Bachelor's Thesis

Geolocalization and routing in complex multi-floor hospital environments

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Thanksssssss

Abstract

Contents

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

PoC proof of concept. 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

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 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 [16]. 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.

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.

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 [5]. 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 [9].

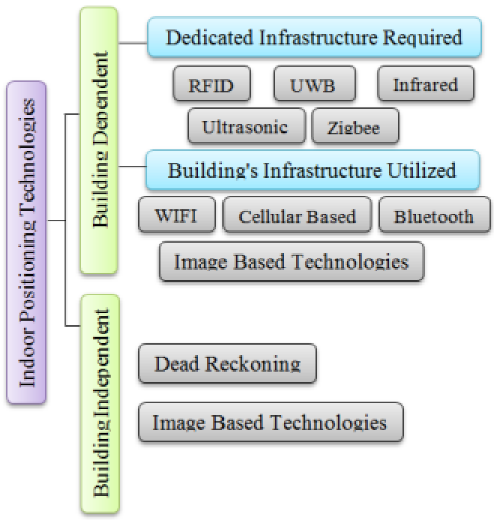

Figure 4.1: Classfication of indoor positioning technologies [**ComparativeSurvey**]

4.3.1 Wireless LAN

4.3.2 RFID

4.3.3 Bluetooth

4.3.4 Ultra-wideband

4.3.5 Infrared

4.3.6 Ultrasound

4.3.7 Zigbee

4.3.8 Cellular

4.3.9 Location Information for Positioning Systems

There are four commonly used types of information for IPS[11].

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.

4.4 Distance Measurement Techniques

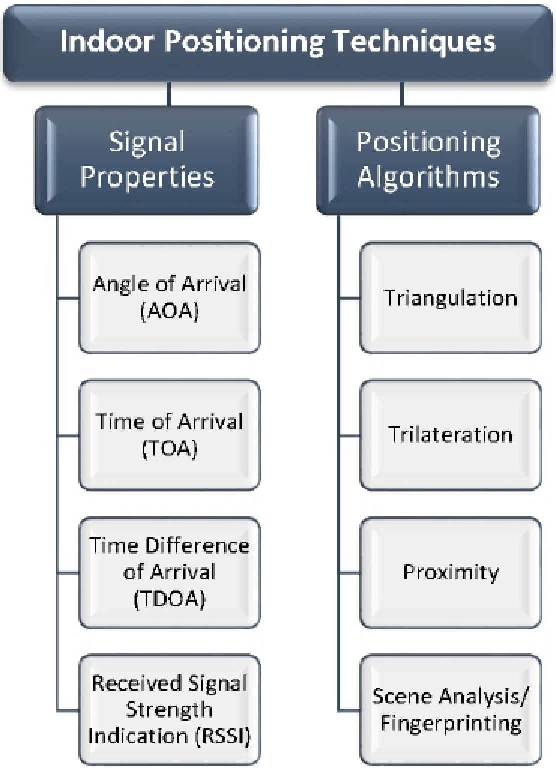

Figure 4.2: Classification of indoor positioning techniques [16]

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 [12]:

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

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 [15]. 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 [8].

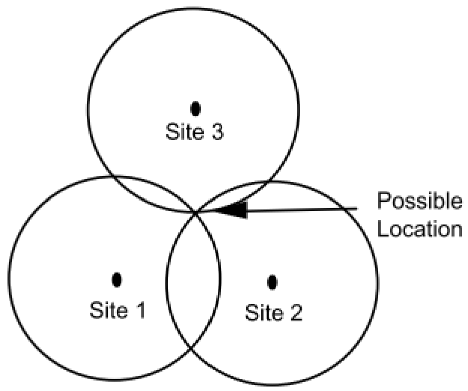

Figure 4.3: Determining position in a two dimensional space by time of arrival [8]

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. This requires additional set up: directional antenna, thus transmitters. The intersection point of the lines indicating a direction signal resemble the possible location of the device, albeit without an exact error margin. The problem lies with the necessity of installing directional antenna arrays which contributes to higher cost than time of arrival and time difference of arrival [8].

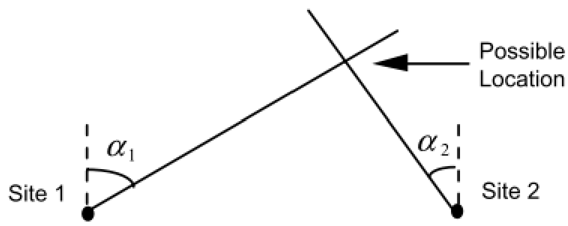

Figure 4.4: Determining position in a two dimensional space by angle of arrival [8]

4.4.4 Received Signal Strength Indication

4.5 Indoor Positioning Techniques

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.

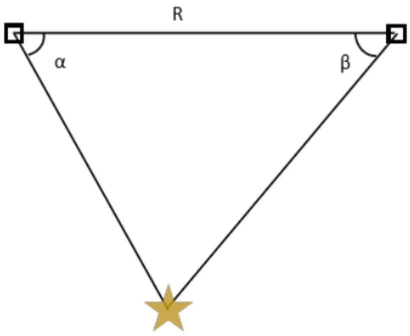

Figure 4.5: Determining position using triangulation [12]

4.5.2 Trilateration

4.5.3 Scene Analysis/Fingerprinting

4.5.4 Proximity

4.6 Performance Metrics

4.6.1 Security and Privacy

4.6.2 Cost

4.6.3 Performance

4.6.4 Robustness and Fault Tolerance

4.6.5 Application Use

4.6.6 Commercial Availability

4.6.7 Conclusion

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

Chapter 5

WLAN Indoor Positioning

5.1 Introduction

One of the easiest indoor positioning technologies to implement is WLAN (specified by IEEE in their 802.11 specification) IPS. 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 [10]), which does not come without its problems as discussed in a later chapter [18] [3][1]. 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 Indoor Positioning Topology

Three topologies exists that can be used for gathering information about the position, as listed below [6]:

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

5.2.1 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.

5.2.2 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: active probing and RF monitoring. The RF monitoring is a form of passive scanning that listens to the periodic broadcasting by the access points,

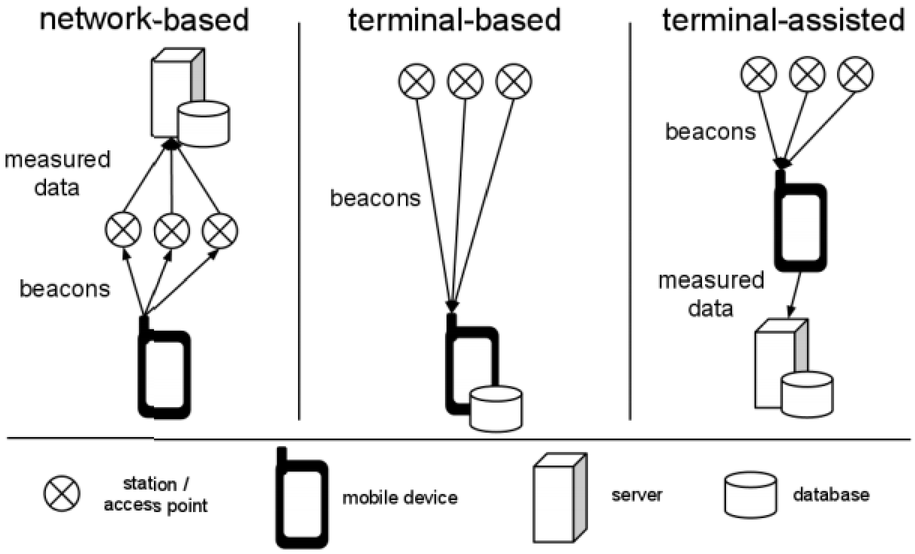

Figure 5.1: IPS Topologies [6]

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[14, p. 8].

5.2.3 Terminal-Assisted

5.3 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) [4].

5.3.1 Proximity or Cell of Origin Technique

This technique does not result in an absolute or relative position, rather the position of a specific access point which can then be used to determine a symbolic location. This is a straightforward technique that uses the position of the AP with the strongest radio signal strength to the mobile user. This is an optimal technique to provide symbolic location-based services [16].

5.3.2 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) [17, p. 1] [13, 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 [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.

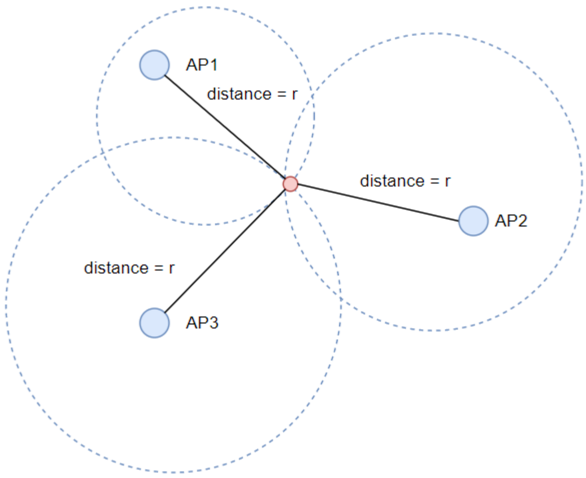

Figure 5.2: Euclidean distance resulting in geometric intersection of three circles, determining the position of a point in between these three points.

5.4 Distance Measurement Techniques

5.4.1 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 [17, 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 [15, p.16]. The path-loss model revolves around the calculation of the distance based

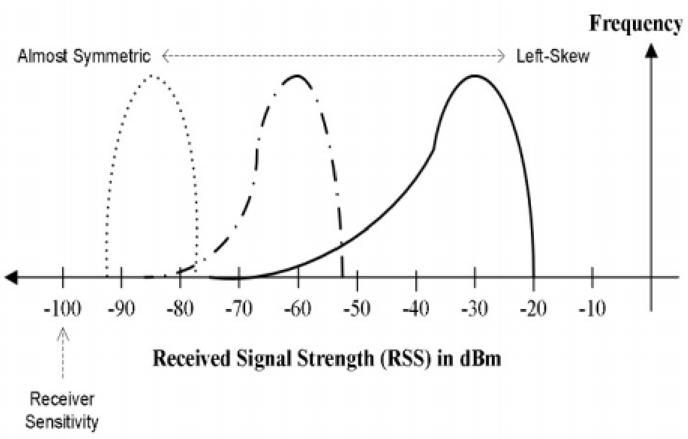

Figure 5.3: Distribution of radio signal strength indicator [15, p.16]

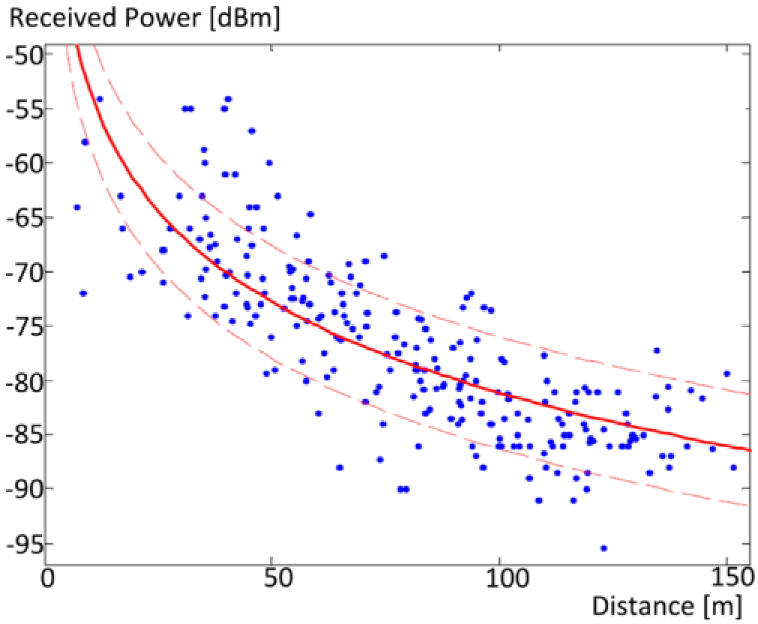

Figure 5.4: Dependency of radio signal strength indicator and distance [13, p.61]

on the attenuation of the signal [**Mautza**]. The empirical formula, solely based on measurements from the experiment so not a standard analytical model, provided by [15] 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).

Conclusion Based on the research done in [17], 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 [13, p 61] [12, p 2].

5.4.2 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 [17], 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) [17, p.178].

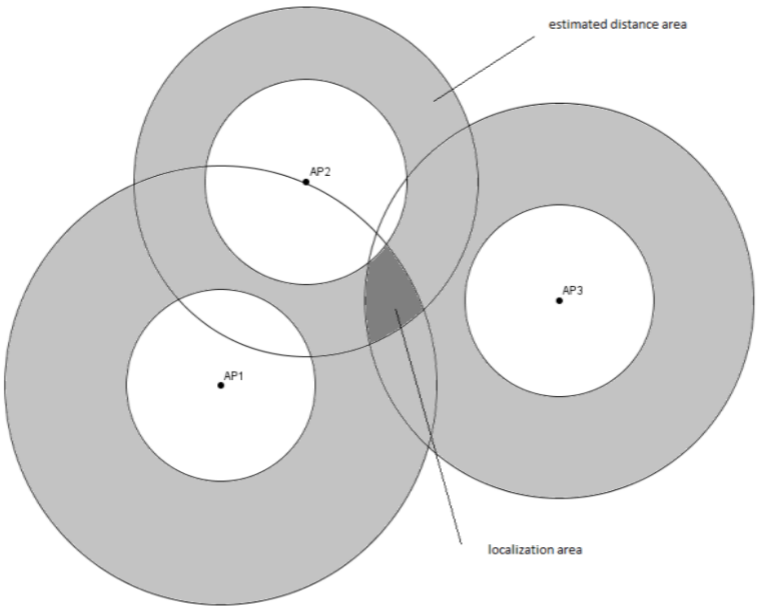

Figure 5.5: Estimated distance segments [17, p.179]

Conclusion As seen in the trials performed in the research of [17], 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.

Time of Arrival

Time Difference of Arrival

Angle of Arrival

To enable the use of the AoA method, the network needs to be equipped with additional directional antennae that are able to calculate the distance. Based on this requirement alone, which comes at a high cost, this approach is not feasible for production environments .

Round Trip Time

5.4.3 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 [14, p. 9]. This method bases itself only on the strength of the signal compared to trilateration that incorporates multiple methods to calculate the distance.

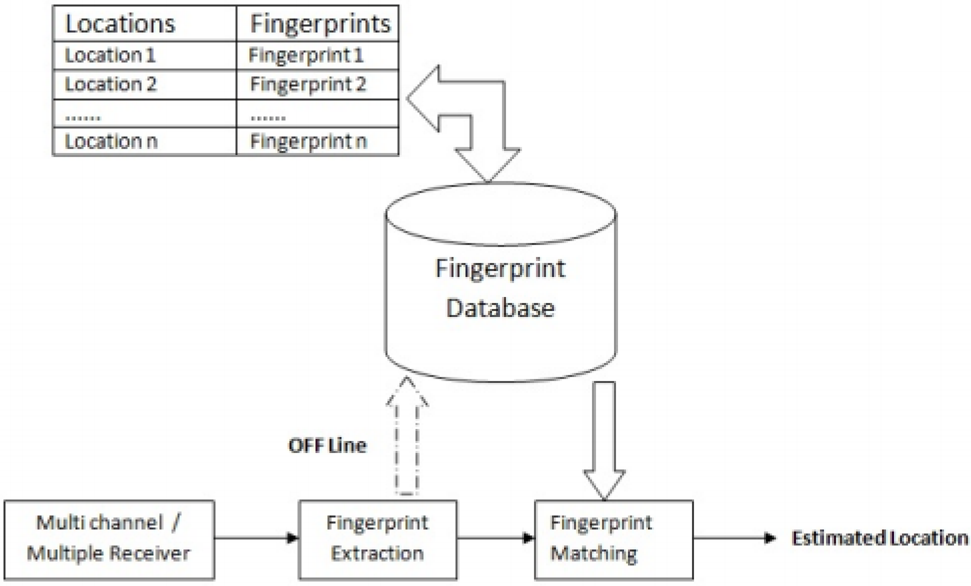

Figure 5.6: Fingerprinting Stages [15, p.11]

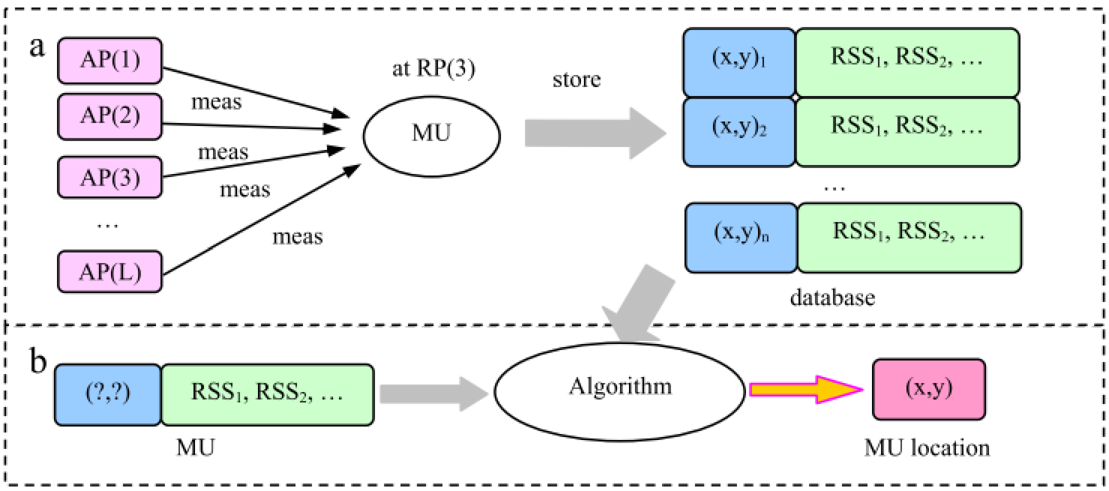

Figure 5.7: Fingerprinting Stages [10, p.2]

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 [13]. 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 radiomap 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.

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 [15].

Indoor Environment

Based on a study performed in [19], 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.

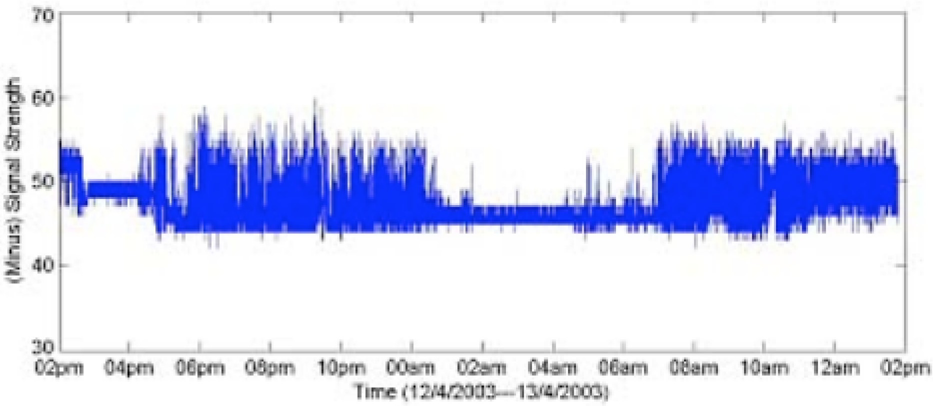

Figure 5.8: 24 hour static signal strength measurements [19]

Conclusion of experiment conducted in [19] 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).

Climate

Interfering Signals

Human Body

The human body also has an effect on signals that are transmitted through the human body. As seen in the experiment by [15] the difference of the standard deviation is 2.32dBm. The research conducted in [**Mautza**] 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

6.2 Performance Metrics

6.2.1 Accuracy & Precision

6.2.2 Coverage Area

6.2.3 Scalability

6.2.4 Cost

6.2.5 Privacy

6.2.6 Conclusion

6.3 Cisco CMX Configuration

6.3.1 Case Study

6.3.2 Configuration Metric

Chapter 7

Integration using MapWize and IndoorLocation

7.1 Indoor Mapping

7.1.1 MapWize

7.1.2 MapWize SDK for Android Applications

Application Setup

7.2 Indoor Location tracking

7.2.1 IndoorLocation Framework

Application Setup

7.2.2 Applying IndoorLocation Framework to Android Applications

Chapter 8

Conclusion

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