Bachelor's Thesis

# Geolocalization and routing in complex multi-floor hospital environments

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Thanksssssss

# Abstract

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# Acronyms

**AP** access point. 15–17

**API** application programming interface. 9, 12

**IPS** indoor positioning technologies. 13, 15

**IR** infrared. 13

**LBS** location-based services. 13

**MAC** media access control. 16, 17

**MU** mobile user. 16, 17

**PN** personal network. 15

**PoC** proof of concept. 9

**POI** point of interest. 13

**RF** radio frequency. 16

**RFID** radio-frequency identification. 13

**RSSI** radio signal strength indicator. 17

**SDK** software development kit. 9, 12

**SNR** signal-to-noise ratio. 16

**TDoA** time difference of arrival. 17

**ToA** time of arrival. 17

**UML** unified modelling language. 12

**UWB** ultra wideband. 13

**WLAN** wireless local area network. 13

# Chapter 1

# Summary

# Chapter 2

# Context

# Chapter 3

# Project Specification

## 3.1 Project Description

The emphasis of the PoC is on developing it in such a way that it should be easy to re-implement the application elsewhere. The PoC is developed in the two current formats for mobile development: iOS and Android. This bachelor's thesis will cover the implementation of the Android architecture. Firstly the existing application is reworked from using the Ionic framework to a native mobile application (Swift for iOS and Kotlin for Android). In addition to this part, geolocalization is implemented in the native mobile app using the MapWize service [**MapWize.io2019**] and the IndoorLocation framework [**IndoorLocation.io2019**], both service provide working software development kit (SDK) for iOS and Android. Finally the application is revised by the team of interns and the developers at IBM and uploaded onto the Apple Store and the Google Play Store.

### 3.1.1 Technical Design Specs

The communication with the hospital happens with a server provided by IBM and the hospital's application programming interface (API). This means that the mobile device interacts with a intermediary server from IBM which in its turn communicates with the API of the hospital. This model is an example of a highly reusable architecture. If another hospital needs to be attached to the IBM server, only a small 'translator' for the endpoints of the additional hospital's API needs to be created whilst the structure of the IBM server remains the same.

### 3.1.2 Features

The main features of the project are specified below [6]:

1. Login with hospital provided credentials;
2. Synchronization of appointments with the hospital;
3. Ability to set reminders for an appointment;
4. See the hospital's location (and venues) as well as contact details;
5. Allow geolocalization inside the hospital;
6. Provide feedback after an appointment;
7. Localization in French, English and Dutch;

8. Available on both iOS and Android
9. Distributed in the Apple Store and Google Play Store;

### 3.1.3 Detailed View of Features

#### Login and Registration Process

Firstly a patient should create an account to login into the application at a hospital site (mandatory to provide some details). Afterwards the patient will be able to login to the application and has the option to execute the following actions:

- Change userId, password (using the IBM BlueMix API)
- Set an additional authentication method: pincode, face id or fingerprint when launching the app

To register upon arrival at the hospital, two of the following options can be provided: unique cipher code or via scanning a QR-code (displayed at the reception of the hospital).

#### Appointments

Overview of appointments:

1. View the upcoming or past appointments
2. Go to the notification screen and view notifications
3. Search appointments
4. The first upcoming appointment of the patient

Available user actions possible in the overview:

- View the upcoming or past appointments
- Go to the notification screen and view notifications
- Search appointments

Individual view of an appointment:

1. Link to the specific doctor that will handle the appointment
2. Location
3. Preparatory notes
4. Description
5. Status

The following user actions should be available for the end user:

- Register upon arrival at the specified location
- Request a cancellation of the appointment

- Call the hospital site
- After registration, meaning the user is at the hospital site, the option to show the indoor route to the place of appointment
- Information and link to the hospital site

To create an appointment the user will have to fill in a specific form and is given the option to select a hospital site, service that he/she requires and a specific doctor. Upon submitting the form the hospital will receive a request for an appointment and can notify the user of his or her confirmation.

**General Information**

Users of the application should be available to view any information available on doctors, services and other important facets of the hospital (for instance: a news feed featuring health tips, recipes and important news on the hospital). This includes possible contact options such are telephone and email possibility. For the doctors, this means the following information needs to be displayed accurately:

- List of all available doctors
- Possibility to search and filter doctors by name, function and service
- Display the languages a doctor is able to converse in
- A timetable that indicates availability based on time and place
- Contact information if available

Other than the doctor's information, the services that the hospital provides should be able to be consulted. This includes the following information:

- List of all available services
- Possibility to search and filter on the hospital site that offers this service and a concrete body part that situates the service.
- Ability to contact the hospital site providing this service, either via email or phone.
- Important times of day: office hours and visiting hours

For the sites this is:

- List of all sites of a specific hospital
- Map view (Google map) that shows a location using a marker
- Ability to contact the hospital site via email or phone.
- Link to the specific website of this site, if it is available.

**Geolocalization**

The indoor map of the hospital displays general points of interest, such are: restaurant, toilets, elevators, staircases and reception. The route from the reception to the location of the appointment will be displayed when the user requests it inside the detailed view of an appointment (after registration process).

**User Settings**

The following settings should be displayed inside the application:

- Notification settings
- FAQ
- Feedback on the application
- Information about the application: disclaimer, version, developer(s), privacy agreement
- Level of mobility
- Authentication method
- Profile: email, password, userId, phone
- Doctors of the user (where he or she has or will have an appointment)
- Ability to sign out of the application

**Ideas**

Ideas for the application that can be implemented in future releases:

1. Symptom checker;
2. Chatbot to schedule and handle appointments
3. Prescriptions for medicines that can be used in apothecaries
4. 3D scan of patient's limb so a doctor can detect possible fractures or other superficial problems
5. Emergency button that will display the nearest emergency exit
6. Data integration of smart devices to determine possible health risks
7. Set reminder for medicine intake
8. Home Assistant integration
9. Details of the medical records of a patient

### 3.1.4 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. This chapter gives a brief overview of different types of indoor positioning technologies (IPS)s and covers the function of a WLAN-based IPS in further detail, examining topology, positioning methods and techniques to determine current location [10].

## 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 [7]. 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 (thus giving the best approximation possible).

## 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 [4]. There are already numerous systems available on the consumer market that implement one or multiple of these technologies to provide an accurate implementation of an IPS.

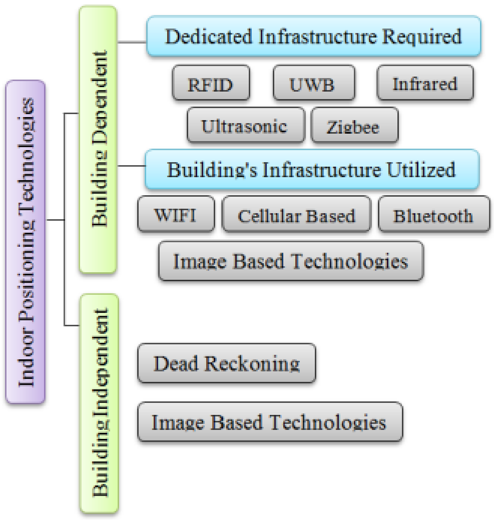


Figure 4.1: Classfication of indoor positioning technologies [**ComparativeSurvey**]

## 4.4 Indoor Positioning Techniques

### 4.4.1 Triangulation

### 4.4.2 Fingerprinting

### 4.4.3 Proximity

### 4.4.4 Vision Analysis

## 4.5 Indoor Positioning Algorithms

### 4.5.1 Time of Arrival

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### 4.5.4 Received Signal Strength

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### 4.7.3 Infrared

### 4.7.4 Ultrasonic

## 4.8 IPS for Personal Networks

The need for IPSs in personal network (PN) has seen an increase in practical applications. The case that will be used throughout this thesis will focus on the need for a patient to navigate inside a hospital, thus requiring PN location-based routing. 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.

**Case of a patient 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.

### 4.8.1 Location Information for Positioning Systems

There are four commonly used types of information for IPS[8].

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.

## 4.9 WLAN Indoor Positioning Technology

One of the easiest IPS to implement is WLAN IPS. The adaptation of such a system comes without extra cost as most of the hardware is already prevalent in large, indoor environments. WLAN is specified by IEEE in their 802.11 specification, determining the WLAN protocols and most widespread operating bandwidth of about 2.4GHz and 5.8GHz [12] [3][1].

### 4.9.1 Indoor Positioning Topology

Three topologies exists that can be used for gathering information about the position, as listed below [5]:

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., where

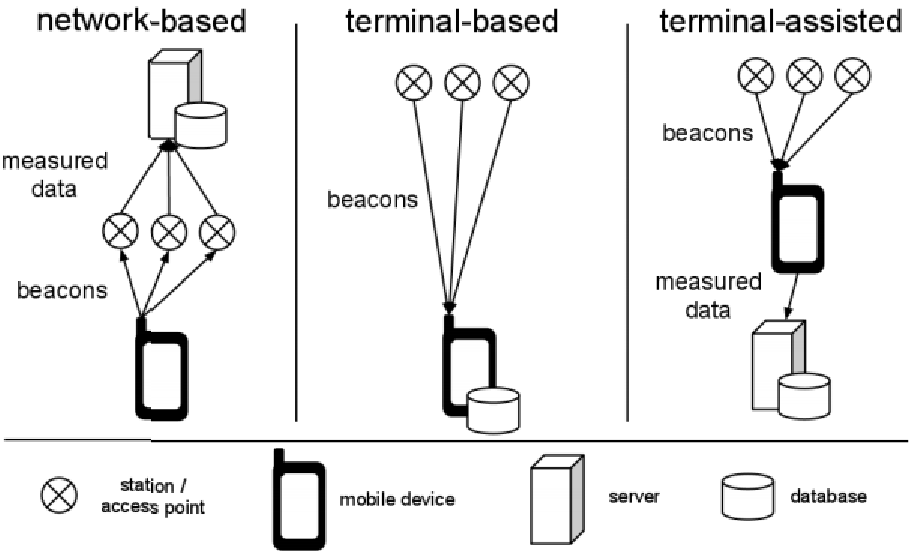


Figure 4.2: IPS Topologies [5]

**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.

**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: active probing and RF monitoring. The 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[9, p. 8].

### 4.9.2 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: multi- or trilateration and fingerprinting.

### 4.9.3 Trilateration Technique

Trilateration, or multilateration, is based on geometric models that require three base points to calculate and determine a point in range of these three base points. Applying this approach 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. Trilateration uses parameters available, 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. Commonly used methods to determine the distance between both the AP as well as the mobile user include: received signal strength, time of arrival (ToA) from transmitters or time difference of arrival (TDoA) [11, p. 1].

#### Distance Technique

The signal propagation model proposed in the previous paragraph indicates the need of an equation system containing three measurements of distance between AP and mobile user. Using the euclidean distance between two points, this results in the following system or model [2]:

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

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

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

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. The difficulty of using a trilateration mathematical technique lies within the estimation of the distance from the AP to the MU. Some methods to determine a model with a satisfactory accuracy and precision already exist, mostly relying on empirical (observational) data rather than pure mathematics.

#### Signal Propagation for distance estimation

### 4.9.4 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 [9, p. 9].

#### Offline Acquisition

#### Online Phase

#### Implications using fingerprinting

### 4.9.5 Conclusion

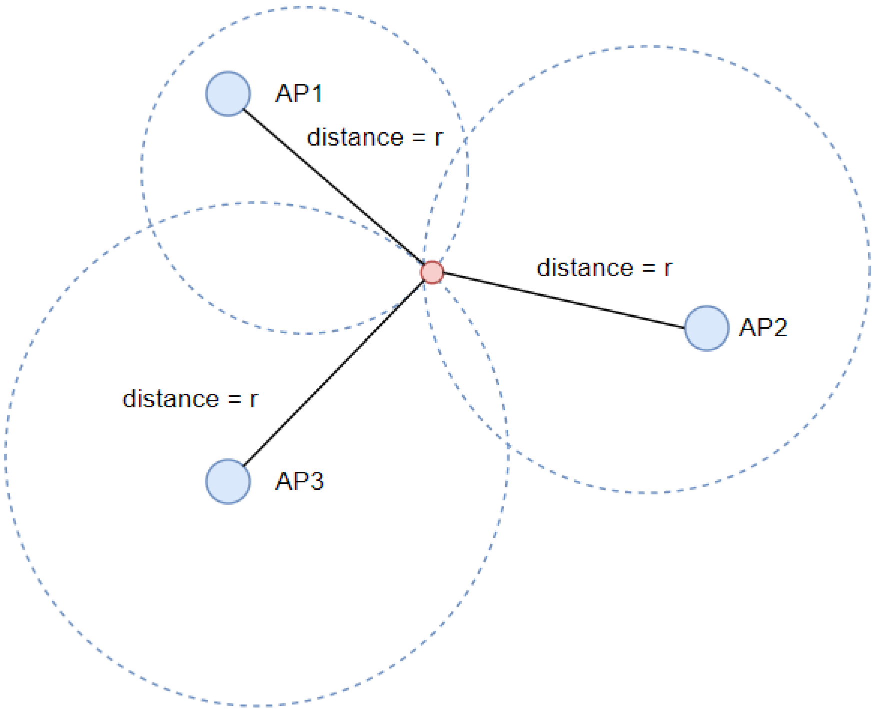


Figure 4.3: Euclidean distance resulting in geometric intersection of three circles, determining the position of a point in between these three points.

# Chapter 5

# Cisco CMX

## 5.1 Cisco CMX as IPS

## 5.2 Cisco CMX Specifications

### 5.2.1 Precision

### 5.2.2 Complexity

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### 5.2.4 Scalability

### 5.2.5 Operating Costs

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# Chapter 6

# Integration using MapWize and IndoorLocation

## 6.1 Indoor Mapping

### 6.1.1 MapWize

### 6.1.2 MapWize SDK for Android Applications

#### Application Setup

## 6.2 Indoor Location tracking

### 6.2.1 IndoorLocation Framework

#### Application Setup

### 6.2.2 Applying IndoorLocation Framework to Android Applications

# Chapter 7

# Conclusion

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