Master Thesis

Smartphone based Indoor-Navigation

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Kurzfassung

Diese Diplomarbeit beschreibt zunächst die grundlegenden Techniken der Navigation und Positionierung. Messprinzipien wie Received Signal Strength (RSS) (empfangene Signalstärke) und Positionierungsansätze wie Location Fingerprinting werden erklärt. Danach gibt sie einen detaillierten Überblick über Technologien der Positionierung auf dem aktuellen Stand der Technik, wie zum Beispiel GPS, WLAN oder mittels Erdmagnetfeld. Diese Technologien werden dann miteinander anhand bestimmter Leistungsmerkmale wie Genauigkeit und Robustheit verglichen. Hauptaugenmerk ist dabei die Umsetzbarkeit der Technologie für ein Positionierungssystem für Smartphones innerhalb von Gebäuden. Moderne Smartphones bieten eine Vielzahl von Möglichkeiten, haben aber auch einige Restriktionen um ein Indoor Positionierungssystem umzusetzen. Kameras und Sensoren wie Gyroskop, Kompass, GPS, WIFI und Bluetooth sind bereits Standard und auch RFID Chips werden bald in Smartphones zu finden sein. Aber wegen dem vergleichsweisen geringen Preis von Smartphones sind diese Sensoren oft von mangelnder Qualität oder nicht geeignet für Indoor Positionierungssteme wie zum Beispiel GPS. Der praktische Teil der Diplomarbeit beschreibt die Implementierung eines Indoor Positionierungssystems für Smartphones. Grundlegend verwendet das System WLAN Router und den Location Fingerprinting Ansatz. Ein Algorithmus wurde entwickelt, der sich mit dem Aufwand jeden einzelnen Fingerprint während der Lern-Phase zu messen beschäftigt. Die Anzahl der Grid Punkte, die für die Radio Map gemessen werden müssen, wird dabei wesentlich verrringert. Evaluierung haben das Potenzial des Algorithmus gezeigt.

Abstract

This diploma thesis first of all deals with the fundamentals on positioning and navigation techniques. Measuring principles like the Received Signal Strength (RSS) method and positioning approaches as Location Fingerprinting are explained. Afterwards it provides a detailed overview of state-of-the-art technologies of positioning, such as techniques based on GPS, WLAN or the earth's magnetic field. The technologies are compared to each other by certain performance issues as accuracy and robustness with the main focus on the implementation on smartphones and indoor positioning. Modern smartphones offer many possibilities but have also some restrictions for realizing an indoor navigation system. Cameras and sensors as gyroscope, compass, Global Positioning System (GPS), Wireless Fidelity (WIFI) and Bluetooth are standard and also Radio Frequency Identification (RFID) will find it's way into smartphones in the near future. But due to the low price of smartphones this sensors often have a very low quality or are not suitable for indoor navigation like GPS. The practical part of this thesis describes the implementation of an indoor positioning system for smartphones. The system basically uses WLAN routers and the Location Fingerprinting approach. An algorithm that deals with the complexities of measuring each and every grid point in the learning phase has been developed, that substantially lowers the number of grid points that have to be measured for the Radio Map. Evaluations showed the potential of the algorithm.

Contents

List of Abbreviations

ACK	Acknowledgement
AGPS	Assisted Global Positioning System
ADOA	Angle Difference of Arrival
AOA	Angle of Arrival
AP	Access Point
API	Application Programming Interface
BCE	Before the Christian Era
BIPS	Bluetooth Indoor Positioning System
CADMS	Computer Aided Disaster Management System
CDF	Cumulative Probability Functions
CHA	Channel of High Accuracy
CI	Cell Identification
CSA	Channel of Standard Accuracy
COO	Cell of Origin
DE	Differential Evolution
DGPS	Differential Global Positioning System
DOA	Direction of Arrival
DOD	Department of Defense
ESA	European Space Agency
EU	European Union
FCC	U.S. Federal Communications Commission
GB	Gigabyte
GCS	Ground Control Segment
GHz	Gigahertz
GLONASS	GLobal Orbiting Navigation Satellite System
GMS	Ground Mission Segment
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GSS	Galileo Sensor Stations
HMD	Head Mounted Display
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IPS	Indoor Positioning System
IR	Infrared
IRIS-LPS	Infrared Indoor Scout - Local Positioning System
ISM	Industrial, Scientific and Medical
kB	Kilobyte

kbit/s	kilobits per second
KNN	K-Nearest Neighbour
LAN	Local Area Network
LBS	Location Based Service
LOB	Line of Bearing
LOS	Line of Sight
MEMS	Micro-Electro-Mechanical System
MHz	Megahertz
MSC	Mobile Switching Center
NAVSTAR	NAVstar System with Timing And Ranging
NFC	Near Field Communication
NICT	Japan's National Institute of Information and Communications Technology
NLOS	Non Line of Sight
PAN	Personal Area Network
PDA	Personal Digital Assistant
PGPS	Pseudolite Global Positioning System
PZ-90	Russian, Parameter of Earth 1990
QR-Code	Quick-Response-Code
RAM	Random-Access Memory
RFID	Radio Frequency Identification
RSS	Received Signal Strength
RTOF	Round-trip Time of Flight
SA	Selective Availability
SIG	Bluetooth Special Interest Group
SPS	Standard Positioning Service
SSID	Service Set Identifier
STA	Simple Triangulation Algorithm
TDOA	Time Difference of Arrival
TOA	Time of Arrival
TOF	Time of Flight
TTFF	time-to-first-fix
UDP	User Datagram Protocol
USNO	US time standard kept by the US Naval Observatory
UTC	Universal Co-ordinated Time
UWB	Ultra-Wideband
WGS84	World Geodetic System 1984
WIFI	Wireless Fidelity
WKNN	Weighted K-Nearest Neighbour
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WTA	Weighted Triangulation Algorithm

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1 Introduction

1.1 Motivation

Positioning and navigation are basic needs of humans for coping with every day life, because nearly everyone has to find its way to an previously unknown location from time to time. So researchers have been keen on navigation and positioning for a long time. The earliest map dates back to the late 7th millennium Before the Christian Era (BCE) and people began to research in the field of navigation about one millennium later. From that time on maps and navigation techniques became better and better. Today in the age of knowledge and globalisation navigation and positioning at any time is very important because professional as well as private life gets more mobile. Since the turn of millennium GPS outdoor navigation systems have become very popular and can nowadays be found in nearly every car. Even smartphones are capable of using this technology.

There is a system that works well for outdoor navigation and positioning but what system is there for indoor navigation? Since fifteen years scientists all around the world intensely study in the field of indoor navigation systems, starting with the Active Badge System developed by AT & T Laboratories in Cambridge between 1989 and 1992 (Want et al., 1992). Many promising theories and solutions have been developed so far. But due to the fact that the most promising solutions base on different technologies (Koyuncu & Yang, 2010), there is not one commonly agreed solution for indoor positioning as GPS is for outdoor positioning. The reason for this incident is that there is no perfect solution that achieves high accuracy within adequate costs and in addition satisfies other important matrices.

Due to the fact that the world is now as Marc Weiser predicted 1988 in the ubiquitous computing phase (Weiser, 1993), indoor navigation for mobile devices as smartphones is a very exciting field of research. A study that was released by the global research organization Strategy Analytics on 17 October 2012 says that the number of smartphones being used worldwide exceeded the one billion mark in the third quarter of 2012 for the first time in history (Strategy Analytics, 2012). This means that today one out of seven persons worldwide has a smartphone in use and the number is still growing. So to accurately determine the position of a smartphone indoor opens many possibilities for applications. For example think of social networks that could use this information to find close friends in large public shopping centres, or other Location Based Services (LBSs) like simple indoor navigation from the parking lot to a specific store. Indoor navigation systems can also be an aid for first responders and fire-fighters in dangerous situations and environments. As recent developments show, the future for smartphone based indoor positioning systems is very promising.

This thesis gives an overview over the fundamentals of positioning and navigation in indoor environments and investigate state of the art solutions that have been developed so far. It will then describe the implementation of an indoor positioning system for smartphones using the WLAN technology.

1.2 Identification of Central Questions and Objectives

Within the scope of this master thesis a new system for indoor navigation especially for public buildings, such as shopping centres and universities, will be developed. Main criteria is the implementation of an indoor navigation system for smartphones which is as robust and accurate as possible. The positioning solution operates with the WLAN technology. The system will basically work with the known methods of Location Fingerprinting and Triangulation. Location Fingerprinting solutions are divided in an off-line (or trainings) and an on-line (or localisation) phase. In the off-line phase particular measurements are taken and saved in a database. With the help of this database the position is then determined in the on-line phase (see chapter 2.2.3.1 on *WLAN Location Fingerprinting* for further details).

The off-line phase is a complex and very time-intensive process, especially for big buildings. The bigger the building, the higher is the effort to create the map needed for the on-line phase to determine the position of a device. In order to cope with this complexities a new approach for optimizing the off-line phase has to be realized. The system's goal is to substantially lower the positions at which fingerprint measurements have to be taken. It will be able to identify ideal locations for measuring fingerprints on the basis of a building's plan and the positions of the WLAN emitting routers in the first phase. Based on this measurements all other non measured points can then be calculated by using a signal distribution model. The number of positions at which measurements have to be taken will be as small as possible, but nevertheless enough to get a good interpolation for every walk-able non-measured point. Is such a system realizable in a way that it is possible to create a Radio Map for big buildings like shopping centres with a manageable effort and an acceptable positioning accuracy to allow navigation from one point to a store? The goal is that the system substantially lowers the effort to create the Radio Map in the off-line phase, but nevertheless achieves a positioning accuracy in the on-line phase that is comparable with a fully measured Radio Map.

1.3 Overview

Chapter 2 deals with the fundamentals on positioning and navigation techniques. First of all the basic methods for measuring distances like Cell of Origin (COO) or Received Signal Strength (RSS) are described and summarized to gain an overview. Based on this measurement techniques the chapter further on explains positioning and navigation approaches such as Triangulation and Location Fingerprinting.

State of the art technologies and solutions of positioning systems are described in **chapter 3**. It gives insight into conventional techniques such as GPS and WLAN based approaches and also investigates more modern solutions like navigation based on inertial sensors or the earth's magnetic field. The technologies are summarized and compared to get a better orientation at the end of the chapter.

Chapter 4 describes the implementation of a system using WLAN and the Location Fingerprinting method for smartphones running the Android operating system. It first of all gives an overview over the prototype and then explains the theory behind and the implementation of the optimization algorithm to overcome the complexity of the off-line learning phase in the Location Fingerprinting approach. At the end of the chapter some thoughts about further additional implementations are noted.

The process of the evaluation as well as the evaluation results concerning the optimization algorithm are described in **chapter 5**.

Chapter 6 analyses the evaluation results, summarizes them and draws conclusions out of it.

Chapter 7 takes a look into the future of indoor navigation for smartphones and for what the results of this thesis are useful.

2 Fundamentals on Positioning and Navigation Techniques

This chapter describes the basic measuring principles and techniques of positioning and navigation approaches which are used in indoor and outdoor systems such as GPS or WLAN solutions.

2.1 Measuring Principles and Techniques

2.1.1 Introduction

In the past fifteen years many systems for location positioning, especially indoor positioning, have been developed. Most of these systems, like GPS or all WLAN - positoning technologies base on different positioning principles, such as Angle of Arrival (AOA), Time of Arrival (TOA) and others.

The described principles in this chapter - Angle of Arrival (AOA), Cell of Origin (COO), Received Signal Strength (RSS), Time of Arrival (TOA), Time Difference of Arrival (TDOA) and Round-trip Time of Flight (RTOF) - are called cellular based techniques. But not all navigation solutions make use of such a principle. There are also other possibilities, which use for example the earth's magnetic field, image recognition or inertial sensors to navigate.

Zeimpekis et al. (2003) categorizes positioning systems into two major subcategories: self-positioning techniques and remote-positioning techniques. Systems which work by self-positioning techniques use the signals sent by fixed base stations (antennas) to determine the position of a mobile device, like GPS does. In contrast to self-positioning techniques remote-positioning techniques do not only use the signals sent by fixed base stations, there is a two-way communication. The mobile devices also sends signals to the base stations to calculate the position of the device.

Positioning technologies distinguish between physical position and symbolic location and absolute versus relative position as described in Hightower & Borriello (August 2001). A physical position is an exact position description as GPS systems stage such as 32°15”2’ N by 17°27”12’ W. In contrast to physical locations, symbolic locations are just approximate position statements as ’in Graz’ for example. Absolute position information is based on so called shared reference grids. All objects can be located with the help of a grid. GPS for example uses latitude, longitude and altitude for determining a position. Relative positions are positions that are specified by a certain point which could be anything. For example the devices used by rescue teams to search for avalanche victims state the position of the rescuer by the position of the buried people.

2.1.2 Cell of Origin (COO)

The Cell of Origin (COO) or also often called Cell Identification (CI) method belongs to the category of remote-positioning techniques. It is the easiest and most basic way of positioning. The idea behind this technique is that the location of the mobile device can be approximately determined when you know which signal emitting station the device uses at a given time and where this station is localized, as shown in figure 2.1.

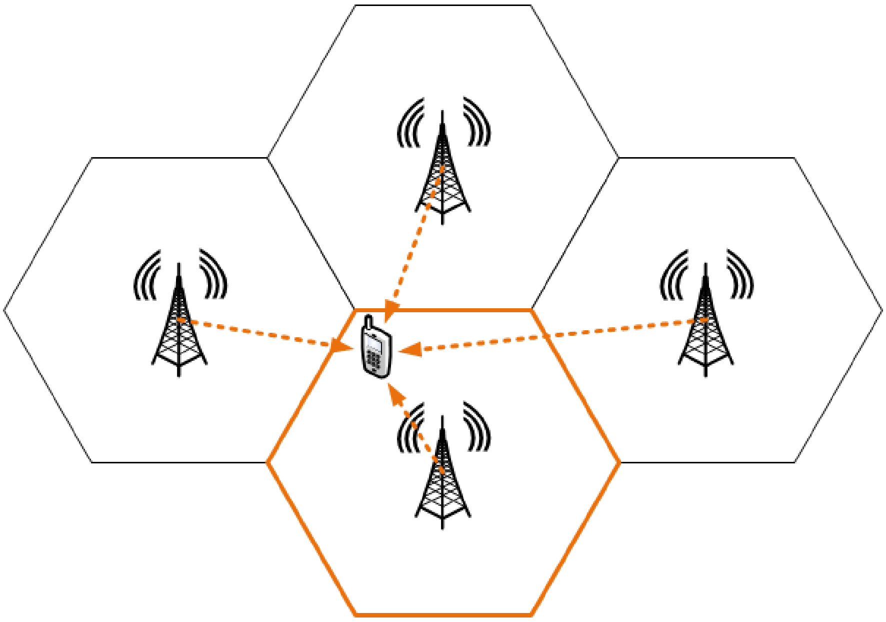


Figure 2.1: Cell of Origin Method (personal design)

The main advantage of this system is that it can be easily implemented for nearly all mobile devices. Mobile phone providers for example can determine the approximate position of its customers by Global System for Mobile Communications (GSM) or you can also use WLAN - routers in large buildings to determine the approximate position of a smartphone. The main disadvantage of this technology is accuracy. It is overall very low and at best in a range of 50 to 250 meters, but can also be up to kilometres. The accuracy rises with the number of emitting stations in a specific area.

[(Zeimpekis et al., 2003), (Liu et al., November 2007)]

2.1.3 Angle of Arrival (AOA)

This method is a remote-positioning technology and uses the angles of arrival of at least two signal sending base stations to determine the position of a signal receiving device. In order to calculate the position, the distance between the base stations has to be known. The device has also be able to locate the direction where the signals come from. For that phased arrays of directional antennas are used very often. The distances from the base stations to the device are called Line of Bearings (LOBs), as shown in figure 2.2. The location of the device can then be calculated by the intersection of the LOBs.

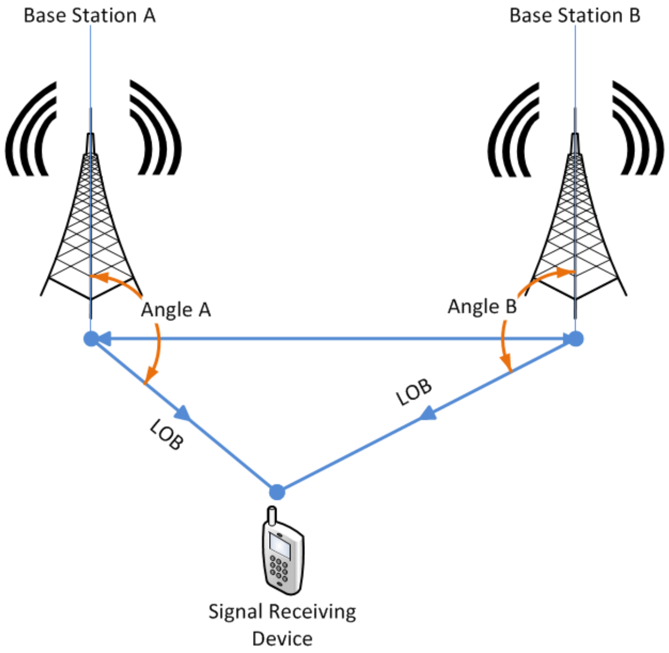


Figure 2.2: Angle of Arrival Method (personal design)

The advantage of this method is that only two signal sending base stations are needed to localize a device in a 2-D environment. For 3-D localization at least three signal sending base stations are needed. In comparison to other methods, such as TOA no time synchronization is necessary. Disadvantages are complex hardware and the decreasing accuracy with large distances to the base stations. To achieve greater accuracy more base stations need to be installed. This method is also often referred to by Direction of Arrival (DOA).

[(Dardari et al., 2011), (Liu et al., November 2007), (Zeimpekis et al., 2003)]

2.1.4 Received Signal Strength (RSS)

The RSS method or also called Signal Attenuation-Based method is part of the group of remote-positioning techniques. This technology works by measuring the strength of the received signal, as shown in figure 2.3 and can so be implemented for nearly every mobile wireless device. The fundamental idea behind this method is very simple. The further away the signal sending base station is, the weaker is the received signal on the mobile device. In order to identify the position of a device theoretical and empirical models are used. These models calculate the location by the difference between the strength of the transmitted and the received signal. This method is often used in WLAN - positioning solutions.

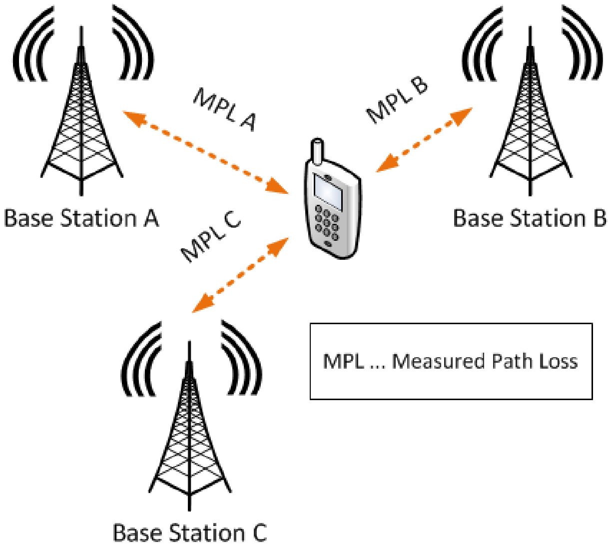


Figure 2.3: Received Signal Strength Method (personal design)

The big advantage of the RSS method compared to others is that it can be implemented for many wireless devices. As for AOA methods there is also no need for time synchronization. But this method has some basic disadvantages. The positioning gets inaccurate due to shadowing. Shadowing is signal attenuation that is caused by obstacles as for example walls. These environments are called Non Line of Sight (NLOS) environments. To counter this problem some algorithms and path-loss models exist. An increased number of signal sending base stations can improve the positioning as well.

This method is one of the most commonly used methods because it can be easily implemented for almost all mobile devices.

[(Dardari et al., 2011), (Liu et al., November 2007)]

2.1.5 Time of Arrival (TOA)

The TOA or sometimes also referred as Time of Flight (TOF) method belongs to the category of remote-positioning techniques. In theory the distance between a signal sending base station and a signal receiving device can be calculated by measuring the time the signal takes to travel because the distance is directly proportional to the time of travel. This method is used for GSM, UWB, WLAN or satellite based positioning solutions. In order to achieve accurate positioning it is important that the clocks of the sending base stations and the receiver are exactly synchronized. Another requirement is that the communication protocol allows to transfer a time stamp from the sender to the receiver. As shown in figure 2.4 the intersection of the circles of at least three different base stations is needed to calculate the position of the device by triangulation. The accuracy for this method differs from within a view metres for indoor positioning solutions based on UWB or WLAN to 300 hundred metres or more for outdoor positioning solutions that are based on GSM for example. The accuracy is dependent on the used technology, hardware and the area the solution covers.

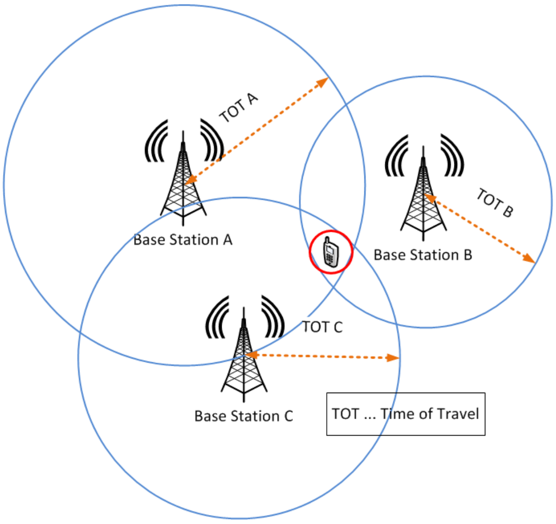


Figure 2.4: Time of Arrival Method (personal design)

One advantage of the TOA method is that it could be used for WLAN indoor positioning solutions and is suitable for Line of Sight (LOS) and NLOS environments. The major disadvantages of this method is the problem of ensuring synchronized clocks as well as avoiding measurement errors to achieve a good accuracy.

[(Dardari et al., 2011), (Liu et al., November 2007), (Zeimpekis et al., 2003), (Bill et al., 2004), (Ciurana et al., 2007)]

2.1.6 Time Difference of Arrival (TDOA)

The TDOA method or also called Hyperbolic Technique is very similar to the TOA method and falls into the same category of remote-positioning techniques. In contrast to the TOA method the TDOA method does not have to fulfil the requirement of synchronized clocks between the signal sending base stations and the signal receiving devices. It also does not have to fulfil the requirement that the communication protocol has to be able to transfer timestamps between the communication partners. The system can be implemented with WLAN routers too and needs at least three base stations to calculate the position. The more base station, the higher is the achieved accuracy of the calculated position. The system works as follows: As shown in figure 2.5 three signal sending base stations at predefined locations are needed. First of all base station A sends a packet to the signal receiving device. When the device gets the packet it replies to the same base station with an Acknowledgement (ACK) message. In the meantime the other base stations B and C log the communication between the base station A and the mobile device. The position of the device can then be calculated by the delays between the sent packet and the ACK messages of every base station by triangulation.

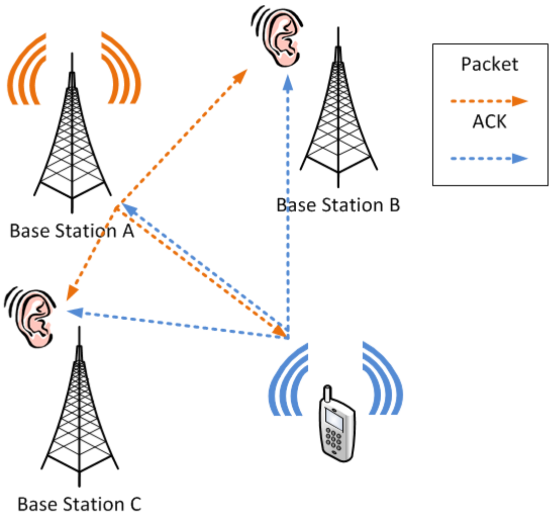


Figure 2.5: Time Difference of Arrival Method (personal design)

The major advantages of this method are, as mentioned before, that it does not require synchronized clocks or a a communication protocol that allows sending of time stamps. One still remaining problem is that a high-precision timer is needed at each base station to calculate the delays between the sent packet and the ACK message.

[(Dardari et al., 2011), (Liu et al., November 2007), (Zeimpekis et al., 2003)]

2.1.7 Round-trip Time of Flight (RTOF)

The RTOF method is related to the TDOA method and belongs to the category of remote-positioning techniques. In contrast to the TDOA method a more moderate clock can be used. The idea behind this system is the Time of Flight (TOF) of the signal transmitted from the device to the base stations and back, the so called round-trips as shown in figure 2.6. The device has to know the exact locations of the base stations and can then calculate the position equally to the TOA method.

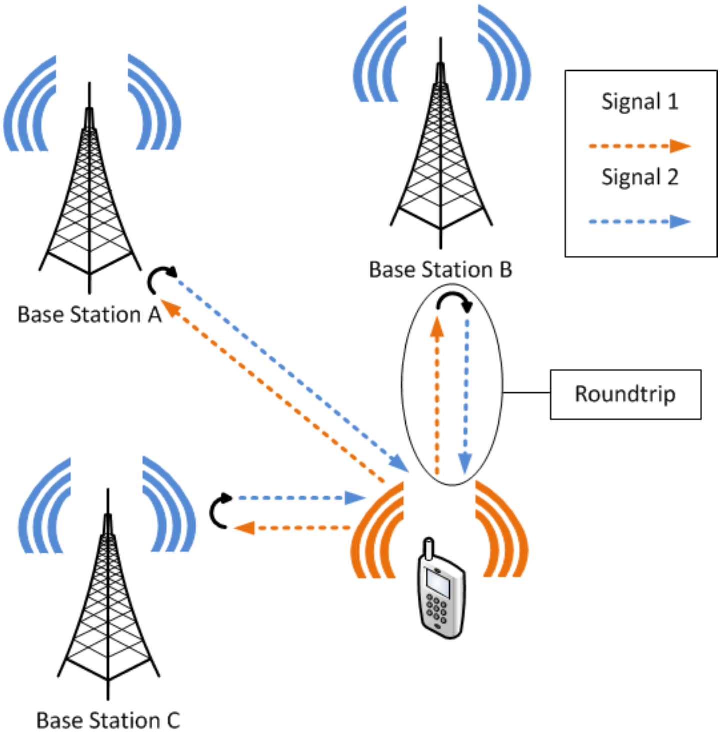


Figure 2.6: Round-trip Time of Flight Method (personal design)

The main advantage compared to the TOA and TDOA method is that the RTOF method can use a more moderate clock. The big disadvantages of this systems are that it will be very inaccurate if the device does not know the exact delay of the base stations that they take to respond to the signal. It is said that this delay can be neglected in medium or long range environment but not for short ranged ones. Concerning indoor positioning an algorithm for WLAN technology has been developed which has only a measurement error of a few metres.

[(Liu et al., November 2007)]

2.1.8 Summary and Overview

The following table 2.1 summarizes the presented measuring principles and technologies in this chapter and helps to gain an overview over the advantages and disadvantages of these methods.

Principles	Advantages	Disadavantages
COO	simple, compatible with existing technologies	low accuracy
AOA	only two base stations needed, no clock synchronisation	complex hardware, decreasing accuracy with large distances, highly dependent on antenna quality
RSS	compatible with existing hardware, can achieve high accuracy, no clock synchronization	creation of database, inaccuracy due to shadowing
TOA	can achieve high accuracy, suitable for LOS and NLOS environments	clock synchronization
TDOA	can achieve high accuracy, no clock synchronization	high-precision timer at base stations needed
RTOF	can achieve high accuracy, no high accuracy clock needed	time delay problem in short ranged environments

Table 2.1: Overview Measuring Principles and Techniques (personal design)

[(Renaudin et al., July 2007), (Dardari et al., 2011), (Liu et al., November 2007), (Zeimpekis et al., 2003)]

2.2 Positioning and Navigation Approaches

2.2.1 Introduction

The previous section 2.1 described the *Measuring Principles and Techniques* which results are used for positioning and navigation approaches to calculate the physical or symbolic location of a device.

Reliant on the different possibilities of measurements, such as AOA, COO, RSS, TOA, TDOA and RTOF different positioning and navigation approaches can be implemented. Dardari et al. (2011) and Liu et al. (November 2007) classifies this approaches into three main categories:

- Geometric Techniques - Triangulation
- Mapping Techniques - Location Fingerprinting
- Proximity Techniques

Most of the implemented indoor positioning or navigation solutions use the WLAN technology and RSS measurements to determine the position of a device. This systems either use Triangulation or Location Fingerprinting or sometimes hybrid solutions of different approaches to calculate the locations. The measurement techniques TOA, TDOA and RTOF are avoided in most of the systems because it is hard to achieve exact measurements using appropriate and not highly expensive hardware as explained in the previous section 2.1. The COO method does often not fulfil the requirements of positioning solutions because it is pretty inaccurate.

The following subsections will give on overview of the three different techniques mentioned above.

[(Dardari et al., 2011), (Liu et al., November 2007)]

2.2.2 Geometric Techniques - Triangulation

The geometric technique called Triangulation or also often referred to as Location Sensing method makes use of the geometric properties of triangles to calculate the position of a target device. Triangulation is divided into two main subcategories:

- Lateration
  This method is also called Range Measurement Technique and determines the position by the help of measured distances from at least three or more reference points.

- Angulation
  This technique uses angles or bearing measurements of at least three or more reference points in order to compute the position of a target device.

2.2.2.1 Lateration

As mentioned before, the Lateration technique is based on measured distances from at least three or more reference points. To calculate the location of a target device in a 2-D environment (latitude and longitude) it takes distance measurements from at least three points which are non-collinear to each other. Collinear points are points which are lying on a single line. The principle of Lateration is shown in figure 2.7.

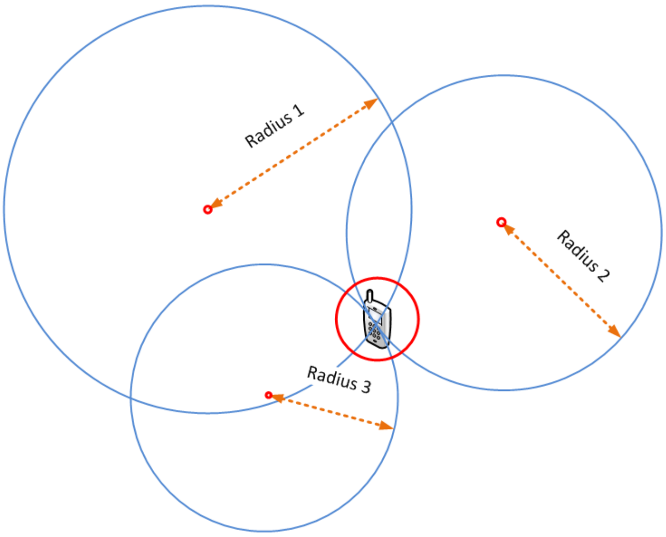


Figure 2.7: Lateration Method (personal design)

In a 3-D environment (latitude, longitude and elevation) the distance measurements of at least one more point, so four non-coplanar points are required to determine the position. Coplanar implies the same for geometric spaces as collinear does for lines. So points are coplanar if the are lying on the same geometric plane. The position in a 3-D environment can also be calculated with less than four points if domain-specific knowledge is available. The Active Bat System (see chapter 3.5 on UWB) developed by the Cambridge Computer Laboratory Digital Technology Group for example, does only need three measurements to compute the position of a target device. This is possible because the ultrasonic sensors are built in the ceiling and the system knows that it has to be below these sensors in order to work. So this system can easily identify the floor in which the target device resides and needs only three distance measurements to calculate the position on the floor.

According to Hightower & Borriello (July 2001) there are three procedures to measure the distances needed by the Lateration technique:

- Direct
  Direct measurements need a physical action to determine the distance between two points and is only practicable for small environments. The bigger the distance, the harder it is to do physically measure.

- Time-of-Flight
  As the name suggests this technique measures the time the signals take to travel from one point to another to calculate the distance. These method often causes some problems for example with synchronizing clocks as described in the previous chapter 2.1.
  Measuring principles that belong to that category are: TOA, TDOA and RTOF (see chapters 2.1.5, 2.1.6 and 2.1.7).

- Attenuation
  This technique simply works by measuring the strength of the received signals. Easy to say the further away the signal emitting station is, the weaker is the received signal on the target device. This technique works fine in free space environments and causes some troubles in indoor environments because of signal propagation issues as reflection due to walls or suchlike.
  Measuring principles that belong to that category are: RSS and COO (see chapters 2.1.4 and 2.1.2).

2.2.2.2 Angulation

The Angulation technique is related to the Lateration method and uses angles or bearing measurements to calculate the position of a target object. In 2-D environments two angles and the distance of one length between two points are needed as shown in figure 2.8.

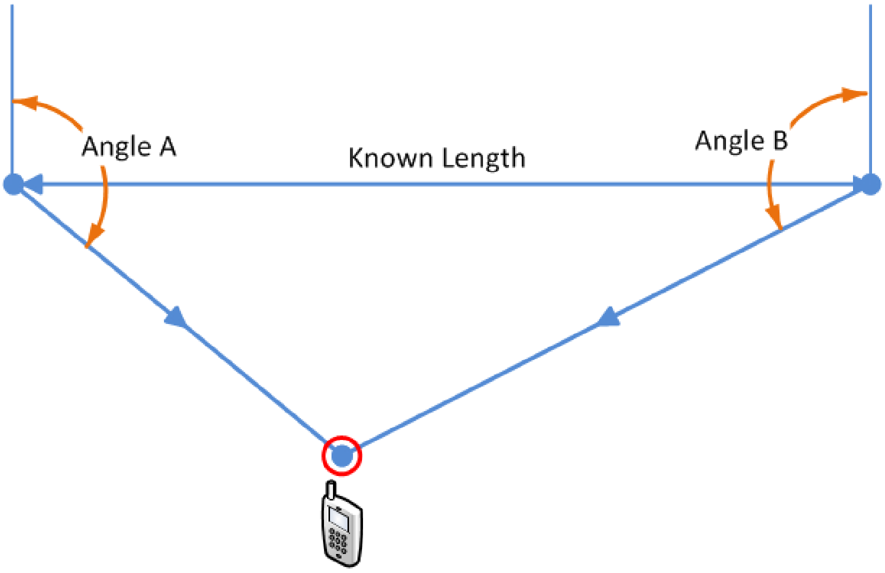


Figure 2.8: Angulation Method (personal design)

In contrast to 2-D environments for 3-D environments an additional azimuth measurement is required. An azimuth is an after geographic directions oriented horizontal angle.

For locating the direction where the signals come from usually phased arrays of directional antennas are used as also described in the previous chapter at the AOA method (see 2.1.3).

A measuring principle that belong to that category is the AOA method (see chapter 2.1.3).

[(Liu et al., November 2007), (Hightower & Borriello, July 2001)]

2.2.3 Mapping Techniques - Location Fingerprinting

The Mapping Technique called Location Fingerprinting or also often referred to as Scene Analysis locates an object in an environment by a feature, e.g. WLAN - fingerprints, at a particular point.

Hightower & Borriello (July 2001) differentiates between two methods of Scene Analysis:

- Static Scene Analysis
  With this technique features at a certain point are looked up in a pre-calculated database that maps features to real object locations. A common method that uses this technique is for example the WLAN - Fingerprinting method which will be closer described later on in this chapter (see chapter 2.2.3.1).

- Differential Scene Analysis
  This technique works by tracking the differences of consecutive scenes to determine the position of a target object. An approach that uses this technique is for example the Image Recognition method that uses images of cameras to track the movement and try to locate the camera and its user for example by keeping track of certain shapes.

The best known Scene Analysis method is Static Scene Analysis because the most widely used systems work with predefined datasets. The Term *Location Fingerprinting* is generally understood when speaking of Mapping Techniques as it is in Dardari et al. (2011). To give a detailed insight the next chapter will have a closer look on the Static Location Fingerprinting method as commonly used in WLAN IPSs.

2.2.3.1 WLAN Location Fingerprinting

As described this specific technique uses a database to store and later on look up certain features to determine the position of a target object. The feature in WLAN Location Fingerprinting methods are RSS (see chapter 2.1.4) based fingerprints of available WLAN - routers in the environment. This technique can be divided into two phases or stages:

- Off-line or Training Phase
  In the first step the database of location fingerprints is built up and stored. For this fingerprints of available WLAN signals are taken at different points within a predefined environment. At every point the fingerprint is measured and stored with a location information, for example coordinates, in the database.

- On-line or Locating Phase
  In the second step the target object can now be located by measuring a fingerprint somewhere in the predefined environment and comparing it to the stored database. There are many different ways to calculate the position. One very easy way for example would be to identify the three most similar fingerprints in the database and calculate the position with triangulation of these points. Other commonly used algorithms are *k-nearest-neighbour* and *neural networks* or *Probabilistic Methods*.

The advantage of the WLAN Location Fingerprinting technique is that the location can be determined passively because it does not have to measure geometric quantities. But this method has also some typical drawbacks such as changing fingerprints because of changing environments, for example walls or even doors can cause problems. The accuracy of this method highly depends on other factors such as appropriateness of the mode which is used to create the database because signal signatures often change over time.

[(Dardari et al., 2011), (Hightower & Borriello, July 2001)]

2.2.4 Proximity Techniques

Proximity Techniques are characterized by only allowing inaccurate and low ranged localization of target objects. Hightower & Borriello (July 2001) describes three different approaches:

- Detecting physical contact
  This method is the most easiest technique of Proximity Techniques and works by physical contact of sensors and detectors. Often used sensors are pressure, contact or capacitive sensors.

- Monitoring wireless cellular access points
  This technique just keeps track of different Access Points (APs), for example Bluetooth, IR or WLAN APs and tries to determine the approximate position of the target device. Figure 2.9 shows the possible spreading of a Bluetooth, IR and WLAN - router in an indoor environment.

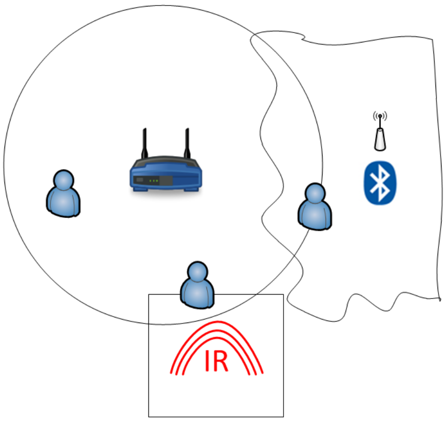


Figure 2.9: Spreading of different Wireless Signals (personal design)

- Observing automatic ID systems
  This technique uses identification systems to locate a device. The position of the device can only be located if the location of the ID scanning system is known. Such systems could be for example: computer logins, telephone records or credit card terminals.

These systems are as mentioned very inaccurate and hence not suitable for most indoor navigation solutions.

[(Hightower & Borriello, July 2001)]

3 State of the Art Technologies and Solutions of Positioning

This chapter provides an overview of the current technologies of positioning used in modern indoor and outdoor positioning solutions. It investigates the advantages and disadvantages of each system and the usability for indoor positioning with smartphones.

3.1 Introduction and Overview

Many technologies have been developed to this day. Due to the fundamental and major differences in these technologies it is hard to find a clear classification for them. Renaudin et al. (July 2007) describes three ways to classify positioning systems:

- Type of sensors: active or passive.
- Location of the position calculation: handset or network.
- Signal metrics: such as AOA, COO, RSS or Triangulation as described in chapter 2 *Fundamentals on Positioning and Navigation Techniques.*

These systems can be compared by several performance matrices as described by Liu et al. (November 2007) and Lin & Lin (2005):

- Accuracy
- Precision
- Complexity
- Robustness
- Scalability

- Cost

The main factor for positioning techniques is of course **accuracy**. The positioning error is calculated by the mean Euclidean distance between the calculated $(\hat{x}, \hat{y})$ and the real position (x,y).

$$E(positioning\ error) = E\left(\sqrt{(x-\hat{x})^2 + (y-\hat{y})^2}\right) \tag{3.1}$$

All techniques seek for high accuracy, but often have to make trade-offs in order to achieve other above-mentioned factors.

Whereas accuracy only examines the mean error, **precision** more focuses on the consistency of the technology. In case of positioning it describes the variation of the calculated positions for one real position over a higher number of measurements. In general the Cumulative Probability Functions (CDF) is used to state the precision of a system and hence given in %.

Complexity aims on the hardware and software that the system needs. Typical questions that aim on complexity are: Does the system only require some cheap antennas or expensive radio stations? Are there some complex algorithms for the system to develop or not? Can the computation be made on the mobile device or has it to be outsourced to a more powerful computer?

Robustness is described as a factor to which extent a system is fully functional when a system shows unconventional or unexpected behaviour. This could be for example due to hardware errors (dropping out of a signal sending base stations) or measurement errors caused by changing environment (illumination, open/closed doors).

Scalability means that a system is able to reliably calculate the position of a device when the geographic density or number of devices in a certain area rises.

Last but not least a very important factor is **cost**. There are positioning solutions, such as PGPS that are very accurate but are extremely expensive too. Besides deployment costs there are also other factors belonging to the category of costs such as time, energy and maintenance.

The following chapters describe a technology approximately following the historical progression, beginning with the oldest one - GPS - and ending with more modern approaches such as magnetic field based solutions.

[(Renaudin et al., July 2007), (Liu et al., November 2007), (Lin & Lin, 2005)]

3.2 Global Positioning System (GPS)

GPS is the best known and oldest positioning and navigation technology. There are different GPS systems which can be divided as follows:

- Global Navigation Satellite Systems (GNSS)
    - NAVstar System with Timing And Ranging (NAVSTAR)
    - GLobal Orbiting Navigation Satellite System (GLONASS)
    - GALILEO
- Differential Global Positioning System (DGPS)
- Assisted Global Positioning System (AGPS)
- Pseudolite Global Positioning System (PGPS)

NAVSTAR, GLONASS and GALILEO are global systems which are used for outdoor navigation and positioning only. DGPS is an additional system to GNSSs that deals with location dependent positioning errors and improves the accuracy significantly. Hence it is also used only outdoor. AGPS is similar to DGPS and fixes some known problems of GNSS, but this system can also be used indoor. The PGPS was developed for indoor positioning and navigation only and can achieve an accuracy of centimetres. The following chapter will give detailed insight in the before-mentioned technologies.

3.2.1 Global Navigation Satellite Systems (GNSS)

3.2.1.1 NAVSTAR

NAVSTAR was the first developed GNSS and is so also often referred to as GPS. It was designed for military use by the US Department of Defense (DOD) in 1973 and belongs to the group of radio navigation positioning systems. This system became popular in the year 2000 when it was unlocked for public use. Between 1973 and today this system has been improved consistently.

The NAVSTAR system consists of 24 satellites and is the most widely used system today. The satellites are equally distributed on six orbital planes. At any point around the world the signals from at least five to a maximum of eight satellites can be received.

According to Lechner & Baumann (January 2000) the system can be categorized into three segments as also shown in figure 3.1:

- satellite segment
- control segment
- user segment

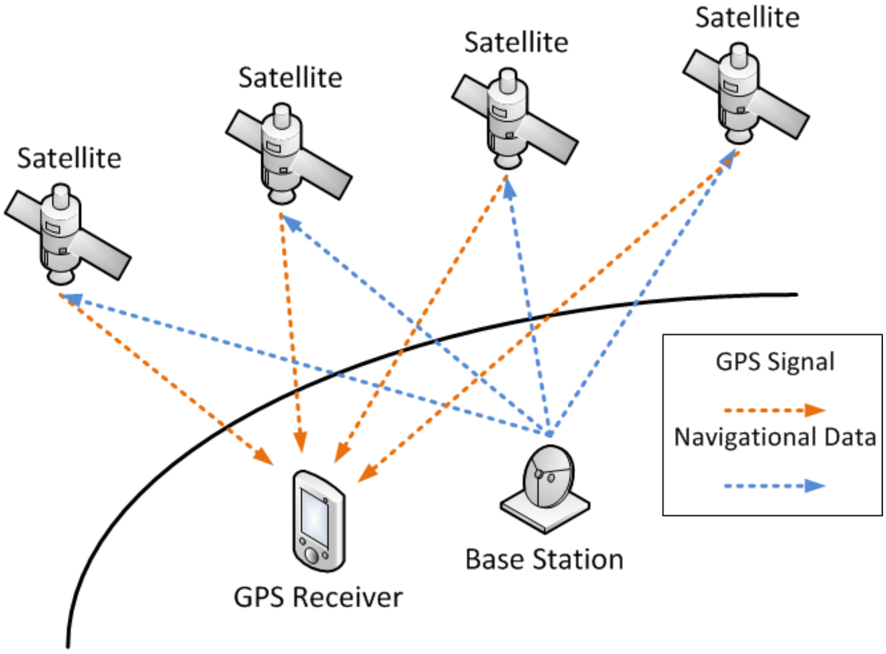


Figure 3.1: GPS or NAVSTAR System (personal design)

The satellite segment includes the satellites circling around the earth. The control segment is placed on the earth and consists of several base stations around the world. These stations keep track of the satellites. The main station is located at Falcon Air Force Base in Colorado and uploads navigational data including ephemeris and clock data to the satellites. These data is sent back by the satellites to GPS receivers. The user segment is the total of GPS receivers. Receivers can transfer the signal into position, time and velocity estimates. In order to calculate the position in latitude, longitude and altitude at least signals from four satellites are needed. GPS systems are commonly used today for outdoor positioning and navigation. Lechner & Baumann (January 2000) describes two signals at different Megahertz (MHz) levels which are transmitted by the satellites:

- L1 signal or Course/Acquisition Code or Standard Positioning Service (SPS)
  This signal is sent at 1575.42 MHz and was intended for private users. The accuracy was intentionally reduced by the so called Selective Availability (SA) to avoid hostile forces from accurate positioning. The calculated positioning error was about 100 metres. The SA was turned off in May 2000.

- L2 signal or Precise Code
  The L2 signal is encrypted and can only by used by the military or authorized users. The signal is sent at 1227.70 MHz.

The accuracy that can be achieved with the NAVSTAR system today is between five to ten metres. Although with additional improvements like the Differential Global Positioning System (DGPS) method, which will be explained in chapter 3.2.2, the system is able to achieve centimetre-accuracy.

[(Alkan et al., June 2005), (Lechner & Baumann, January 2000)]

3.2.1.2 GLONASS

GLONASS is a similar system as NAVSTAR and was developed by Russia in 1976 also for military use. According to the Federal Space Agency (2012) the system today consists of 31 satellites, from which 24 are in operational use. In contrast to NAVSTAR each satellite in the GLONASS system sends its signals on its own frequency but they all use similar codes. The GLONASS system can also be used by civilians and uses like NAVSTAR two different levels of service as described in Lechner & Baumann (January 2000):

- Channel of Standard Accuracy (CSA)
  This version can be used by private users. It achieves a horizontal accuracy of 60 metres and vertical accuracy of 75 metres both with 99.7% probability.

- Channel of High Accuracy (CHA)
  This channel can only be used by the military and authorized users like the L2 signal originally was intended for in the NAVSTAR system.

The system was for the first time fully functional in January 1996. In the same year also the first GLONASS signal receivers were introduced to the global market.

Although both system are very similar and were developed for the same purpose there are also some basic differences. The systems use different geographic reference systems. NAVSTAR uses the standardized World Geodetic System 1984 (WGS84), whereas GLONASS makes use of its own model, the Russian, Parameter of Earth 1990 (PZ-90) system. There is also a difference in time zones. NAVSTAR or GPS use the Universal Co-ordinated Time (UTC) and US time standard kept by the US Naval Observatory (USNO) time format, the Russian system works with UTC in Moscow time. Another basic difference between the two systems already mentioned is the difference in the sent signals. All GPS satellites use the same frequencies but different codes, whereas NAVSTAR satellites share the same code but differ in the frequencies they use. The following table 3.1 published by Zarraoa et al. (1997) gives an overview of the differences between the two systems.

Parameter	GPS or NAVSTAR	GLONASS
Number of satellites	21 + 3 spares	21 + 3 spares
Number of orbital planes	6	3
Orbital inclination	55.0°	64.8°
Orbit altitude	20 180 km	19 100 km
Orbit period	11 h 58 min	11 h 16 min
Ground track repeat	1 sidereal day	8 sidereal days
Geodetic system	WGS84	PZ-90
System time corrections	UTC (USNO)	UTC (Moscow)
Signal divison method	Code divison	Frequency divison
Frequency L1	1575.42 ± 1.0 MHz	1602+ n x 0.5625 MHz ± 0.5 MHz (n=1,2,...,24)
Frequency L2	1227.60 ± 1.0 MHz	1246+ n x 0.4375 MHz ± 0.5 MHz (n=1,2,...,24)
Number of code elements	1023	511
Code rate (MHz)	L1 = 1.023, L2 = 10.230	L1 = 0.511, L2 = 5.110

Table 3.1: Overview Differences NAVSTAR and GLONASS (Zarraoa et al. (1997))

Although the USA and Russia were enemies during the cold war when both systems were developed, the systems can be combined today to achieve a higher accuracy.

[(Alkan et al., June 2005), (Lechner & Baumann, January 2000)]

3.2.1.3 GALILEO

GALILEO belongs as NAVSTAR and GLONASS to the group of GNSS and is a European system. The first beginnings of GALILEO date back to 1994. The project was funded by the European Union (EU) and the European Space Agency (ESA). It is the first system that was not intended for military but for civilian use only. The system is under development and will consist overall of 30 satellites when it is finished. GALILEO can be used in combination with the Russian GLONASS and the American NAVSTAR system.

As its relative techniques GALILEO will also provide two frequencies, but in contrast to NAVSTAR and GLONASS both will be available for civilian use. The system promises a higher accuracy of about a meter compared to the other GNSS systems. Availability is one of the mature goals defined by the project. The system will be able to inform users of failures and usable for safety-critical applications like landing an aircraft. The satellites will be able to send ten different navigation signals which allows to offer at least the following services:

- Open Service (OS)
- Safety of Life Services (SOL)
- Commercial Services (CS)
- Public Regulated Services (PRS)

All satellites send their signals at the same frequency of 1575.42 MHz. As mentioned the system uses different codes in order to determine the satellite the signal comes from and to measure the time. The frequency used by GALILEO is exactly the same frequency that is used by NAVSTAR. A modulation makes it possible to use the same frequency but differ between NAVSTAR and GALILEO signals. This incident makes it a lot easier to build receivers for hybrid systems.

So far four satellites have been sent to the space. The first two satellites, GIOVE-A and GIOVE-B, started in 2005 and 2008 to test the GALILEO system. In October 2011 another two operational of totally four operational satellites were sent to space to validate the concept.

Figure 3.2: GIOVE-B Satellite (ESA (2012))

The system is divided into three segments by ESA (2012):

- space segment
- ground control segment
- mission control segment

The space segment will consist of 27 operational and 3 active spare satellites when it is finished. The satellites will only be distributed on three orbital planes, whereas NAVSTAR satellites are distributed on six planes. Each plane will have nine operational satellites and one spare satellite in case one of the satellites drops out due to a failure. The ground control segment mainly exists out of two control centres which are responsible for satellite maintenance and navigation system control, called Ground Control Segment (GCS) and Ground Mission Segment (GMS). The mission control segment is also placed on earth and will consist of 30 Galileo Sensor Stations (GSS). These stations are responsible for monitoring navigational signals. Another task of this segment is time synchronization and integrity processing.

Table 3.2 below shows some technical data of the European GALILEO navigation satellite system in comparison with the American NAVSTAR and Russian GLONASS system. It is based on table 3.1.

Parameter	NAVSTAR	GLONASS	GALILEO
Intention	Originally military use, later on civilian use	Originally military use, later on civilian use	Civilian use only
In use since	M: 1990, C: 2000	M: 1996, C: 2008	scheduled: 2020
Number of satellites	21 + 3 spares	21 + 3 spares	27 + 3 spares
Number of orbital planes	6	3	3
Orbital inclination	55.0°	64.8°	56°
Orbit altitude	20 180 km	19 100 km	23 222 km
Orbit period	11 h 58 min	11 h 16 min	14 h 07 min
Ground track repeat	1 sidereal day	8 sidereal days	10 sidereal days
Signal divison method	Code divison	Frequency divison	Code divison
Frequency L1	1575.42 ± 1.0 MHz	1602+ n x 0.5625 MHz ± 0.5 MHz (n=1,2,...,24)	1575.42 ± 1.0 MHz
Frequency L2	1227.60 ± 1.0 MHz	1246+ n x 0.4375 MHz ± 0.5 MHz (n=1,2,...,24)	1278.75 ± 1.0 MHz

Table 3.2: Overview Differences NAVSTAR, GLONASS, GALILEO (personal design)

For the sake of completeness, it must be mentioned that there exists also a fourth Chinese GNSS which is called COMPASS and still under development. It will be finished by 2015.

[(Alkan et al., June 2005), (Lechner & Baumann, January 2000), (ESA, 2012)]

3.2.2 Differential Global Positioning System (DGPS)

DGPS systems were developed to deal with some basic problems of GPS for example as mentioned by kowoma.de (2012): satellite geometry, multipath effects as shown in figure 3.3, atmospheric effects, clock inaccuracies and rounding errors and relativistic effects. These systems are also like GNSS only suitable for outdoor navigation and positioning.

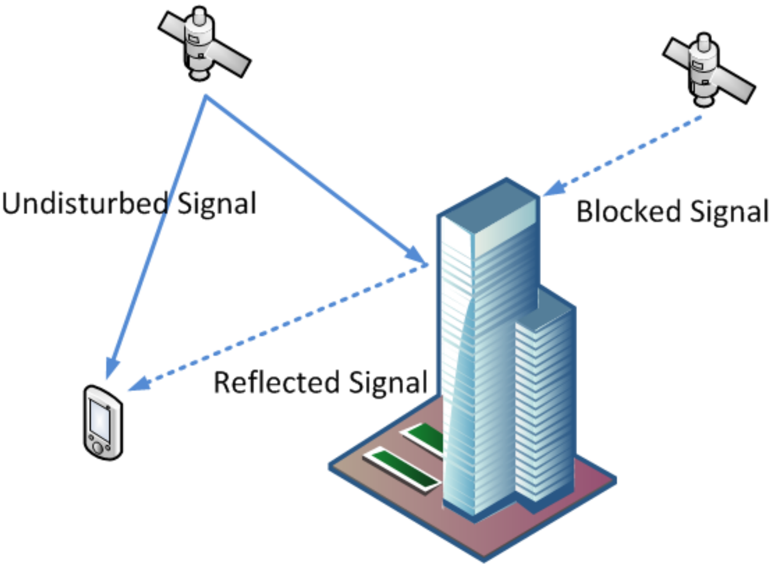


Figure 3.3: Different GPS Signals (personal design)

The technology is based on the concept that positioning inaccuracies at one specific place are similar for all locations around up to 100 kilometres. Fixed receivers at specific locations on top of buildings keep track of measuring errors, for example due to atmospheric effects. The data is gained by the knowing of the exact location of the fixed receiver and the calculation of its place by the communication with a set of satellites. The difference between the known and calculated location is the error which is called differential correction data. The fixed receivers transmit the differential correction data to GPS or GLONASS receivers in the area around them. The mobile receivers use this data to correct the information received from the navigation satellites and can determine the position more precisely. With this technique an accuracy between three to five metres can be achieved.

[(Lechner & Baumann, January 2000), (Walsh et al., 1997), (kowoma.de, 2012)]

3.2.3 Assisted Global Positioning System (AGPS)

AGPS is a technique to transfer additional supportive data for GPS positioning to determine the position faster and more accurately. The system is designed especially for handsets. An AGPS consists of three main components as described by Djuknic & Richton (February 2001) and shown in figure 3.4:

- Handset: For AGPS the mobile device only needs a partial GPS receiver.
- AGPS System: Consisting of a server and a GPS receiver which communicates with exactly the same satellites as the handset.
- Wireless Network Infrastructure: Composed of a so called Mobile Switching Center (MSC) and base stations to send the additional supportive data to the mobile handset.

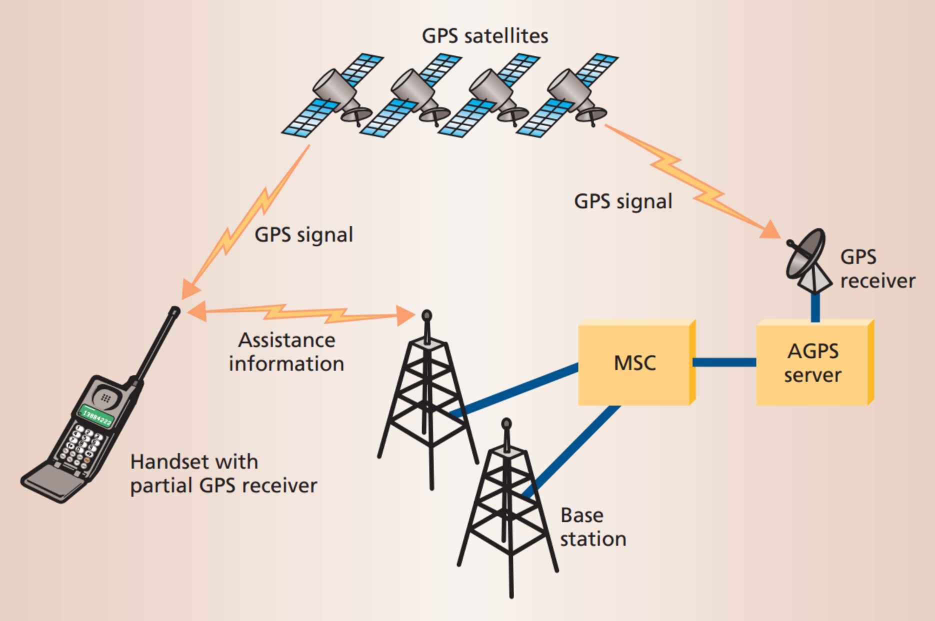


Figure 3.4: AGPS (Djuknic & Richton (February 2001, p. 124))

The problem of common GPS receivers is that it often takes them one or two minutes to search for satellites. This time is called time-to-first-fix (TTFF) and is dramatically lower for AGPS systems like it is with battery consumption. This is due to the fact that the AGPS System determines the approximate position of the device by communication with the satellites and sending the information to the handset. The handset now knows its approximate position and only needs a partial GPS receiver to determine the exact position. This system achieves an accuracy of 15 metres for outdoor positioning and can also be used to some extent for indoor positioning. Common AGPS systems can reach an indoor accuracy of 50 meters. van Diggelen (2002) describes an AGPS based approach by adding two sensors to a cell-phone which reached an accuracy of 17 metres in a test in a shopping mall.

[(Djuknic & Richton, February 2001), (van Diggelen, 2002)]

3.2.4 Pseudolite Global Positioning System (PGPS)

One of the major problems of GPS is the weak signal strength. PGPS is a system that was developed for positioning in areas where common GPS positioning was not possible, for example such as mines, canyons or indoors.

The technique was investigated in the 1970ties and uses additional GPS transmitters located on the ground. Pseudolite transmitters usually make use of the L1 signal frequency as described in the chapter 3.2.1.1. PGPS helps to improve the accuracy, availability and reliability of the GPS system in certain areas. Concerning indoor navigation PGPS transmitters totally replace the satellites. This technology is very interesting due to the fact that nowadays all smartphones are able to receive GPS signals.

Outdoor navigation satellites have atomic clocks in order to make accurate positioning possible. Because they are very expensive, pseudolites use other clocks and different systems to cope with the problem: an asynchronous and synchronous system, which differ in the way they handle the clock synchronization. Figure 3.5 shows an overview of a possible ubiquitous positioning solution with GPS satellites and pseudolites for both indoor and outdoor navigation.

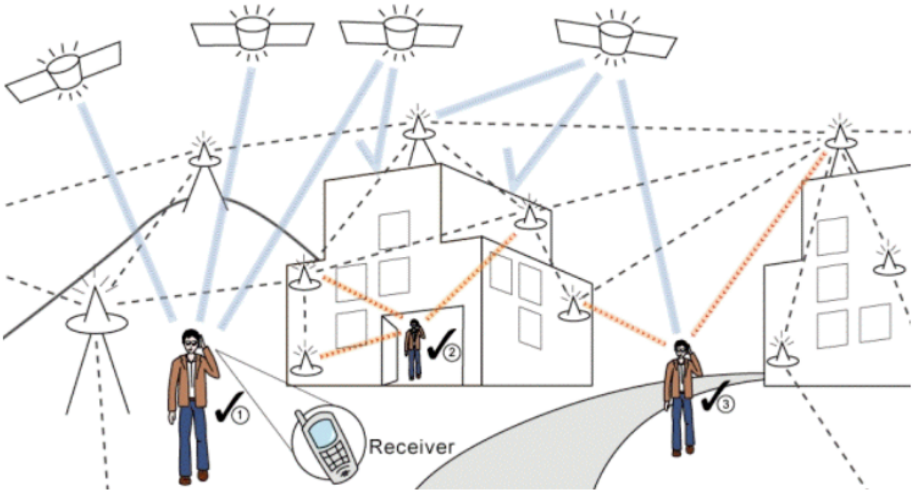


Figure 3.5: Ubiquitous Positioning Solution (Rizos (2005, p. 7))

The publication by Kee et al. (November 2001) describes an indoor PGPS based positioning solution that reaches centimetre accuracy with ceiling-mounted pseudolites. Unfortunately the paper does not state the exact costs that were necessary to realize the system. They just claim to proceed the research in order to make the technology practical to use and inexpensive. The solution sounds very promising, but there are also some problems in practice which are mentioned by Rizos (2005):

- L1 frequency signal
  In order to receive the signals from GPS pseudolite transmitters with common receivers as they are built in in smartphones, the signals have to be sent at the same frequency. The problem is that this frequency band is protected by law worldwide.

- Combination of satellites and pseudolites
  It is very likely that pseudolites totally cover the signals from satellites which makes a combination impossible. Also distortion and so false positioning is hard to avoid.

- Insufficient multipath mitigation for indoor pseudolites.

Rizos (2005) also mentions two geolocating systems which work with pseudolites and overcome some of the before mentioned problems: **Novariant** and **Locata**. Locata is a system developed by Locata Corporation. The network is called LocataNet and consists of time-synchronized pseudolite transceivers named LocataLite and Locata receivers. The system uses a special time-synchronisation solution and operates on a different frequency band than L1. Although the system reaches accuracy within a centimetre it is not suitable for wide-spread indoor navigation in public buildings. The costs for a LocataSystem consisting of ten LocataLite transceivers and two Locata receivers would be about US $250K. Additionally Rikard & Vlad (2005) claim in their thesis that they were not able to find and buy any pseudolites.

[(Kee et al., November 2001), (Rikard & Vlad, 2005), (Rizos, 2005)]

3.3 Infrared (IR)

According to Gu et al. (2009) indoor positioning systems using IR are the most widespread ones. Main reason for this is that IR chips are built-in in many mobile devices, such as mobile phones and Personal Digital Assistants (PDAs). The IR technology has some basic constraints compared to other technologies. In order to determine the position of a mobile device the LOS between receiver and transmitter must be free of any obstacles. Hence every room needs its own IR infrastructure. The IR signal is also vulnerable to the interference of light sources (Gu et al. (2009)).

The **Active Badge** Location System is one of the first indoor positioning solutions using IR technology. It was developed in the early 1990s by engineers at AT & T in Cambridge. The system is the predecessor of the UWB based solution Active Bat developed in 1999 by the same engineers (see chapter 3.5). The system consists of three main components:

- Badges
  These are IR senders which are carried by the persons to track. Every emitter has its own unique IR signal in the system. Every 15 seconds the badge sends a signal. It is very small and measures only 55x55x7 millimetres.

- Receivers
  Receivers are placed in every room to detect the signal sent from the badges. The more receivers the more accurate is the position that the system can determine. One receiver per room for example would be enough to achieve room level accuracy. The receivers are connected to a PC which collects the data and determines the position of the badge.

- Central Server PC
  The Central Server PC receives the location data from the receivers and has a running application on it. The system was used in Cambridge to help the telephone receptionist forwarding calls to people. The application held a table of badges carried by people, their location (room number) and the telephone which was closest to the badge.

Advantages of the system are that it is very cheap and easy to install. Major disadvantages stated out are that the persons can not be tracked in real-time but ever 15 seconds to reach an acceptable battery-life-time of about half a year. The capacity of batteries might have improved in the last twenty years. The accuracy of the system was overall very low and within several metres, but this was not important for their application. The Active Badge Location System using IR was not further improved by

AT & T due today. (Gu et al. (2009), Want et al. (1992))

Another more accurate commercial system using IR is **Firefly**. It is developed by Cybernet System Corporation and enables 3D position and motion tracking. For that several IR tags are mounted on the object and connected to a Tag Controller as shown in figure 3.6. The tags are sending IR signals which are tracked by the Camera Array. As mentioned Firefly is a commercial system and hence does not give detailed insight in its system. The Tag Controller is connected via wires to the small tags and so time-consuming to be applied. The Camera Array consists of three cameras receiving the IR signals and calculating the position. The motion and positioning information can be used for many applications such as computer games.

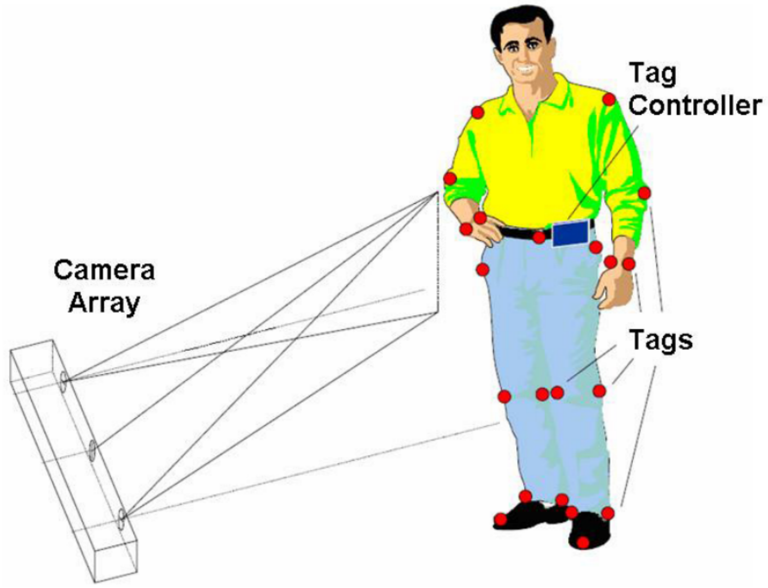


Figure 3.6: Firefly System Overview (Gu et al. (2009, p. 20))

Really impressive, the system can reach an accuracy of 3 millimetres and the tracking is possible in real-time with doing about 30 scans per second. The costs of a Firefly system consisting of a Camera Array, a Tag Controller and 32 tags is US $27500. And the system has some more disadvantages. The area in which tracking is possible is limited to seven meters and so not suitable for many applications as indoor navigation in buildings. Last but not least the system is as all IR based solutions vulnerable to light interference. (Gu et al. (2009))

Infrared Indoor Scout - Local Positioning System (IRIS-LPS) is another IR, more modern based indoor positioning approach developed at Darmstadt University of Technology. The system uses fixed cameras to receive the signals of an IR emitting tag. The position of the tag is calculated by measuring the angles of arrival using the AOA (see chapter 2.1.3) measuring principle and the triangulation (see chapter 2.2.2) positioning approach. As all IR based systems IRIS-LPS needs its own environment for every room. The solution was tested in a lecture hall of about 100 square-metres using two cameras. The cameras receive the signals and hand the information on to a computer which determines the location of the tag. The system reached an accuracy of within 16 centimetres in the evaluation. Although it is not so accurate as the Firefly technology the result is well and the accuracy enough for many applications. Major advantage of the IRIS-LPS system is that it is not commercial, cheap, easy to employ and can cover much larger areas as Firefly. (Gu et al. (2009), Aitenbichler & Mühlhäuser (2003))

For the sake of completeness, it must be mentioned that there are also so called passive IR indoor localization systems as described by Kemper & Linde (2008). These systems are characterized by using thermal radiation detected by IR cameras to determine the position of a person and so do not need any sensors on the target object. Due to the fact that this certain technique has no importance to smartphone based indoor navigation systems it is not further described in this thesis. (Kemper & Linde (2008))

In conclusion IR may be an acceptable possibility for some indoor positioning and navigation applications using smartphones. Main disadvantage is that the technology is not very robust because the IR signal is influenced by light and it does only work in LOS environments, even clothes can cause a problem. Another disadvantage is the expensive hardware. The emitters are cheap but the receivers recognizing are very expensive due to the fact that you need several of them in every room for accurate positioning determination. Another very interesting point is that the paper by Gu et al. (2009) written in 2009 states out that IR is a widespread indoor positioning solution because amongst others, mobile phones are equipped with IR sensors. This fact was true for mobile phones, but now - three years later - there is no new smartphone that has a built in IR chip, except the Lumigon T2 which is a designer smartphone and expensive. The first smartphones developed by Nokia, Motorola and Sony Ericsson had IR chips. Main reason for this incident is that Bluetooth more or less replaced IR because of better transfer rates and range. The Android SDK for example never supported IR.

[(Gu et al., 2009), (Want et al., 1992), (Aitenbichler & Mühlhäuser, 2003), (Kemper & Linde, 2008)]

3.4 Bluetooth

Bluetooth was developed by engineers of the Swedish company Ericsson in 1994. It is defined in the Institute of Electrical and Electronics Engineers (IEEE) 802.15.1 standard for Wireless Personal Area Networks (WPANs). Five companies funded the Bluetooth Special Interest Group (SIG) which more or less own the technology and are responsible for further developments. Bluetooth's newest version is v4.0 which achieved some great advances over the old versions. The technology operates in the 2.4 Gigahertz (GHz) Industrial, Scientific and Medical (ISM) Band and makes communication possible up to 100 metres. Bluetooth chips can nowadays be found in nearly every smartphone, car, laptop and many other mobile devices. Regarding smartphones Bluetooth replaced the IR ports of the phones of almost all manufacturers. The chips are very small in size and of low cost. Each Bluetooth device has a unique ID and the technology allows networking services such as Internet Protocol (IP). The newest version is especially marked out by its low power consumption. This features of Bluetooth make it possible to use the technology for indoor navigation and positioning systems. (Gu et al. (2009), bluetooth.com (2012), Liu et al. (November 2007))

The most well-known and one of the first indoor navigation systems that uses Bluetooth is **Topaz**. As described by Gu et al. (2009) and Liu et al. (November 2007) the solution mainly consists out of three components as shown in figure 3.7:

- Location Server
- Bluetooth Server
- Mobile Tags

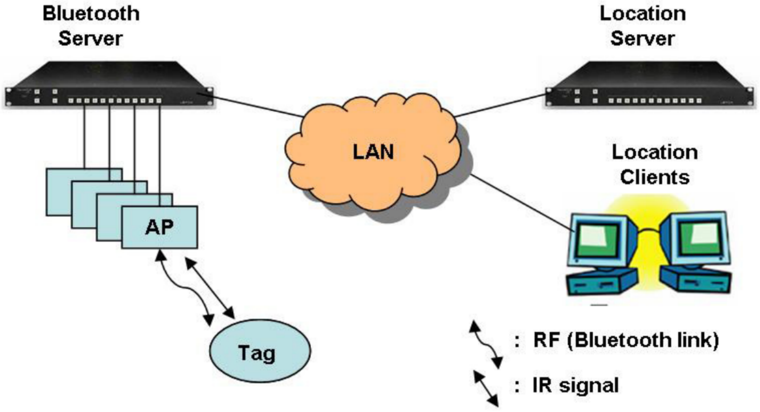


Figure 3.7: Topaz System Overview (Gu et al. (2009, p. 25))

The solution allows the tracking of mobile tags within an accuracy of two metres and a positioning delay between 15 and 30 seconds. The system was improved by also using the IR technology and reaches room-level-accuracy. Main disadvantages are the low accuracy compared to other systems, the high delay time and the charging of the batteries of the mobile tags every week. (Gu et al. (2009), Liu et al. (November 2007))

A more modern system described by Fischer et al. (2004) uses Bluetooth and the TDOA measuring technique (see chapter 2.1.6) to calculate the position indoors. TDOA needs exact time measurements in order to determine the position accurately. So the system consists out of four time measurement stations which communicate via Bluetooth with the mobile device. The stations are connected to a PC which is the main control unit and calculates the position by the time measurements. The most important part of the system is the time measurement unit since the accuracy is only dependent on these measurements. In experiments this system reached an accuracy within two meters.

Anastasi et al. (2003) reports on another indoor navigation solution. The system is not designed for highly accurate indoor positioning, just for tracking walking and standing users within a building. It uses Bluetooth piconets in every room for determining at which room the device is located. The piconets are connected over Local Area Network (LAN) with a Bluetooth Indoor Positioning System (BIPS) Server. Each piconet covers an area of about 20 meters. Whenever the device enters another piconet the event is communicated to the server. The approximate position within a piconet cell can be estimated by the average walking speed.

Finally one can say that Bluetooth is a justified solution for indoor positioning with smartphones for certain applications. All modern phones have a built in Bluetooth chip, the technology is of very low-cost and low-power consumption. Major disadvantages are of course the overall low accuracy and the positioning delay.

[(Gu et al., 2009), (bluetooth.com, 2012), (Anastasi et al., 2003), (Fischer et al., 2004), (Liu et al., November 2007)]

3.5 Ultra-Wideband (UWB)

The military developed the UWB technology in 1960. It is a radio system that is suitable for communication and radar applications because it uses large bandwidths of over 500 MHz. UWB ensures reliability and accuracy. It counters the problem of Multipathing. Signals can go through barriers as doors or walls and the location can be determined very accurately. The technology received a growth of interest in 2002 as the U.S. Federal Communications Commission (FCC) allowed unlicensed use. UWB was firstly intended for use in low ranged networks called Personal Area Networks (PANs) as described in the IEEE 802.15.3a standardization attempt, which was never specified. The system can also be used for wireless sensor networks and so indoor navigation. The main advantages are low-power consumption, low-cost implementation and especially the high accuracy of positioning within centimetres that can be reached. The UWB technology for positioning is an intense field of research because it can be used for many applications like logistics, rescue and military. These possibilities of UWB pushed the development of a standard for a physical layer for low data rate communication defined in the IEEE 802.15.4a standard. (Renaudin et al. (July 2007), Gezici et al. (July 2005)) Indoor navigation systems that are implemented with UWB use different measuring techniques: AOA, TOA, TDOA and RSS as described in chapter 2.1 (Gigl et al. (2007)).

Hightower & Borriello (August 2001) describes two slightly different solutions that make use of UWB:

- **Active Bat**
  This solution was developed by AT & T in 1999 and uses TOA (see chapter 2.1.5) measuring and the lateration (see chapter 2.2.2.1) technique to determine the position. It consists of ceiling-mounted receivers, controllers and so called Active Bats that can be located. The controller is the main element. To determine the position of the Bat the controller orders the Bat to send a signal to the ceiling-mounted receivers. At the same time the controller also sends a reset signal to the receivers to reset the clock and exactly measure the time the signal takes to travel from the Bat to each receiver. The receivers calculate the distance by the measured time and forward it to a main controller which can then calculate the position of the Bat by lateration. This system reaches an accuracy of nine centimetres but has also some disadvantages: accurate placement of ceiling-mounted receivers, the number of receivers needed and so scalability and costs.

- **Cricket**
  The Cricket system works somehow similar to the Active Bat solution, but instead of using ultrasonic receivers on the ceiling and a controller that sends the signals

> it uses a couple of emitters placed around the room and only one receiver to locate. The system is also based on TOA, but uses lateration and proximity techniques see chapter 2.2.4) to determine the position. The time synchronisation and calculation is done by the mobile receiver. Because the calculation is done by the mobile receiver, the emitters does not have to be placed at fixed location like it is in the Active Bat system. Compared to Active Bat the system's advantages are privacy and decentralized scalability, but the system has also some major disadvantages. The computation is more complex and due to the fact that the system uses more than one emitter the power consumption is a multiple. The accuracy is also much lower. It does only achieve an accuracy in a range of 4 x 4 feet, which is approximately 1.5 square-meters. (Priyantha et al. (Augsut 2000))

According to Fujitsu (2012) Japan's National Institute of Information and Communications Technology (NICT) and Fujitsu together develop an indoor guidance technology using UWB and smartphones especially for blind people since July 2012. The system is under development and consists at the moment of several fixed UWB emitting base stations, mobile stations - one applied to the smartphone and some to predefined destinations - and a PC which is the main control unit as shown in figure 3.8.

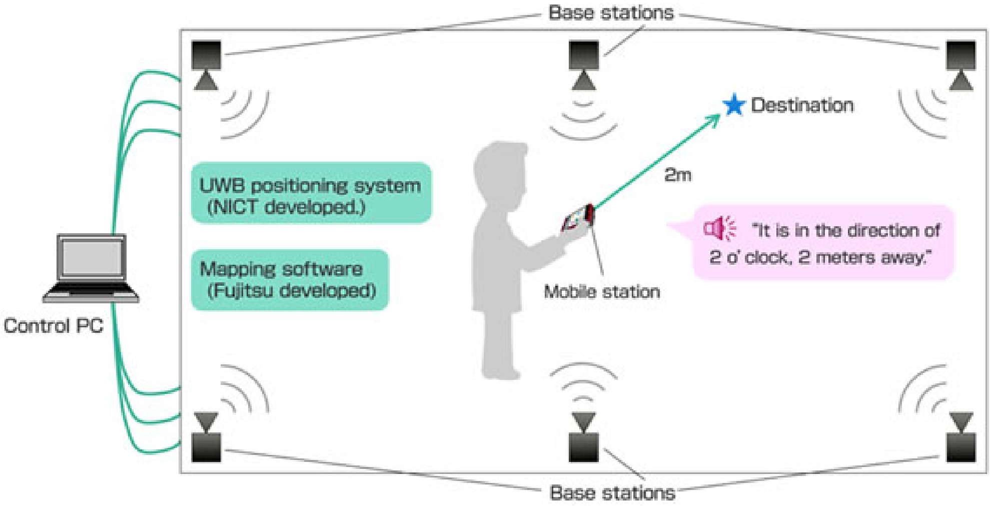


Figure 3.8: NICT and Fujitsu Indoor Guidance Technology System Overview (Fujitsu (2012))

The system determines the position as follows: The distances between the base stations and the mobile stations are determined by the base stations and sent to the control PC which can perform the intense positioning calculation in real-time. The information is then sent via Bluetooth to the smartphone. The technology achieves an accuracy within 30 centimetres. Main advantage of the system is that is implemented for the use with smartphones, although it is only a receiver for location information via Bluetooth. The smartphone is not able to do the calculation and needs an additional UWB receiver attached to it.

Modern UWB systems can reach an accuracy within millimetres as described by Zhang et al. (2006). The technology seems pretty suitable for indoor navigation with smartphones in the near future, although it might be hard to calculate the position in real-time with smartphones, but the computational power of smartphones as well as the performance of algorithms will improve. It was also not possible to find a smartphone that already supports UWB by itself.

[(Renaudin et al., July 2007), (Gezici et al., July 2005), (Gigl et al., 2007), (Hightower & Borriello, August 2001), (Priyantha et al., Augsut 2000), (Zhang et al., 2006), (Fujitsu, 2012)]

3.6 Wireless Local Area Network (WLAN)

WLAN is one of the most common used technologies for indoor navigation. It is defined in the IEEE 802.11 standard and uses the same band as Bluetooth, the ISM Band at 2.4 GHz. The range covered by a WLAN network is up to 100 metres. Many WLAN indoor positioning solutions are based on RSS (see chapter 2.1.4) and Location Fingerprinting (see chapter 2.2.3.1), because these systems are suitable for any indoor environment and often no additional hardware has to be deployed. Different WLAN hotspots are available in nearly every bigger building, such as shopping centres, and WLAN antennas have become standard in many mobile devices like smartphones, PDAs, laptops or even some MP3-players. These devices are capable to passively scan the RSS values of surrounding WLAN APs. Many platforms such as Android offer an easy way to query the RSS values over their Application Programming Interface (API). Besides RSS, also TOA, TDOA or AOA (see chapter 2.1) measurement techniques can be used to implement a positioning system with WLAN. The accuracy of WLAN indoor positioning systems is usually between three to 30 metres and is dependent from many different factors as mentioned by Gu et al. (2009): movement and orientation of the device, overlapping of APs, number of devices around, walls and doors. (Liu et al. (November 2007), Leppäkoski et al. (2010), Gu et al. (2009))

RADAR is one of the most well known IPS using WLAN. It was developed at Microsoft Research and described in Bahl & Padmanabhan (2000). The system is a common one using RSS, Location Fingerprinting and Triangulation (see chapter 2.2.2) to determine the position of a mobile device. RADAR is split into two phases: off-line phase and real-time phase. A total of four Pentium-based PCs was used to develop the system for a 43.5 x 22.5 metres area, three working as base stations and one mobile host. The first step in the off-line phase is synchronizing the clocks of the mobile host and the base stations. Afterwards Fingerprints are measured at some positions by clicking on a map showed by an application on the mobile host which then sends User Datagram Protocol (UDP) packets to the base stations. The base stations saves the RSS value and a timestamp to latter on link the measurement to a position on the map. During their tests the researchers at Microsoft recognized that the Fingerprints also depend on the direction the mobile host is facing and so started to additionally record the orientation to the Fingerprints. At the end of the off-line phase the different measurements concerning the orientation for one point are averaged and saved in a database. In the real-time phase the mobile host gets located by measuring the RSS values at a specific point and searching for the most similar measurements in the database. The position is then determined by Triangulation. The system reaches an accuracy of two to three metres for locating and tracking the mobile host inside a building. (Bahl & Padmanabhan (2000))

Yamasaki et al. (2005) describes a TDOA (see chapter 2.1.6) based approach for indoor positioning using WLAN. Compared to AOA (see chapter 2.1.3), time based approaches do not need complex systems with multiple antennas. The TDOA system is composed of three main components: a location server, AP (receivers) and a special signal emitting tag (station). In order to calculate the position of the tag by TDOA measurements the clocks of the access points have to be synchronized. This is done by sending a synchronization packet by a dedicated master access point to its slaves. All access points additionally know it exact location. An overview of the system is shown in figure 3.9.

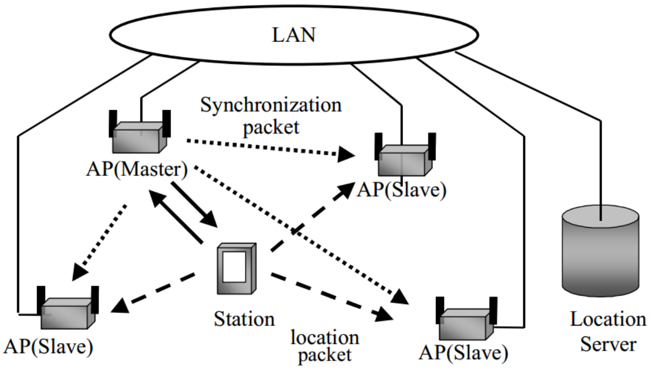


Figure 3.9: TDOA based WLAN IPS Overview (Yamasaki et al. (2005, p. 2340))

Besides the synchronization problem there is also a packet selection problem. In order to determine the position with TDOA different packets has to be sent at different times. To determine the time, the APs have to differ between so called control and location packets. In this system APs are not WLAN emitting stations, but they receive them and additionally consist of a CPU, a wireless and a computational module. This makes the system a lot more complicated and harder to implemented compared to RSS based systems. The system was evaluated in a storehouse using ten APs. It reached an accuracy within 2.4 metres in 67% of all measurements. (Yamasaki et al. (2005))

To realize an accurate IPS for smartphones using WLAN only RSS based solutions are realizable. AOA requires additionally hardware to determine the angles of arrival and for time based approaches, as TOA and TDOA accurate time measurement units are needed. According to Kaemarungsi (2006) AOA and TDOA are not as good suitable for NLOS environments and multipath effects as Location Fingerprinting because they suffer from inaccurate angle and time measurements.

[(Liu et al., November 2007), (Leppäkoski et al., 2010), (Gu et al., 2009), (Bahl & Padmanabhan, 2000), (Yamasaki et al., 2005), (Kaemarungsi, 2006)]

3.7 Radio Frequency Identification (RFID)

The RFID technology is based on radio-frequency electromagnetic fields that allow the communication between a tag and a reader. It is similar to the well-known barcode system, where the barcode is replaced by a RFID tag with an antenna and a reader that communicates by radio-frequency instead of optics. RFID systems consist of three main components: a number of RFID tags, readers and the communication between them. Basically we differentiate between two RFID technolgies:

- Passive RFID
  Passive RFID tags are small and very cheap because they work without any battery. This tags allow communication with readers in short ranges of about one to two metres. The reader sends a signal to the passive tag which simply reflects information by modulation of the received signal. Passive RFID is typically used for replacing the traditional barcode system.

- Active RFID
  In comparison to passive RFID, active RFID tags are more expensive and bigger in size because they make use of their own battery and so allow communication of up to several metres. The tags are able to actively transmit their ID and additional information to a reader. This systems can for example be used for IPSs.

[Renaudin et al. (July 2007), Liu et al. (November 2007), Gu et al. (2009)]

WhereNet is a positioning solution using RFID developed by Zebra Technology Company that allows indoor as well as outdoor real-time positioning. It uses a form of TOA (see chapter 2.1.5) in order to calculate the position of tags. The system consists of the following components which are shown in figure 3.10:

- Tags
  The system can keep track of RFID tags which can be mounted to objects and persons. It is an active RFID system and so the tags use batteries. The tags are 6.6x4.4x2.1 centimetres in size and their battery power lasts seven years on average.

- Location Antennas
  Several antennas are placed on the ceiling at predefined known locations. These antennas receive the signals from the tags and hand the information on to the location processor.

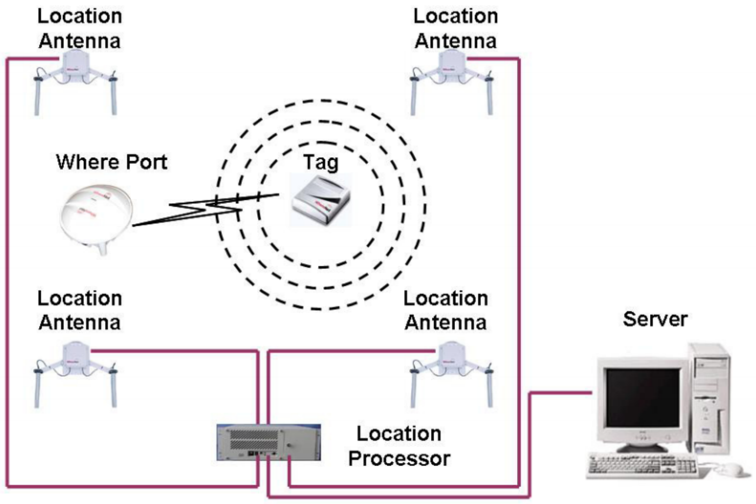


Figure 3.10: WhereNet System Overview (Gu et al. (2009, p. 23))

- Location Processor
  It receives the information from the antennas and is able to determine the position of the tags. The position information of the tracked tags is sent to the server.

- Server
  The server stores the location information of all tags and makes it available to applications.

- Where Ports
  The ports are placed at different locations and are responsible for sending electromagnetic signals to the tags dependent on the application running to trigger the transmission of certain information to the antennas.

The overall accuracy that can be reached with this system is within a range of two to three metres which is not very accurate for IPSs but due to the low price suitable for many applications. (Gu et al. (2009))

Another very well-known system is **SpotON**. It was developed at the University of Washington and allows 3D location determination. For that the solution makes use of an aggregation algorithm using RSS and triangulation (see chapter 2.1.4 and 2.2.2). The system consists of mainly three components: a server, base stations to receive the signals and tags that can be located. Hightower et al. (Feburuary 2000) specify the total hardware costs in their paper between $30 and $40 and claim that it will be possible to reach an accuracy within one cubic metre, although the system had several problems such as accuracy, measurement frequency and power consumption during development.

(Liu et al. (November 2007), Hightower et al. (Feburuary 2000))

The **LANDMARC** system is another very similar approach to SpotON. The system tries to improve the accuracy by placing additional fixed tags at known locations to help the positioning determination. It is also based on RSS and uses the K-Nearest Neighbour (KNN) algorithm to calculate the position of a tag. The error distance reached by this system is between one to two metres. Ni et al. (November 2004) describes three main problems with RFID based IPSs: no RFID chip reports the RSS directly, long delay when trying to track a tag, variation of the emitted RSS by tags. (Liu et al. (November 2007), Ni et al. (November 2004))

RFID based sytems for indoor positioning can be a justifiable alternative for smartphones in the future when they get equipped with RFID readers. As we have seen the system has some drawbacks as accuracy and robustness but is also very cheap in price and can be used for several LBSs in indoor environments.

[(Renaudin et al., July 2007), (Liu et al., November 2007), (Gu et al., 2009), (Hightower et al., Feburuary 2000), (Ni et al., November 2004)]

3.8 Near Field Communication (NFC)

The NFC technology is based on the RFID technology described in the previous chapter (see chapter 3.7). NFC chips belong to the category of passive RFID. This means that NFC is a wireless communication that only works in short ranges of up to a few centimetres. The signals are sent at 13.56 MHz and a bandwidth of 424 kbit/s. NFC based IPS are very simple and can not be used for real-time tracking of objects or users. The system basically consists out of two components: a set of NFC tags and a NFC or RFID reader. The tags are mounted at certain locations within a building, for example at room labels. A user can use a smartphone with a RFID reader, for example the Google Nexus S, to determine his or her location. At the building's entrance a NFC tag can link to a map of the building with the locations of the NFC chips inside. An application can now show the route to a specific room which is linked to an NFC tag. As already mentioned, NFC does not allow real-time tracking, but the user can just check the position by scanning any NFC tag inside the building. Figure 3.11 shows the principle of such a system.

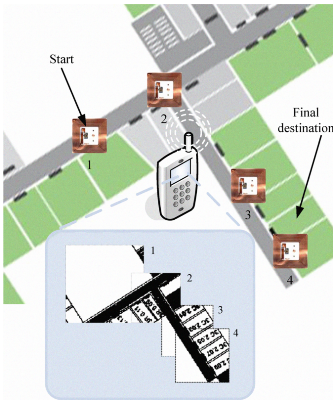


Figure 3.11: NFC IPS Principle (Loeffler et al. (2009, p. 472))

The system provides exact accuracy in front of NFC tags but is not able to allow real-time tracking. NFC might be interesting for some applications because it is very cheap and easy to install. Today there is only a very small number of smartphones that have built in RFID readers, but due to the fact that in future RFID will allow us to unlock our cars or pay, RFID readers will become a standard chip in smartphones. Till then Quick-Response-Codes (QR-Codes) and smartphone cameras can be used instead of NFC chips and RFID readers to implement such a system.

[(Ozdenizci et al., April 2011), (Loeffler et al., 2009)]

3.9 Inertial Sensors

Navigation based on inertial measurements is a promising field of research. In comparison to all other approaches such as WLAN or GPS no additional signal emitters are used. The main components of an inertial measurement based indoor navigation solution are a Micro-Electro-Mechanical System (MEMS), including the inertial measurement unit, and a floor plan. Due to the fact that all smartphones are equipped with a gyroscope and accelerometers, such a solution is also realizable for smartphones.

At Graz University of Technology researches in this field have been driven by the need for disaster management systems, for example for first responders in case of fire. These systems are called Computer Aided Disaster Management System (CADMS). Very important for them is that they are fully functional in environments where no additional hardware is employed and no further measurements have to be taken. It uses inertial measurements, a floor plan and a magnetometer to estimate the position of a person inside a building. It is very hard to determine the exact position only by the circular acceleration caused by the movements of a person. In order to cope with the inaccuracies the position of the user is automatically fixed by the system using the floor plan. The user is also able to manually update his current position. The system has to be configured by walking a hundred meter distance. As mentioned in Walder (2009) the system reaches an accuracy within two metres and is also able to determine altitude differences of about 30 centimetres within three metres. One of the major drawbacks of this system is that the used MEMS costs about 1.650€, but the price would be dramatically lower when these systems would be produced in greater quantities. Out of this researches a spin off company called **AIONAV** has been funded which are selling this system to fire-fighters, the military, the police or as LBS systems. (Walder (2009), Glanzer et al. (2009))

Link et al. (2011) describes the development of an indoor navigation system called **FootPath** for smartphones using the accelerometer and magnetometer. The accelerometer is used for step detection, the magnetometer is required for determining the direction in which the user is moving. Sequence alignment algorithms serve to match the steps to the defined route. FootPath was implemented for Android and is integrated in OpenStreetMap. These systems are mostly inaccurate and not very robust, because they depend on the quality of the hardware sensors and the estimation of several factors, such as the orientation of the user, the average walking speed or the step size. The described system reached an accuracy of at best 1.6 metres to 5.6 metres in indoor experiments. Very often inertial measurements are combined with other technologies such as WLAN, Bluetooth or IR to achieve a better accuracy. (Glanzer et al. (2009))

[(Link et al., 2011), (Walder, 2009), (Glanzer et al., 2009)]

3.10 Camera Based Solutions

When it comes to camera based indoor navigation approaches a distinction between two basic techniques can be made:

- Positioning by the detection of tags
  This technique is simple and similar to the NFC approach (see chapter 3.8). Certain tags are placed at specific locations inside a building. A camera is used to recognize the tags and to locate the position of the user. These approaches have in common that they can not provide exact continuous localization as GPS for example. Often the position between tags is estimated by the help of other sensors as a gyroscope to count steps. Such systems are a reasonable alternative to continuous localization systems because they do not require any expensive hardware.

- Camera-based positioning by Location Fingerprinting
  This method is somehow similar to the *WLAN Location Fingerprinting Method* (see chapter 2.2.3.1) and is able to provide continuous localization. In an off-line or learning phase a camera is used to take pictures and store them with location information in a database. Due to the fact that pictures would need a big amount of disk space, often only certain features that are extracted using computer vision out of the pictures, are stored. In the on-line or locating phase the camera is used to take pictures and try to extract the same features as in the off-line phase to determine the location. In comparison to the first method by detection of certain tags, this method is much more complicated. Early researches have been especially driven by indoor navigation for mobile robots.

Cameras have become standard for smartphones today and the quality of cameras is still improving. The next paragraphs will give you a more detailed insight in both above mentioned approaches and will highlight the advantages and disadvantages of them. Some great researches in that field have been done at the Institute for Computer Graphics and Vision at Graz University of Technology.

3.10.1 Positioning by the Detection of Tags

Mulloni et al. (2009) describes a solution for indoor navigation using square markers and a smartphone's camera. This technique does automatic real-time scanning of the environment for tags, whereas NFC or QR-Code based approaches require that the user manually scans tags because of its short range, which usually takes a few seconds. The tag consists of 36 black and white squares which encode 36 bit of information. The system can detect tags where one square is at least two pixels in size in the camera image and the angle is not greater than 70 degrees. The authors implemented an application for Windows Phones called Signpost to allow indoor navigation. In order to make it possible to navigate inside a building someone first of all has to create a database of marker locations linked to a map. Secondly the markers have to be attached to the specified locations. The last step is the release of the application which is a pack of the map, the database and the navigation application. The application was tested at four international conferences where it allowed the guidance inside the building on the basis of a schedule. Users found the application useful although it had some drawbacks as problems with camera drivers and power consumption.

Mulloni et al. (August 2011) explains another system developed for smartphones which uses tags. The approach belongs to the so called 'activity-based' systems. The camera is used to scan a tag. The user can enter a destination. The application then uses augmented reality and displays arrows to show the path and the orientation of the smartphone by the help of the compass. Between the guidance of two tags the system displays activities. Activities are simple turn-by-turn instructions that additionally show the number of steps to the next turn. The graphic 3.12 below shows screenshots of the application.

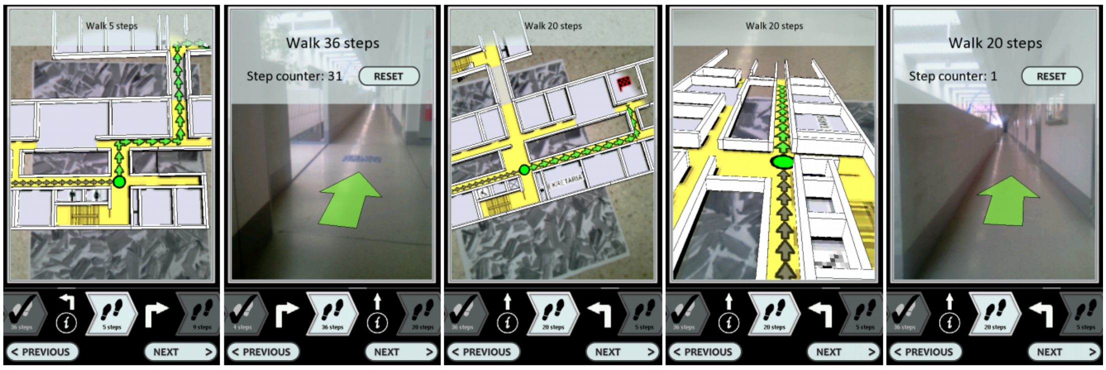


Figure 3.12: Scrennshots of Augmented Reality Activity-Based Indoor Navigation Application (Mulloni et al. (August 2011, p. 1))

The system showed an overall good performance in the evaluation phase. Participants were more comfortable in using this system compared to a system without tags, although some of them had problems. A miscount of steps lead to a navigational error at about half of all participants. Once the application showed the wrong direction of the arrow on the display because of magnetic influences that disturbed the compass. Two out of ten persons had also a problem with the interface showing the turn-by-turn instructions. The system was developed further as described in Mulloni et al. (May 2012). To avoid erroneous navigation due to the interface, the system uses mixed reality, a combination of augmented and virtual reality. Augmented reality views are shown when the system knows the exact position of the user, for example at tags. To make a clear visual distinction virtual reality is used when the system cannot determine the exact location. The newer system always shows an overview of the map and the current position to get a better feeling of the location. Hence screenshots as the second one in figure 3.12 are strictly avoided.

[(Mulloni et al., 2009), (Mulloni et al., August 2011), (Mulloni et al., May 2012)]

3.10.2 Camera-based positioning by Location Fingerprinting

Blanc et al. (April 2005) describes an indoor navigation solution for mobile robots. In the learning stage the robot is guided by a user through the building and takes a series of pictures with the mounted camera to build up navigation paths. This information is saved to the so called visual memory. In the positioning phase the robot has to determine its location by mapping the first picture to his visual memory. If this succeeds the robot can then follow the predefined routes or also called visual paths. In experiments the robot showed a positioning error of approximately five centimetres.

The authors of Jongbae & Heesung (August 2008) developed a system similar to the idea of the one described above. In the first phase, a series of pictures is taken from routes inside a building. The system was designed for indoor navigation of persons and uses augmented reality. The user has a Head Mounted Display (HMD) that is connected to a mobile PC which communicates over WLAN with remote PCs. The remote PCs hold the Location Model and Location Dictionary and try to map the pictures from the HMD to the database. Additionally the system uses 20x30 centimetres large markers to firstly identify the location of the user and start the navigation process by image matching. The markers also allow the authors to cope with the problem of changing illumination in the environment. The system showed a recognition rate of 89% in tests.

The research work by the Institute for Computer Graphics and Vision at Graz University of Technology described in Arth et al. (2009) tries to localize a user by the help of its smartphone camera and computer vision and graphics. One of the major problems of developing such a system is the restriction of computational power, memory and the quality of the built-in cameras of smartphones. Because of that, common solutions for modern PCs are not suitable for smartphones and a completely new system had to be developed.

The system is very complex and makes use of many computer graphics and vision algorithms. As already mentioned the system is divided in two stages: an off-line learning phase and an on-line locating phase. The system uses image based reconstruction algorithms from computer vision to create a complete 3D reference model in the learning phase based on the idea of potentially visible sets. In order to cope with the problem of similar textures inside a building, the phase is divided into suitable blocks, for example rooms. For each block images are taken from one or more specific points. An algorithm then tries to reconstruct the environment by the help of the pictures and extract features which are mapped to a global coordinate system as shown in figure 3.13. It shows a global map of eight blocks.

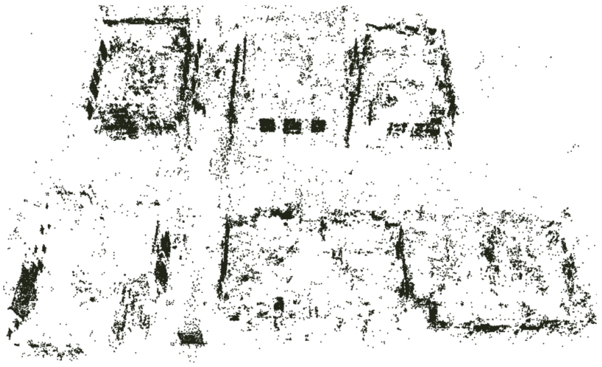


Figure 3.13: Global coordinates system of reconstructed blocks (Arth et al. (2009, p. 4))

Due to the fact that the smartphone was not able to hold the whole map in the memory, the map was separated in a few chunks of data that could be loaded separately. The total map shown in figure 3.13 had a size of 16,789 kB. This incident forces the user to give the system a hint in the location phase where to start the search in order that the system does not have to load all the data. Basically to determine the position the features of the camera's image have to be extracted and matched to the database map. The matching percentage highly depends on the image resolutions and the algorithms used and was between 50% and almost 90%.

In conclusion camera-based approaches by the detection of tags are realizable and as NFC based solutions suitable for some indoor applications that do not need accurate real-time positioning using smartphones. Camera-based systems by Location Fingerprinting are much more complicated because they make use of computer vision and graphics algorithms and hence need much computational power. In comparison to other more simple solutions, for example based on WLAN, the approach has no real advantages.

[(Arth et al., 2009), (Blanc et al., April 2005), (Jongbae & Heesung, August 2008)]

3.11 Magnetic Field

Positioning systems based on the earth's magnetic field is no new area of research, but it gained special attention when Janne Haverinen founded a spin-off company at the University of Oulu (Finland) named **IndoorAtlas** in July 2012. The idea of orientation by the help of the earth's magnetic field derives from the findings that animals, such as spiny lobsters, use it to orientate. The company has developed a system using only the magnetometer of smartphones for indoor navigation and positioning. The system uses the compass to measure the magnetic field inside a building. The combination of the earth's magnetic field and the disturbances caused by steel or other indoor environments make it possible to generate unique floor plans which can then be used to locate a user in the second phase. The figure 3.14 below shows a sketch of how the magnetic field could look like in an indoor environment.

Figure 3.14: Sketch of an Indoor Magnetic Field (IndoorAtlas (July 2012, p. 2))

The solution is somehow similar to a WLAN Location Fingerprinting approach (see chapter 2.2.3.1), but instead of using RSS values of WLAN APs IndoorAtlas makes use of the emitted magnetic field. The major advantages of the Finnish solution are: only a modern smartphone with a built-in magnetometer is needed and no additional hardware as signal emitting base stations have to be deployed. Very promising the researchers claim to reach an accuracy between ten centimetres and two metres.

As already mentioned, the system is similar to a Location Fingerprinting approach and so an off-line phase where magnetic field measurements are taken inside the building is required to make positioning possible. IndoorAtlas provides a complete software solution which consists of three parts:

- Floor Plans
  Floor Plans is a web application which allows the user to upload a floor plan of a building to the company's cloud and link it to coordinates by laying the floor plan over the building on a satellite map.

- Map Creator
  If the floor plan was uploaded to the cloud, the map of the building is available in the smartphone application Map Creator. The user can now identify paths on the plan and record the magnetic field by walking along these paths. The data is transmitted to IndoorAtlas. The cloud then creates the magnetic field map.

- API
  Developers can now make use of the created magnetic field maps using an API to create their own applications. The API as well as the Map Creator application are currently only available for Android smartphones.

(IndoorAtlas (July 2012))

IndoorAtlas is based on the researches leaded by Janne Haverinen. Most of the ideas are illustrated in Haverinen & Kemppainen (2009). The magnetic field inside a building is almost static, depending on steel, concrete, electric power systems, electronic devices and of course the natural magnetic field. The inspiration for magnetic field positioning comes from animals which are able to identify their approximate position by the natural emitted magnetic field. The figures 3.15 show the test setup for indoor localization using a 3-axis-magnetometer for both, robot and person location experiments.

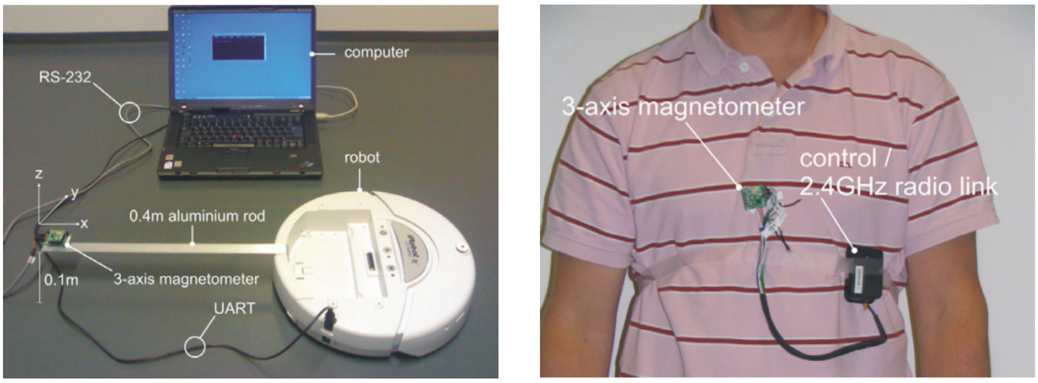


Figure 3.15: Setup for Robot and Person Localization (Haverinen & Kemppainen (2009, p. 1029))

The system is considered as a good alternative for one-dimensional indoor localization systems. Experiments showed that the magnetic field inside a building stays nearly the same over time. In comparison to camera-based systems (see chapter 3.10), it is not dependent on illumination or a change of non-emitting magnetic field objects. (Haverinen & Kemppainen (2009))

IndoorAtlas is the most modern approach of all mentioned in this chapter and has clear advantages over all of them for realizing an IPS. The developers claim that the system achieves high accuracy between ten centimetres and two metres. Additionally it does not need any hardware such as signal emitting base stations. A modern smartphone which allows internet communication and has a built in magnetometer is all the system needs. The described solution could get the leading technology for IPS. Unfortunately IndoorAtlas is still under development and only available for selected developers. The efforts to find any independent evaluations of the software system as well as getting a developer account and testing the solution were unsuccessful.

[(IndoorAtlas, July 2012), (Haverinen & Kemppainen, 2009)]

3.12 Summary

The following table 3.3 and figure 3.16 provide a better overview of the technologies in this chapter by comparing them to certain factors:

- Suitability for Indoor and Outdoor Positioning Systems
- Accuracy, Precision, Complexity, Robustness, Scalability, Cost (see chapter 3.1 for description)
- Range and Accuracy

The values depend on estimations gained by the investigation of the systems described in this chapter and the associated sources. It should be noted that it is hard for some technologies to classify them accurately because there exists different solutions based on the same technology, for example WLAN, that highly differ in accuracy and cost.

Technology	Outdoor	Indoor	Accuracy	Precision	Complexity	Robustness	Scalability	Cost
GPS:								
• GNSS	+	−−	+	+	−	+	++	−−
• DGPS	++	−−	++	++	o	+	o	o
• AGPS	++	−	+	o	−	+	o	−
• PGPS	−−	++	++	++	−−	−	o	−−
IR	−−	+	o	−	+	−−	−	+
Bluetooth	−−	+	o	−	+	+	+	+
UWB	−−	++	++	++	−−	−−	−	−−
WLAN	−	++	+	+	+	+	+	++
RFID	−−	++	++	++	++	++	o	+
NFC	−−	++	++	++	++	++	o	+
Inertial Sensors	+	+	+	−	−	o	++	o
Image Recognition	o	o	o	o	−	−	++	++
Magnetic Field	−	++	+	+	++	o	++	++

Table 3.3: Overview Technologies (personal design)

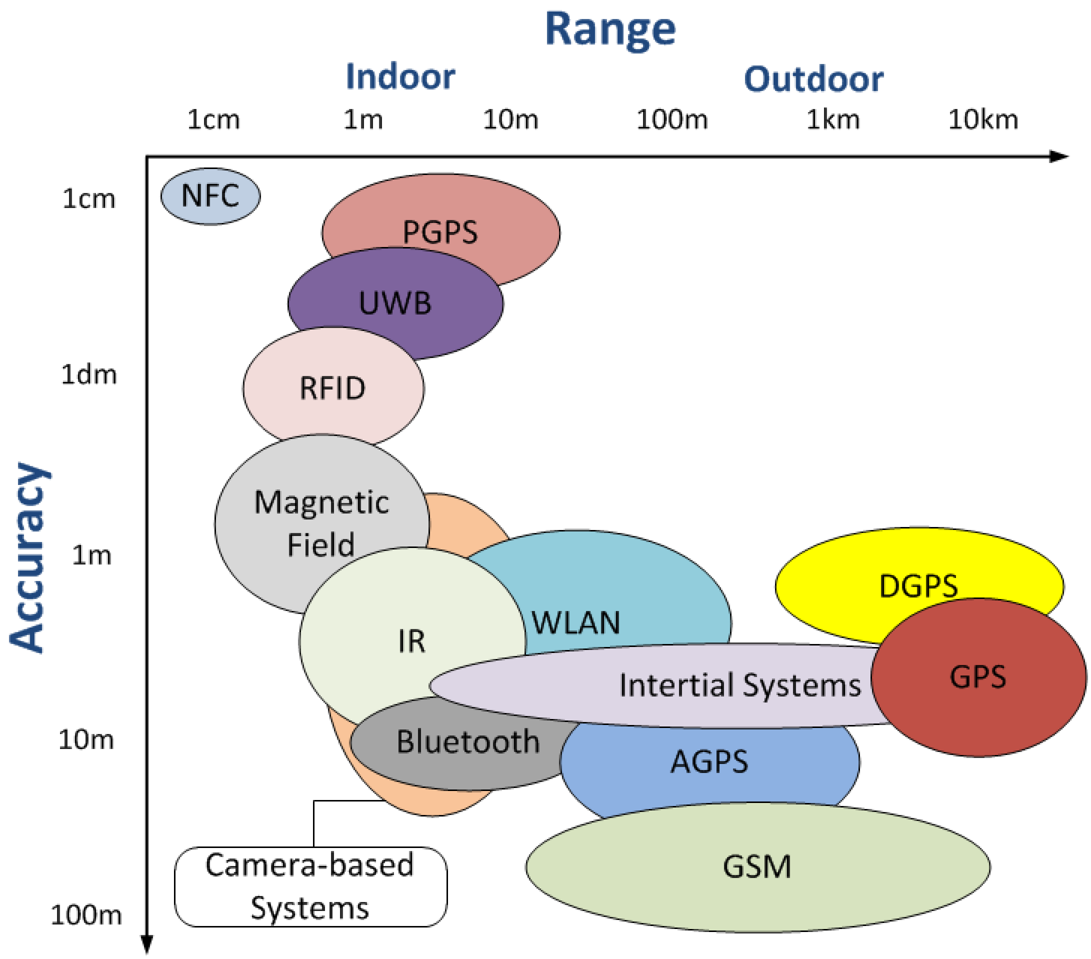


Figure 3.16: Overview Technologies (personal design)

[(Mautz, 2009)]

4 Implementation of a System using fixed WLAN - Routers

4.1 The Idea

The idea is to implement an IPS for smartphones based on WLAN and Location Fingerprinting. The overall goal is that the final system can be deployed to large public buildings like shopping centres, hospitals and museums. The application shall determine the position of a device as accurate as possible and work robustly. As described in chapter 2.2.3.1 on *WLAN Location Fingerprinting*, Location Fingerprinting approaches are divided in two phases and work using the RSS (see chapter 2.1.4) measuring principle. To determine the position in the on-line phase a big amount of reference fingerprints have to be measured in the off-line phase. The number highly depends on the buildings size and the accuracy the final system have to achieve. Common grid widths can range from one to five meters. For a large shopping center and a grid width of five meters the number of reference fingerprints can easily grow up to 2500 or more. In order to overcome the complexity of measuring each and every fingerprint for the Radio Map in the off-line phase an algorithm will be implemented that substantially lowers the number of reference fingerprint measurements. The algorithm must be able to suggest good grid points at which reference measurements have to be taken on the basis of a building's plan, the building's dimensions, the exact course of the walls and the exact places of APs. The idea is that the fingerprint for each and every grid point which distance to a certain AP is crossed by the exact same walls can be interpolated easily and exactly by measuring only one of them. Figure 4.1 shows an example for one suggested grid point for one AP. The red solid line points to the suggested grid point. All other green grid points will be interpolated by the measurement of the suggested one, because the distances between these and the suggested grid points are crossed by the same wall.

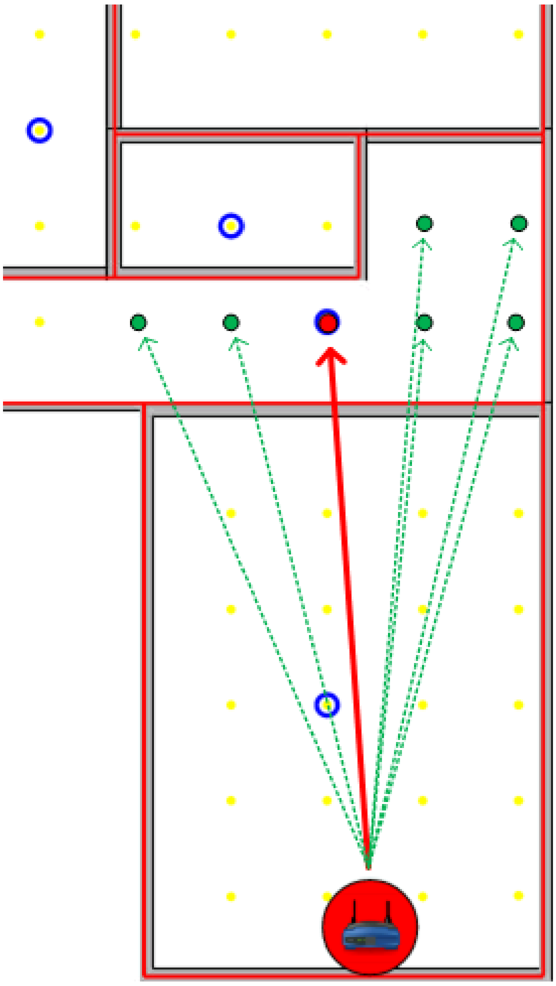


Figure 4.1: Algorithm Description (personal design)

The model for interpolation used is the Log-Distance Path Loss model for LOS environments. The number of measurements that have to be taken is substantially lower and a good accuracy can still be achieved because the system takes care of attenuation factors. The prototype will be developed for the operating system Android.

4.2 Related Work

- *Optimizing Radio Map for WLAN Fingerpriting* (Leppäkoski et al. (2010))
  The publication focuses on improvements during the off-line or learning phase. First tests according probabilistic methods using histograms focus on the distribution and number for histogram bins for every fingerprint location in order to increase accuracy are done. The authors also found out that additional direction information for every RSS measurement at one fingerprint location might be helpful. Evaluation showed that a map averaging RSS measurements from four directions to one fingerprint showed the best values concerning accuracy and memory load, comparing to a map having a separate fingerprint measurement for four directions at one location and another one considering a lower amount of all samples. They also tried to combine RSS measurements from different access points which were comparable to one, by calculating the mean and median. These tests did not show any improvements.

- *Indoor APs Location Optimization Using Differential Evolution* (Zhao et al. (2008))
  The authors of the publication implemented a Differential Evolution (DE) algorithm to optimize the number and locations of APs for WLAN IPSs. It basically tries to maximize the variety of the fingerprints to improve location determination. Their tests show that symmetrical placement is worse than the calculated one by the DE algorithm. According to Zhao et al. (2008) it is better to place the APs in a 'zigzag' pattern. An increasing number of APs stops showing improvements when the system proposes to place them closely together. Importantly, the experiments were made in a single room of 6x12 metres with a number of up to eight APs. Hence the tests did not consider any multipath effects or effects occurring in NLOS environments.

- *Distribution of WLAN Received Signal Strength Indication for Indoor Location Determination* (Kaemarungsi (2006))
  This publication investigates the impacts of using different WLAN cards for Location Fingerprinting IPS. The authors found out that different cards are not developed equally and hence often measure different RSS values at the same location. WLAN cards also do not cover the same ranges. The measurement process is implemented differently by every manufacturer and thus has an effect on accurate location determination. The authors suggest to use the same WLAN card for creating the radio map and location determination or introduce mappings between the cards to the system.

- *Toward Environment Indicators to Evaluate WLAN-Based Indoor Positioning System* Baala et al. (2009)
  The authors of the publication did research on the placement and number of APs depending on the building's architecture. For that the experiments were done at one place only having a few obstacles and another one with a higher number of obstacles like walls (office rooms), both having the same size of 80x40 metres. For places with a lower number of obstacles, a setup with symmetric distributed APs which guarantees a high signal strength distribution is best. Adding APs not always improves the accuracy of such systems, it highly depends on the placement of the APs. Tests in an environment with a higher number of obstacles showed that objects can be located better, because there are higher differences in the measured fingerprints. Overall the best layout of the APs depends on the architecture of a building.

- *Optimization of WLAN Indoor Location Network Based on Signal Coverage Requirement* (Xu et al. (2010))
  The paper describes the so called 'WLAN Indoor Signal Propagation Model' which considers different types of obstacles to calculate the expected signal strength at a certain location and infers the so called 'Coverage Requirement Matrix' from it. The matrix can be used to calculate the number and location for the deployment of APs. Experiments showed that this method is a good trade-off between accuracy and the time costs for the deployment of a suitable WLAN infrastructure.

- *Properties of Indoor Received Signal Strength for WLAN Location Fingerprinting* (Kaemarungsi & Krishnamurthy (2004))
  The authors did some interesting researches on factors which influence the RSS values. They found out that the user shadowing the signal from a device has an impact on the measured RSS values and so does the user's orientation. Measured RSS values at the same location tend to be different when examined over time, for example a day. They also state that the interference of the emitted WLAN signals from different APs is no problem for such systems.

[(Leppäkoski et al., 2010), (Zhao et al., 2008), (Kaemarungsi, 2006), (Baala et al., 2009), (Xu et al., 2010), (Kaemarungsi & Krishnamurthy, 2004)]

4.3 Application in General

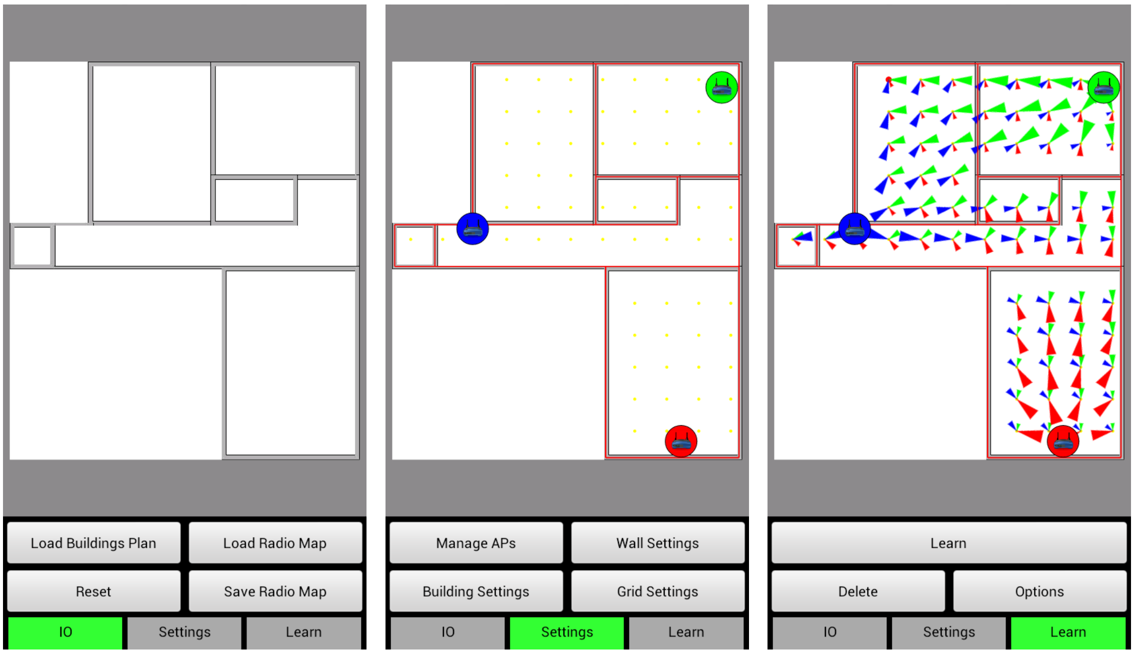
4.3.1 Overview

The prototype is developed for Android version 4.0.3 *Ice Cream Sandwich*. The system mainly consist out of three components which can be selected when opening the application:

- Map Creator
- Navigator
- Testbed

The Map Creator represents the off-line phase of the Location Fingerprinting approach and serves the creation of a map, namely the Radio Map. The Navigator determines and shows the position in a target area using the created Radio Map and hence be compared to the on-line or second phase of the Location Fingerprinting approach. The third component is called Testbed. It is used for testing and the evaluation of the accuracy of the developed algorithm.

4.3.2 Map Creator



(a) Tab IO (b) Tab Settings (c) Tab Learn

Figure 4.2: Screenshots of Map Creator

The Map Creator is the biggest and most complicated part of the application in terms of code. The Map Creator generally consists of one Android Activity holding a SurfaceView for drawing the buildings plan and a menu at the bottom. The menu consists of three tabs, each holding some buttons needed for creating the Radio Map. As you can see in figure 4.2 at the bottom end of the screenshots the tabs and its features are:

- IO
  The tab 'IO' stands for Input/Output and its buttons are mostly self explaining.
  - Load Buildings Plan
    The button 'Load Buildings Plan' is for loading an image of a buildings plan from the smartphone's memory.
  - Load Radio Map
  - Save Radio Map
    Once you have loaded an image the application creates an instance of a Radio

  Map which can then be saved and loaded with the homonymous buttons 'Load Radio Map' and 'Save Radio Map'.

  - Reset
    The 'Reset' button can be used for resetting the Activity.

- Settings
  The 'Settings' tab holds all functions to set different options that are needed for the learning phase and the algorithm.

  - Manage APs
    With the button 'Manage APs' APs can be added, some settings edited or deleted from the current Radio Map. When adding a new AP the application scans the environment for APs and shows their Service Set Identifiers (SSIDs) to select one of them. Afterwards the system asks for some further informations of the AP. The place of the AP has to be set using the plan of the building. In order to set the position of the AP exactly, the distances of the current selected place to the closest walls is shown on the plan. The user can also set the range of the signals the AP covers, as well as a color to visually distinguish between the APs on the buildings plan.

  - Building Settings
    The option 'Building Settings' is needed to set the dimensions of the whole building in width (x-direction) and height (y-direction) in meters. There is also a field to determine the direction with the help of the compass in order to show the user the direction he is facing in the navigation phase.

  - Wall Settings
    The button 'Wall Settings' is used to select the walls of the building. It also allows the user to assign a color for the walls and an option to set whether the selected walls should be shown in the assigned color on the buildings plan or not. Figure 4.2b shows three different APs and the selected walls in red.

  - Grid Settings
    The last button of the 'Settings' tab called 'Grid Settings' serves the settings of the grid width in meters and a color in which the points shall be displayed. As also for walls there is an option to choose whether the grid points shall be shown or not.

- Learn
  The 'Learn' tab provides all options to gather fingerprints.

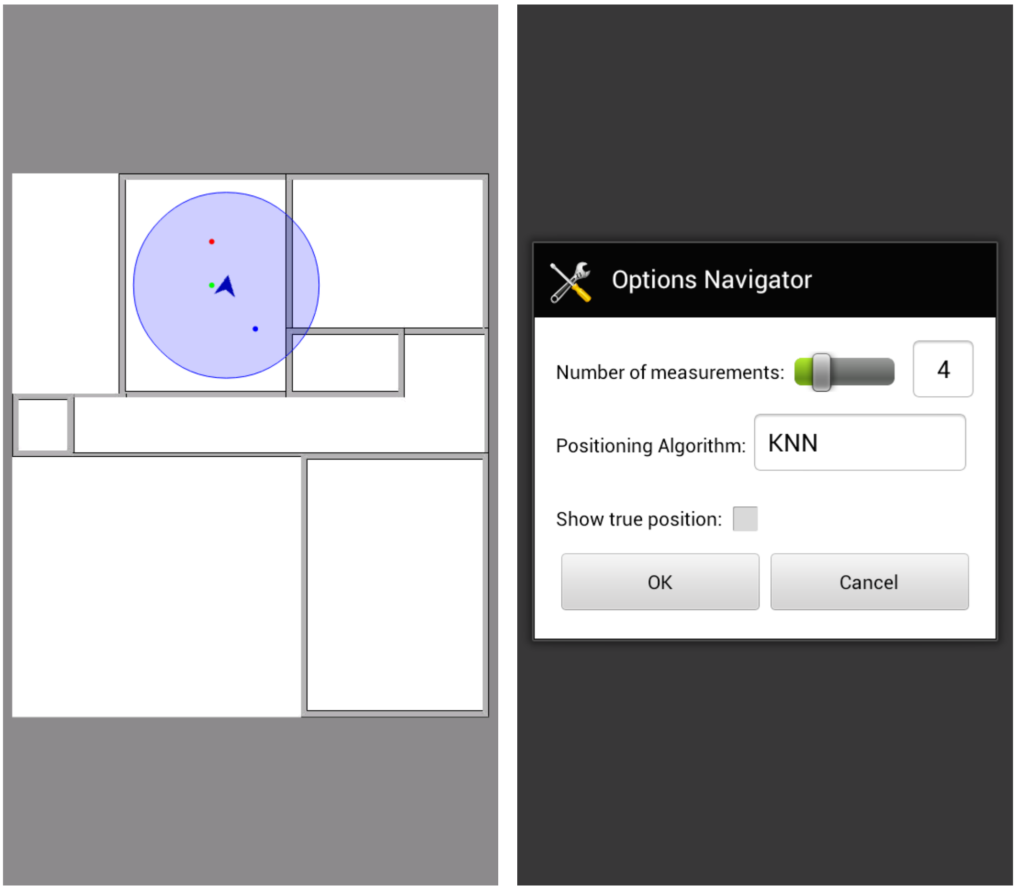
- Learn
  The 'Learn' button records a fingerprint on the selected grid point.

- Delete
  The 'Delete' button can be used to delete the recorded fingerprint at the selected grid point.

- Options
  The 'Option' button holds some settings for learning as well as the options for the implemented optimization algorithm. The user can select how often the environment shall be scanned for gathering a fingerprint. The values are then averaged to one fingerprint. There is also an option to take measurements from all directions to avoid some inaccuracy issues as described by Kaemarungsi & Krishnamurthy (2004). For the algorithm two functions are needed. One is called 'Suggest Grid Points' which is used to determine the Grid Points where fingerprints should be measured in order to interpolate the other non-measured ones by the help of the Log-Distance Path Loss Model (see chapter 4.4 *Log-Distance Path Loss Model*). To trigger the interpolation the 'Interpolate Fingerprint Measurements' option has to be selected.

[(Kaemarungsi & Krishnamurthy, 2004)]

4.3.3 Navigator


Options Navigator

Number of measurements: 4

Positioning Algorithm: KNN

Show true position: ☐

(a) Simple Triangulation (b) Navigator Options

Figure 4.3: Screenshots of Navigator

Once the Radio Map has been recorded using the Map Creator, the Navigator can be used to determine the position of the device in the target area. As figure 4.3 shows the Navigator is a full-screen Activity. Via the Menu-button of the device two menu items can be selected. One is for simply choosing the Radio Map which shall be loaded the other one holds some options. The option dialogue allows the user to set the number of measurements which shall be taken to average one fingerprint. The user can also select which algorithm shall be used to calculate the position. The implemented algorithms are:

- Simple Triangulation
  The Simple Triangulation Algorithm (STA) just looks up the three most similar

fingerprints from the Radio Map and determines the position by calculating the balance point of the triangle that is defined by the coordinates of the three most similar fingerprints.

- Weighted Triangulation
  The Weighted Triangulation Algorithm (WTA) is similar to the STA. It additionally takes the error rate of the three most similar fingerprints into account and weights the edges of the triangle by its errors.

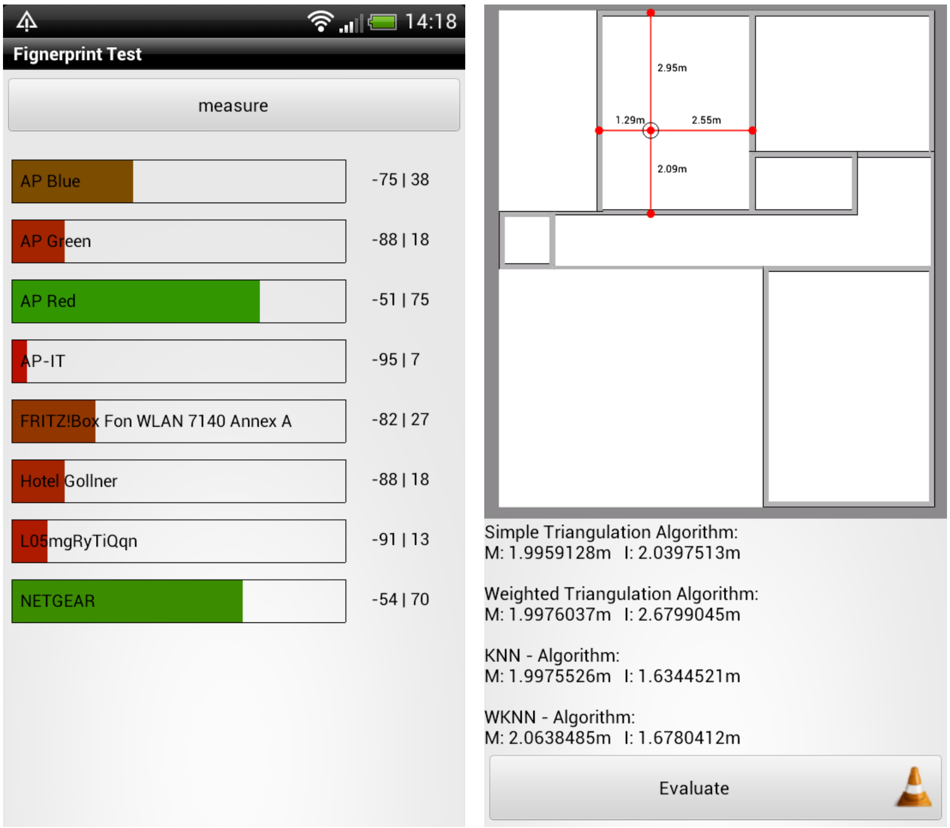
- KNN
  The KNN algorithm is a very well known algorithm in computer science. The position of the device is calculated by using the k most similar fingerprints.

- Weighted K-Nearest Neighbour (WKNN)
  The WKNN algorithm compared to the KNN algorithm just additionally weights the k edges by its errors.

Figure 4.3 shows screenshots of the navigation activity. The left one shows the position of the user using the STA. The blue circle around the arrow is a calculated inaccuracy value which is calculated using the distances between the calculated position and the most similar fingerprints of the Radio Map. The small coloured points around the calculated position show the place of the most similar fingerprints in the order red, green and blue. The blue arrow points in the direction the device is heading to. There is also an option to turn off the calculation of the inaccuracy and show the distances to the closest walls instead of the blue circle.

Once the Radio Map has been loaded the Navigator starts scanning the environment for WLAN signals. The scans are filtered for the APs that were used to create the Radio Map and summed up over a series of scans. The number of scans that are summed up and averaged to get one fingerprint depends on the number set in the options dialogue. When the Navigator finished the calculation of one fingerprint the fingerprint is compared to the stored fingerprints of the Radio Map. The mean square error for every fingerprint of the Radio Map is calculated and the most similar fingerprints and its coordinates are used to calculate the position. The number of the most similar fingerprints used for the calculation depends on the selected positioning algorithm. For the STA and WTA only three fingerprints are needed, for the KNN and WKNN the number of neighbours is selected empirically, but is at least three. When the calculation has finished the application starts scanning for WLAN signals again.

4.3.4 Testbed



AP Blue -75 | 38
AP Green -88 | 18
AP Red -51 | 75
AP-IT -95 | 7
FRITZ!Box Fon WLAN 7140 Annex A -82 | 27
Hotel Gollner -88 | 18
L05mgRyTiQqn -91 | 13
NETGEAR -54 | 70

Simple Triangulation Algorithm:
M: 1.9959128m I: 2.0397513m

Weighted Triangulation Algorithm:
M: 1.9976037m I: 2.6799045m

KNN - Algorithm:
M: 1.9975526m I: 1.6344521m

WKNN - Algorithm:
M: 2.0638485m I: 1.6780412m

(a) Fingerprint Test (b) Evaluation Activity

Figure 4.4: Screenshots of Testbed

The third part of the developed application is called Testbed. It provides two different functions. The first one is a simple fingerprint test which scans the environment for WLAN signals and shows the RSS values in a bar diagram as shown in figure 4.4a. The second function is an evaluation Activity which supports the evaluation process. Two Radio Maps, one with all grid points measured and one which used the optimization algorithm, of the same target area can be loaded. The test device can then be exactly placed somewhere in the area using the distance measurements shown on the screen as in figure 4.4b. To start the evaluation the 'Evaluate' button has to be pressed. The application then creates a series of fingerprints which are used for every implemented positioning algorithm to calculate the mean distance error. The results are then shown in meters once for the measured Radio Map (M) and for the interpolated one (I). The activity also allows to calculate the absolute difference between the RSS values of both Radio Maps - the measured and the interpolated - and show it graphically.

4.4 Log-Distance Path Loss Model

The Log-Distance Path Loss Model is the model used by the optimization algorithm of the Map Creator to interpolate the non-measured fingerprints by the help of the measured ones. It is a commonly used radio propagation model to calculate the strength of a signal at a certain point by the distances between a transmitter and a receiver. The model is used for many different purposes and hence some modifications of the basic Log-Distance Path Loss Model exist. The model is described here because it is used for implementing the optimization algorithm which will be explained in more detail in the next chapter.

The basic Log-Distance Path Loss Model is the most simple one and described by Mulligan (1997, p. 40).

$$\overline{PL}(d) = \overline{PL}(d_0) + 10n \log\left(\frac{d}{d_0}\right) \tag{4.1}$$

The wanted value $\overline{PL}(d)$ is the path loss or signal strength at distance d. $\overline{PL}(d_0)$ is a measured signal strength or path loss at reference distance d_0, whereas n is the path loss exponent. The exponent varies for every environment and is usually evaluated using empirical data. For LOS environments the path loss exponent is 2. The distances shall be given in meters.

The plot 5.52 shows the difference of the real measured signal strengths in a LOS environment compared with the calculated optimal signal strength determined by the Log-Distance Path Loss Model.

One popular modification of the Log-Distance Path Loss Model tries to take multipath fading and shadowing effects between transmitter and receiver into account. The model is referred to as by Log-Normal Shadowing Model by Mulligan (1997, p. 41).

$$\overline{PL}(d) = \overline{PL}(d_0) + 10n \log\left(\frac{d}{d_0}\right) + X_\sigma \tag{4.2}$$

An additional value is added to the model in order to deal with the shadowing effects. X_σ is the so called shadowing factor which is a Gaussian random variable with zero mean and a standard deviation σ. Like the path loss exponent n the value of σ is also evaluated using empirical data. This model is for example used in Zhao et al. (2008) to optimize the APs locations inside a building.

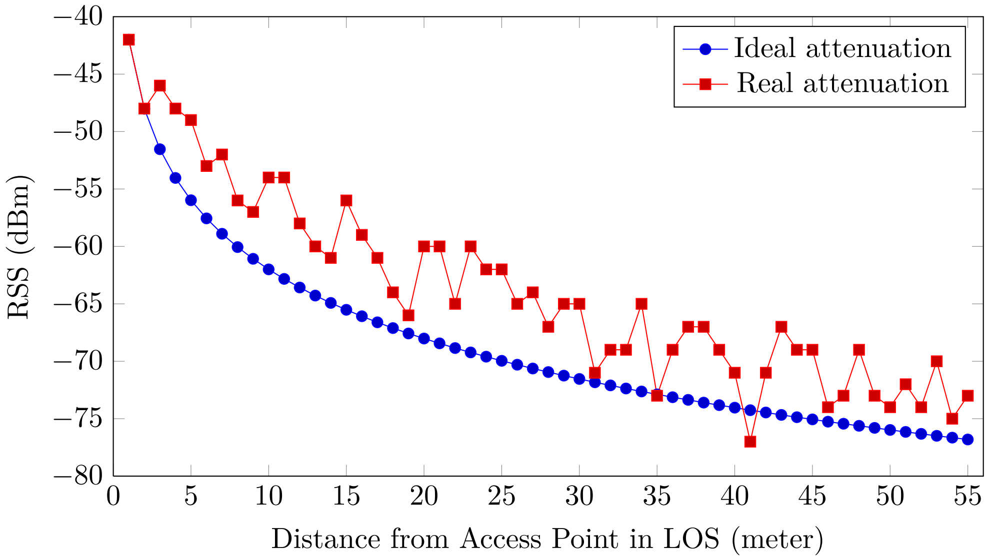


Figure 4.5: Differences between calculated RSS attenuation and real recorded attenuation

Another very popular modification of the Log-Distance Path Loss Model is done by adding certain measured attenuation factors to the model. Some slightly different models of this type has been released by researchers which try to take attenuation factors such as walls, floors and other obstacles into account. The example mentioned here is used by Xu et al. (2010) also to optimize the location of APs.

$$P(r) = P(r_0) + 10\alpha n \lg\left(\frac{r}{r_0}\right) - \sum_{i=1}^{N_1} K_i F_i - \sum_{j=1}^{N_2} I_j W_j \tag{4.3}$$

The model is similar to the basic Log-Distance Path Loss Model. It has an additional factor α and two sums which take certain attenuation factors into account. The wanted value $P(r)$ is the signal strength at distance r in meters away from the AP. $P(r_0)$ is the reference signal strength value at distance $r_0 = 1$ meter away from the AP. The value of α is again empirically estimated and used for large-scale variations between r and $P(r)$. The sum $\sum_{i=1}^{N_1} K_i F_i$ describes the number and attenuation of floors, where N_1 is the number of floors. This sum can be omitted when all APs are placed on the same floor. The second sum $\sum_{j=1}^{N_2} I_j W_j$ describes the number and attenuation of walls, where N_2 is the number of walls.

[(Faria, 2005), (Mulligan, 1997), (Zhao et al., 2008), (Xu et al., 2010)]

4.5 The Implemented Optimization Algorithm

4.5.1 Description

The implemented algorithm optimizes the off-line phase. It overcomes the complexity of measuring a fingerprint at each and every grid point for the Radio Map, by suggesting certain grid points at which measurements should be taken into account in order to be able to interpolate all remaining non-measured fingerprints. The algorithm basically consist out of two parts:

- Part 1 - Determine Good Grid Points
- Part 2 - Interpolate Fingerprint Measurements

Part 1 of the algorithm determines good grid points at which measurements have to be taken. The account of good grid points depends on the number of APs, the grid density and hence the number of grid points, and the number of unique walls an AP crosses on the path to the grid points. As also already explained in chapter 4.1 figure 4.6 shows an example for one suggested grid point for one AP. The red solid line points to the suggested grid point. All other green grid points will be interpolated by the measurement of the suggested one, because the distances between these and the suggested grid points are crossed by the same wall.

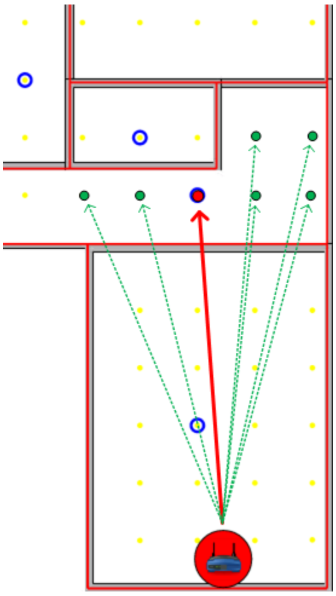
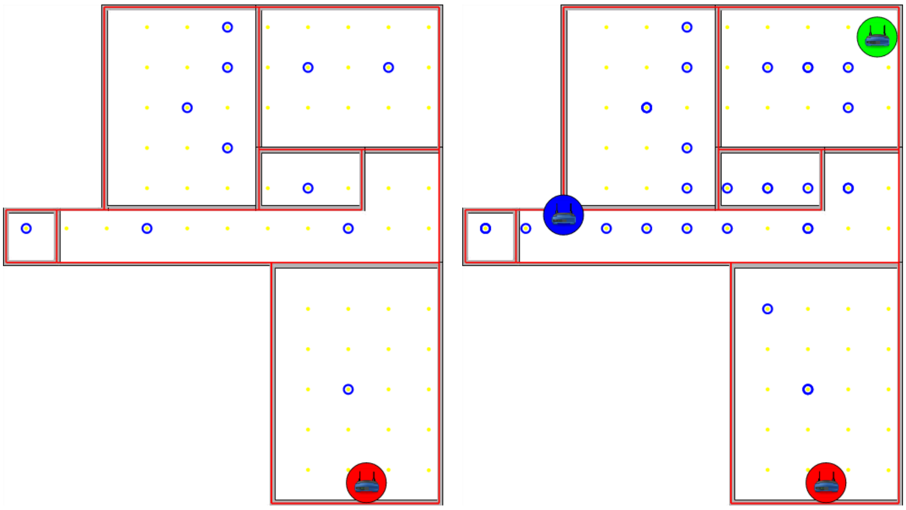


Figure 4.6: Algorithm Description (personal design)

The idea behind the algorithm is to interpolate the non-measured fingerprints with the help of the basic Log-Distance Path Loss Model for LOS environments. The signals of all grid points which are covered by the exact same walls from an AP have nearly the same attenuation factors. So if the signal strength of one of those grid points is measured, the signal strength of all other surrounding grid points which are covered by the same walls can easily and very precisely be calculated by using the Log-Distance Path Loss Model for LOS environments. In order to determine the grid points at which measurements have to be taken the algorithm needs the following information:

- True scale buildings plan
- Dimensions of the building
- Exact course of walls
- Exact positions of APs
- Grid points

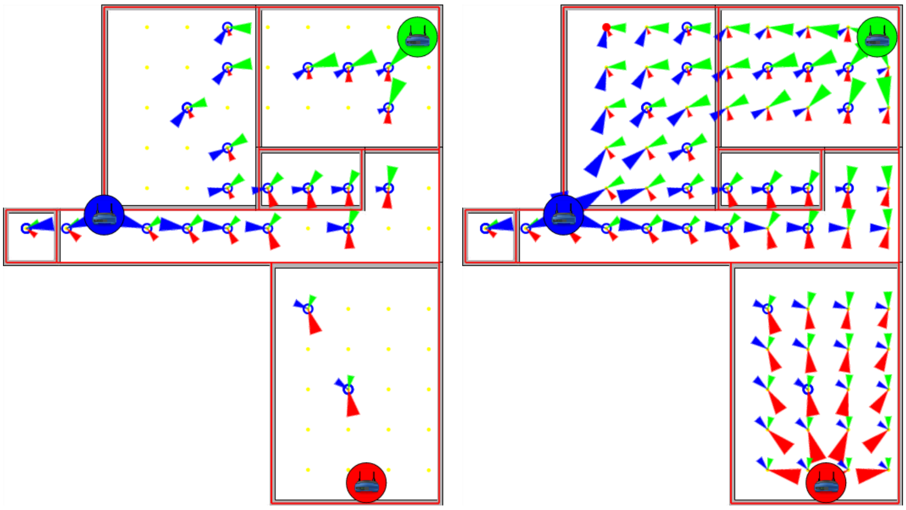
Figure 4.7 gives a graphical overview of part 1 - determination of good grid points - of the algorithm. It shows the determined grid points for the charted APs. Determined grid points are marked with a blue circle around a yellow grid point. The left screenshot 4.7a shows the determined grid points for one AP, screenshot 4.7b for all three APs that where used to generate the Radio Map in the shown environment.



(a) Determined Grid Points for one AP (b) Determined Grid Points for all APs

Figure 4.7: Screenshots of Determined Grid Points

Figure 4.8 provides a graphical overview of part two - interpolation of fingerprints - of the algorithm. Screenshot 4.8a shows the measured fingerprints at all determined grid points which are used to interpolate all the other non-measured ones. The result of the interpolation is shown in screenshot 4.8b.



(a) Measured Fingerprints (b) Measured and Interpolated Fingerprints

Figure 4.8: Screenshots of Measured and Interpolated Fingerprints

As already mentioned the algorithm helps to overcome the complexity of the off-line learning phase. In the test scenario shown in figure 4.8 only 22 out of a total of 66 fingerprints had to be measured for the interpolated Radio Map, which are savings of 66%. Chapter 5 describes the performance and test results of the algorithm in three different environments in more detail.

4.5.2 Pseudocode

4.5.2.1 Determine Good Grid Points

The method *findGridPoints()* takes the list of APs, grid points and the list of walls of the Radio Map as input. The output is a list of those grid points which the optimization algorithm suggests where the signal strengths should be measured in order to interpolate all other ones. For every AP and grid point the procedure first of all determines the walls which are crossed by the distance from the AP to one grid point. Every time a new combination of walls is determined a new entry is added to the HashMap. An entry is the combination of walls as key and a list of grid points as values. If the calculation has finished the ideal grid point for every entry is calculated. The ideal grid point is the grid point which is closest to the mid point of all grid points of one entry and added to the output list. This process is done for every AP. A certain grid point is of course added only once to the output list.

Algorithm 4.1 Determine Good Grid Points

```
function findGridPoints()
Input: $accessPoints, gridPoints, walls \in List$
Output: $foundGPs \in List$
    for all $accessPoints$ do
        $wallHashMap \leftarrow newHashMap < String, List < Point >> ()$
        for all $gridPoints$ do
            for all $walls$ do
                if $wall.intersects(gridPoint, accessPoint)$ then
                    $wallHash \leftarrow wallHash + wall.hashCode()$
                end if
            end for
            $wallHashMap.add(wallHash, gridPoint)$
        end for
        for all $wallHashMapEntries$ do
            $goodGridPoint \leftarrow selectGoodGridPoint(wallHashMapEntry.value)$
            if $!foundGPs.contains(wallHashMapEntry.key)$ then
                $foundGPs.add(wallHashMapEntry.key, goodGridPoint)$
            end if
        end for
    end for
    return $foundGPs$
end function
```

4.5.2.2 Interpolate Fingerprint Measurements

Once the suggested grid point have been measured part 2 of the algorithm can be executed. The method *determineGoodGridPoints()* additionally takes a list of the measured grid points as input parameter compared to the method *findGridPoints()*. The output is a list of the interpolated non-measured fingerprints.

The method iterates over all APs and grid points and determines the walls which are crossed by the distance between the grid point and the AP for every non-measured grid point. Once the walls have been determined the reference grid point which distance is crossed by the exact same walls is selected out of the list of measured grid points. The RSS value can now be calculated by using the Log-Distance Path Loss Model which is realized by the method *logDistancePathLossModel()*. The method takes the AP, as well as the measured fingerprint and the non-measured grid point as input parameter. The distances between the measured grid point and the AP as well as the distance between the non-measured grid point and the AP are calculated and employed with the reference RSS value to the formula of the Log-Distance Path Loss Model. The method returns the interpolated RSS value and the value is added to the output list of interpolated fingerprints. The process is repeated for every non-measured grid point and all APs.

Algorithm 4.2 Interpolate Fingerprint Measurements

```
function INTERPOLATEFINGERPRINTMEASUREMENTS()
Input: $accessPoints, gridPoints, walls, measuredGPs \in List$
Output: $interpolatedFingerprints \in List$
    for all $accessPoints$ do
        for all $gridPonts$ do
            if $!gridPoint.wasMeasured()$ then
                for all $walls$ do
                    if $wall.intersects(gridPoint, accessPoint)$ then
                        $wallHash \leftarrow wallHash + wall.hashCode()$
                    end if
                end for
                $referenceGP \leftarrow searchGridPointWithSameWallHash(measuredGPs)$
                $value \leftarrow logDistancePathLossModel(accessPoint, referenceGP, gridPoint)$
                $fingerprint \leftarrow interpolatedFingerprints.get(gridPoint.coordinate$
                if $fingerprint == null$ then
                    $fingerprint \leftarrow newFingerprint(gridPoint.coordinate))$
                end if
                $fingerprint.addMeasurement(accessPoint.BSSID, value)$
                $interpolatedFingerprints.add(fingerprint)$
            end if
        end for
    end for
    return $interpolatedFingerprints$
end function

function LOGDISTANCEPATHLOSSMODEL()
Input: $accessPoint, referenceGP, gridPoint \in Point$
Output: $interpolatedRSS \in Integer$
    $dO = calculateDistance(accessPoint.coordinate, referenceGP.coordinate)$
    $d = calculateDistance(accessPoint.coordinate, gridPoint.coordinate)$
    $interpolatedRSS \leftarrow referenceGP.getRSSValue(accessPoint.BSSID) - 10.0 * 2.0 * Math.log(d/d0)$
    return $interpolatedRSS$
end function
```

4.6 Further Implementations

The implemented application focuses on the realization of an IPS for smartphones using the WLAN fingerprinting technology and on the overcoming of the complexity of the off-line learning phase. To improve and make the application usable for navigation in multi-floor public buildings such as shopping centres the application has to be extended with some implementations. This chapter mentions these additional implementation theoretically.

4.6.1 Automatic Positioning of Access Points (APs)

For creating the Radio Map the user has to manually set the positions of the used APs. Many researches have focused on determining the number and best positions for APs in order to get a good signal coverage and hence improve the positioning accuracy based on different factors.

The paper Zhao et al. (2008) describes how to optimize the location of APs in order to make indoor positioning more accurate. They described a so called Differential Evolution algorithm which is based on the Log-Distance Path Loss Model. The APs are basically placed in a way such that the difference and diversity of the received signal strength is maximized over all grid points. The evaluation of the algorithm showed that APs should be placed asymmetrically. Tests also showed that the positioning accuracy improved constantly with a rising number of APs from three to six using the KNN algorithm.

The researches in Xu et al. (2010) also focus on the optimization of the layout of APs in order to improve the accuracy of IPSs. The researchers invented a model to determine the number and positions of the APs also based on the Log-Distance Path Loss Model, taking attenuation factors such as walls and floors into account. The best places can be calculated using the so-called Coverage Requirement Matrix. Evaluations showed that their proposed model helps to set up the layout of the APs. The results confirmed that the model is useful to lower the time costs for APs distribution.

4.6.2 Multiple Floor Handling

The implemented prototype does not support multiple floor handling. Only one picture of a buildings plan can be loaded. In order to make the system practically useable for public buildings multiple floor handling would have to be implemented. Currently one Radio Map basically consist of an image of a buildings plan, the dimensions of the building, the position of the walls, the APs and the fingerprints. The code and the functions of the Map Creator would have to be adapted in a way such that a Radio Map consists of floors. Each floor then consists of what the Radio Map now consists of: an image of the buildings plan, the dimensions of the floor, the position of the walls and the fingerprints. To recognize the floor in which the device is located in the on-line phase the most easiest way would be to use own APs for every floor.

4.6.3 Navigation Algorithm

The Navigator of the the implemented prototype currently only supports indoor positioning and does not support any navigation from one place to another. In order to make the system able to navigate from the user's current determined position to any target location, the Map Creator could be extended to select any position of the buildings plan and tag it with a specific name. The navigator could then be enhanced implementing a search function for tagged places or simply select from a list of tagged places. Dijkstra's shortest path algorithm can then be used to calculate and show the path from the user's current position to the target location. To make use of the algorithm an additional function to add doors to the buildings plan would have added to the Map Creator. For supporting multiple floor navigation a function for marking staircases and elevators would have to be added.

[(Zhao et al., 2008), (Xu et al., 2010)]

5 Evaluation

5.1 General

The evaluation aims to investigate the performance of the algorithm in complexity-savings as well as accuracy. The tests were done in three different surroundings: two NLOS environments - one office building and a flat - and one LOS environment, a tennis court. For each test scenario two Radio Maps were created to compare the accuracy. One Radio Map where all grid points of the test environment were measured and one Radio Map that used our optimization algorithm to create the Radio Map. In each environment some test points were randomly picked and the average error rate in meters determined for all implemented positioning algorithms. To make the evaluation as accurate as possible and hence ensure the integrity all distances including distances to APs, grid points and test points were exactly displayed by the application and measured in the real environment using a digital range measure.

During the creation of the Radio Map as well as the evaluation all doors stayed either closed or open to avoid inaccuracies caused by the attenuation of doors. The creation of the Radio Maps as well as the evaluation in one environment were done within one day. All fingerprints in the learning phase were measured in four directions and averaged with the user heading in the given direction and holding the smartphone in front of the chest. The test points in the evaluation phase were measured in one random direction, also with the user being present and holding the smartphone.

The next chapter 5.2 describes the Evaluation Activity and how and what it reports. The hardware that was used for the evaluation is described in chapter 5.3. The chapter 5.4 describes each test environment, the setup and the results of the evaluation. Chapter 6 then summarizes and interprets the results of the tests.

5.2 Evaluation Activity

To do the evaluation of the algorithm a separate Evaluation Activity has been implemented. As already mentioned, the evaluation mainly aims on determining the difference in accuracy that can be reached between a fully measured Radio Map and one created with the optimization algorithm.

In order to ensure the integrity of the evaluation both Radio Maps have exactly the following same settings:

- Building Settings (dimensions, orientation)
- AP Settings
- Wall Settings
- Grid Settings
- Learn Options

Both Radio Maps only differ in the way the fingerprints are gathered.

Simple Triangulation Algorithm:
M: 1.0502511m I: 1.0887477m

Weighted Triangulation Algorithm:
M: 1.0408732m I: 1.159362m

KNN - Algorithm:
M: 1.0401275m I: 1.0306622m

WKNN - Algorithm:
M: 1.0390928m I: 1.1332582m

(a) Test Point (b) Results (c) Fingerprint Differences

Figure 5.1: Screenshots of Evaluation Activity

The Evaluation Activity makes it possible to load the buildings plan and select a test point. The Activity exactly shows the distances to the closest walls in order to make the evaluation as accurate as possible as shown in figure 5.1a. With a click on the button 'Evaluate' the following happens: The activity measures ten fingerprints. Each fingerprint is the average of ten RSS values of the surrounding AP. When the measurements have finished, the activity calculates the mean error rate in meters for every implemented algorithm and both Radio Maps. When the calculation has finished, it shows the results for the selected test point as shown in figure 5.1b. The Evaluation Activity is also able to calculate and show the absolute fingerprint differences between both Radio Maps. An example is shown in figure 5.1c.

5.3 Used Hardware

For the evaluation of the optimization algorithm four equal APs, one smartphone and a digital range measure have been used.

5.3.1 Access Points (APs) - Linksys Wireless-G Broadband Router

Figure 5.2: Linksys Wireless-G Broadband Router (personal design)

Specification

Producer: Cisco
Model number: WRT54GL
Version: 1.1
Model name: Wireless-G Broadband Router With 4-Port Switch
Variants: WRT45GL-DE

5.3.2 Smartphone - HTC Evo 3D

Figure 5.3: HTC Evo 3D (personal design)

Specification

Producer: HTC
Model: Evo 3D X515m
CPU Speed: 1.2 GHz, dual core
Platform: Android with HTC Sense
Platform Version: Android 4.0.3
Memory: Internal storage: 1 GB, RAM: 1 GB

5.3.3 Digital Range Measure - Silverline

Figure 5.4: Silverline Digital Range Measure (personal design)

Specification

Producer: Silverline
Measuring Range: 0.6 - 15m
Resolution: 0.01m/1m
Operating mode: Ultrasonic

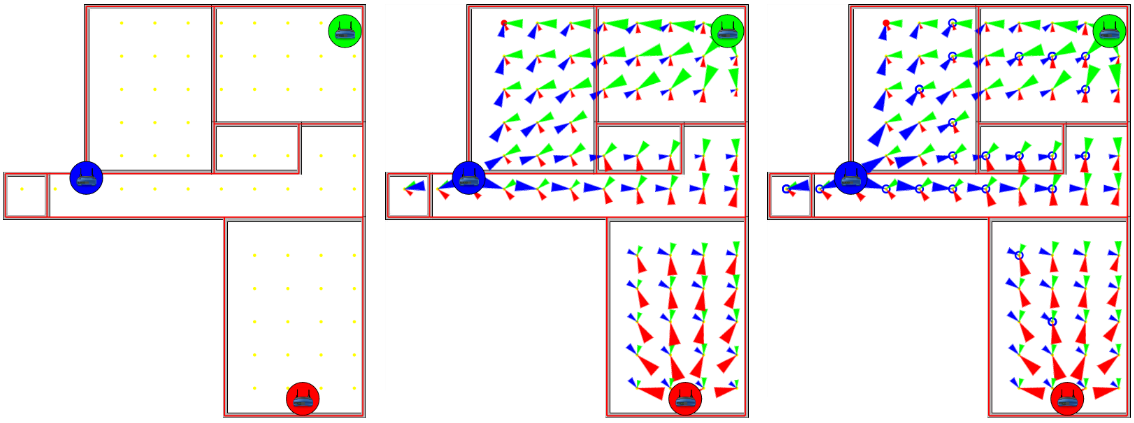
5.4 Test Scenarios

5.4.1 Scenario I

5.4.1.1 Description

Test scenario 1 is a small flat with two rooms, a kitchen, a bathroom, a toilet and a corridor and hence an example for an NLOS environment.

Dimensions: 10.5m x 12.5m
Total Area: 77.0m^2
Number of APs: 3
Grid Width: 1.0m
Number of Grid Points: 66
Learn Options: 4 measurements in each direction
Number of Suggested Grid Points: 22
Savings: 66% of the measurements



(a) Buildings Plan (b) Measured Radio Map (c) Interpolated Radio Map

Figure 5.5: Screenshots of Test Scenario I

Figure 5.5a shows a plan of the test environment with its walls, APs and grid points. Figure 5.5b shows the fully measured Radio Map, whereas figure 5.5c shows the interpolated Radio Map.

5.4.1.2 Results

Test Points

The charts show the mean error in meters (y-dimension) for all four different implemented positioning algorithms (x-dimension) for both Radio Maps, the measured and the interpolated:

- Simple Triangulation Algorithm (STA)
- Weighted Triangulation Algorithm (WTA)
- K-Nearest Neighbour (KNN)
- Weighted K-Nearest Neighbour (WKNN)

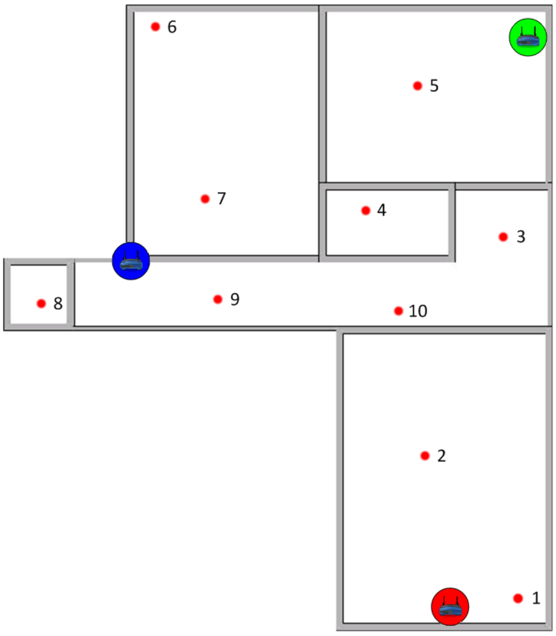


Figure 5.6: Overview Test Points (Scenario I)

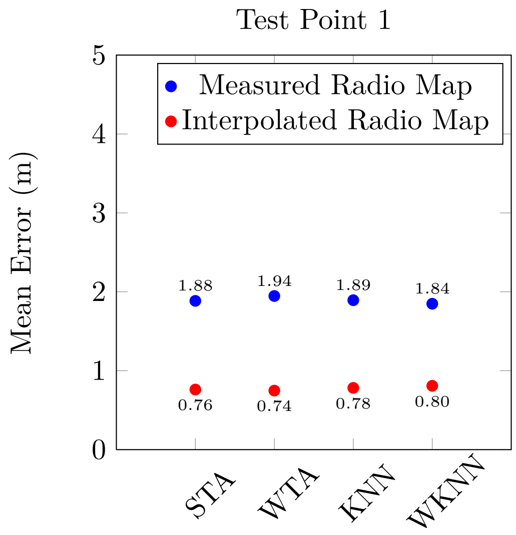


Figure 5.7: Test Point 1 (Scenario I)

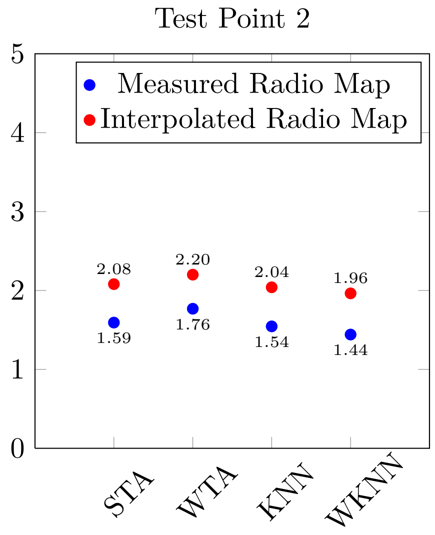


Figure 5.8: Test Point 2 (Scenario I)

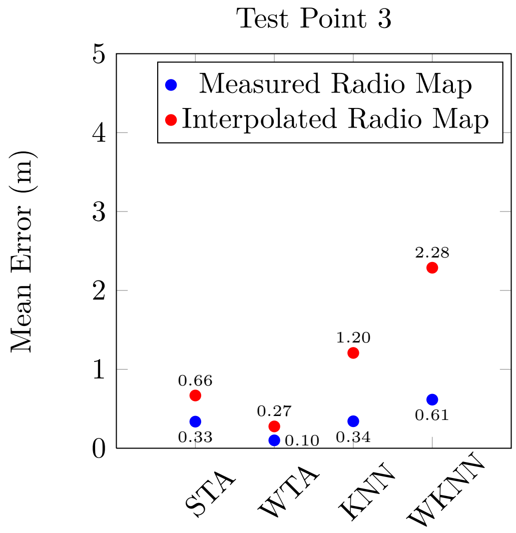


Figure 5.9: Test Point 3 (Scenario I)

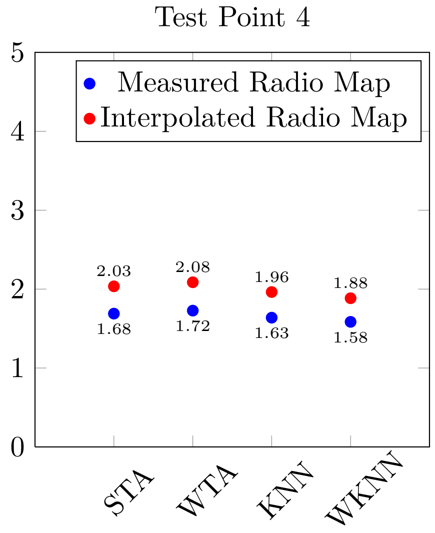


Figure 5.10: Test Point 4 (Scenario I)

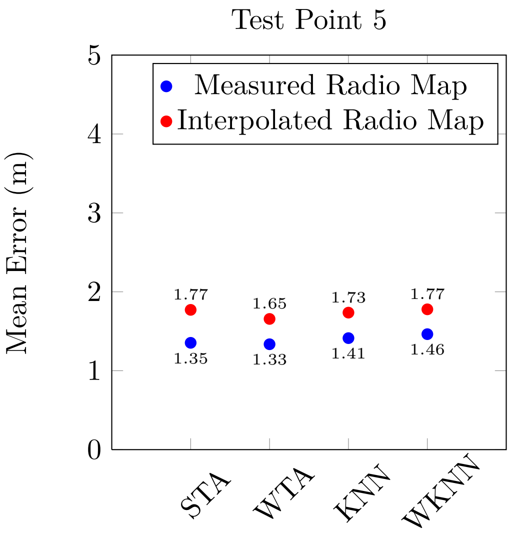


Figure 5.11: Test Point 5 (Scenario I)

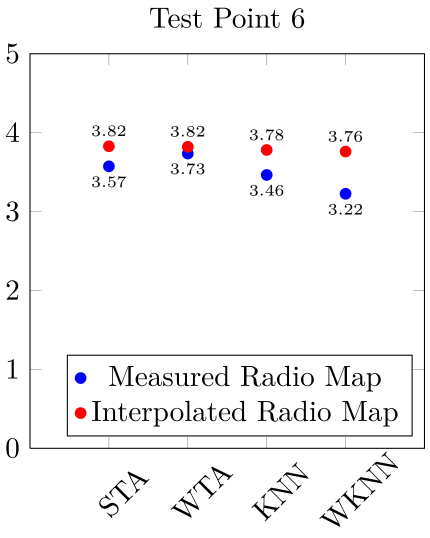


Figure 5.12: Test Point 6 (Scenario I)

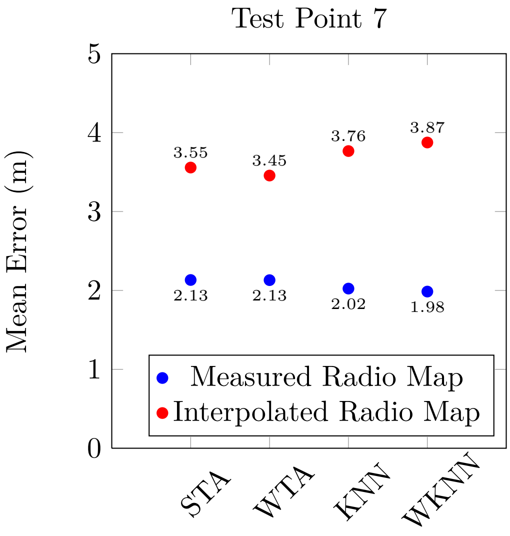


Figure 5.13: Test Point 7 (Scenario I)

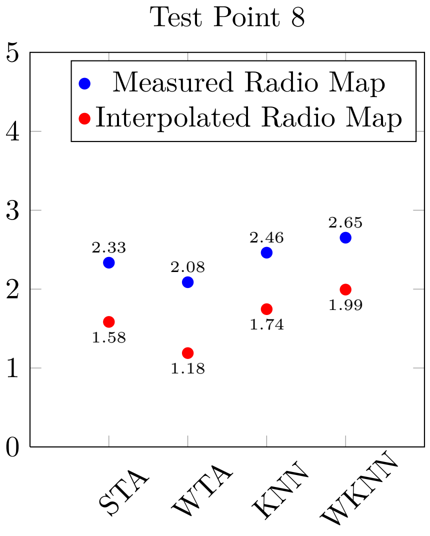


Figure 5.14: Test Point 8 (Scenario I)

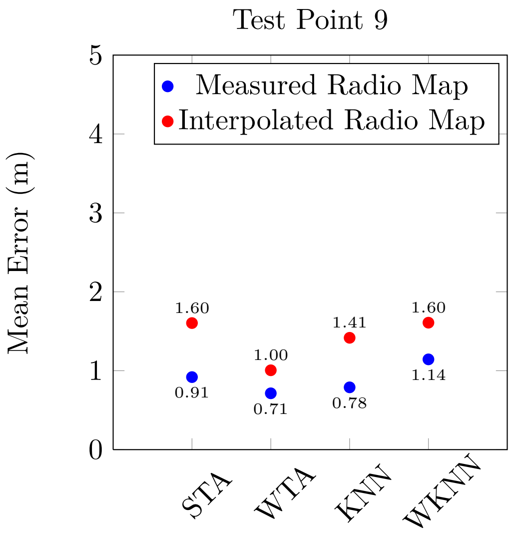


Figure 5.15: Test Point 9 (Scenario I)

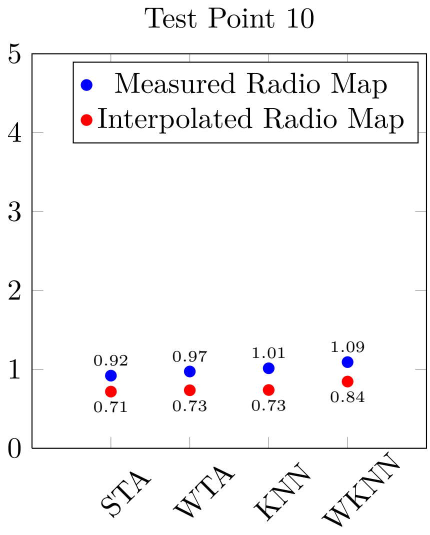


Figure 5.16: Test Point 10 (Scenario I)

Fingerprint Differences

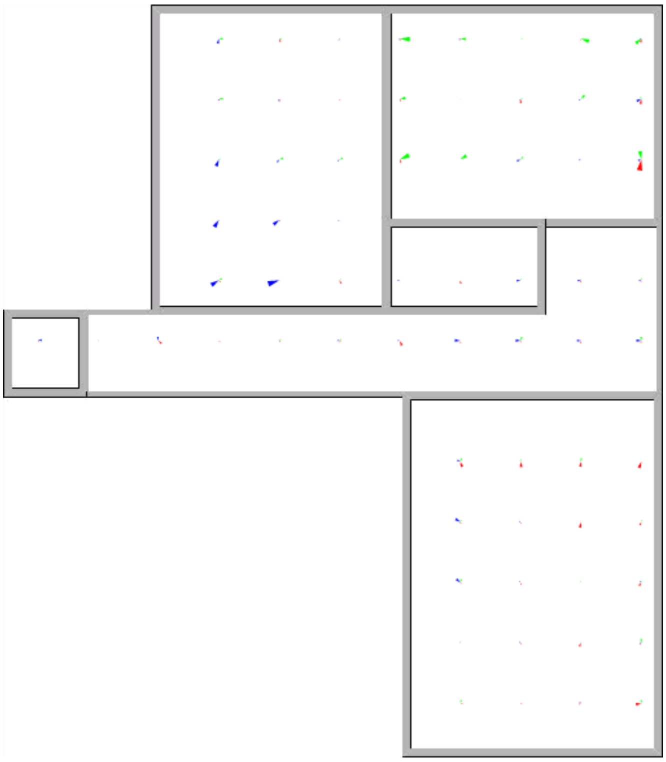


Figure 5.17: Overview Fingerprint Differences (Scenario I)

5.4.1.3 Summary

The overall accuracy achieved by the measured Radio Map is slightly better at seven out of the ten test points compared to the interpolated one. At test point 1, 8 and 10 the positioning by the interpolated Radio Map was more accurate.

At test point 7 the interpolated Radio Map shows clearly weaker performance than the measured Radio Map. This might be because of inaccuracies at measuring and calculating the signal strength of AP blue. If we look at figure 5.17 we can see that we have appreciable differences in the recorded signal strengths between the measured and interpolated Radio Map.

Furthermore it is particularly noticeable that at test point 3 the mean error of the WKNN of the interpolated Radio Map (2.29 m) is far higher than the one of the measured Radio Map (0.62 m). This is be because of a bad selection of the number of neighbours for the WKNN.

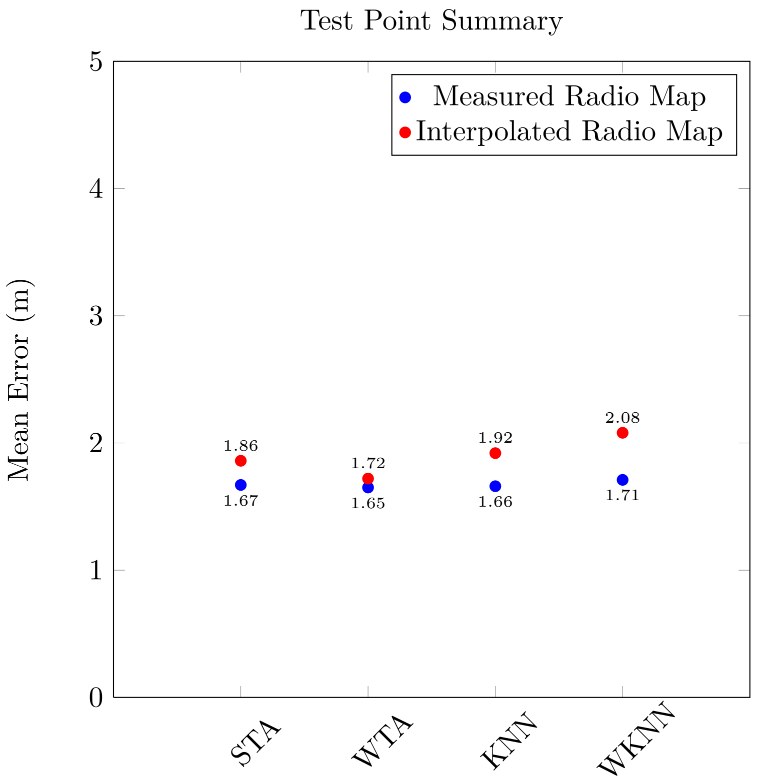


Figure 5.18: Test Point Summary (Scenario I)

The plot 5.18 shows the average of all the test points for each algorithm and every Radio Map. The performances reached by the different algorithms are nearly the same for the measured Radio Map. For the interpolated one the WTA achieved the best overall accuracy.

The overall positioning accuracy reached by the interpolated Radio Map is only 13.98% weaker compared to the measured Radio Map. The results reached by the optimization algorithm for the interpolated Radio Map are hence very acceptable. For the interpolated Radio Map only one third of all grid points had to be measured.

5.4.2 Scenario II

5.4.2.1 Description

Test scenario 2 is another example for a NLOS environment. The evaluation was done at evolaris next level GmbH in Graz.

Dimensions: 21.0m x 15.0m
Total Area: 200m^2
Number of APs: 3
Grid Width: 1.3m
Number of Grid Points: 85
Learn Options: 2 measurements in each direction
Number of Suggested Grid Points: 47
Savings: 44.7% of the measurements

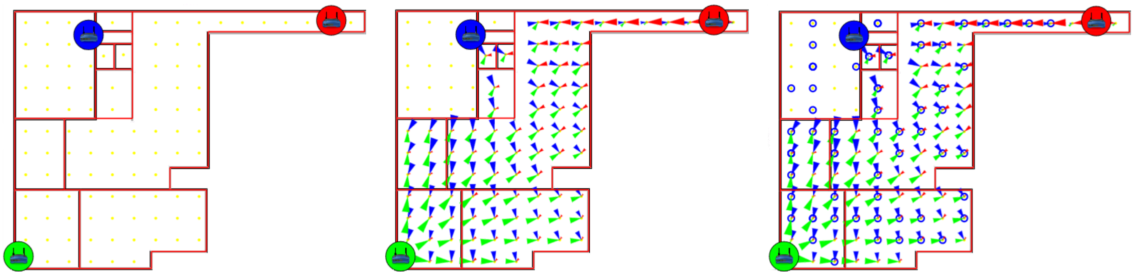

(a) Buildings Plan (b) Measured Radio Map (c) Interpolated Radio Map

Figure 5.19: Screenshots of Test Scenario II

Figure 5.19a shows a plan of the test environment with its walls, APs and grid points. Figure 5.19b shows the fully measured Radio Map, whereas figure 5.19c shows the interpolated Radio Map.

5.4.2.2 Results

Test Points

The charts show the mean error in meters (y-dimension) for all four different implemented positioning algorithms (x-dimension) for both Radio Maps, the measured and the interpolated:

- Simple Triangulation Algorithm (STA)
- Weighted Triangulation Algorithm (WTA)
- K-Nearest Neighbour (KNN)
- Weighted K-Nearest Neighbour (WKNN)

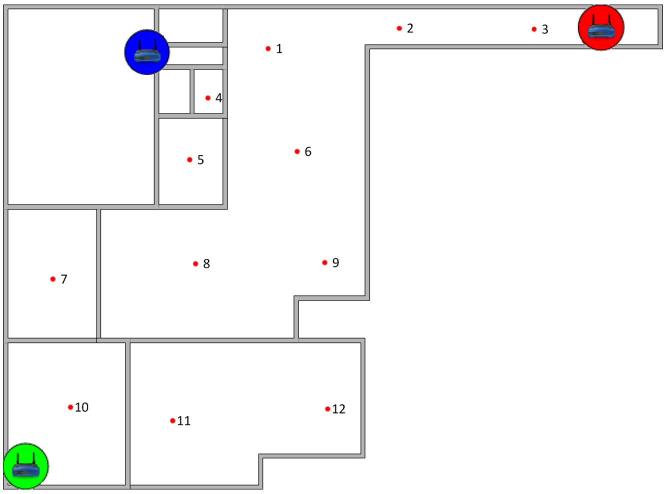


Figure 5.20: Overview Test Points (Scenario II)

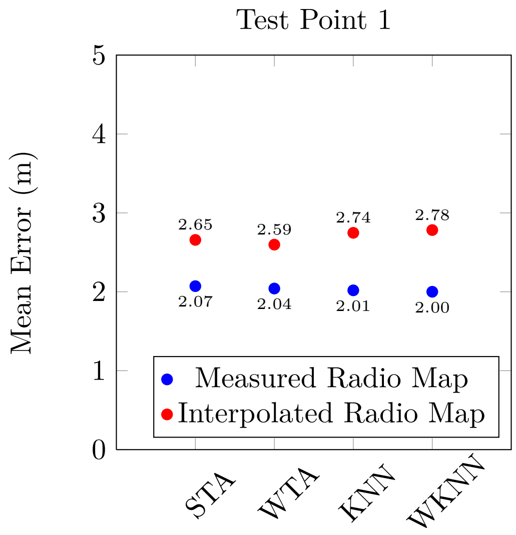


Figure 5.21: Test Point 1 (Scenario II)

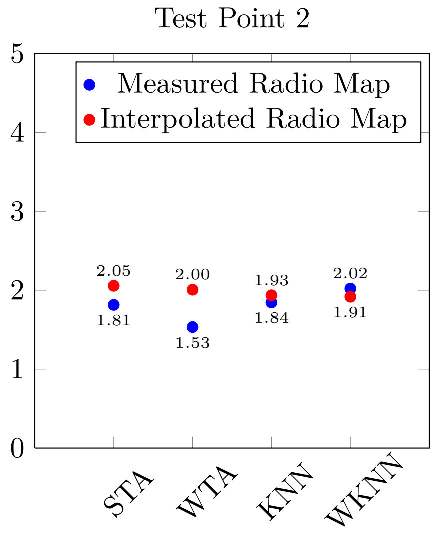


Figure 5.22: Test Point 2 (Scenario II)

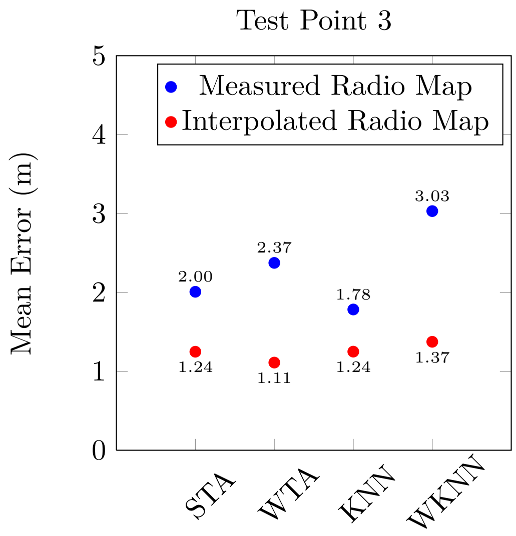


Figure 5.23: Test Point 3 (Scenario II)

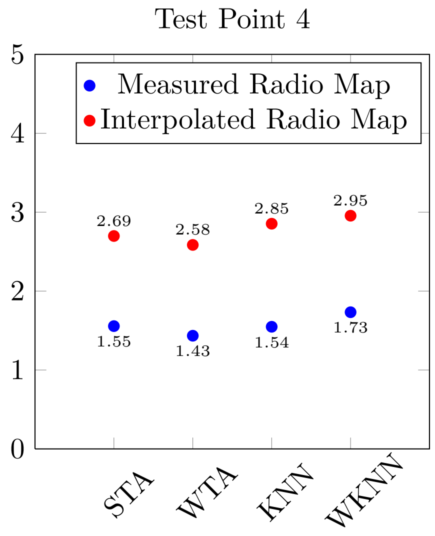


Figure 5.24: Test Point 4 (Scenario II)

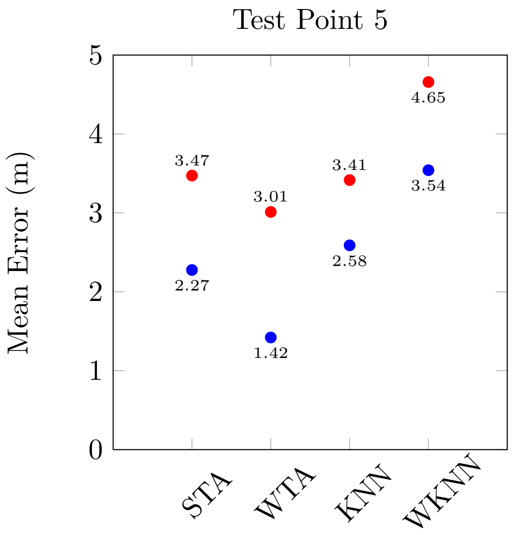


Figure 5.25: Test Point 5 (Scenario II)

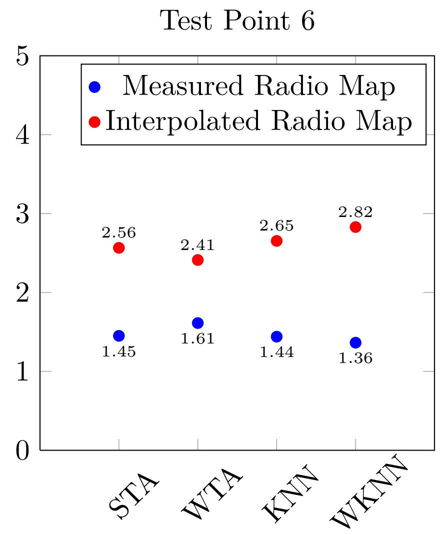


Figure 5.26: Test Point 6 (Scenario II)

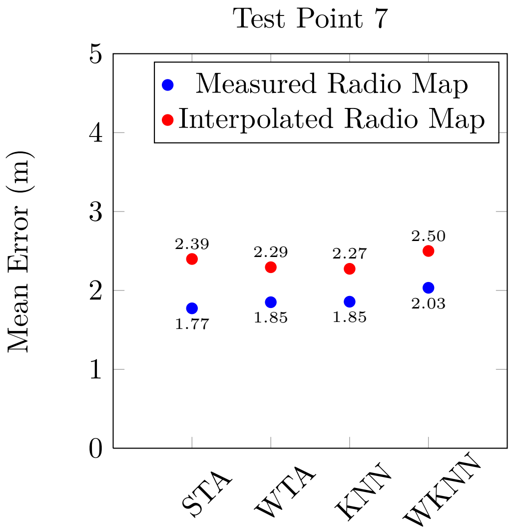


Figure 5.27: Test Point 7 (Scenario II)

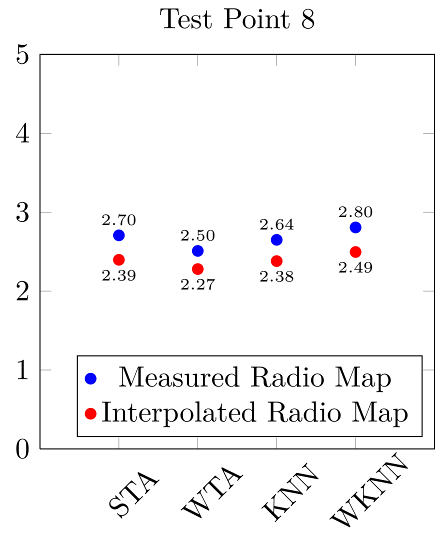


Figure 5.28: Test Point 8 (Scenario II)

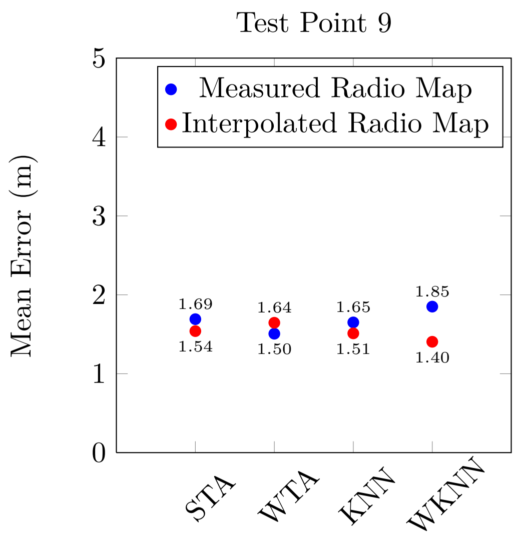


Figure 5.29: Test Point 9 (Scenario II)

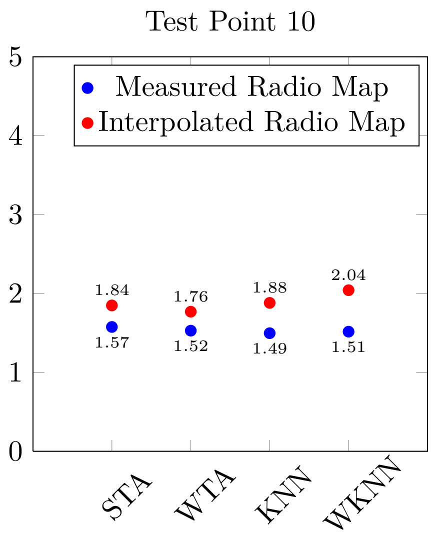


Figure 5.30: Test Point 10 (Scenario II)

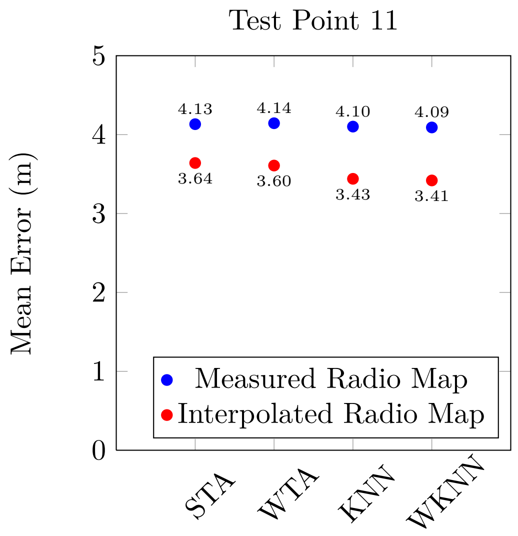


Figure 5.31: Test Point 11 (Scenario II)

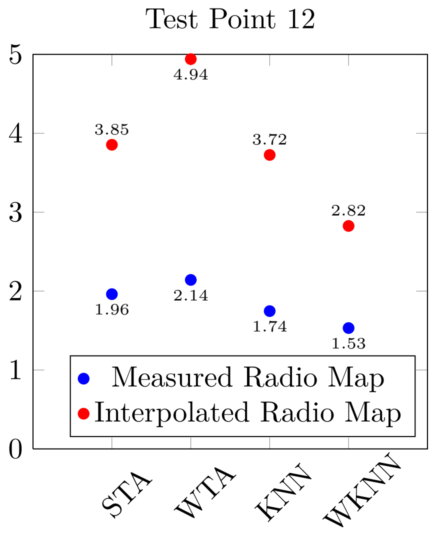


Figure 5.32: Test Point 12 (Scenario II)

Fingerprint Differences

Figure 5.33: Overview Fingerprint Differences (Scenario II)

5.4.2.3 Summary

The positioning was more accurate with the measured Radio Map at 9 out of the total 12 test points.

At test point 3 the mean error calculated by the WKNN is significantly higher compared to the other ones. This is again due to a bad selection of the value of k. Very interesting is that the results for the interpolated Radio Map are clearly better. Figure 5.33 shows the fingerprint differences between the measured and interpolated Radio Map. At the location around test point 3 there are some differences at the recorded signal strength of AP blue.

Very surprisingly is that the mean error calculated for the interpolated Radio Map at test point 4 and 5 is significantly higher than the mean error for the measured Radio Map, although there are no clear differences in the recorded signal strengths between both Radio Maps.

The positioning accuracy at test point 11 and 12 was overall very low. One reason might be because of a bad distribution of AP. The received signal strength of AP red was very low. Another AP placed in the bottom right corner might have improved the accuracy.

The interpolation worked quite well, because there are overall very low fingerprint differences, as shown in figure 5.33. In that scenario approximately the half of all grid points was measured for the interpolated Radio Map.

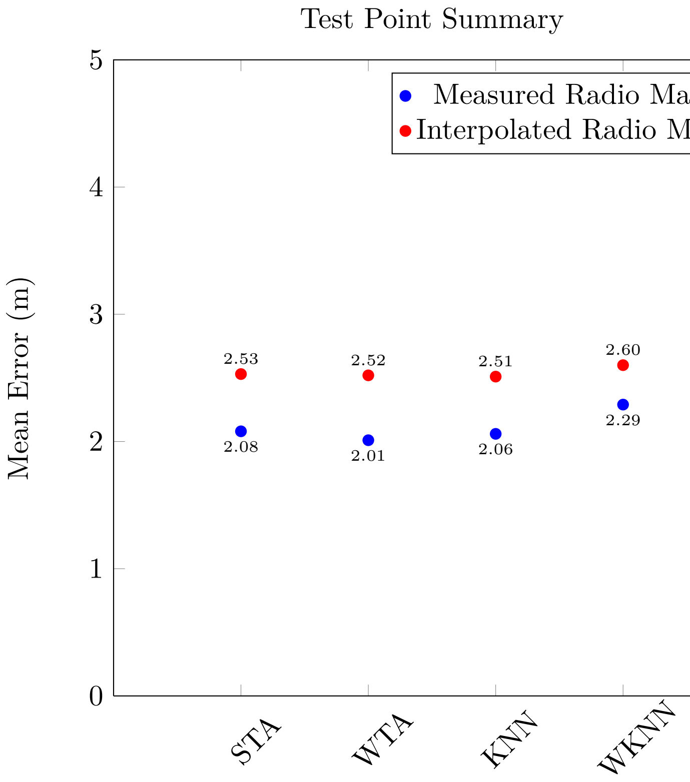


Figure 5.34: Test Point Summary (Scenario II)

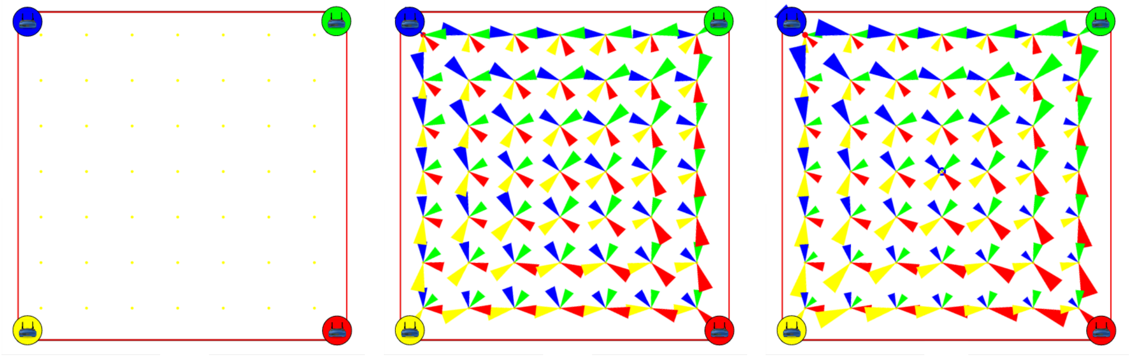
The plot 5.34 shows the average mean error of all test points for every algorithm and Radio Map. Compared to the results of test scenario 1 which was also a NLOS environment the positioning accuracy was lower. There are several reasons which have to be considered in more detail. One reason might be as already mentioned the bad coverage of the area with signal strengths. Another factor why the positioning did not work that well might be that in test scenario 1 all walls are thick concrete ones, whereas in test scenario 2 some walls even were thin glass walls which do not attenuate the signal significantly and hence makes accurate positioning harder.

5.4.3 Scenario III

5.4.3.1 Description

Test scenario 3 is an example for a LOS environement. The tests were done on tennis courts.

Dimensions: 36.0m x 36.0m
Total Area: 1296.0m^2
Number of APs: 4
Grid Width: 5.0m
Number of Grid Points: 49
Learn Options: 2 measurements in each direction
Number of Suggested Grid Points: 1
Savings: 97.9% of the measurements



(a) Buildings Plan (b) Measured Radio Map (c) Interpolated Radio Map

Figure 5.35: Screenshots of Test Scenario III

Figure 5.35a shows a plan of the test environment with its walls, APs and grid points. Figure 5.35b shows the fully measured Radio Map, whereas figure 5.35c shows the interpolated Radio Map.

5.4.3.2 Results

Test Points

The charts show the mean error in meters (y-dimension) for all four different implemented positioning algorithms (x-dimension) for both Radio Maps, the measured and the interpolated:

- Simple Triangulation Algorithm (STA)
- Weighted Triangulation Algorithm (WTA)
- K-Nearest Neighbour (KNN)
- Weighted K-Nearest Neighbour (WKNN)

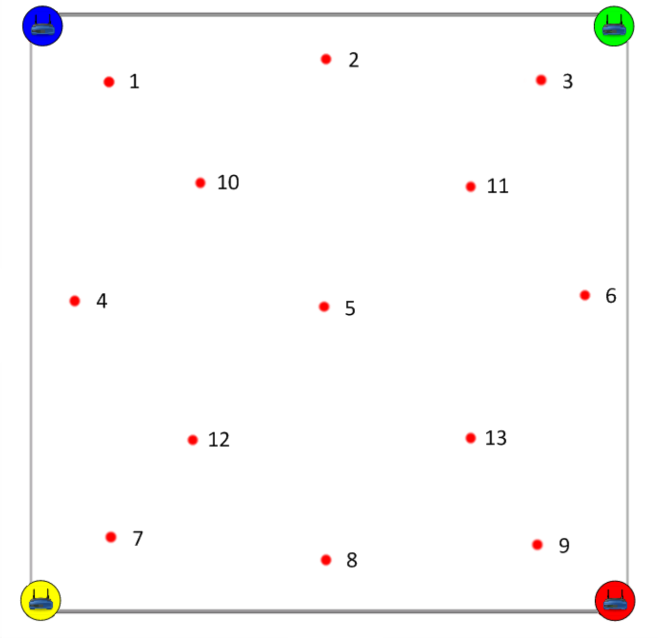


Figure 5.36: Overview Test Points (Scenario III)

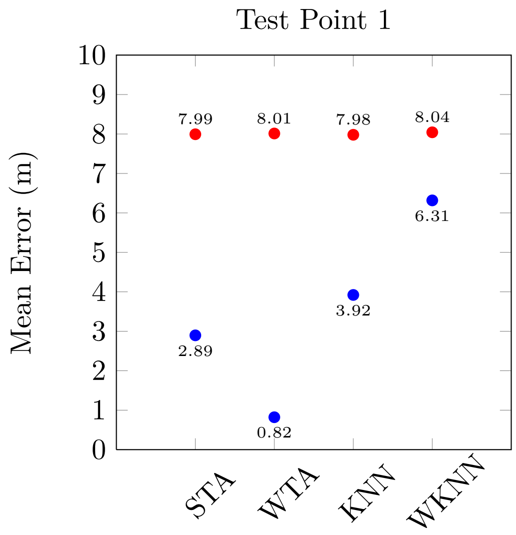


Figure 5.37: Test Point 1 (Scenario III)

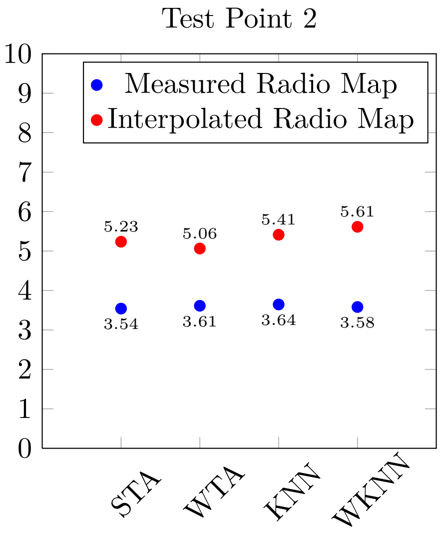


Figure 5.38: Test Point 2 (Scenario III)

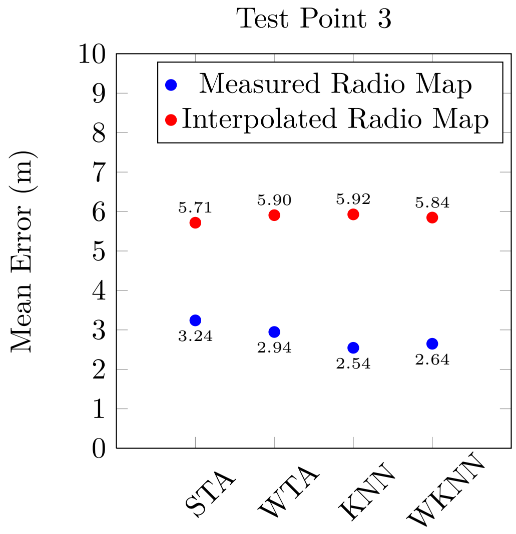


Figure 5.39: Test Point 3 (Scenario III)

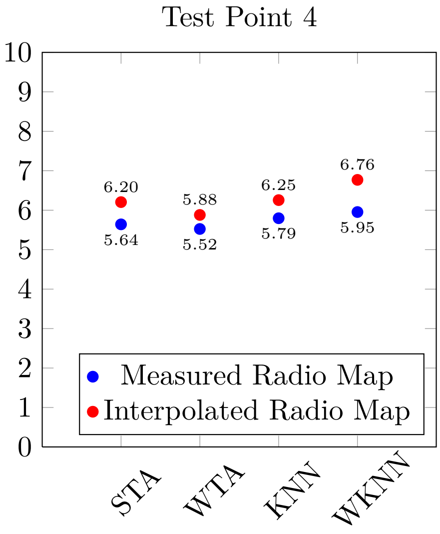


Figure 5.40: Test Point 4 (Scenario III)

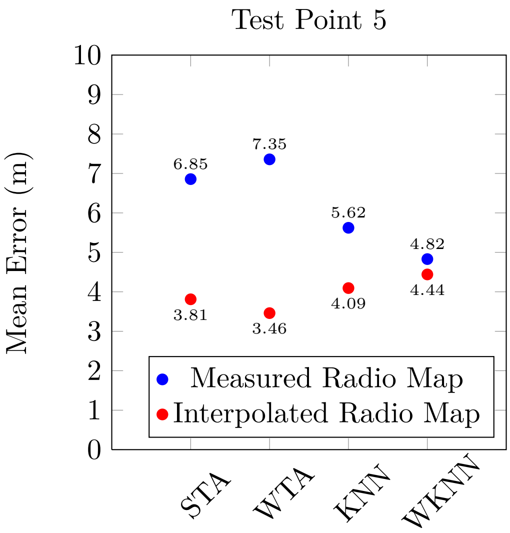


Figure 5.41: Test Point 5 (Scenario III)

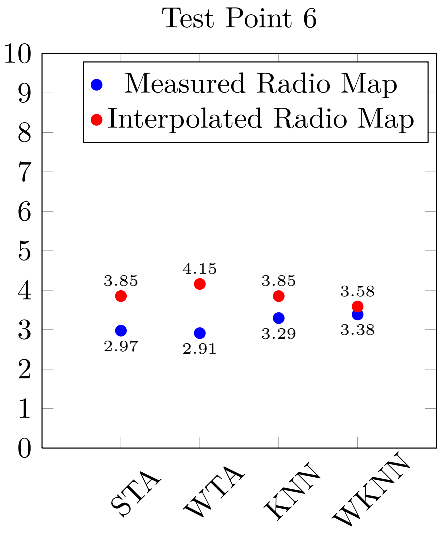


Figure 5.42: Test Point 6 (Scenario III)

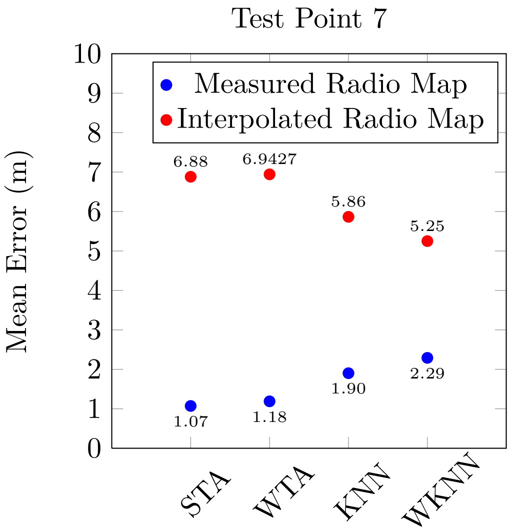


Figure 5.43: Test Point 7 (Scenario III)

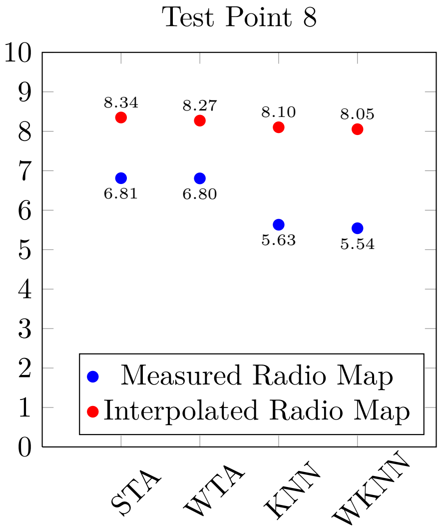


Figure 5.44: Test Point 8 (Scenario III)

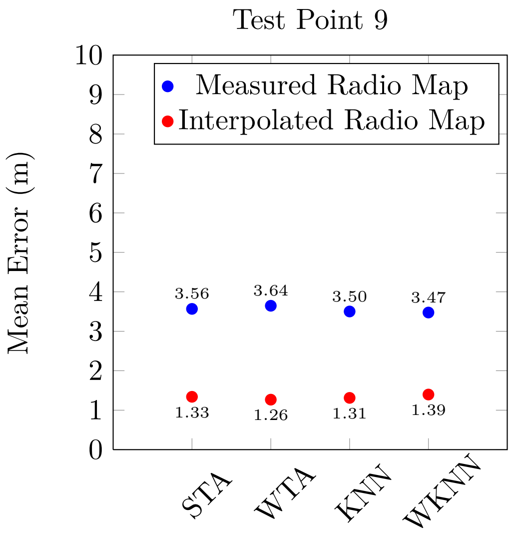


Figure 5.45: Test Point 9 (Scenario III)

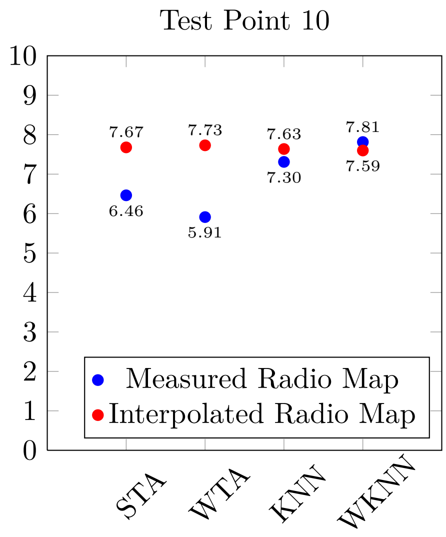


Figure 5.46: Test Point 10 (Scenario III)

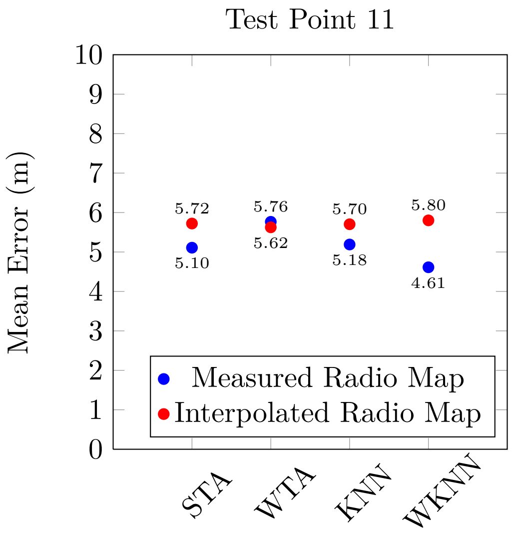


Figure 5.47: Test Point 11 (Scenario III)

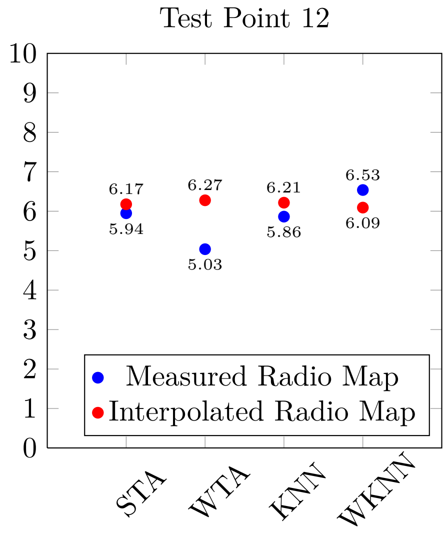


Figure 5.48: Test Point 12 (Scenario III)

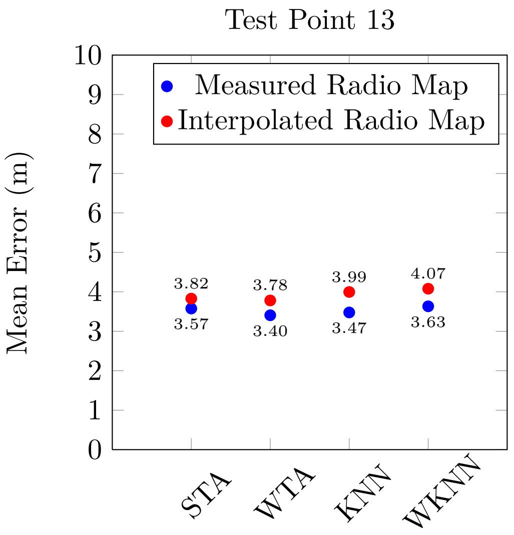


Figure 5.49: Test Point 13 (Scenario III)

Fingerprint Differences

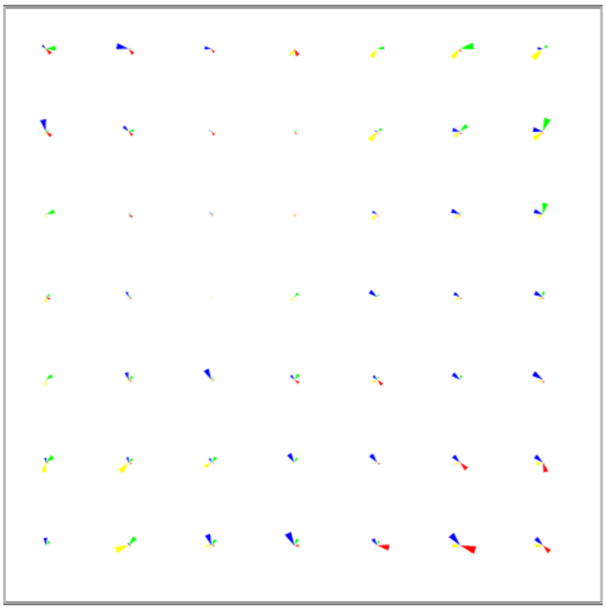


Figure 5.50: Overview Fingerprint Differences (Scenario III)

5.4.3.3 Summary

The accuracy achieved by the help of the measured Radio Map is better in eleven out of the thirteen test cases. The interpolated Radio Map showed better performance at test point 5 and 9.

At test point 1 the interpolated Radio Map had a much worse accuracy than the measured Radio Map. The mean error by the WTA for example for the measured Radio Map was 0.82m, whereas it was 8.01m for the interpolated Radio Map. It seems that the interpolation did not work well for the upper left corner, because the differences are never so remarkably again. The calculation for the interpolated Radio Map was dependent from only one measurement in the center of the environment. Measurement inaccuracies at this point hence have an impact on the total Radio Map. This might be the reason for the bad results at this test point. The WKNN algorithm compared to the WTA for the measured Radio Map showed also a very bad performance. The selection of neighbours for the WKNN might be bad at that test point.

Very outstanding are the results from test point 3, 5 and 7. It seems the better the performance for one algorithm at one Radio Map, the higher is the error for the same algorithm at the other Radio Map.

Figure 5.50 shows that there are broad differences in the the recorded signal strengths between the measured and interpolated Radio Map.

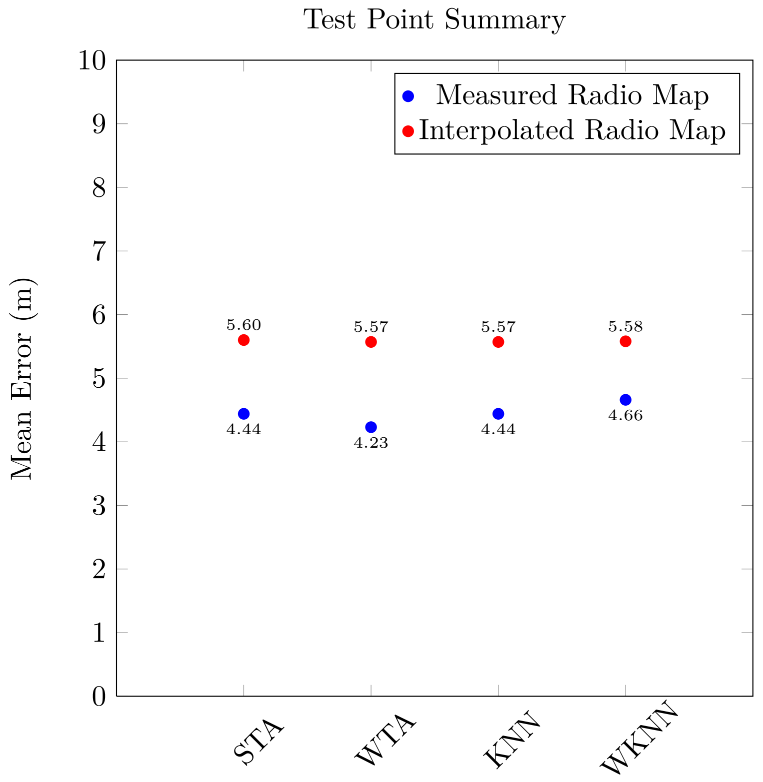


Figure 5.51: Test Point Summary (Scenario III)

The plot 5.51 shows the average mean error of all test points for each algorithm and both Radio Maps. The overall performance of the algorithms are nearly the same. The interpolated Radio Map created by the help of the implemented optimization algorithm achieved a good performance compared to the measured Radio Map. In that scenario the time savings for constructing the interpolated Radio Map compared to the measured Radio Map are very high. For the interpolated Radio Map only one grid point was recorded, for the measured Radio Map the total of 49 grid points were recorded. The results are okay for this test scenario if we consider that this scenario was a large LOS environment. Compared to NLOS environments there are no distinct losses in the received signal strengths that occur because of walls which makes accurate positioning very hard. Another reason for the inaccuracies is the fact that the recorded signal strengths do not accurately follow the Log-Distance Path Loss Model as one test showed (see chapter 5.5.1).

5.5 Other Findings

5.5.1 Comparison of Real and Calculated Signal Attenuation

The plot 5.52 shows the difference of the real measured signal strengths in a LOS environment compared with the calculated optimal signal strength determined by the Log-Distance Path Loss Model.

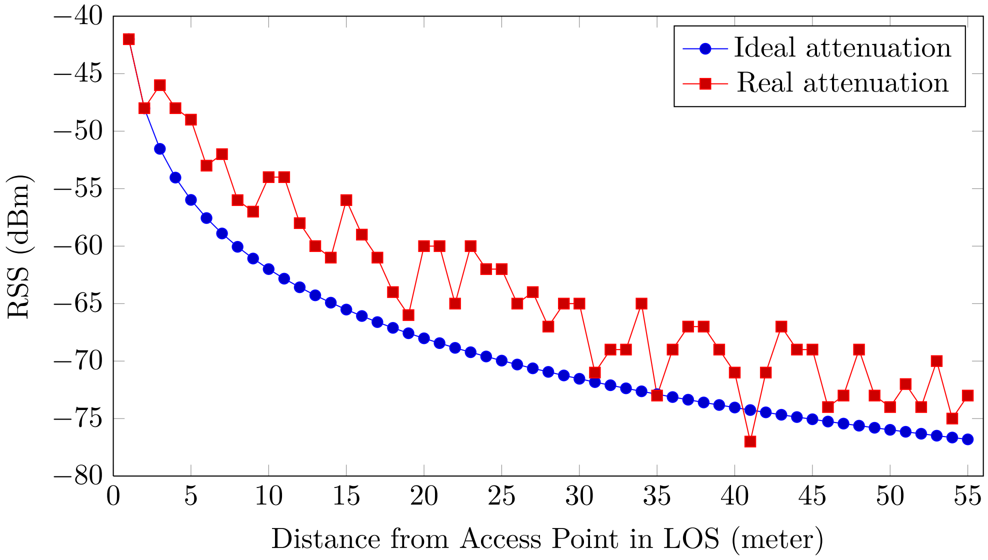


Figure 5.52: Differences between calculated RSS attenuation and real recorded attenuation

5.5.2 Failure of an AP

To evaluate the robustness of the implemented system, a test was done in test scenario 1 (see chapter 5.4.1) that reveals the error that occurs if one of the AP fails. Figure 5.53 shows the layout of the APs and the positions of the test points. The following plots show the results for each test point in one plot. The plot compares the mean positioning error if no AP failed, to the cases if one of the three fails. The given error is the best reached at that test point of all positioning algorithms.

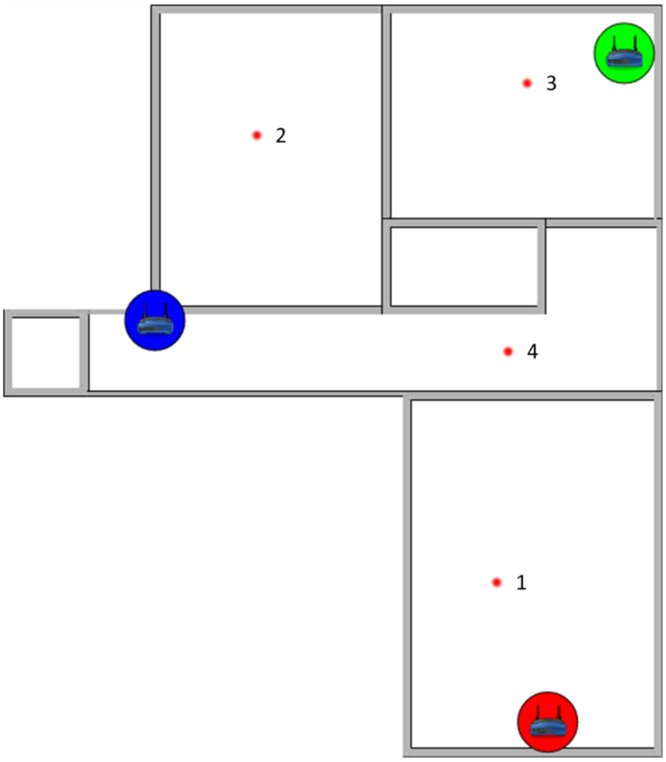


Figure 5.53: Overview Access Points - AP Failure Test

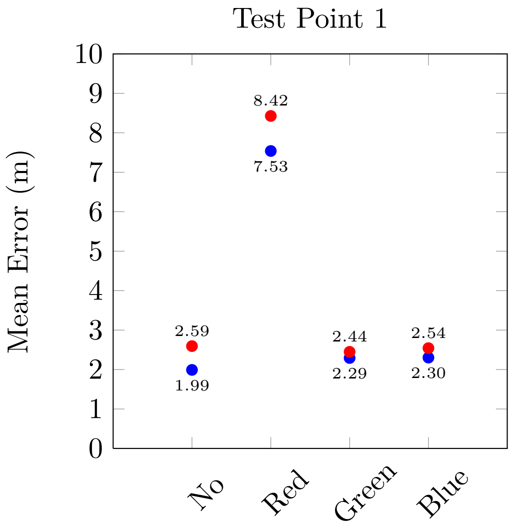


Figure 5.54: Test Point 1 (AP Failure)

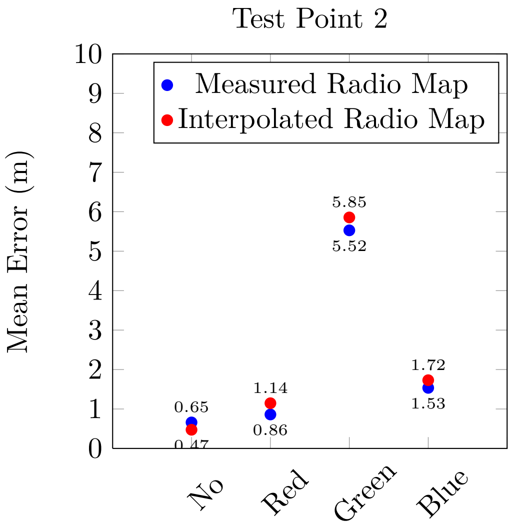


Figure 5.55: Test Point 2 (AP Failure)

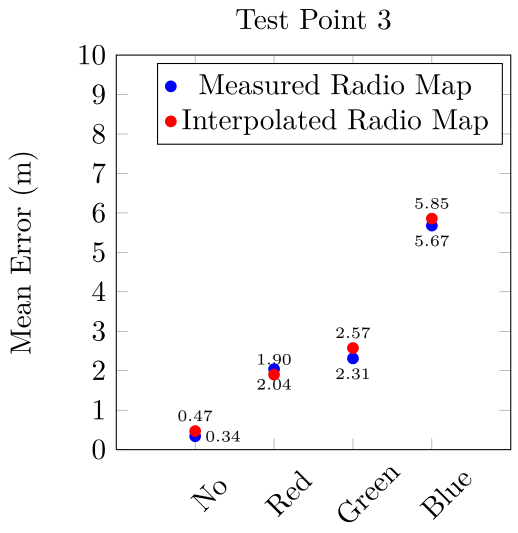


Figure 5.56: Test Point 3 (AP Failure)

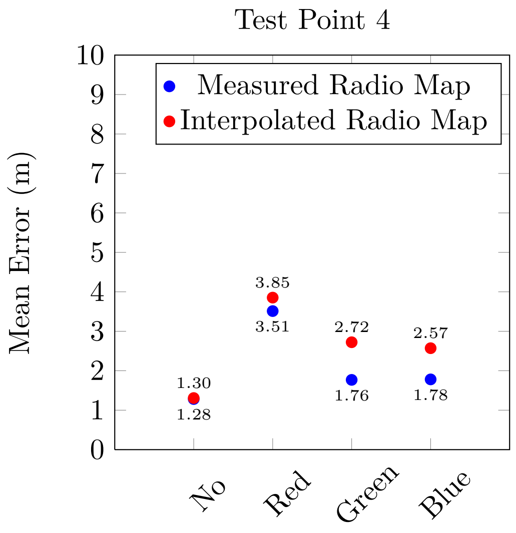


Figure 5.57: Test Point 4 (AP Failure)

If one has a closer look on the plots and the according position of the test points one can recognize that the positioning error is significantly higher if the test point is close to the AP location that failed. The plots of test point 1, test point 2 and test point 3 show this incident very well. The error is clearly higher if the failed AP is close to the test point location. The mean error grows the closer the distance is to the available APs. At test point 4 all APs are nearly the same distance away from the location of the test point and have similar error rates. This incident is easy to explain. The closer the test point is to an AP, the higher is its RSS value saved in the Radio Map. The most similar fingerprints are calculated by the mean square error. Hence the higher the RSS value of the failed AP, the higher is the mean square error and so the positioning error.

5.5.3 Comparison of different grid widths

To determine the influence of the grid width on the positioning accuracy a test was done in an 6m x 6m LOS environment with four APs using six different grid widths from 0.5m to 3m. Graphic 5.58 shows the mean positioning error averaged over 13 equally distributed test points. The best accuracy is achieved with a grid width of 2.5m. Surprisingly the error is higher for all smaller grid widths between 0.5. and 2m. This is because of the deviations that occur when measuring the signal strengths. Grid widths lower than 2.5m do not improve the accuracy.

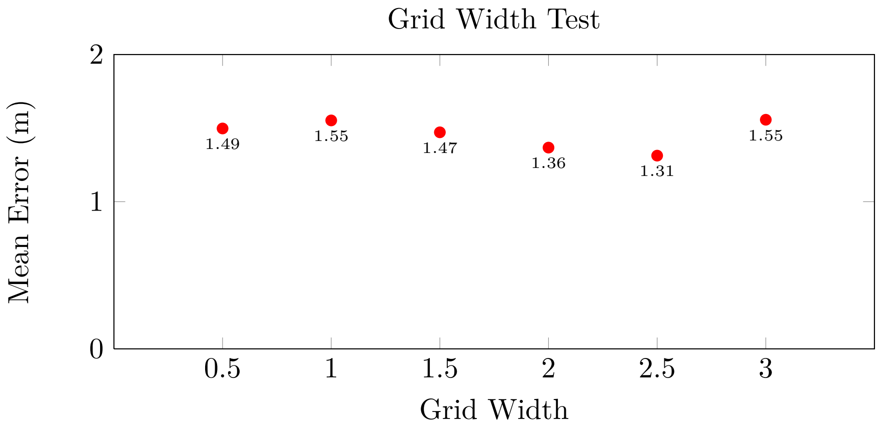


Figure 5.58: Grid Width Test

5.5.4 Comparison of RSS of different devices

The plot 5.59 shows the differences between measured signal strengths of three Android devices at the same positions. The devices used for this test were:

- Samsung Galaxy Tab GT-P6211 7.0 Plus N Wifi (Android 3.2)
- Google Galaxy Naxus (Android 4.0.4)
- HTC Evo 3D (Android 4.0.3)

One RSS value is the average of ten consecutive measurements. The measurements for each device were done in a row. The devices were exactly placed at the same positons heading in the same direction.

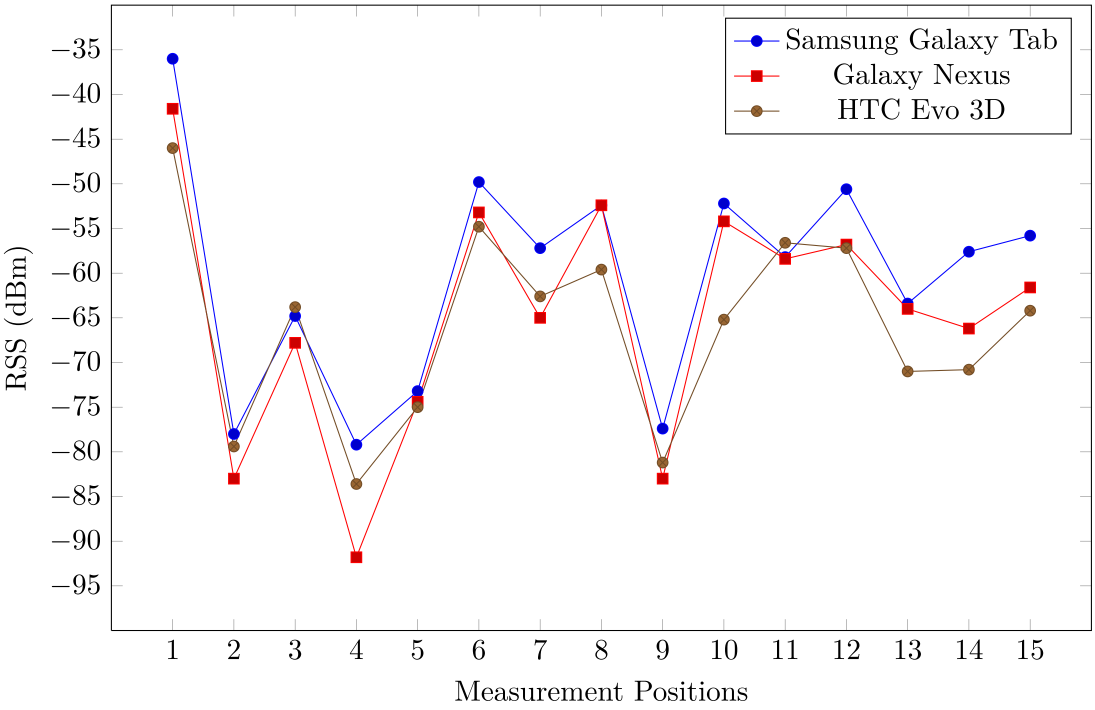


Figure 5.59: Differences between measured RSS values of different Android devices at same positions

The graphic 5.59 shows that different devices slightly receive different signal strengths. The average variation was 7.17dBm. The Samsung Galaxy Tab overall seems to receive the WLAN signals best.

6 Conclusion

The background researches on the existing technologies that were developed or used for IPSs showed that there is no common agreed and perfect solution for indoor positioning as GPS is for outdoor. Hence there is space for research, especially for allowing indoor positioning and navigation with smartphones.

The most promising and newest technology is possibly the positioning by the help of the emitted earth's magnetic field developed at the University of Oulu (Finland) under the responsibility of Janne Haverinen who has longtime experience in this field of research. The system promises great positioning accuracy within two metres and does not need any additional hardware. The system called IndoorAtlas is still under development and its final release could become the leading technology for IPS with smartphones.

The technology used for implementation of an IPS for smartphones within this thesis is WLAN. The aim is to improve the off-line phase of the Location Fingerprinting approach in order to lower the points at which fingerprint measurements have to be taken. The system as described in the previous chapters figures out some grid points at which measurements have to be taken and then calculates the other non-measured ones by interpolation using the Log-Distance Path Loss Model.

The overall goal is to realize a system that deals with the complexities of the off-line learning phase and allows to create a Radio Map with manageable effort. Nevertheless the resulting system should be usable for indoor positioning and navigation within large public buildings like shopping centres. It should at least be possible to locate a device within five meters. Evaluations showed that this approach can help to overcome the complexities of the off-line learning phase of the Location Fingerprinting approach and reach an acceptable accuracy, as well as that there is space for improvements.

The evaluation in NLOS environments showed a very good overall performance. The mean error in test scenario 1 and a grid width of 1.0m for the measured Radio Map of all positioning algorithms is 1.66m. The mean error for the interpolated Radio Map is 1.89m and hence only 23cm or 13.98% higher. At test scenario 2, another NLOS environment, and a grid width of 1.3m the mean error for the measured Radio Map is 2.11m and 2.54m for the interpolated Radio Map, which is a difference of 43cm or

20.37%. These results are promising, but we have to keep in mind that there were high deviations at some test points of nearly up to 5m, in some cases only for the interpolated Radio Map or even both Radio Maps. At test scenario 3, a LOS environment, and a grid width of 5m the mean error for the measured Radio Map is 4.44m and 1.14m or 25.60% higher which is 5.58m for the interpolated Radio Map. In that scenario there were also some test points at which the mean error grew up to over 8m. A test aimed to determine the influence of the grid width on the positioning accuracy showed that a grid width of 2.5m is best. Lower as well as higher grid widths had a negative impact on the resulting positioning accuracy.

The results are overall very promising but there are some points that have to be further investigated. The WLAN Location Fingerprinting approach has some basic restraints compared to other solutions. The Radio Map of one environment is usually created once but the saved signal strengths can change over time because they are influenced by many factors. Every change in the environment can have an impact on the signal distribution of the WLAN routers. Walls, doors or even new or differently placed furnitures will change the received signal strengths at some points in the environment. These things are very hard to deal with. Possibly the only and easiest solution is to check the saved signal strengths of the Radio Map from time to time, especially when changes for example new furnitures or other APs are installed.

The tests were carried out using the same routers as well as the same device for every test. One test case shows that different devices receive slightly different signal strengths from the same AP at the same place, depending on the built-in hardware. The evaluations does not show what happens when different or other routers are used. Different routers have different antennas and hence does not cover the same area or have the same signal attenuation over the same distance. If different routers are used for creating one Radio Map, a constant value might have to be added for every single AP to make the optimization algorithm accurate.

The evaluation revealed some incidents that might have an influence on the accuracy and have to be further investigated and improved. One very basic but important thing is the distribution and number of APs, which was topic of the studies by Zhao et al. (2008) and Baala et al. (2009). At test scenario 3 there is only one grid point out of a total of 49 used for the interpolated Radio Map. The area is 36m x 36m in size. At some test points the mean error for the interpolated Radio Map is dramatically higher compared to the measured one. A test that figures out if measuring more grid points for example at least every 10 meters would improve the results has to be done.

Another issue that have to be reconsidered in detail is the Log-Distance Path Loss Model and the path loss exponent. An evaluation showed that the exponent could be slightly lower, it may also depend on the APs.

In order to increase the usability of the Navigation Activity the application has to avoid jumps in the calculated positions by circling an area around a position at which the user is located. Tests in unknown environments also should that it would be easier for the user if the building's plan rotates with the orientation of the device.

The work shows that the implemented optimization algorithm for the off-line learning phase of the WLAN Location Fingerprinting approach is a legitimate way to deal with the complex, time-consuming way of establishing a Radio Map for big buildings. The grid points at which measurements have to be taken can be substantially lowered and in addition an acceptable positioning accuracy reached compared to a fully measured Radio Map in the on-line phase. As already mentioned evaluations revealed some factors that has to be further considered and explored in future work to increase the positioning accuracy: The number as well as the distribution of APs, the maximum distance between two measured grid points to make the interpolation more accurate, the influence of different hardware - smartphones as well as routers - and the calculation using the Log-Distance Path loss Model, especially the influences on the Path Loss exponent could be a starting point for further work.

7 Outlook

Based on the evaluation and its findings the application will be improved further on. The testing phase revealed some incidents (see chapter 6) that have to be investigated in more detail in order to make positioning and navigation more accurate. A closer look on the influence of the distribution and number of AP on the positioning accuracy has to be done and tested. The optimization algorithm has to be reconsidered and hence the Log-Distance Path Loss Model maybe slightly adapted, although the previous evaluations were satisfying.

The aim is to make the application ready to use for navigation inside a shopping centre. The positioning has to be more stable and a navigation algorithm has to be implemented. The developed source code has to be reworked in order to allow multiple floor handling and navigation as described in chapter 4.6. The resulting application will then be tested in a real shopping centre environment. The overall aim is to make navigation from any point inside the shopping centre to each store possible.

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