in Brussels as part of the Global Business Services (GBS) division.

2.1.1 IBM

IBM, which is an acronym for International Business Machines, is a leading and innovative corporate entity active the field of information technology. The focus has shifted away from hardware-only solutions to a vast array of solutions due to the development in IT and electronics [15]. The predominant solutions that IBM offers are:

1. Blockchain;
2. Cloud Computing;
3. Artificial Intelligence;
4. Watson IoT;
5. Analytics;
6. Java;
7. Security;
8. Open Source;
9. Global Technology Services;

IBM has seen an increase in revenue from their Cloud and Analytics solutions in 2019 due to continuous improvements in their data centers and ever-expanding expert employees [6].

2.1.2 Internship Team

Below, the team of interns is displayed.

Figure 2.1: The team of interns

Chapter 3

Case Study

3.1 Project Description

This bachelor's thesis covers a case study provided by IBM, related to an internship performed at IBM. This chapter will cover the case study, specific requirements and which technologies need to be researched and thus are handled in this paper.

3.1.1 Case Study

Applied case: patient location-based services in a hospital A hospital is a good example of why an IPS can be useful. Many people spend time following the indicated route from the hospital's hall to the specific point of interest (operation room, intensive care, specific doctor's office etc.), however this requires a patient or visitor to constantly check his current location and is therefore intolerant for human mistakes. The routing inside a hospital is a prime example of a static route which is not adaptive to the visitor and does not offer real-time changes. This is where the application of an IPS can be a dynamic technology to guide the user inside the building. Another important note is the user's privacy: when using the PN location-based services it ensures the loss of connectivity - and thus the tracking of the user - when he or she is not in range of the positioning technology.

3.1.2 Technologies to research

Throughout the development of the PoC, several technologies are used, such are: Android SDK, authentication, RoomDB for offline storage, IBM BlueMix API, Unified Modelling Language (UML), dependency injection, MapWize, IndoorLocation and Cisco CMX.

Chapter 4

Indoor Positioning Systems

4.1 Introduction

Due to the increase in wireless connectivity (bluetooth, Wi-Fi, 3G, 4G and soon 5G) numerous wireless positioning technologies have been researched and developed such as the RADAR, Cricket and Active Bat. The indoor positioning is not limited to tracking static objects or assets, but due to the increase in mobile applications, expanded to humanoid tracking as well.

The need for IPSs in personal network (PN) has seen an increase in practical applications. One of the main factors that pushed for rapid development of different applications is the widespread use of personal devices equipped with different sensors, such are: laptops, smartphones and smart devices (smart watches and such) with expanded connectivity (GPS, Bluetooth, 3G, 4G, cellular networks and Wi-Fi). By interconnecting personal devices in enterprise, public or home area networks, the devices are able to communicate with each other and provide adaptive and personalized services.

4.2 Definition of Indoor Positioning

An indoor positioning system, also known as indoor GPS or indoor location-based services (LBS), permits users to navigate in an indoor environment and follow a route to a specific point of interest (POI). This technology was developed out of the necessity to provide indoor location and routing due to the inability of GPS technologies to work indoors [17]. One of the key functionalities of an IPS is to provide a real-time location system that will work until turned off by the end user. It should provide a highly accurate display of the user's location by minimizing the error, delay and by using different algorithms to minimize cost function [1].

4.3 Indoor Positioning Technologies

The field of indoor location has seen an increase of different types of technologies used in recent years. In practice, these consist of: infrared (IR), wireless local area network (WLAN), bluetooth, radio-frequency identification (RFID), ultrasound, ultra wideband (UWB), magnetic signals, sensor networks, vision analysis and sound waves [12]. There are already numerous systems available on

[1] A cost function, or loss function, evaluates the model used in a certain application and is an important factor in the accuracy of the model. Universally this function should be as minimal as possible, thus giving the best approximation possible. [1]

System	Used Technology	Accuracy
FM Broadcast measuring	RSS, SNR, Multipath, Frequency offset measurements fingerprint database	around 0.3m
Unloc	WiFi RSSm compass, Accelerometer fingerprint database	1-2m
EZ Localizaition algorithm	WiFi RSS multilateration without known AP coordinates	3-10m
Geomagnetism sensing	E-Compass fingerprint database	4.7m
LIFS	WiFi RSS frequency offset fingerprint database	around 5.88m

Table 4.1: Comparison of indoor location systems [19, p.7]

the consumer market that implement one or multiple of these technologies to provide an accurate implementation of an IPS [20].

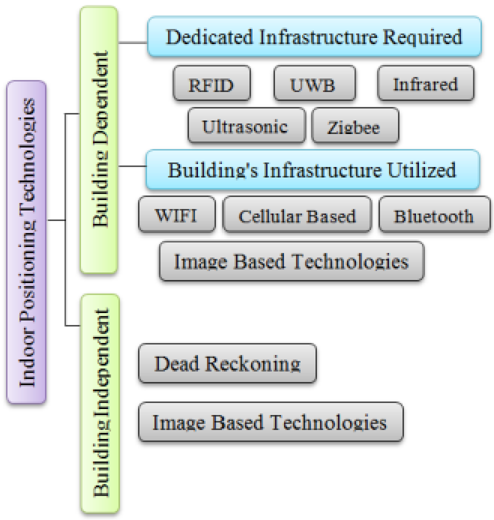

Figure 4.1: Classfication of indoor positioning technologies [**ComparativeSurvey**]

4.3.1 Location Information for Positioning Systems

There are four commonly used types of information for IPS[22].

1. Absolute location: the location as a point inside a reference grid, shared across all objects used in the space.

2. Physical location: location displayed as a point in a coordinate system (x, y, z), either 2D or 3D.

3. Symbolic location: translates a physical location into a more human centred location name, e.g. office 213 on the 1st floor.

4. Relative location: location is based on the relative distance or proximity to a beacon or base point, e.g. rescue helicopter flying over sea trying to locate any survivors.

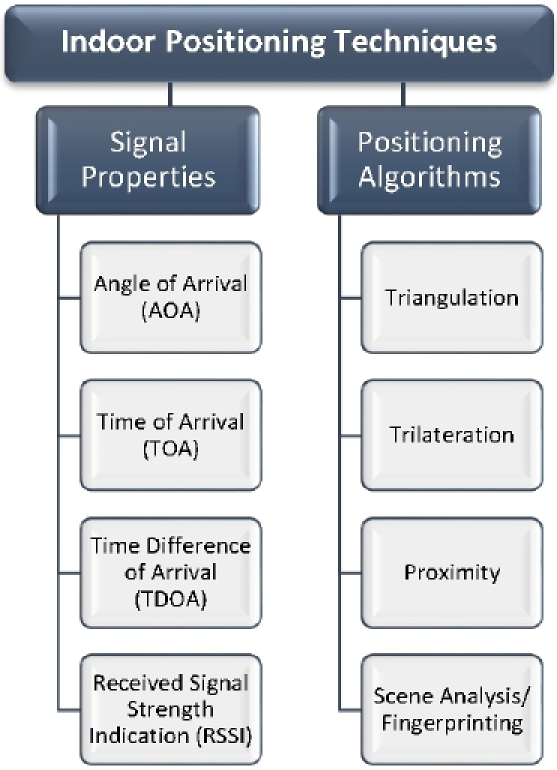

Figure 4.2: Classification of indoor positioning techniques [33]

4.4 Distance Measurement Techniques

4.4.1 Time of Arrival

The time of arrival (ToA) method is used to determine the distance between a transmitter (Tx) and receiver (Rx). In this method, the distance is calculated by the travelling time divided by the wave speed of the radio signal [23]:

$$d = t * c \tag{4.1}$$

Where d is the distance from Tx to Rx and c the constant speed of light (around $3.00 * 10^8 m/s$). This formula is based on research specifying the relationship between the propagation of a radio wave and its traversed range, which is a directly proportional relationship [32]. Using the triangulation method for three available transmitters, the position of the receiver can be calculated. A synchronized clock is mandatory to provide accurate results, as the error rate is partially dependent on the speed of light, thus if there is an error of 1ms, the error in distance will be 300 meters. Hence the reason that global positioning system (GPS) uses an atomic clock to ensure optimal accuracy [18].

4.4.2 Time Difference of Arrival

4.4.3 Angle of Arrival

By using the angle of arrival (AoA) method, the position of a device or mobile user can be determined based on the angles of deployed antennae. This requires additional set up: directional antenna, thus transmitters. The intersection point of the lines indicating a directional signal resemble the possible location of the device, albeit without an exact error margin. The problem lies with the necessity of

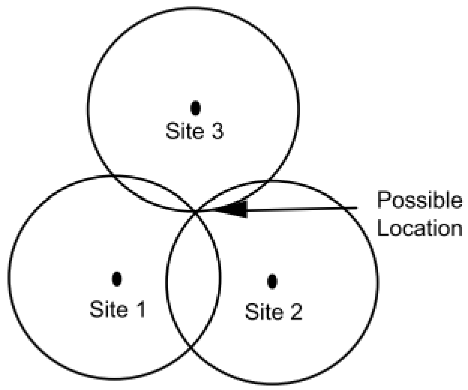

Figure 4.3: Determining position in a two dimensional space by time of arrival [18]

installing directional antenna arrays which contributes to higher cost than time of arrival and time difference of arrival [18].

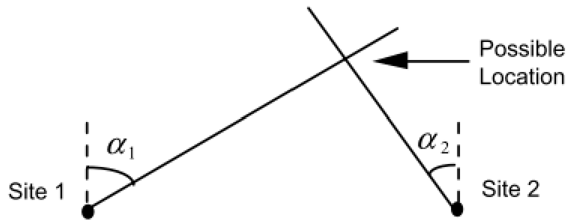

Figure 4.4: Determining position in a two dimensional space by angle of arrival [18]

4.4.4 Received Signal Strength Indication

4.5 Indoor Positioning Techniques

By calculating the distance between the Tx and the Rx, the position remains unknown. This is why the calculation of the distance happens first whereas the position can be determined afterwards.

4.5.1 Triangulation

The angles of reference points are measured to calculate the position of the current position of the point, as visualized in [**fig:triang**]. This method can only be used in combination with the distance method of angle of arrival, meaning that α and β need to be known.

4.5.2 Trilateration

4.5.3 Scene Analysis/Fingerprinting

4.5.4 Proximity

4.6 Conclusion

This thesis will cover the WLAN indoor positioning technologies technology and its implementation in a mobile application based on the provided project requirements.

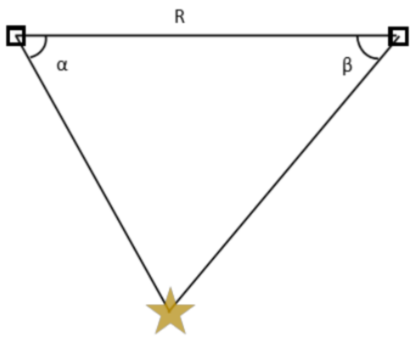

Figure 4.5: Determining position using triangulation [23]

Chapter 5

WLAN Indoor Positioning

5.1 Introduction

One of the easiest indoor positioning technologies to implement are WLAN (specified by IEEE in their 802.11 specification) IPSs. The adoption of such a system comes without extra cost as most of the hardware is already prevalent in large, indoor environments. The globally adopted operating bandwidth of WLAN is 2.4GHz (IEEE 802.11b, also known as Wi-Fi [21]), which does not come without its problems as discussed in a later section in this chapter [37] [9][5]. In this chapter the most commonly used techniques to calculate the position of a mobile user and the distance between a transmitter and a receiver, being the mobile user, are covered. After having covered the specific techniques, this chapter discusses the feasibility of this specific indoor positioning technologies with the complications of the 2.4GHz bandwidth as well as already commercially available systems.

5.2 WLAN Characteristics

5.2.1 Signal Properties

5.2.2 Available Channels

To minimize the chance of occurring interference, channels 1, 6 and 11 should be used for connecting devices. The WLAN channel width (of the 2.4GHz spectrum) is only 100MhHz wide, meaning channels 1, 6 and 11 are the only ones free of overlap [30].

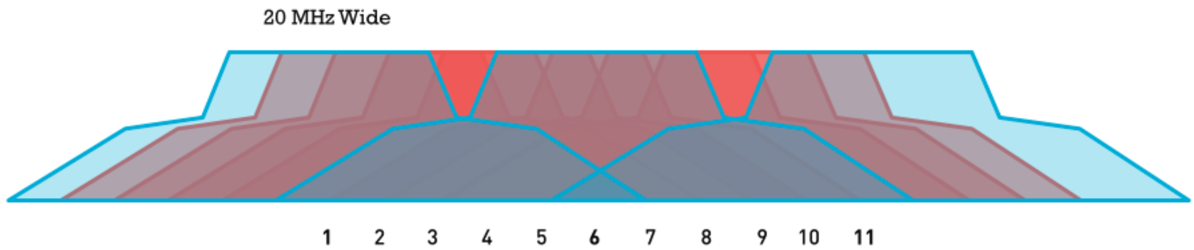

Figure 5.1: Available WLAN channels in the 2.4 GHz spectrum [30]

5.2.3 Access Points

5.3 Indoor Positioning Topology

Three topologies exists that can be used for gathering information about the position, as listed below [14]:

1. Network-based topology: position is determined by a central server and different APs;
2. Terminal-based: the position is identified by the mobile device;
3. Terminal-assisted: hybrid version of 1. and 2.

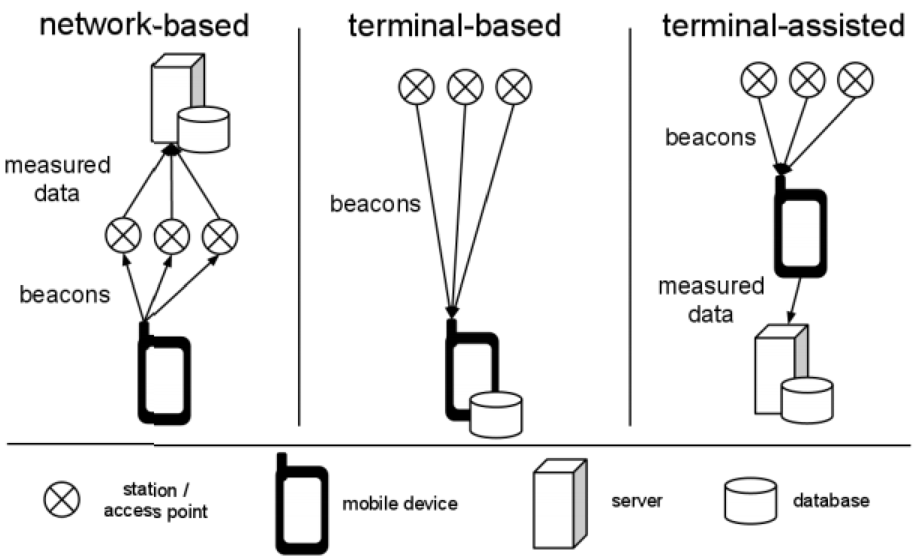

Figure 5.2: IPS Topologies [14]

5.3.1 Network-based

This method only functions when the APs are adapted to not only receive network data but also signal data and redirect this to a central server that can handle and compute the data. This requires a change in the software of each access point.

5.3.2 Terminal-Based

In this specific topology, the device driver of the AP or terminal broadcasts beacons in its signalling range so a client can determine the best connectivity to a certain AP and determine which AP will be used. There are two ways of obtaining this information:

1. active probing;
2. RF monitoring

RF monitoring is a form of passive scanning that listens to the periodic broadcasting by the access points, this is important to identify a connection in decline (due to significant noise on the signal, also known as signal-to-noise ratio (SNR)). When using active probing, the driver sends request frames to each known channel to detect any active WLAN connections. Each AP receiving a request frame will in its turn respond with a response frame. These packets contain the MAC addresses of available devices. Based on this list of available devices and the corresponding signal strength (obtained from services that provide the information via the MAC-layer) an optimal AP is selected[31, p. 8].

5.3.3 Terminal-Assisted

5.4 Indoor Positioning Techniques

The main difficulty in using this technique is determining the position of a device, relative to a Wi-Fi access point (AP). There are two mainly used technologies to determine the location of a mobile user (MU), being: positioning based on RSSI measurements (used in trilateration) and on empirical observations (fingerprinting) [10]. Another less popular option is the proximity, presence or Cell of Origin technique that has less accuracy than the other two options.

5.4.1 Proximity or Cell of Origin Technique

This technique is not optimal to determine an absolute or relative position, however this technique is used when accuracy is not the most important factor. This method simply locates the AP with the strongest RSSI value, which often is the closest to the mobile user. This is an optimal technique to provide symbolic location-based services [33].

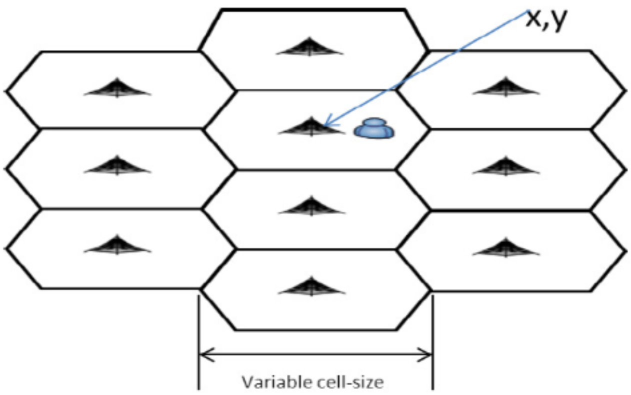

Figure 5.3: Visual representation of the Cell of Origin technique [32, p.12]

Conclusion This technique is ideal when the accuracy is a less important factor and provides location-based services with a very low cost and fast response time.

5.4.2 Trilateration Technique

Trilateration, or multilateration, is based on a mathematical approach that incorporate the characteristics of the AP and its signals, such are: characteristics of the radio signal (wavelength, frequency, noise etc.), media access control (MAC) address of the access point and the position of WLAN APs, without being limited to taking the signal strength in account. This approach requires three base points to calculate and determine a point in range of these three base points. Applying this method to the current case in which the available base points are the APs and the MU, one has to calculate the distance of the mobile user to each of the three APs in the vicinity. The main difficulty using this method is the estimation of the distances between both the APs and the device. Commonly used methods to determine the distance between both the AP as well as the mobile user include: time of arrival (ToA) from transmitters or time difference of arrival (TDoA) [36, p. 1] [26, p. 60].

Geometric Principle

As stated in the previous paragraph, trilateration requires an equation system containing three distance measurements between AP and mobile user. Using the euclidean distance between two points, this results in the following system or model [8]:

$$\sqrt{(x-x_1)^2-(y-y_1)^2}=d_1$$

$$\sqrt{(x-x_1)^2-(y-y_1)^2}=d_2$$

$$\sqrt{(x-x_1)^2-(y-y_1)^2}=d_3$$

By solving this system of equation, each distance is considered to be the radius of a circle, starting at the AP. The three circles created by according radius contain an intersection point, the specific location of the user, as visualized in figure 4.1.

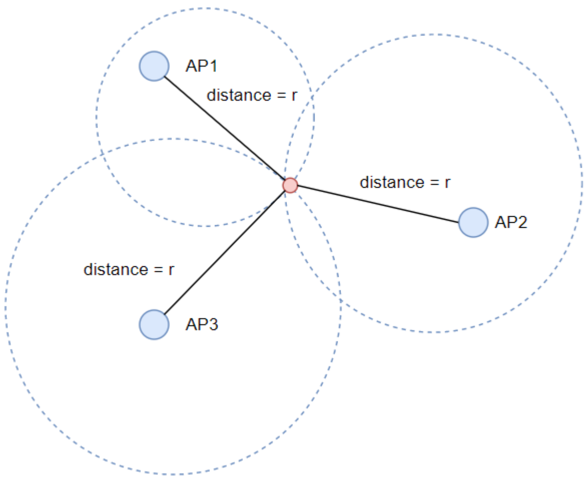

Figure 5.4: Euclidean distance resulting in geometric intersection of three circles, determining the position of a point in between these three points.

5.4.3 Path Loss Positioning based on RSSI Measurements

To handle the loss and gain of the radio signal, a free-space path loss model is used, as seen in an experiment in [36, p.178]. Shchekotov's research is funded on the research of Sklar in 1997 that suggests that the average RSSI is distributed lognormally and can therefore be predicted by using a path loss model [32, p.16]. The path-loss model revolves around the calculation of the distance based on the attenuation of the signal [26]. The empirical formula, solely based on measurements from the

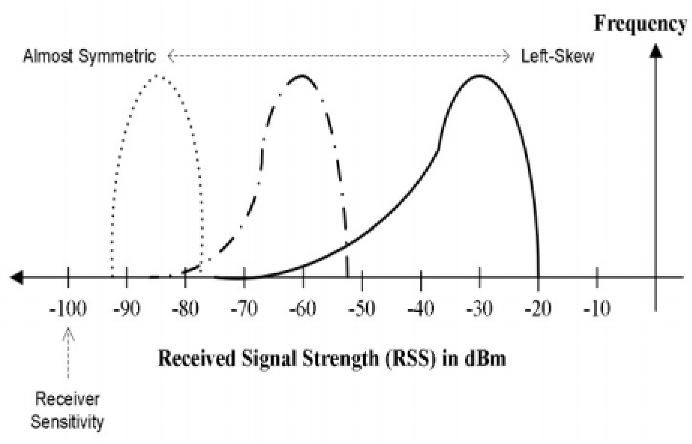

Figure 5.5: Distribution of radio signal strength indicator [32, p.16]

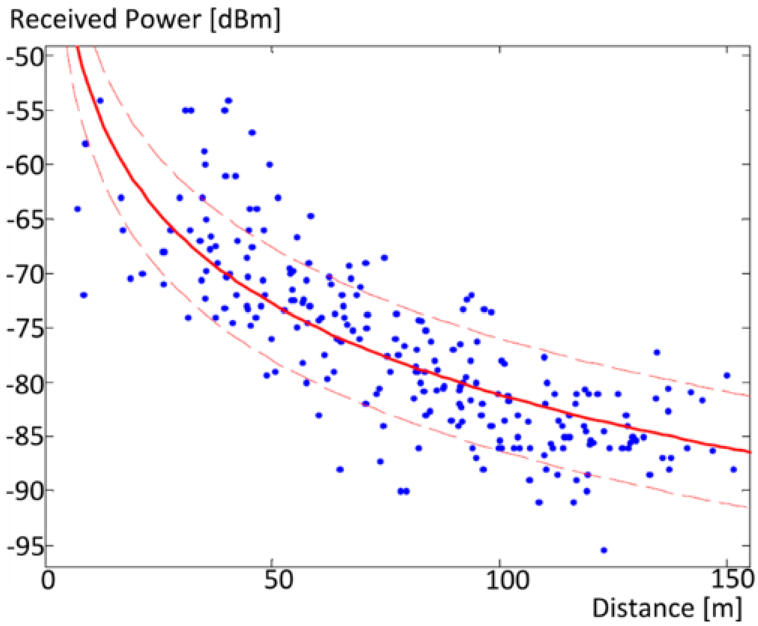

Figure 5.6: Dependency of radio signal strength indicator and distance [26, p.61]

experiment so not a standard analytic model, provided by [32] is as follows:

$$FPSL = 20log10(d) + 20log10(f) - 27.55$$

Where the transmitter-receiver separation distance is annotated by the variable d and the frequence in megahertz (MHz) by f. $FPSL$ indicates the received signal strength path loss in decibel-milliwatts (dBm). Based on the formula above and the one specified below, as specified in the research in [32, p 13] and [38, p 6], the distance between a transmitter and receiver can be calculated.

$$P_r = P_t G_t G_r \frac{\lambda^2}{(4\pi d)^2}$$

In this formula, G specifies gains of both Tx and Rx antennae, λ specifies the wavelength, d resembles the distance between the transmitter and receiver

Conclusion Based on the research done in [36], the signal propagation model using a free-space path loss approach does not provide an accurate estimation of the user's current position due to fluctuations in the radio wave channel and decrease of accuracy with an increasing distance [26, p 61] [23, p 2]. Nonetheless, this technique can be feasible in environments with less fluctuations and a denser distribution of APs, resulting in a smaller margin of error.

5.4.4 RSS Measurement Collection

This method uses an empirical (observational) model, generated by trial runs using different calibration points with different access points. As seen in experiment in [36], this experiments results in a table containing different measurements of different distances and the received signal strength in dBm, from transmitter to the receiver. This empirical method results in a usable mathematical formula:

$$\Delta = \sqrt{\sigma * t)^2 + A^2}$$

In this equation Δ annotates the observational error in dBm, σ is the standard deviation of the experiment, t is the function of the t-distribution and A is the observational error of the receiver (Rx) [36, p.178]. The error margin can be taken into account by applying this formula in a trilateration approach.

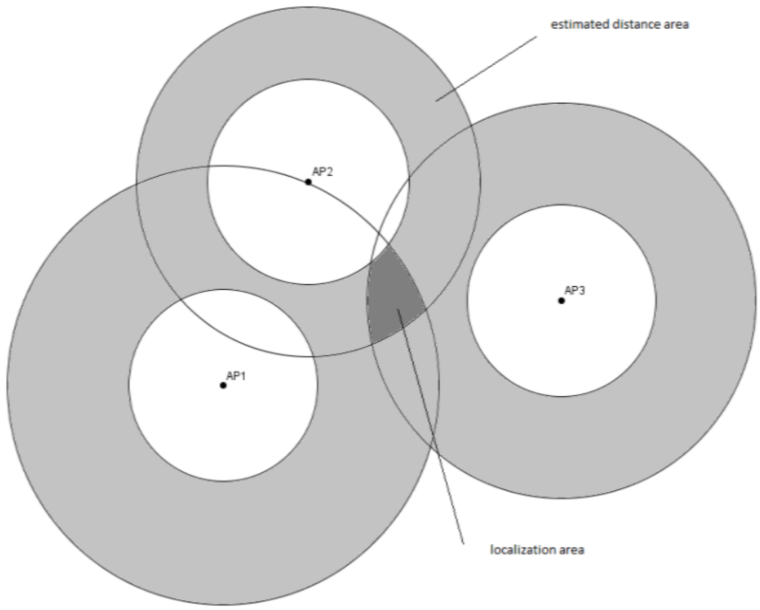

Figure 5.7: Estimated distance segments [36, p.179]

Conclusion As seen in the trials performed in the research of [36], this approach can be perceived as a special case of fingerprinting due to the creation of a RSS to AP table. This method results in a more accurate estimation of the user's location by taking the error and deviation into account. However, this research was not based on extensive measurements and it is uncertain this approach will yield an optimal accuracy and precision.

5.4.5 Fingerprinting Technique

A computationally effective method of determining a user's location is the fingerprinting technique. This technique consists of two phases: offline acquisition of RSSI values at particular locations and an online phase with the actual implementation of periodically sent signals from a MU [31, p. 9]. This method bases itself only on the strength of the signal compared to trilateration that incorporates multiple methods to calculate the distance.

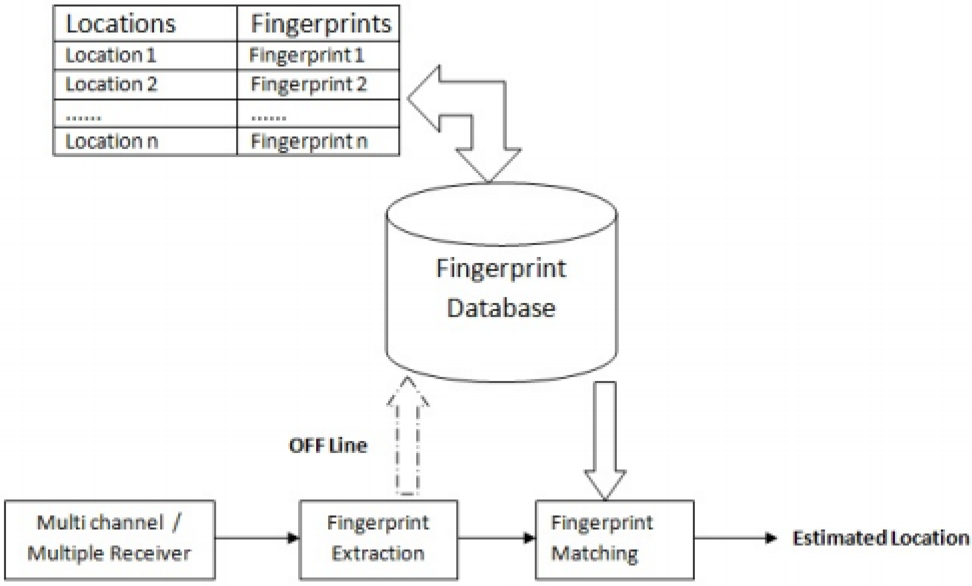

Figure 5.8: Fingerprinting Stages [32, p.11]

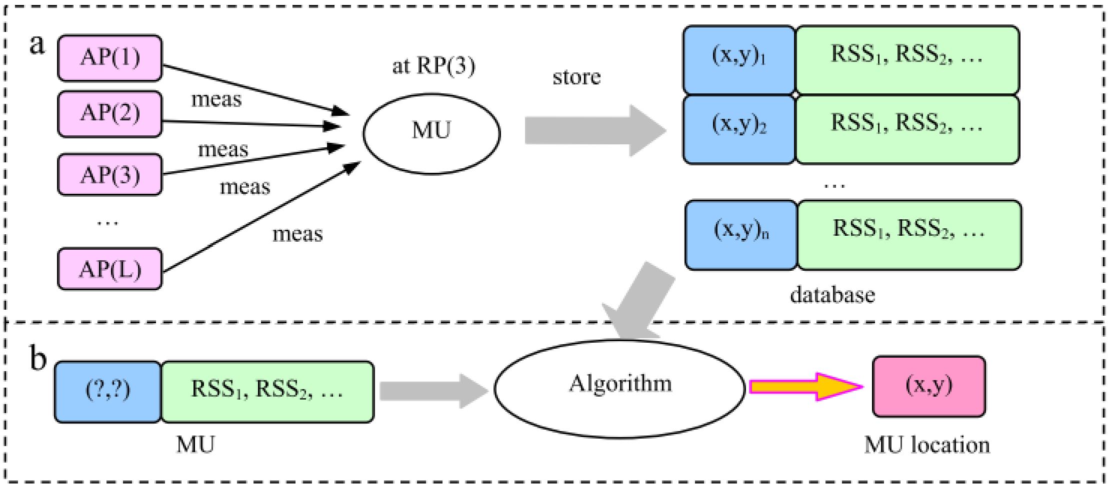

Figure 5.9: Fingerprinting Stages [21, p.2]

Offline Acquisition

The offline stage of fingerprinting consists of defining and measuring calibration points, which is a major drawback as this is a time-consuming task. The result of the empirical measurements of different points is a radio map with signal strengths in relation to the specific points. The RSSI is measured a few times on each calibration points and afterwards stored inside a database. Each entry in the database is a fingerprint, f, with a corresponding ground-truth (RSSI), symbolized as a vector in a three dimensional vector space.

Online Phase

In the online phase, the fingerprints stored in the database are used to determine and estimate the current position of a MU. The estimation of the distance is in most cases calculated using the Euclidean distance method as shown in [**fig:euclidean**]. The most straightforward method is to determine the minimum distance between the observation (current position) and the APs in the vicinity. Another method is a probabilistic method that calculates the probability that the current radio signal strength indicator measurements have the same position as a fingerprint corresponding in the fingerprint database [26]. This approach is based on the correlation values of the current observation and the fingerprints available in the database. This requires additional computing power but results in an increased accuracy.

Improving Performance

Contributing factors to increasing the performance, mainly accuracy and precision, are: number of APs per m^2, the amount of calibration points measurement in the offline phase, the density of those points and the fluctuations in RSSI values.

Conclusion This method requires a lot of time to set up the radio map in the offline phase, but results in a satisfactory accuracy, generally several meters, and precision. This is the preferred method of providing indoor location using a WLAN-based technology as it does not require additional equipment to be installed or configured. However, this technique is complex, hard to initially set up and does not scale well with an increase in users due to the increasing fluctuations in the radio signal that arise because of environmental factors, resulting in the need for re-calibrations at certain points in time with an increasing number of users.

5.5 Feasibility

5.5.1 Security and Privacy

5.5.2 Cost

5.5.3 Performance

5.5.4 Environmental Effects on Radio Frequency and Fault Tolerance

Radio frequency signals are subjected to interference from other signals. This included reflection, diffraction and scattering. These interferences on a radio frequency signal can result in a loss of accuracy and precision in an indoor positioning technologies and are therefore implications of this specific indoor positioning technology [32].

Indoor Environment

Based on a study performed in [38], where the signal strength of a 2.4GHz radio wave was tested over a period of 24 hours, the signal strength contains some interferences but overall results in a mean signal strength of 47.17dBm. In [**fig:wang_test**] the samples of the experiment are plotted in function of the time.

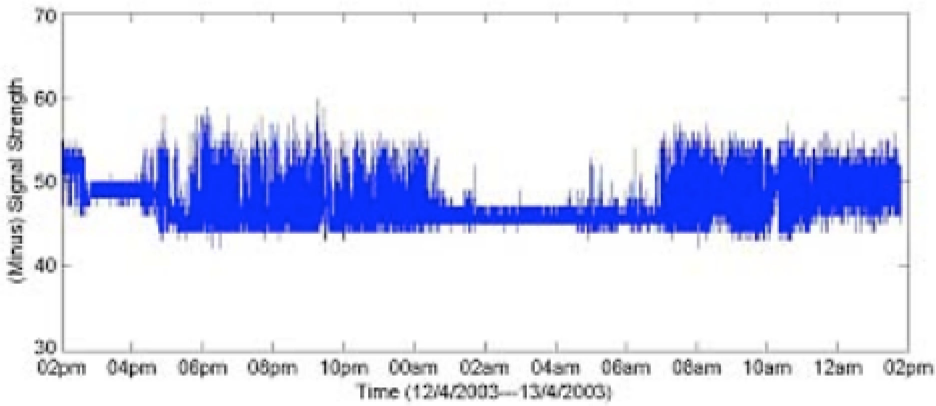

Figure 5.10: 24 hour static signal strength measurements [38]

Object	**Signal Attenuation**
Plasterboard wall	3 dB
Glass wall with metal frame	6 dB
Cinder block wall	4 dB
Office window	3 dB
Metal door	6 dB

Table 5.1: Objects with corresponding signal attenuation [13, p.99]

Conclusion of experiment conducted in [38] The experiment concludes that the radio signal of a WLAN infrastructure, operating on a 2.4GHz frequency, is stable and consistent, thus this signal can be used in calculations for positioning algorithms. However, the developer of such an algorithm needs to take the standard deviation into account as this differs throughout the use of different indoor environments, even on the level of floors, meaning that the signal strength on the first floor can differ on the third, based on environmental changes (e.g. moving persons, microwaves, other interfering electronic devices).

SNR in WLAN

The signal to noise ratio is the difference between the signal strength and the interfering signals. This is a factor to take into account when deploying any WLAN indoor positioning technologies. A satisfactory signal-to-noise ratio should lie above 20 to 25 [13].

Signal Attenuation

Signal attenuation, or signal loss, represents the loss of signal strength in decibel (dB) of radio signals travelling through certain objects. The most common objects and their derived signal attenuation are represented below:

Human Body

The human body also has an effect on signals that are transmitted through the human body. As seen in the experiment by [32] the difference of the standard deviation is 2.32dBm. The research conducted in [26] even reports a measurement error of nearly 15dBm. This is why the fingerprinting technique is the favourable method to estimate the current position of a mobile user, the fingerprinting provides a fault-tolerant method due to the multiple calibration measurements conducted in the offline phase, where the calibration should include signals passing through the human body.

5.5.5 Complexity

5.5.6 Application Use

5.5.7 Commercial Availability

RADAR

COMPASS

Ekahau

5.6 Conclusion

Chapter 6

Cisco CMX

6.1 Cisco CMX as IPS

One of the companies that jumped on the bandwagon of the implementation of indoor positioning technologies is Cisco. Over the years they have developed a dashboard to gain intelligence from user's position such as hotspots where users gather most frequently and heat maps of different routes mobile users take. The definition provided by Cisco, states: "Cisco's CMX solution allows venues to simultaneously provide users with highly personalized content, provide services to customers to increase the customer experience, and gain visibility into customer behavior in their venues. CMX detects in-venue Wi-Fi enabled devices, prompts customers to connect to the wireless network, and engages them with value-added content and offers." [13, p. 24].

6.1.1 Cisco MSE

Cisco Mobility Services Engine (MSE) is a platform that enables developers and users of this platform to centralize data, analyses and other WLAN-related statistics (e.g. coverage). Not only centralizing data but view the data is an important component of Cisco's MSE. Graphical plots such as heatmaps, interactive charts for user flows are part of this ecosystem (in CMX Analytics). It acts as the hardware engine behind the Cisco CMX technology, another option is to run the Cisco CMX platform on a dedicated server but to leverage all the possibilities of both CMX and MSE it is better to purchase the MSE appliance [35].

6.2 CMX Services

6.2.1 CMX Cloud

To leverage the latest cloud possibilities, Cisco developed a single cloud platform: DNA Spaces. This platform aims to centralize all location solutions into one single platform. It offers an improved experience for location-based services that are implemented using Cisco APs [4] [2]. DNA Spaces provides an application programming interface (API) that can be used to connect to other applications.

Figure 6.1: Positions of mobile users and which access point they are connected to [34]

6.2.2 CMX Connect

6.2.3 CMX Analytics

6.2.4 CMX Engage

6.3 Location

6.3.1 Location Techniques

Proximity, Presence

This technique is most feasible when dealing with outdoor positioning as it requires less access points but has less accuracy. According to the datasheet of Cisco [3], the accuracy of this technique is limited to 10 to 30 metres. To calculate the user's position, the AP with the strongest radio signal strength indicator is picked as a correct representation of the MU's location.

RSSI Triangulation

Hyperlocation

FastLocate

6.3.2 CMX Connect

6.3.3 CMX Analytics

6.4 Performance Metrics

6.4.1 Accuracy & Precision

6.4.2 Coverage Area

6.4.3 Scalability

According to documents provided by Cisco, most of the WLAN controllers are scalable with a decent throughput. Some statistics:

1. Cisco 5508: up to 500 APs and 7,000 clients are supported with a throughput of 8gigabit per second (Gbps)

2. Cisco 7510: up to 6,000 APs and 64,000 clients are supported with a throughput of 1gigabit per second (Gbps) in centrally switched traffic [1]

There are numerous devices available that are not only dedicated to small or medium office, but also applicable to large multi-floor environments.

6.4.4 Cost

6.4.5 Privacy

6.4.6 Conclusion

6.5 Conclusion

[1] All WLAN traffic is switched through a user-only WLAN network, meaning a locally switched WLAN can be active for employees without interfering with the user-only network. [39]

Chapter 7

Integration using MapWize and IndoorLocation

7.1 Indoor Mapping

The case study used throughout this thesis is the need for indoor geolocalization and routing inside a hospital muiltifloor environment. In this chapter the needed actions to implement the usage of Cisco CMX inside an android application are discussed. Firstly, the mapping component, being MapWize, is discussed, followed by the part of indoor location tracking and an indoor location framework provided by IndoorLocation. Finally the implementation is concluded with the advantages and disadvantages of using the android platform to develop an indoor location application.

7.1.1 MapWize

MapWize is a company that allows developers of an indoor location application to translate architectural floor plans into a digital mapping. Not only do they convert the existing plans but also implement routing and specific points of interest. This eliminates the need for a specific developer team of the company or agency that implements this systems as this is part of the service MapWize provides.

7.1.2 MapWize Competitors

MazeMap

MazeMap offers a digital platform to create and editor architectural maps. One of their biggest advantages is the fact that they can incorporate changes in their digital maps based on a .DWG or .DXF file, which is the used file format for Computer-Aided Design (CAD) applications [7]. Other than that it offers positioning and wayfinding by integrating the Cisco Connected Mobile Experiences technology. Moreover, MazeMap provides an API to integrate legacy software or other applications, such as Outlook Exchange, into the ecosystem of indoor location [29] [28]. An additional feature is the ability to add Internet of Things (IoT)-driven devices and sensors to enable asset tracking.

Case study of Bergen University College One of the case studies performed by Cisco is the implementation of Cisco CMX inside the Bergen UC. The goal of implementing Cisco CMX was to provide students with a Bring Your Own Device (BYOD) policy by creating an 802.11ac WLAN that was scalable to provide each student with Internet access. As stated in the case study, the following devices were used [24]:

- Cisco Aironet 3702e and 3702i access points;
- Cisco 5760 WLAN controllers;
- Cisco 3850 and 4500-X Series switches;
- Cisco Catalyst 6500 Series switches;

To enable students to use the wayfinding feature, Cisco partnered with MazeMap to create the service and keep it up-to-date with changes in the campus. The major benefit, as mentioned in the case study, is the elimination of crowded hallways that in its turn resulted in a higher, overall happiness amongst students of this University College.

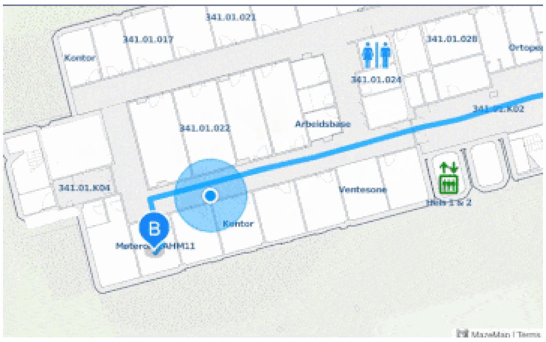

Figure 7.1: Routing feature of MazeMap [28]

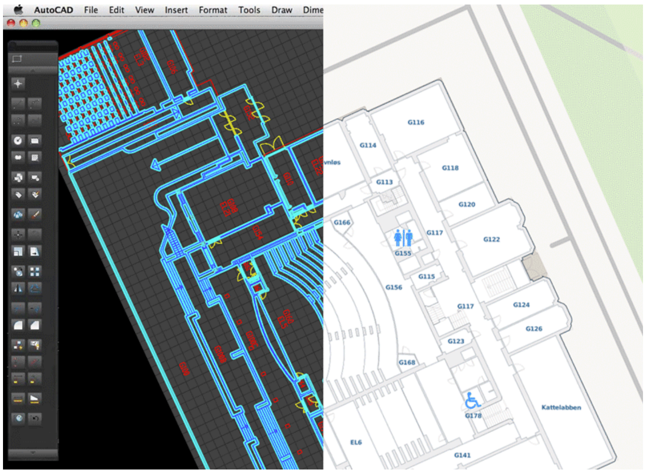

Figure 7.2: Translating floor plans into an interactive map for MazeMap [27]

MapsIndoors

Another company providing digital indoor mapping is MapsIndoors. This company focuses on providing an ecosystem of both routing and indoor maps by offering a Content Management System (CMS) and a cloud environment that serves the indoor navigation platform. Other than a SDK they implemented a data API to allow statistics to be drawn from user data and allowing existing systems, such are booking, Enterprise Resource Planning (ERP) and Customer Relationship Management (CRM) systems, to use this data to analyse and visualize. On their website, there is no indication of price or the specific indoor location techniques used in the service. The unique feature of MapsIndoors, as stated on their website, is the seamless integration of outdoor navigation based on Google Maps and indoor navigation, which is resemblant to Google Maps [25].

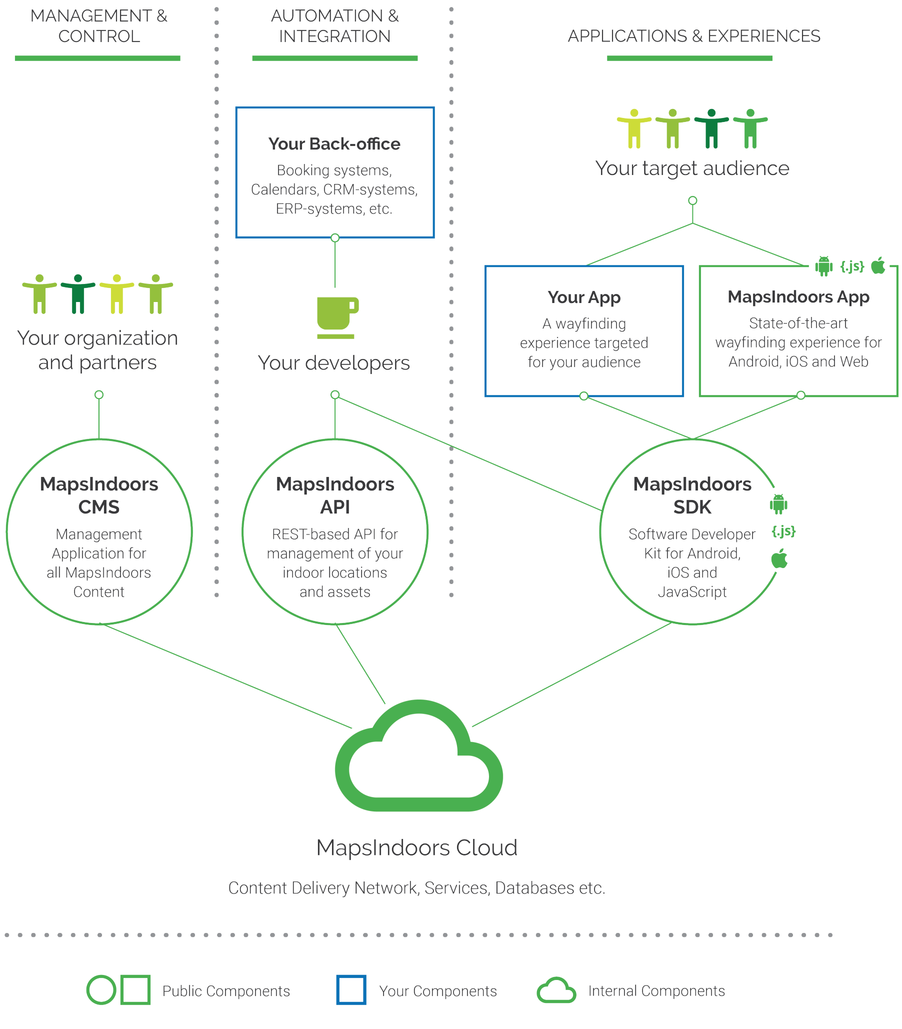

Figure 7.3: Architecture of the MapsIndoors platform [25]

Google Indoor Maps

Google Indoor Maps is a free service to create an interactive map of an environment. It is based on the Google Maps UI with the corresponding universal icons and allows users to navigate inside a building. There is however no indication of which technology used to accurately display a user's position. As this is a Google product, developers can expect an easy-to-use API with sufficient code examples and documentation as well as cross-platform integrations: web, Apple and Android applications. A downside to this service is that changes to a digital map are not easily applied, the different offices of Google responsible for applying changes need to be notified of the changes, which can presumably result in some waiting time. Other than that disadvantage, this service offers a free alternative to other competitors [11].

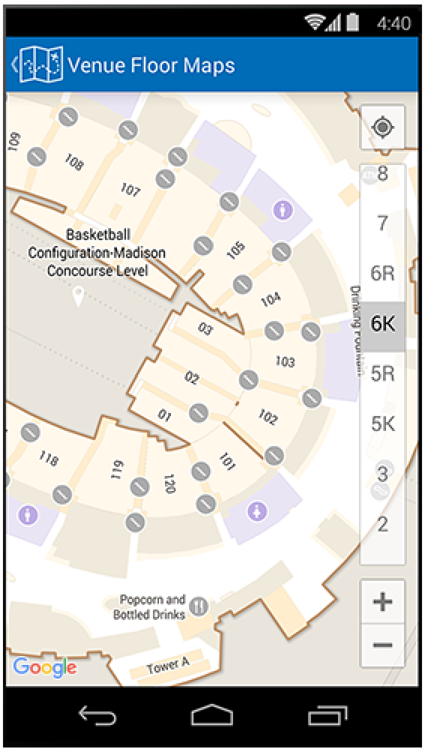

Figure 7.4: Screen view of an application using the Google Indoor Maps [11]

Competitor Analysis

An overview of the metrics used to compare competitors:

1. Ability to read and create digital floor plans from CAD files;
2. Interactive editor to edit digital maps;
3. Wayfinding functionality to declare a point of interest and determine routes.
4. Position of the mobile user shown on the map;
5. If the company creates the interactive maps itself or if the team of developers need to create it.
6. Customizability of the color scheme and icons;
7. Automation: the degree in which changes and modifications to the architectural structure of the environment translates automatically in a changed digital map.
8. Developer support by providing an API or SDK;
9. Pricing options;
10. Usability;
11. Additional Features;

	MapWize	MazeMap	Google Indoor Maps	MapsIndoors
Convert CAD files	Yes	Yes	No	No
Interactive editor	Yes	Yes	Yes	Yes
Wayfinding	Yes, manual	Yes, manual	Yes, manual	Yes, manual
Location tracking	Yes	Yes	Yes	Yes
Updates	Automated, real-time	Automated, real-time	Manual by email	Automated, real-time
Customizability of UI	Fully customizable	Fully customizable	Standard Google Maps UI	Fully customizable
Developer support	Barebones and UI SDK / API, open source	SDK / API	API	SDK / data API
Pricing	Paid	Paid	Free	Paid
Usability	Easy to use, integration for iOS, Android and JS	Easy to use and support for the blind and visually impaired, integration for iOS, Android and JS	Easy to use, integration for iOS, Android and JS	Easy to integrate in legacy software, integration for iOS, Android and JS
Additional features	Private PoI, CMS system, integration of other indoor location technologies,cloud-based or on-premises deployment, integration of IndoorLocation frameworks	IoT platform for asset tracking, system integrations, availability of meeting rooms, private maps	Standard Google Maps Features	Cloud-based ecosystem with integration for legacy systems

Table 7.1: Comparison of MapWize, MazeMap, Google Indoor Maps and MapsIndoors

Conclusion The differences in features of each competitor are nuanced, each company provides the same basic set of features, where the largest difference will be in price. However, Google Indoor Maps does not provide all the features of MazeMap, MapWize and MapsIndoors, and offers only a bare-bones service, which is not a surprise considering the free usage of the platform. All in all, Google Indoor Maps is a suitable service to use for small-scale applications but cannot be applied to this specific case. The main advantage that MapWize and MazeMap have in comparison to their competitors is the ability to seamlessly integrate Cisco CMX, with MapWize being able to integrate more IPSs such as Meraki, OledComm and Lucibel [16]. The option to host MapWize on-premises can result in a higher performance by eliminating the need to interact with a server outside of the network and allows full control over the MapWize environment. MazeMap would be a great service to use inside 'smart building, where multiple sensors and IoT-devices are present. Another great feature of MazeMap is the ability to view meeting rooms and their status (open, booked or free), this is not applicable to the case study in this bachelor's thesis, thus not a feature that can be directly used. If it were to be customizable and applicable to hospital rooms, this would present the hospital with an interesting way to manage and book rooms and/or offices. Both MazeMap and MapWize provide an integration of Cisco CMX that results in both being well-rounded services to use in this case study.

7.1.3 MapWize SDK for Android Applications

By providing an SDK to aid developers, MapWize hopes to gain an advantage over its competitors. There are currently two different SDKs available:

1. Bare-bones SDK;
2. UI SDK;

7.1.4 MapWize Editor

To create the interactive map, MapWize provides an editor which enables users to perform the following actions:

- Create venues;
- Create multiple floors;

- Define PoIs;
- Create one or multiple routes from different locations in the venue to specific points of interest;
- Export the map;
- Import CAD files into the map;

7.2 IndoorLocation Framework in Android

MapWize itself does not provide a technique to interact with an indoor positioning technologies, they have however partnered with IndoorLocation.io to interact with numerous indoor location applications, such are: Cisco CMX, Cisco Meraki, beco, OledComm, Basic Beacon, Polestar and Lucibel [16].

7.2.1 Integrating IndoorLocation Framework in Android Applications

To integrate both MapWize (using the UI SDK) and IndoorLocation inside an Android app only a few steps are necessary:

1. Add MapWize and IndoorLocation dependencies.
2. Create an Application context that instantiates a manager with API key.
3. Setup the MapActivity, displaying a specific venue.
4. Initiate a socket listener for a Cisco CMX server to get the position.
5. If needed, add some options to the MapWizeUISettings fragment.

7.2.2 Project Setup

To start working with the MapWize UI SDK, an Android project is required. To initiate an Android project, installation of Android Studio is mandatory. In Android Studio a project can be created and then used for further developments.

Adding the MapWize and IndoorLocation Dependencies

The dependencies in an Android app are managed by either gradle or maven, this specfici implementation makes use of gradle 5.4+ and Android Studio 3.4+. To add the dependencies of MapWize and IndoorLocation, simply add the following lines to the build.gradle file under the dependencies section of the project:

```
 // MAPWIZE
implementation('io.mapwize.indoormaps:MapwizeForMapbox:2.0+') {
exclude group: 'com.github.IndoorLocation', module: 'indoor-location-android'
transitive = true
}
implementation 'com.github.IndoorLocation:indoor-location-android:1.0.5'
implementation('io.socket:socket.io-client:1.0.0') {
exclude group: 'org.json', module: 'json'
}
mplementation 'com.github.Mapwize:mapwize-ui-android:1.2.0'
```

Creating an Application Context

The code below creates a child class of the Application base class and overrides the onCreate() method.

```
public class MapApplication extends Application {

    @Override
    public void onCreate() {
        super.onCreate();
        AccountManager.start(this, "1f04d780dc30b774c0c10f53e3c7d4ea");// PASTE YOU MAPWIZE API
    }
}
```

To automatically run the application using the custom MapWizeApplication, the following code needs to be present in the AndroidManifest.xml file of the Android app:

```
<application
        android:allowBackup="true"
        android:icon="@mipmap/ic_launcher"
        android:label="@string/app_name"
        android:roundIcon="@mipmap/ic_launcher_round"
        android:supportsRtl="true"
        android:theme="@style/AppTheme"
        android:name=".MapApplication">
        <activity android:name=".MapActivity">
            <intent-filter>
                <action android:name="android.intent.action.MAIN" />

                <category android:name="android.intent.category.LAUNCHER" />
            </intent-filter>
        </activity>
    </application>
```

MapActivity

Appendix 1 shows the complete code of the MapActivity that contains the following fields:

- A fragment for displaying the map: mapwizeFragment;
- The SocketIndoorLocationProvider to integrate the IndoorLocation framework in the activity: socketIndoorLocationProvider;
- The plugin provided by the MapWize SDK: mapwizePlugin;
- To display the map, the field that holds a MapboxMap is created: mapboxMap;

The basic options used in the example app are: restricting view of the map to a specific venue, showing the menu button and the follow user button. Upon adding the mapwizeFragment to a specific container, the event onFragmentready is fired, where the mapboxMap and mapwizePlugin are set for this particular activity. Afterwards, the socketIndoorLocationProvider is instantiated with an IP address, that of the emitter of the position of the mobile user. This provider is then set as a property of the mapwizePlugin and afterwards the provider is started. To follow the user when moving, the FollowUserMode is set and the mapwizePlugin gets the user position by calling that method. When implementing the MapWize SDK, some methods are required to be implemented:

- shouldDisplayInformationbutton: whether or not the information button needs to be displayed.
- shouldDisplayFloorController: if a user should be able to control the view of different floors;
- onFollowUserButtonClickWithoutLocation: if anything needs to happen when a user clicks the the follow button without having granted access to his or her location, this is handy for displaying errors to the MU.
- onInformationButtonClick: this event can be used to display information on a specific venue when the user clicks on the corresponding button.
- onrequestPermissionsResult:

7.3 Conclusion

The integration of MapWize and the IndoorLocation went without any actual errors coming up. It is easy to combine both MapWize and IndoorLocation as the SDK already contains the necessary boilerplate code to generate a user interface. The implementation of the barebones SDK would require a lot of additional steps to connect the UI with the code. It would also be difficult to correctly handle the specific events that are able to fired during the lifecycle of the application. Problems such as optimizing performance, rendering the UI, handling the lifecycle of the app are already solved in the UI SDK. This implementation concluded in a straightforward way of integration Cisco CMX indoor location and the Android app.

Chapter 8

Possible fields of exploration

8.1 Smart Devices

8.2 Biometrics

8.3 Safety Cultivation

8.4 Optimizing Routes

8.5 Applied Radio Signal Artificial Intelligence

8.5.1 Convex Optimization

8.5.2 Kalmann Filter

8.5.3 Denoising Autoencoder

Chapter 9

Conclusion

Chapter 10

Appendices

10.1 Source Code MapWize Activity

```
package com.ibm.geolocationframework.ViewLayer.Activities

class MapActivity : AppCompatActivity(), MapwizeFragment.
    OnFragmentInteractionListener {

    private var mapwizeFragment: MapwizeFragment? = null
    private var socketIndoorLocationProvider: SocketIndoorLocationProvider? = null
    private var mapwizePlugin: MapwizePlugin? = null
    private var mapboxMap: MapboxMap? = null

    override fun onCreate(savedInstanceState: Bundle?) {
        super.onCreate(savedInstanceState)
        setContentView(R.layout.activity_map)


        // Uncomment and fill place holder to test MapwizeUI on your venue
        val opts = MapOptions.Builder()
            .restrictContentToVenue("5c64254258338d00167965a4")
            .centerOnVenue("5c64254258338d00167965a4")
            .build()

        // Uncomment and change value to test different settings configuration
        val uiSettings = MapwizeFragmentUISettings.Builder()
            .menuButtonHidden(false)
            .followUserButtonHidden(false)
            .build()


        mapwizeFragment = MapwizeFragment.newInstance(opts, uiSettings)
        val fm = supportFragmentManager
        val ft = fm.beginTransaction()
        ft.add(fragmentContainer.id, mapwizeFragment!!)
        ft.commit()
    }
```

```
override fun onFragmentReady(mapboxMap: MapboxMap?, mapwizePlugin: MapwizePlugin
    ?) {
    this.mapboxMap = mapboxMap
    this.mapwizePlugin = mapwizePlugin

    this.socketIndoorLocationProvider = SocketIndoorLocationProvider(this, "http
        ://9.134.135.64:3003")
    this.mapwizePlugin?.setLocationProvider(socketIndoorLocationProvider!!)

    socketIndoorLocationProvider!!.start()

    FollowUserMode.FOLLOW_USER_AND_HEADING
    mapwizePlugin?.getUserPosition()
}

override fun onMenuButtonClick() {
}

override fun onRequestPermissionsResult(requestCode: Int, permissions: Array<
    String>, grantResults: IntArray) {
    when (requestCode) {
        MY_PERMISSION_ACCESS_FINE_LOCATION -> {
            if (grantResults.size > 0 && grantResults[0] == PackageManager.
                PERMISSION_GRANTED) {

                setupLocationProvider()
            }
        }
    }
}
private fun setupLocationProvider() {
     socketIndoorLocationProvider = SocketIndoorLocationProvider(this, "http
         ://9.134.135.64:3003")
    mapwizePlugin?.setLocationProvider(socketIndoorLocationProvider!!)

}

override fun onInformationButtonClick(mapwizeObject: MapwizeObject?) {

}

override fun onFollowUserButtonClickWithoutLocation() {
    Timber.i("onFollowUserButtonClickWithoutLocation")
}

override fun shouldDisplayInformationButton(mapwizeObject: MapwizeObject?):
    Boolean {
    Timber.i("shouldDisplayInformationButton")
    when (mapwizeObject) {
        is Place -> return true
    }
```

```
        return false
    }

    override fun shouldDisplayFloorController(floors: MutableList<Double>?): Boolean
        {
        Timber.i("shouldDisplayFloorController")
        if (floors == null || floors.size <= 1) {
            return false
        }
        return true
    }

    companion object {
        private const val MY_PERMISSION_ACCESS_FINE_LOCATION = 0
    }
}
```

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