Master's Thesis

Evaluation and testing of techniques for indoor positioning

By

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Abstract

Today it is possible to position wireless devices such as smartphones in an outdoor environment, using GPS, global positioning system. Unfortunately this technology does not work in indoor environments.

Being able to position smartphones indoors could be beneficial in many different environments. In hospitals when tracking hospital beds and patients, in prisons in order to track prisoners, in malls when a customer is searching for a store etc. Indoor positioning could also be used to analyze human behavior.

There are many different methods and techniques existing today that could benefit to an indoor positioning solution, all of them providing different results. Some are friendlier towards larger scaled areas providing less satisfying precision, meanwhile others provide higher precision but increases significantly in cost for larger scaled areas.

In this master thesis project a significant amount of time was spent on researching different techniques for indoor positioning as well as analyzing the current state of the art and the market of existing indoor positioning solutions.

The aim of the proof of concept is to provide a suitable indoor positioning solution to one of the three different use cases with focus on the following aspects:

- Usability
- Precision
- Scalability

This master thesis has provided a fully working solution to position multiple devices simultaneously. It uses anomalies in earth's magnetic field, created by the structure of the building and different objects in the indoor environment, together with a set of Bluetooth beacons to navigate. The work has resulted in a fully working server together with an android application. The solution is an interesting approach to indoor positioning, it is fast and easy to set up and performs reasonably well compared to similar solutions.

Indoor positioning based on magnetic field fingerprints

Indoor positioning, one of today's technical challenges. How can it be solved when there is no standard solution? One approach is by discretizing earth's magnetic field and use it as fingerprints.

Today there is a standard technology called global positioning system, GPS. This is a system that is commonly used to position smartphones outdoors. Unfortunately, GPS is not reliable indoors as it requires satellite connection. Indoor positioning is a problem today as there exists no standardized solution. However, there exists some technologies that can be used to perform indoor positioning. The problem with these are that they were not created for the purpose of locating devices, which makes the task a bit trickier. But it can be done, just like the situation with the GPS.

An increasing number of devices are connected and designed to communicate with each other. Concepts such as "internet of things" might benefit from indoor positioning in the future at the same time widespread use of smartphones, tablets and other mobile communication devices location based applications are becoming increasingly popular.

When trying to develop an indoor positioning system, there are several problems to tackle. The first problem to encounter is the main one, how can a device be positioned? As mentioned earlier there exists no standard technique solving this problem today. Companies have been trying to produce their own solutions for years, trying to create a product that is marketable. Therefore analyzing the market is a good start, trying to avoid what has already been classified as dead-ends.

There are several methods that can be used to estimate the position of a smartphone. These methods often rely on already existing technologies such as Wi-Fi, Bluetooth as well as different smartphone sensors. A popular choice these days is to combine technologies in a fusion solution to achieve better precision.

Then there is another problem, how stable is the data? Smartphone sensors drifts, Wi-Fi and Bluetooth signals tend to be interfered due to the choice of a popular bandwidth, or the signal strength decreases when it propagates through walls. Don’t worry though, these problems can be diminished using smart filters and algorithms.

We developed an android application which uses magnetic field strength data together with Bluetooth data to position itself. The application achieves fairly good accuracy and the developed solution can be installed quick and easy in most indoor environments.

Acknowledgments

We would like to thank our supervisor, Stefan Höst, for guidance during this master thesis project. We are also indebted to thank Dennis Zikovic and Cybercom for giving us the opportunity to perform our master thesis project at their office in Malmö, as well as sharing their knowledge and expertise with us during the project.

Hampus Engström & Fredrik Helander

Contents

1. Introduction

Today there is a standard technology called global positioning system, GPS. This is a system that is commonly used to position smartphones outdoors. Unfortunately, GPS is not reliable indoors as it requires satellite connection. Indoor positioning is a problem today as there exists no standardized solution. However, there exist some technologies that can be used to perform indoor positioning. The problem with these are that they were created for other purposes than to locate devices which sometimes make them very unreliable.

An increasing number of devices are connected and designed to communicate with each other. With concepts such as “Internet of things”, also known as IOT, and the widespread use of smartphones, tablets and other mobile communication devices location based applications are becoming increasingly popular.

This master thesis project report is divided into several parts, starting with some explanations of the fundamental techniques, technologies and methods commonly used in indoor positioning today. This knowledge is then used further on to analyze the different commercial solutions described in the state of the art section, as this requires some understanding of the different indoor positioning concepts.

In this master thesis project a significant amount of time was spent on analyzing the current state of the art and the existing market of existing indoor positioning solutions. The conclusions drawn from this analysis were taken into consideration when presenting solutions to the different use cases introduced as well as in the implementation of proof of concept.

The aim of the proof of concept is to provide a suitable indoor positioning solution to one of the three different use cases with focus on the following aspects:

- Usability
- Precision
- Scalability

This master thesis project was performed at Cybercom. Cybercom is a company with vast experience within the fields of connectivity and “Internet of things”. They are now exploring the possibilities of indoor positioning and is in need of a good solution to apply on their upcoming projects.

2. Use cases

In this master thesis project we have put together three different use cases that exists and represents three different approaches to indoor positioning.

1. **No additional software or hardware**

In the first use case we evaluate a suitable solution where the person being tracked carry only a mobile phone. The phone has no special software installed, the person can be tracked without being aware of it. This means that this solution will have to be network-based.

2. **Additional software**

In the second use case we evaluate a suitable solution where the person being tracked carry only a mobile phone. However, in this use case, the mobile phone contains special software to enhance the positioning performance. This means, since the phone need special software running, the person cannot be tracked without being aware of it.

3. **Additional hardware**

In the third use case we evaluate a suitable solution where the person being tracked is carrying special hardware to improve the positioning accuracy.

This master thesis will be performed based on use case 2, which is required by Cybercom.

2.1. Outline

This report is composed in such a way that Chapter 1 will introduce the subject indoor positioning and its problems. Then Chapter 2 will introduce the background that is necessary in order to understand the subject’s elements such as technologies and methods etc. There will also be presented some common filters and a matching algorithm, together with two different approaches for constructing an indoor positioning system. Then when the basic elements of the indoor positioning are covered we will start to present the results of a state of the art analysis where the market of existing solutions will be analyzed. This will be taken in consideration when we decide for our solution described in Chapter 5, which will be aiming towards fulfilling one of three different use cases that is presented in the prior, Chapter 4. Then in Chapter 6, the proof of concept, the solution architecture and implementation will be presented as well as experiments with some reflections and arguments used as basis in decision makings. This is followed by Chapter 7 where our solution is evaluated based on three key focuses that are already presented in the introduction. At last there will be some discussion and conclusions drawn based on the evaluation.

3. Background

3.1. Wireless Communication Technologies

Wireless communication technologies are used worldwide in order to communicate and share data. Indoor positioning systems often rely on various wireless communication technologies. These technologies are primarily designed to provide communication and data access. However, it is possible, based on the characteristics of a received radio signal, to estimate the distance to the signal source.

This section will provide information regarding different wireless technologies that is commonly used for communication and data sharing. These are mainly: Wi-Fi, mobile networks, Bluetooth and UWB which are different technologies with different approaches and benefits.

3.1.1. Wi-Fi

Wi-Fi is widely used all over the world and is one of the most common local area networking techniques today. Wi-Fi is to be applied in a local network by setting up wireless Access Points (AP) providing devices to connect to the network wirelessly. This provides the possibility to move around the device in the local area while being connected to the AP. This means that wherever the device appears in the local area it can communicate with the AP. The AP is usually part of a network that is connected to the Internet, which provides the device with the possibility of communicating with devices of different local area networks. Wi-Fi emerged as the marketing branding name of the latest wireless local area network (WLAN), which was based on the Institute of Electrical and Electronics Engineers IEEE 802.11 standard. IEEE 802.11 operates under different protocols with various frequencies: 2.4GHz, 3.6GHz, 5GHz and 60GHz; all providing different range and speed of communication.

The IEEE 802.11 was first developed in 1997, later on providing the protocols, “a” in 1999, “b” in 1999, “g” in 2003, “n” in 2009 and “ac” in 2013; they all induce further opportunities [1].

Wi-Fi is a half-duplex system, meaning that it supports communication of both directions but not at the same time. It works by encoding data on a radio wave (carrier), which is then applied to a frequency by broadcasting it. The radio waves are then received and decoded back into readable data. In order to send data on a radio frequency one of two ways of modulating the radio signals must be applied, either by amplitude modulation (AM) or by frequency modulation (FM).

3.1.2. LTE

Long-Term Evolution is the newest of the currently used mobile networks for wireless data communication. LTE is divided into cells where each of them contains a base station that forwards communication between devices within the cell or to other base stations outside the cell. It is designed to offer significantly higher bitrates than the earlier used 3G network, which is using GSM (Global System for Mobile Communications) and UMTS (Universal Mobile Telecommunications System) [2].

It works by providing a devices the opportunity to connect to its nearest base station and letting it communicate with other devices connected to other base stations via that base station. This is briefly explained with Fig. 1.

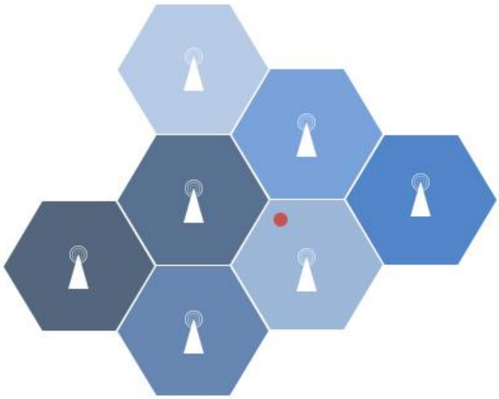

Fig. 1. This figure shows the structure of the mobile networks today. The covered area are divided into cells, each one with a cell tower, creating channels for communication between each tower.

5G

The 5th generation mobile networks (5G) also known as Tactile Internet is the upcoming future network. According to 5G Private Public Partnerships (5G PPP), the new mobile network provided will be saving 90% of the energy per service provided. It will provide a much higher wireless area capacity meanwhile creating a secure, reliable and dependable Internet. It will support 7 trillion connected wireless devices and provide 10 to 100 times higher data rate as well as an End-to-End latency less than 1ms [3].

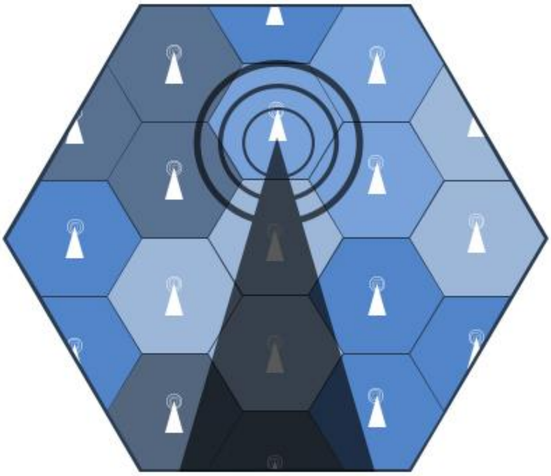

Fig. 2. This figure shows the structure of the upcoming 5G mobile network, where each already existing cell used in LTE, macro cell, is being split into micro cells.

This should all be done by applying a micro cell technology to the already existing macro cells, where all communication with other macro cells is done through its radio tower, as illustrated in Fig. 2. This would also provide higher resolution in terms of positioning, which will be important aspect of the upcoming 5G network. Further on the standards of the 5G mobile network is set by 3GPP, the 3rd Generation Partnership Project, which unites 7 standard development organizations in telecommunications [2].

3.1.3. Bluetooth

Bluetooth is a widely used wireless communication technology, it has become very popular in homes with, for example, wireless speakers using this technology to receive music from a device. The technology is primarily designed for communication over short distances and its original application was to act as a cable replacement protocol in wireless keyboards, wireless headsets etc. Its short distance low power characteristics makes Bluetooth very suitable in communication between small wireless devices.

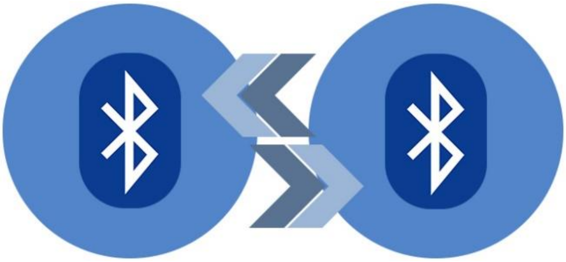

Fig. 3. This figure shows an illustration of two Bluetooth devices communicating wirelessly.

Bluetooth unites a set of protocols that devices can use in order to communicate, which is roughly illustrated in Fig. 3. The technology operates in the 2.4 GHz frequency band. This frequency band is called Industrial, Scientific and medical(ISM) and is used by several other technologies. To minimize interference Bluetooth uses a technique called normal frequency hopping. Normal frequency hopping is to avoid interference by changing the carrier among several frequency channels at high speed in a random sequence [4].

BLE

Bluetooth Low Energy, also known as Bluetooth Smart, evolved from the classic Bluetooth technology aimed to offer significantly lower energy consumption than its predecessor and is specifically designed to be applied in wearable technology, internet of things and beacons. BLE was merged into Bluetooth version 4.0 in 2010 [4].

Beacons are BLE devices with the ability to broadcast short messages to nearby Bluetooth devices. Beacons are usually designed to take full advantage of the low energy consumption characteristics of BLE, small discrete devices that melt into the environment and with very long battery life. Beacons are specifically designed for various location based applications such as indoor positioning and location aware marketing applications [5].

3.1.4. UWB

Ultra-wideband radio is a technology with high-bandwidth communication capabilities over short distances. UWB is a very low-energy technology that is used in applications where high bit-rate at short range is required and, due to its power characteristics, can also be used at medium-to-long ranges where only low bit-rate is required.

UWB uses short pulses over a large frequency spectrum to send data. This property have been proven to be useful for high-precision ranging applications. The use of a large frequency spectrum also means that UWB is less vulnerable to reflections when going through obstacles than technologies using smaller bandwidth [6].

3.2. Sensors

Nowadays smartphones have become much more advanced than a decade ago thanks to its many components. They have also become smarter in sense of awareness. Most of the mobiles today have awareness in shape of integrated sensors providing the opportunity of reading its state of position and motion etc. There are some sensors worth mentioning due to their relevance of this master thesis. The accelerometer, which measures non-gravitational acceleration; the gyroscope, which can sense orientation; and the magnetometer, which reads the magnetic field strength and direction surrounding the device.

3.2.1. Accelerometer

The majority of today's smartphones has an integrated accelerometer. Its purpose is to measure acceleration forces. It measures the force applied when a device is moving. A non-constant movement results in an acceleration applying a force on the accelerometer making it sense the force changing. This data can be obtained as three values consisting of the accelerometer in x-axis, y-axis and in z-axis.

Fig. 4. This figure shows a simplified visualization of how a gyroscope can look like.

3.2.2. Gyroscope

The gyroscope is used to sense the orientation of a device. It is useful for example in aircrafts to determine or maintain orientation in space. It is often visualized as in Fig. 4.

The gyroscope works based on the principles of angular momentum, which basically means that the gyroscope prevents the outer force that is applied by applying a force equal to the outer one. This preventing force can be measured and therefore also the orientation.

3.2.3. Magnetometer

Most smartphones are equipped with a magnetometer. The compass is probably the most well-known application where the magnetometer is involved. In a compass the magnetometer is used to read the earth's magnetic field and use it to find the direction of north.

Earth’s magnetic field is affected by objects in the environment. The magnetometer in a smartphone is usually very sensitive and can give disturbed readings due to anomalies in the magnetic field caused by walls, structures or electrical wiring and devices.

3.3. Measurement methods for positioning

To be able to use radio signal properties in an indoor positioning context a suitable measurement method is needed. A measurement method can be used to, for example, estimate the distance to the source of a received signal or estimate the angle of an incoming signal. The measurements data are often based on some kind of wireless communication technology which is transmitted into the air and can be received by anyone listening.

3.3.1. Angle of Arrival

Angle of Arrival (AOA) is a measurement method that determines the direction of a radio frequency wave when its propagation encounters multiple antennas. The direction is determined by measuring the difference in time the wave strikes each individual antenna, this is what is called Time Difference of Arrival. It is commonly used to estimate the angle from which a radio signal originated for example locating wireless devices. By observing Fig. 5, it is seen how a provided set up of two antennas with distance D in between each other, and a signal wave that is registered by the right antenna [7].

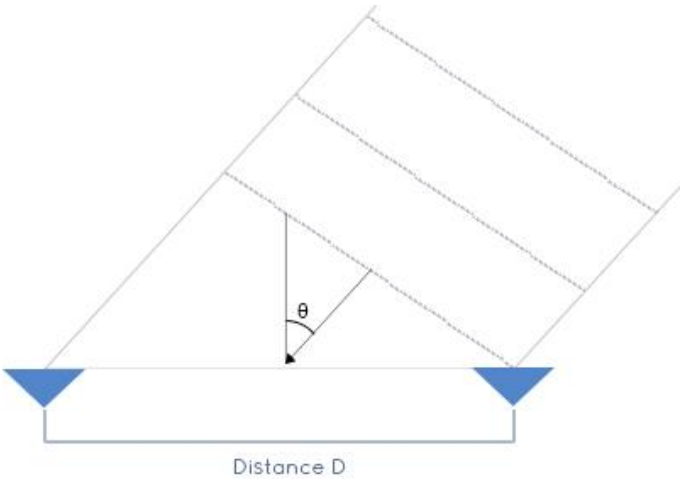

Fig. 5. This figure shows the concept of angle of arrival with two antennas receiving an incoming plane wave.

The angle of arrival is calculated due to the delay between the receiving of the radio wave with:

Δt is the Time Difference of Arrival

c is the Speed of light in air

D is the distance between the receivers

The angle θ can be derived as

$$\theta = \sin^{-1} \frac{c\Delta t}{D}$$

3.3.2. Time of Arrival

Time of arrival, also known as time of flight, is basically measuring the time it takes for the radio signal sent by the transmitter to arrive at the receiver. After obtaining this time, the distance can be calculated due to known speed of the radio signal. The distance from each of the receivers, minimum three, results in intersecting circles with known radius pointing out the position of the transmitter related to the receivers [8].

In order for this method to be used, there must exist a way of measuring the time. This is usually done by synchronizing the transmitters and the receiver's clock, unfortunately this process is very complex due the difficulties of estimating the travel time between the access points.

3.3.3. Time Difference of Arrival

Time difference of arrival, TDOA, is based on multiple receivers picking up the same radio wave emitted by an unknown transmitter as illustrated in Fig. 6. This method relies on synchronized receivers measuring the time difference between each antenna receives the signal, in contrast to TOA which needs the transmitter to be in sync with the receivers [8].

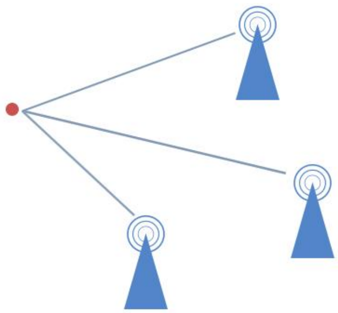

Fig. 6. This figure shows the concept of Time Difference of Arrival using one transmitter, the red circle, and three antennas.

The location of the transmitter is estimated with the following equation where

E is the device
P_m are the receivers
x_m, y_m and z_m are coordinates of the receiverP_m

The distance R_m between the transmitter and receiver is determined by:

$$R_m = |P_m - E| = \sqrt{(x_m - x)^2 + (y_m - y)^2 + (z_m - z)^2}$$

The equation system consists of three equations provided by three different receivers. The device's coordinates are calculated due to three equations with three variables.

3.3.4. Received Signal Strength Indication

Received signal strength indication (RSSI) is an indication of the strength still present in the propagated radio wave when it is received. The signal strength is measured when a transmitted signal is received, it is basically the remaining energy of the radio wave. The signal strength is often measured and interpreted in dBm. However, there is no standard way of measuring the signal strength.

The power of the signal decreases with the propagation time, interference and changes of the medium of the pathway, such as when the signal propagates through a wall. This makes the signal strength behave inconsequently and could in a histogram be describe with a normal distribution. It is possible to smoothen this error by using propagation models adapted to the environment that is used [9].

3.4. Estimation Techniques

Indoor position estimation techniques can be divided into two different approaches. Propagation approach, where the position is calculated by estimating the distance to various APs, and the fingerprinting approach where a location is uniquely identified by certain signal characteristics.

Estimation techniques use what is provided by the measurement method and estimate the position based on that.

3.4.1. Trilateration

Trilateration is probably the most well-known position estimation method. It is commonly used in surveying, navigation and GPS. Trilateration uses three known positioned APs. The propagation time or RSSI between the device and the AP is calculated in order to determine the radius from the AP on which the device could be located. This is done by three APs resulting in three spheres. The device's position is then determined by observing the intersection of the three radiuses. Three APs are the minimum number of APs required to be able to determine a position. The accuracy can be enhanced by calculating distances to multiple APs, this is called multilateration.

Trilateration prefers a line-of-sight environment due to the fact that obstacles in the environment affects the propagation time and signal strength of radio signals. As distances are estimated based on RSSI or propagation time, delayed or weakened signals may cause poor positioning accuracy.

The three spheres in Fig. 7 can be interpreted as circles on a 2D map. In reality, due to inaccuracies the three circles will not always intersect perfectly [10].

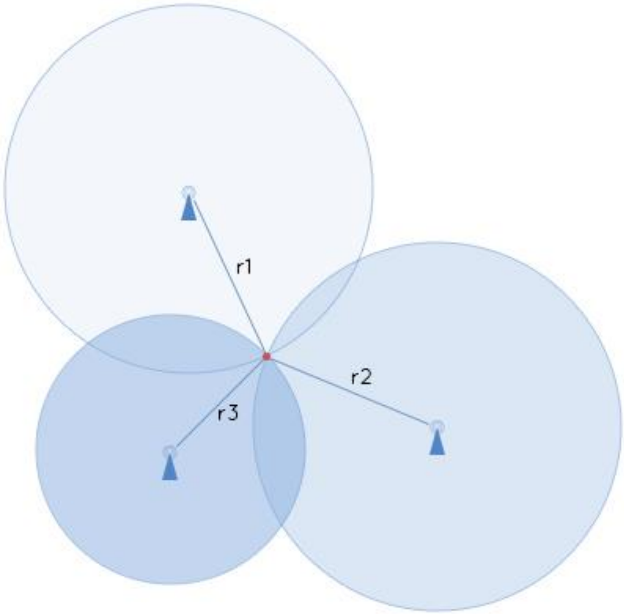

Fig. 7. This figure shows the concept of trilateration, estimating the position using the intersection point of three receivers estimated distances.

Wi-Fi is the most commonly used technology in trilateration based indoor positioning systems, mainly due to its widespread availability. Bluetooth and LTE can also be used, although in case of LTE, precision is usually lacking due to the fact that long distance between base stations usually means more obstacles in the way that can cause disturbance.

UWB is particularly useful for position estimation using trilateration due to its ability to determine distances very accurately even when obstacles are in the way. However, as the range of UWB is limited, multiple UWB nodes are required to cover a relatively small area.

3.4.2. Triangulation

Triangulation is based on geometric calculations using triangles. This is done by having two receivers obtain a signal emitted by a device and calculating the angle of which the signal arrived at each receiver. The setup is illustrated and briefly explained in Fig. 8.

After obtaining the angles, α and β, the distance D is determined using the equation

$$D = L\frac{\sin(\alpha)\sin(\beta)}{\sin(\alpha+\beta)}$$

Where L is the known distance between both receivers.

As the case with Trilateration, Wi-Fi is probably the most commonly used technology in triangulation based indoor positioning systems although technologies such as BLE, UWB and LTE could be used as well.

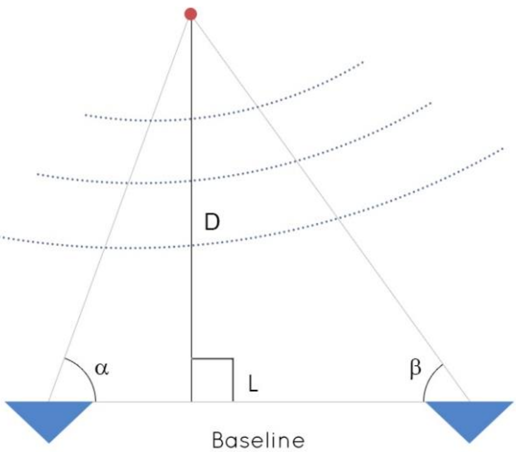

Fig. 8. This figure shows how to triangulate a device using two receivers based on the device’s transmitted signal.

3.4.3. Proximity

Proximity, is a technique that estimates the location of a device to the same location as the AP/unit it recognizes. It estimates the device's location to a local area rather than a set of coordinates providing less accuracy than other techniques.

To perform positioning using proximity estimation technique the used technology needs to be able to detect if a device is within range or not. Most radio technologies have this property. Wi-Fi and Bluetooth, usually using BLE beacons, can be used.

3.4.4. Fingerprinting

Fingerprinting is a commonly used estimation method today. It has the potential to estimate the position of a mobile device very accurately. The idea of this approach is to let certain signal properties or sensor measurements identify a certain location. Different signal properties and their corresponding locations are stored in a database effectively creating a map of the radio properties at different locations. The locations that make up the radio map are often referred to as reference points. The location of a mobile device is determined by matching detected signal properties with the reference points stored in the database. Besides the accuracy this approach also has the advantage of not relying on the placement of APs. In fact, the location of APs can be unknown and a fingerprinting approach would still work.

A fingerprinting typically consists of two phases, the offline phase where the signal properties in the environment are measured and the radio map is built. The second, the online phase, is when a user location is determined by collected data that is matched with the radio map in the database.

Various technologies can be used when deploying a fingerprint based indoor positioning system. In fact, the technologies do not necessarily need to be based on radio signals. An example is magnetic anomalies, which can be used to create fingerprints of an area, resulting in a magnetic map that in combination with magnetic sensors can be used in a way similar to a radio map. In this case magnetic properties can be measured at different locations and a certain location can be identified by the mobile device by measuring magnitude and magnetic strength in z-axis.

Offline Phase

The offline phase can also be referred to as the calibration phase. This phase include certain procedures required to set up a fingerprint based positioning system, it involves collecting data, creating the radio map and creating the database. This is done by first dividing the indoor area into sub-areas, where each sub-area is represented by a reference point. This is done by applying a grid, as presented in Fig. 9, and a coordinate system to the indoor area providing the possibility of referring to a certain point of the indoor map. This grid will represent the radio map.

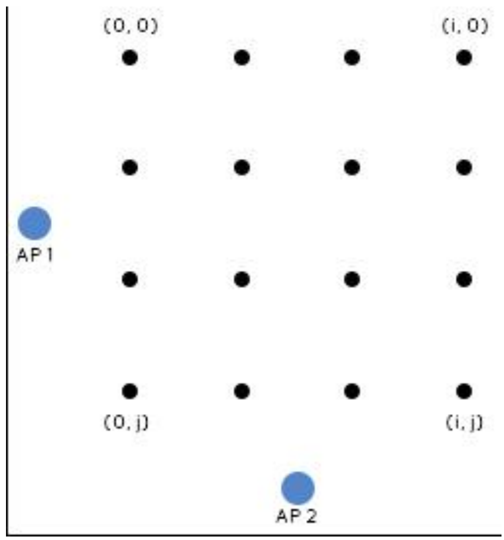

Fig. 9. This figure shows a radio map with reference point. Each reference point is represented by a set of coordinates.

After creating a radio map, a unique identification is provided at every reference point. This id is represented in terms of APs names or ids together with corresponding RSS. The theory is that broadcasted signals from the APs can take multiple paths all providing different combinations of various distances; obstacles such as walls, windows, roofs, floors, interior design; and phenomenon's like interference, etc. This large amount of combinations provides each reference point with a rather unique identification. This identification is often referred to as a fingerprint, hence the name fingerprinting. The identification is created by measuring the RSS from surrounding APs and is performed at every single reference point of the radio map as seen in Fig. 10. Since the RSS varies over time due to smaller environmental changes like people changing their positions, this is taken into consideration by taking multiple samples during the measuring, or by filtering the signal in some other way, in order to get a more approximate fingerprint. These fingerprints are embedded in a vector that is stored in a database together with its corresponding coordinate.

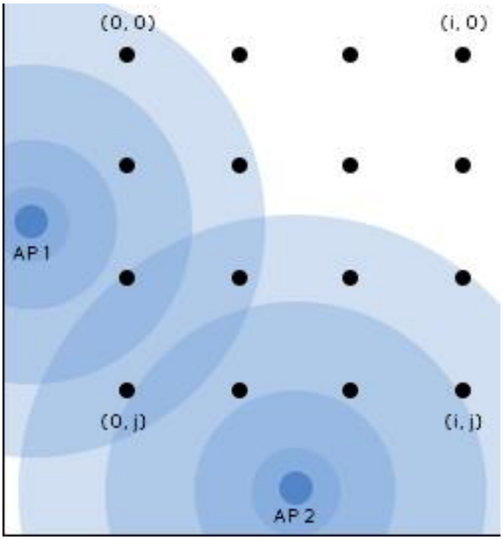

Fig. 10. This figure shows the radio map with reference points at which different combination transmitted signals appears origin from different access points.

Online Phase

The online phase consists of the user sending and receiving data to and from the server.

When the user is entering the radio map, the device should start collecting RSS from surrounding APs. This collected vector of name/ids together with RSSs is then sent to the server and matched towards the fingerprints in the database.

Wi-Fi is the most commonly used technique for generating a radio map. Bluetooth and LTE signals can be used as well as LTE signal strengths tend to vary at different locations within a building. To achieve a more accurate radio map a combination of technologies can be used. More technologies means more parameters that will contribute to the uniqueness of a reference point.

3.4.5. Pedestrian Dead Reckoning

Pedestrian dead reckoning, also known as PDR, is an offline estimation method that calculates a position with the use of data obtained by the mobile device's sensors which is exemplified with figure 11. The sensors provide the estimation with data such as step length, number of steps, direction of movement, changes in direction, velocity, and acceleration.

Fig. 11. This figure shows an illustration of the PDR positioning.

All this data can be used to track a device and its movement. It can be all based on sensors, the disadvantage though is that the error will increase successively since there is no reference to a true location such as a fingerprint reference point or an AP. The only reference is the one relative to the previous position.

3.5. Filters and Matching algorithms

Filters and matching algorithms represent important components in an indoor positioning system. Filters and matching algorithms can be used to improve the quality of the location estimation.

3.5.1. Filters

Results from signal strength measurements and results obtained from smartphone sensors can vary significantly from one moment to another. Selecting an appropriate filter to reduce the noise is of great importance in terms of positioning performance. Filters are used to estimate parameters of interest from uncertain observations.

Kalman Filter

A Kalman filter is a filter that estimates parameters of the current state only using information from the current measurement and the previous state, a so called recursive estimator. A Kalman filter is an optimal estimator, this means that the filter minimizes the mean square error of the estimated parameters if the noise is Gaussian.

Kalman filters are very popular due to its convenience in real time processing applications, new observations can be processed as soon as they arrive. Kalman filters are also relatively easy to implement and provides good results.

The Kalman filter is based on two equations:

$$x_k = Ax_{k-1} + Bu_k + w_{k-1}$$
$$z_k = Hx_k + v_k$$

Where x_k is a vector representing the true state, ex. the true location of the user, at time k and u_k is a control signal. Each estimated value is a linear combination of the previous estimated value,x_{k-1}, plus a control signal plus process noise, denoted as w_{k-1}.

z_k is the measured value, it is derived as a linear combination of the true state, x_k, and some measurement noise v_k. A, B and H are matrices, A is the state-transition model, B is the control-input model and H is the observation model.

The Kalman filter iterates over two phases as new measurements are made, the time update phase and the measurement update phase. During the time update phase the next state is estimated and during the measurement update phase the estimated state is updated with measured values. The state retrieved from the measurement update phase is the estimated state [11].

Particle Filter

The particle filter also known as Sequential Monte Carlo is as mentioned by Changjiang Yang, Ramani Duraiswami and Larry Davis, a Bayesian sequential importance sampling technique [12].

Particle filters are popular solutions to provide optimal estimation in nonlinear non-Gaussian scenarios. Compared to extended Kalman filtering particle filters have the advantage of not relying on any (functional) approximations. Particle filters are commonly used to track moving objects. The main disadvantage is that particle filters are more computationally expensive, however, this is usually not a problem with today’s hardware.

The basic idea of a particle filter is to generate a set of weighted “particles” where each of them can be interpreted as a guess, where its weight represents the posterior probability. A particle can be implemented as a data-object containing x and y coordinates, weight, speed and direction.

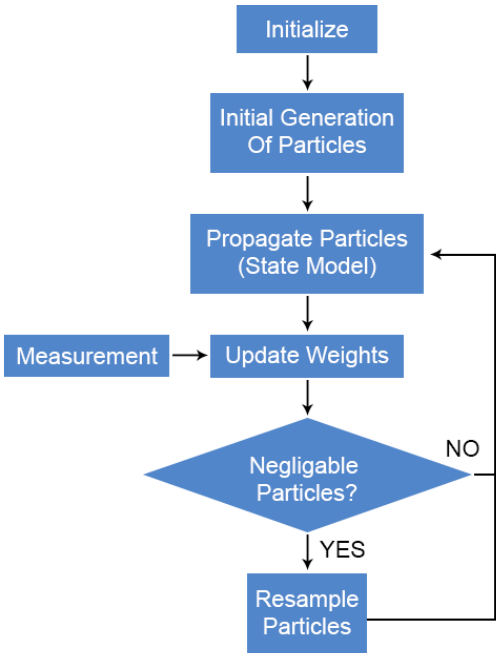

Fig. 12. This figure shows a flowchart of the particle filter's behavior.

A particle filter works as the flow graph presents in Fig. 12 [13] and can be explained as an algorithm in 5 steps.

1. Initially a finite number of particles are generated and spread randomly across all different positions in which the target object might be located.
2. Then each particle is propagated using a state model representing the movement behavior of the target.
3. Each particle's weight is then adjusted to the particles new state. This weight is set in relation to the received data/measurement which represents a new position. If a particle represent a guess that is fairly accurate the weight will be higher and if not, weight will be lower.
4. The least relevant particles are removed and replaced by new particles spread of out from the most relevant particles.
5. Then the algorithm loops from step 2.

Essentially, in a particle filter a computer generates a large amount of “guesses” that are later evaluated against new measurements.

Signal filtering and user location filtering

In an indoor positioning system filtering is usually performed on the actual sensor/signal data or on the user location coordinates, or both. When filtering sensor/signal data the filter is used to estimate a more accurate value on the currently measured sensor/signal data. This will lead to less fluctuations in the measurements meaning that a more accurate user position can be determined.

When filtering is applied on user location the filter is used to minimize the error of the estimated coordinate values. This means that the system will adapt to past fluctuations in the coordinate estimation [14].

3.5.2. Nearest neighbor

The Nearest neighbor algorithm is used to determine the vector, from a set of vectors that has the least distance to a certain vector. The distance between two vectors can be calculated using Euclidean distance, assuming that the system is a Euclidean space. The Euclidean distance between two vectors (a and b) is determined by:

$$E = \sqrt{(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2}$$

The Nearest neighbor algorithm is particularly useful when determining the nearest reference point in a fingerprinting based estimation approach.

3.6. Implementation approaches

In this section the overall system architecture will be discussed. In an Indoor positioning system it is not always obvious where to perform the estimations and measurements discussed in previous sections. RSS can, for example, be measured either on the mobile device itself or at an AP. Estimations and algorithms can be calculated either on the device or on a remote server. Two different implementation approaches will be considered: network-based and device-based positioning. Both contributing with different advantages and disadvantages.

3.6.1. Network-based positioning

A network-based solution in terms of positioning means that a device is tracked by the network. This method could be recognized as a more passive tracking solution since the device does not need any positioning software to perform any task related to the positioning system. This means that the person carrying the device can be tracked without actually being aware of the positioning system's existence.

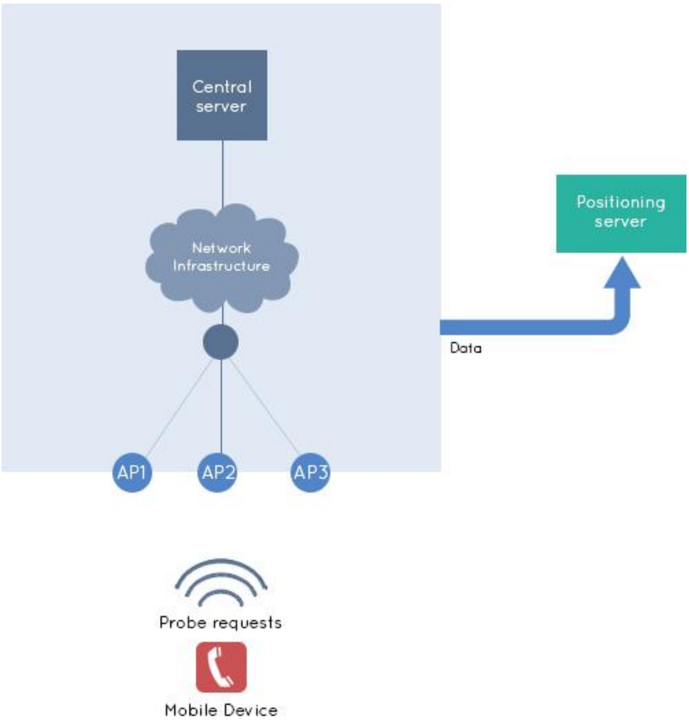

Fig. 13. This figure shows a network-based positioning infrastructure which performs all positioning based on probe requests transmitted by a mobile device.

A network-based positioning system relies on the device's ability to communicate with the surrounding network. There are multiple ways of communications between device and network. One of them is called probing and it is a method of making the network aware of the device's existence. This concept is briefly explained with Fig. 13 where a mobile device sends out probe request which is received by the network via its access points. The data is then forwarded to a positioning server.

Network-based positioning systems designed for indoor positioning are almost exclusively based on Wi-Fi. Most measurement and estimation techniques discussed in this master thesis can be successfully implemented in a network-based positioning solution, except for dead reckoning of course since it relies entirely on sensors on the mobile device.

Probe requests

Probe request is a WLAN packet type of the 802.11 standard family, which is used by a device when it wants the surrounding access points to reveal themselves. It works as followed:

- A device broadcast a probe request.
- The device awaits a probe response from all nearby APs that received the packet.

It is also illustrated with Fig. 14, providing the first request and responses that is called probing.

Since APs on a network often operates on different channels the requests must be broadcasted on every available channel. The packet frame is commonly used when initializing a network connection, the connection process is followed by authentication packets.

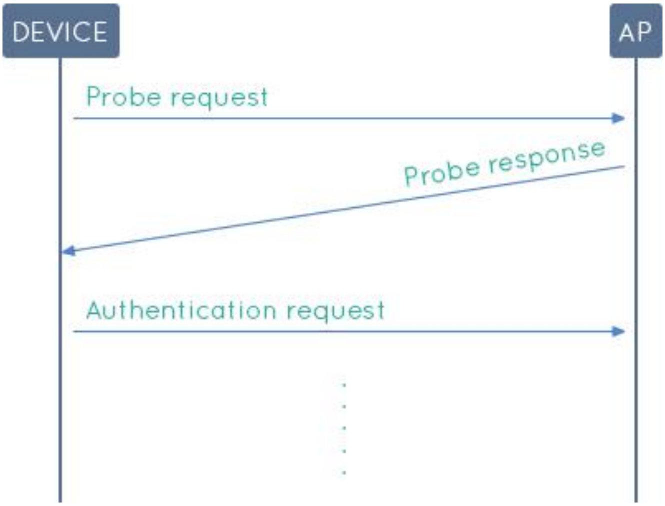

Fig. 14. This figure visualizes the communication between a device and an access point, using probing.

The packet consists of MAC (Media Access Control) address, operation channel and encryption mode. The SSID (Service Set Identifier) of the network is also sent with the packet if the network is already known, for example when the connection is handed over between APs while a device is moving [15].

Probe requests are not only sent when a device is not connected, it is also sent while being connected in order to reveal if there is another access point that can provide with more sustainable communication.

Probes in network-based positioning is acknowledged and valued since it does not only reveal a device’s existence but also potentially its position. The information obtained from probes consists of valuable information that is used as foundation in algorithms. The information obtained, such as signal strength from received probe requests, from various access points provides the ability to locate a device with most of the estimation techniques mentioned in the report.

The advantage with this approach is that the device does not need to be connected to the network and the use of an application can be avoided. An important disadvantage though is that probe requests are sent out rather unfrequently, between five seconds and five minutes depending on device. The network as well takes some time forwarding the probe requests to the server, which will transform the data into a position [16]. All these delays would affect the system in such a way that a position would be estimated rather unfrequently. This reveals a problem that is usually not appreciated in a real time system. One way of providing better resolution would be to accept the use of an application providing more frequent probing. However, that would prevent the system from working without the need of additional software on the mobile device and thereby neglecting the benefits of passive tracking. There is obviously a need of weighing pros and cons.

3.6.2. Device-based positioning

Device-based positioning refers to techniques where the device position itself in the environment using on-board sensors and measurement instruments. In a device-based positioning solution, as opposed to a network-based solution, the device is always aware if it's being tracked or not.

The information derived from sensors and measurement instruments together with a suitable estimation technique is used in order to calculate the geographical position of the device. These calculations can either be performed on a remote server or on the device itself, allowing the device to position itself without communicating with any remote party.

These properties can achieve high accuracy due to the fact that it allows the solution to access various sensors and hardware on the mobile device. There are several disadvantages however and suitability of device-based positioning depends on the actual application. Device-based positioning requires software to be executed on the mobile device. This means that the user actively needs to start the service, meaning that devices cannot be tracked secretly. Running software on the mobile device can also lead to power drain issues. The idea of device-based positioning is presented with Fig. 15, where the mobile device listens to the network and forwards the data to a positioning server.

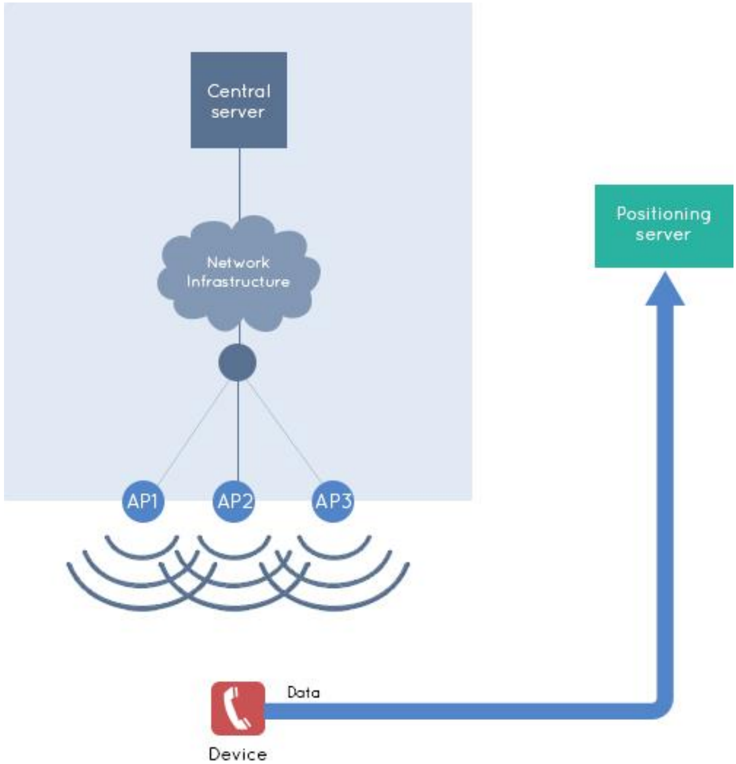

Fig. 15. This figure shows the concept of device-based positioning in a Wi-Fi network. The device measures the signal strengths from nearby access points and sends the information to a server.

There are multiple estimation techniques to use with multiple different positioning technologies. Further, there are two different approaches to apply these techniques and technologies to. Table I contains a summary of what positioning technologies provides support for each estimation techniques. Each and every one is presented together with a device-based and a network-based approach.

It shows that in a network-based environment, there are not that many options. Bluetooth beacons are an ad-hoc solution in shape of stations focused on pushing out its identification. This provides no network environment, so it does not allow information to be sent and received in the background, only to a user device.

Sensors are used to provide data based on the position and movements, they cannot be used as effective with other techniques as with fingerprinting. Fingerprinting support is provided thanks to the magnetometer which can read the magnetic flow at all time. They are a set of device specific technologies that are not applicable to a network.

TABLE I. ESTIMATION TECHNIQUES SUPPORTED BY THE DIFFERENT WIRELESS COMMUNICATION TECHNOLOGIES AND SENSORS

Device-based	Bluetooth	Wi-Fi	LTE	Sensors
Trilateration	■	■	■	
Triangulation				
Proximity	■	■	■	
Fingerprinting	■	■	■	■
Network-based	Bluetooth	Wi-Fi	LTE	Sensors
Trilateration		■	■	
Triangulation		■	■	
Proximity		■	■	
Fingerprinting		■	■	

The lack of support towards triangulation of a device-based solution lies in the need of multiple antennas as receivers. Therefore it is not as appropriate with the device-based approach as with the network-based solution due to the common use of multiple antennas.

4. State of the art

The market is already established and companies with different backgrounds have been developing their solutions for years. This means that there is a lot of appreciated knowledge to gather and to learn from. The following section mentions existing solutions today provided by various companies. It will be followed by a conclusion of the results provided.

4.1. Market solutions

These studied indoor positioning solutions on the market are based on a wide spectrum of different technologies and methods. These companies have a different range of customers resulting in different priorities concerning the result. An important aspect of the study of different companies and their respective solutions have been to investigate how various technologies and methods, discussed in previous sections, have been utilized and how they perform. This is a difficult task since companies tend not to reveal underlying techniques such as algorithms. Companies are on the other hand very generous with the information regarding what communication techniques and sensors are used.

Apple

Apple provides an API called Core location API to be used with their different iOS devices. The API uses a combination of Wi-Fi, mobile networks and iBeacon data for indoor tracking. The new indoor positioning features in the API is an effort to meet the increasing demand of location aware services. The API does not need iBeacons (useful to improve accuracy however), since it uses Wi-Fi, GSM, GPS, and motion sensors to determine the position of the device.

The core location API is designed to be used for both indoor and outdoor positioning. The API will automatically adapt according to which positioning technologies are currently available. For example, if the user enters a building the application will automatically switch to a technology more suitable for indoor tracking. The description of this solution is very abstract and the underlying technology is hidden [17].

Cisco

Cisco is an enterprise with extensive experience in the fields of IT and networking. The company can in many ways be considered a leader in development of large scale network solutions.

One of Cisco's products, Connected Mobile Experiences (CMX), is interesting in the aspect that it provides a network-based service for locating devices. Devices that are tracked do not require any software applications in order for the network to track it. The technology is based on the probing requests and communication between the device and the network. Probe packets are forwarded from the APs of the network to a Mobile Service Engine (MSE) which parses the RSS, the MAC addresses and time differences in order to locate the device using triangulation and algorithms.

The CMX product delivers together with a Cisco Unified Wireless Network (CUWN) an average accuracy less than five meters and a precision less than eight meters 90% of the time.

The resolution depends on the device software, since it determines the probe request frequency. The probe request frequency can vary between five seconds and five minutes depending on settings and OS. This translated to tracking means that the position of the device is predicted max every fifth second. Cisco also provides a feature, FastLocation, which provides probe requests with higher frequency resulting in more location updates and better resolution [16].

Combain Mobile

Combain Mobile was founded 2009 in Lund, Sweden. It is identified as a new enterprise of high potential growth. It is a company specialized in locating of mobile devices, indoors and outdoors, and have developed its own tracking system based on mobile networks and Wi-Fi providing locations indoors and outdoors. In addition to the positioning system, they have developed a taxi booking service, a mobile invoice service and mobile resource management solutions.

Combain is determined to find a solution to indoor positioning and the problems that it involves. The main focus of Combain's indoor positioning project is the use of learning algorithms making the system self-learning, which is proven very effective when presented at its website. The accuracy reached so far is less than ten meters using trilateration [18].

CSR

CSR mainly focuses on five areas: Voice & Music, Bluetooth Smart, Automotive Infotainment, Indoor Location and Document Imaging. CSR provides various solutions that addresses indoor positioning. The launch of the next-generation product based on the SiRFstarV™ architecture and SiRFusion™ platform was announced in November 2014. It does not require infrastructure upgrades, which makes it less costly. The positioning product uses Wi-Fi signals in combination with satellite information, pedestrian dead reckoning and CSRs own cloud-based positioning center in order to calculate indoor locations accurately. It has also been design to accommodate proximity technology, Bluetooth® Smart beacons, Wi-Fi Round Trip Time (RTT) and Indoor Messaging System (IMES). The solution supports GNSS techniques such as: GPS, GLONASS, Galileo as well as local techniques such as Wi-Fi and mobile networks. The system also utilizes the following mobile sensors: Accelerometer, gyroscope, compass, barometer and A-GNSS. The accuracy during two tests in Tokyo Central Station was estimated to a max error of five meters and seven meters [19].

Google

Google, founded in 1997 by Larry Page and Sergey Brin, is one of the world's largest IT enterprises. Google provides the world with various services such as YouTube, Google Maps, the Android operating system, and many search services etc. Google Maps was launched in early 2005 with features such as street view, navigation and images of places all over the world.

Now they transfer its focus a bit towards indoor mapping, where they let customers extend Google Maps with indoor maps in return for its navigation services inside the building. There is no information available regarding techniques used in Google’s indoor positioning system [20].

Indoor Atlas

Indoor Atlas is a Finnish company that offers an indoor positioning solution for Android and iOS. The solution requires no additional hardware as it relies on magnetic fields for navigation. The company offers an SDK for both Android and iOS. Using the SDK a developer can create a map of the magnetic field within a building that can later be used to position a device. The position accuracy of Indoor Atlas depends on the magnetic signature generated, this is typically within three meters [21].

Indoo.rs

Indoo.rs works every day in order to "get indoor location-based services available on every device", the company was founded in 2010 and claim itself to be the "indoor positioning and navigation technology leader".

The company product supports localization, navigation and visualization of location behavior, heat maps. It is what is called a hybrid, since it uses a combination of techniques, including support for three different methods: Proximity, fingerprinting and Pedestrian Dead Reckoning. It uses Wi-Fi and Bluetooth APs as positioning techniques as basis for the estimation.

Indoo.rs says that it's possible to locate devices with the accuracy of less than two meters and guarantees a precision of less than five meters in 95% of the cases [22].

Insiteo

Insiteo is an indoor location devoted company with focus on retail stores, shopping malls, transportation, fair & events, museums, offices and industries. Its product provides an accuracy of two meters relying on its algorithms and hybrid technology including Wi-Fi, BLE, iBeacons and PDR using the sensors accelerometer, compass and barometer together with fingerprinting. It includes a map for localization and wayfinding and enhanced user experience is obtained thanks to its high update frequency [23].

Navizon

Navizon provides indoor positioning solutions using triangulation as well as fingerprinting technology. According to Navizon specifications their triangulation solution should be able to provide an average accuracy within two to three meters if network nodes are placed approximately 12-15 meters apart in a grid pattern. Their fingerprinting solution should, according to specifications, be able to obtain an average accuracy within one meter if implemented using a special indoor navigation SDK for Android and iOS provided by Navizon [24].

Trusted Positioning

Trusted Positioning has developed a product, the trusted portable navigator (T-PN) which uses inertial sensors together with Wi-Fi or GPS. It works by relying on sensor information with position improvements from GPS for outdoor, and Wi-Fi for indoor use. All components needed exists in today’s mobile devices, which results in a more affordable cost since additional hardware is not needed. The T-PN is recognizes the angle of the mobile and calculates the position accurately. The maximum error measured was less than nine meters after a six minutes’ walk [25].

Ubisense

A company that delivers real-time high-precision location systems using UWB technology. Their technology requires special UWB hardware and is typically used in industry to track the movement of different tools and machines. According to Ubisense their positioning system can obtain an accuracy within 15cm. The Ubisense real-time locating system uses a combination of time-difference-of-arrival and angle-of-arrival [26].

4.2. Summary of commercial solutions

There exist companies of various sizes and backgrounds established on the indoor positioning market, all providing their own solution of measurement methods, positioning techniques and estimation techniques.

TABLE II. THIS TABLE SHOWS A CONCLUDED TABLE PRESENTING THE RESULT FROM THE STATE OF THE ART, EACH COMPANY'S SOLUTION.

	Estimation	Technology	Precision	Aimed Scale
Apple SDK	Trilateration	Wi-Fi, GPS, BLE, LTE,	Low	Large
Cisco	Triangulation	Wi-Fi	Low	Large
Combain	Trilateration	Wi-Fi, Mobile Networks	< 10m	Large
CSR	Trilateration, PDR	Wi-Fi, Mobile Networks, Sensors	~7m	Medium
Google SDK	Trilateration	GPS, Wi-Fi, BLE, LTE	Low	Large
Indoor Atlas	Fingerprinting	Magnetic sensors	Medium	Medium
Indoo.rs	Fingerprinting, Proximity, PDR	Wi-Fi, BLE, Sensors	2m	Medium
Insiteo	Fingerprinting, Proximity, PDR	Wi-Fi, BLE, Sensors	2m	Medium/Small
Navizon	Triangulation Fingerprinting	Wi-Fi	High	Medium/Small
Trusted Positioning	PDR	Sensors, Wi-Fi, GPS	< 9m	
Ubisense	Triangulation	UWB	Very high	Small

Table II presents a lucid conclusion of companies’ different approaches. It is obvious that precision is to be weighed against scale, since companies such as Apple, Google provide a larger scaled solution to encapsulate multiple buildings and floors. It is observed that some approaches uses Trilateration, which is more reliable when the Wi-Fi environment is unknown. Trilateration has the disadvantage that it is very sensitive to indoor environmental obstacles, walls and interior, affecting the measurements.

There are also companies like Indoor Atlas, Indoo.rs, Insiteo, Navizon and Ubisense providing more of a product/solution that focuses on medium/small scaled customers like airports, museums, malls and industry facilities with a more precision dedicated approach since the mapping area is more limited.

It is obvious that Wi-Fi is a dominating positioning technology since the use of this technology is very widespread. Using Wi-Fi as positioning technology allows the system to work with, in many cases, already existing infrastructure.

Three companies aiming towards a fingerprinting approach have been studied. Their solutions seem to provide very high precision, but as mentioned, fingerprinting is usually not optimal in a large scale environment. Two of these solutions also includes BLE in their fingerprints and PDR. The disadvantage with fingerprinting is the cost and scalability, it is more cost effectively applied to smaller facilities due to the offline phase, where each reference point of the radio map is measured.

Ubisense uses the relatively new technology UWB which provides very high precision. This is a technique that is supported by only a few mobile devices and therefore requires new hardware instead of relying on hardware already existing in most mobile devices. The range of UWB is also very limited. Due to this the tags provided by Ubisense only has a range up to a few meters. This increases the cost due to the increasing number of tags needed if the solution is applied on a larger area.

Cisco contributes with a network-based solution in contrast to the rest. It is appropriate for large scaled areas where it uses triangulation instead of trilateration. This is possible due to the composition of Cisco's known products and synchronization.

5. Our Solution

In this section a reached approach and solution will be presented. The conclusions made in this section is based on the research of different techniques, methods and commercial products in previous sections. The solution presented uses a combination of different techniques that are believed to achieve the best possible outcome for the chosen use case 2.

A solution will be described in detail as well as presented in a proof of concept implementation. (The conclusions made in this section are based on the research of different techniques, methods and commercial products in previous sections.) In the description of the proof of concept implementation detailed descriptions on algorithm implementations, system architecture and graphical layout will be provided.

5.1. The solution

A solution using Fingerprinting, Proximity and PDR based on magnetic field strength, Wi-Fi/Bluetooth and sensors.

Use case 2, allowing additional software, opens a few doors. It provides the choice to determine what data to send from a device, meaning what kind of data the solution relies on.

Both fingerprinting and triangulation techniques are possible approaches to this use case. Trilateration is more applicable at larger scaled areas, however, the precision is poor. Fingerprinting provides great precision in small scale buildings and it is therefore more suitable in this particular use case.

A fingerprint solution seem to be the more suitable alternative. This is based on key characteristics in terms of scale and hardware limitations for this particular use case. It is more suitable in the office environment. Fingerprinting can be performed based on Bluetooth, Wi-Fi and magnetic field strength, which all can be reached due to the acceptance of additional software. For this technique to work properly a good filter is needed. Fingerprinting using Bluetooth and Wi-Fi requires a filter to remove noise and compensate for changes in RSS affected by people, movable obstacles and reflections.

Wi-Fi and/or Bluetooth data will be used in order to obtain a broader estimation meanwhile, whereas the magnetic readings will provide more detailed position.

Sensor readings, besides the magnetometer, will be investigated and possibly implemented in order to enhance the positioning performance. Sensors as the accelerometer could make it possible to detect movement and to recognize lack of movement.

The fingerprinting will be needing filtered sensor data which will be done using a simple mean value filter. It will also need a filter in order to better estimate a position. This positioning filter will consist of a particle filter due to the system’s nonlinear behavior making Kalman less suitable. The particle filter requires more calculation effort, but will not be a problem with today's existing hardware.

6. Proof of Concept

This chapter will present the provided solution starting with the implementation and system architecture followed by experiments and some reflection.

6.1. Implementation and system architecture

The implementation and system architecture is divided into several areas, which are fingerprints, magnetic measurements in earth-fixed coordinates, algorithms, then the server-side and the client-side followed by the web page. The procedure of all of these areas will be provided.

6.1.1. Fingerprints

To begin with, the building was divided into several reference areas. The different areas were identified using Bluetooth proximity. Every reference area contains a Bluetooth beacon that can be recognized by mobile devices in its surroundings. The search space for magnetic fingerprints is narrowed down by identifying the SSID of the known positioned Bluetooth beacon from which the strongest signal strength is received.

When the system is trying to find magnetic fingerprint matches the system compares the difference between the current measurement and the fingerprints within the reference area to a certain threshold. The threshold determines whether a good match has been found or not. Since the amount of fluctuations in the magnetic field is different from one part of the building to another it is difficult to find a suitable threshold. The system has been designed so that each reference area have its own threshold calculated based on the magnetic fingerprints within the area. The idea is to let the threshold adapt to the properties of the magnetic field within the reference area in order to maintain accuracy. If the difference between the magnetic fingerprints in the area is small the threshold will be low, if the difference is large the threshold will be high.

6.1.2. Magnetic measurements in earth-fixed coordinates

Magnetometer measurements are given in device-fixed coordinates [27].

The magnetometer returns the magnetic field strengths as a vector containing the magnetic field strength in x, y and z direction. The magnitude, which is independent of device orientation, is given by:

$$m = \sqrt{x^2 + y^2 + z^2}$$

Using the accelerometer the magnetic field strength in z-axis can be calculated independent from device orientation. The inclination Θ, angle between sensors coordinates and earth-fixed coordinates, is given by:

$$\Theta = \frac{\pi}{2} - \arccos(u * v)$$

Where u is the magnetic field vector and v is the gravity vector returned by the accelerometer. This angle is then used to derive the strength in z-axis.

These system works independent of phone orientation. This is an important usability feature that vastly improves usability. It allows the user to remain tracked by the system regardless of what orientation the user is carrying the device.

6.1.3. Algorithms

The matching algorithm used to find good matches for a fingerprint is the nearest neighbor algorithm using Euclidean distance. Euclidean distance is used to evaluate both Bluetooth and magnetic data.

To obtain better estimations of a device's position a particle filter was implemented.

In the implemented particle filter each particle is represented as a data object. The particle movement is propagated using a simple model. Every time particle positions are updated the particles move in a random direction with normal walking speed. Every particle knows the coordinates of its closest magnetic fingerprint. Particle weights are updated using the distance from a particle to its closest likely fingerprint position according to measurements, these likely positions are called “candidates”. If the particle weight is below a certain threshold the particle will be deleted. If the particle weight is above a certain threshold the particle will be set to a “prioritized” state. If a particle is “prioritized” new particles will be generated at the coordinates of the “prioritized” particle. The amount of new particles generated is determined by the amount of particles deleted during the same iteration. This means that the total amount of particles is constant while the filter is running.

In the implemented algorithm a particle contains x and y coordinates to determine its location on the map, a variable indicating the current weight of the particle and a reference to the closest fingerprint. A particle also contains a variable to indicate the number of “lives” the particle has. This variable is used mainly for experimental purposes to increase the lifetime of a particle.

The particle filter that has been implemented in this proof of concept can be broken down into the following steps:

4. Particles are generated and randomly distributed across the map.
5. Particles are moved according to the movement model, meaning that each particle is given a new set of coordinates.
6. The closest fingerprint to each particle is found.
7. Particle weights are updated according to measurements.
8. Particles are resampled according to weight.
9. User location is estimated by finding the largest “particle cloud”.

The algorithm then iterates across step 2 - 6 as long as the filter is active.

6.1.4. Server-side

The architecture is divided into two parts, a server side and a client side. The client side will be responsible for providing the server with measurements. Meanwhile the server will perform all the calculations needed in order for the device's position to be estimated. Basically, as much as possible of the battery draining calculations has been delegated to the server. The measurements provided by the client consist of Bluetooth and magnetic field strength readings, which are filtered and processed in order for the server to perform the calculations under the right conditions.

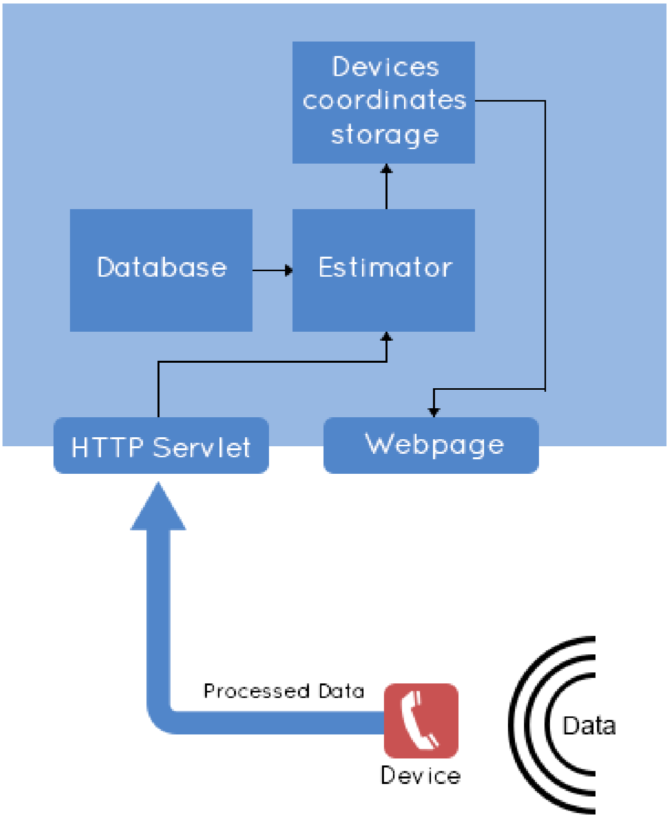

Fig. 16. This figure shows broadly the idea used as a basis for the solution of the master thesis's proof of concept.

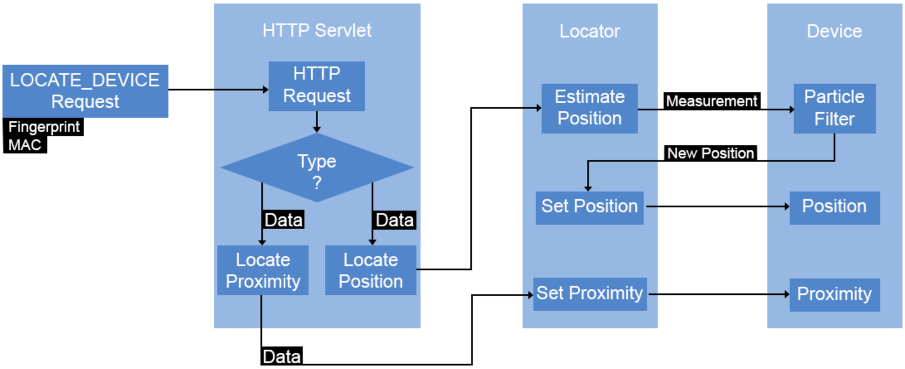

Fig. 17. This figure presents the flowchart of the server during the mapping phase receiving fingerprint data from a smartphone together with its MAC address.

The server side is implemented in Java using servlets, a database and a JavaScript driven web page. It performs all calculations on the data obtained from the connected devices. Fig. 16 briefly illustrates how a device and the server work and communicate.

The online phase is illustrated in Fig. 17 using a flow chart. As seen, the client sends "LOCATE_DEVICE" requests to the server. These messages contain the client's MAC-address and measurement data. The measurement data is equipped with a tag that allows the server to determine whether the received message consists of magnetic data or Bluetooth data. The received measurement data will, depending on its type, trigger different operations in a class called "Locator". If Bluetooth data was received the Locator will update the reference area for the device corresponding to the received MAC-address. If magnetic data was received the Locator will retrieve a set of magnetic fingerprints located within the client's current reference area. By comparing the received data with the set of fingerprints the Locater can determine, using Euclidean distance, which fingerprints to consider as possible matches. The possible matches are sent through a particle filter that estimates the client's location and sets its new position.

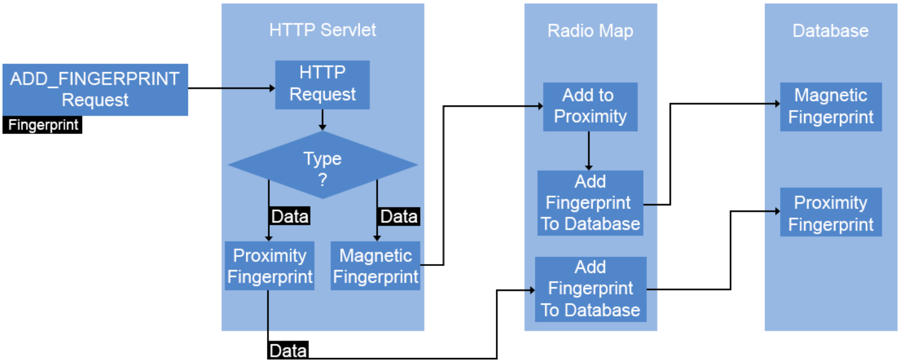

Fig. 18. This figure presents the flowchart of the server during the building of the radio map receiving fingerprint data together with coordinates from a smartphone.

The flow of the server in the offline phase is presented in Fig. 18, where it all starts with a request sent from a smartphone. Then an “ADD_REFERENCE_AREA” request is a message that consists of a list with Bluetooth SSID and signal strengths sorted by signal strength. The client can also send “ADD_MAGNETIC_POINTS” requests. An “ADD_MAGNETIC_POINTS” request consists of a list of several magnetic fingerprints. If reference area data has been received the server will store the Bluetooth SSID of the strongest received signal strength in the database. If a magnetic point’s message has been received the server will parse the data to retrieve the independent magnetic fingerprints. The server will match the magnetic fingerprints with reference areas stored in the database. If a magnetic fingerprint lies geographically within a certain reference area the ID of the reference area will be mapped together with the magnetic data and stored as a magnetic fingerprint in the database.

Servlets

The communication between devices and the server is implemented using servlets. A servlet is a Java component that runs on a thread and communicates via HTTP (HyperText Transfer Protocol) get and HTTP post requests and responses. This setup allows the device to easily transfer collected data to the server which performs the calculations needed to estimate the device's position. The servlets are also able to communicate with the database at startup and during the offline phase.

There are mainly two servlets, one of them handling the offline phase, which is the creation of the radio map, and the other one handling the mapping in the online phase.

Database

The database, seen in Fig. 19 is a MySQL database (My Structured Query Language) which contains all collected fingerprints and reference areas from the offline. In the database each magnetic fingerprint is represented by an x and a y coordinate together with the magnitude of the magnetic field at that coordinate. Each reference area is represented by an x and a y coordinate together with a MAC address of the Bluetooth beacon.

In order to remember previously connected users this solution constructs a table containing user ID, MAC address of the mobile phone, and username.

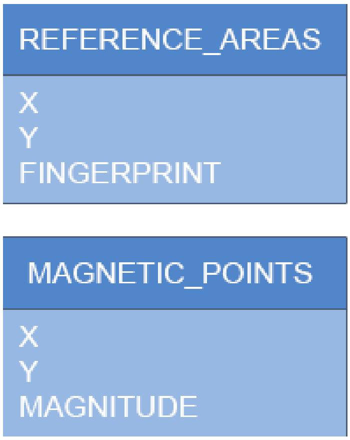

Fig. 19. This figure shows the ER diagram of the database structure containing two different tables. One for reference areas and one for magnetic points.

6.1.5. Client-side

The client works with data on three different layers regardless if it is in the online phase or the offline phase. This system uses a data provider, a controller and an activity together with the two communication API's Greenrobot EventBus and Volley, which can be seen in Fig. 20.

EventBus is an Android optimized publish/subscribe event bus. A typical use case for Android apps is gluing Activities, Fragments, and background threads together [28]. Greenrobot EventBus is basically a channel of communication that is open for activities, services and fragments to use, all data that is sent on the EventBus is received by everyone using it. By giving each package on the EventBus a receiver the problem of everyone receiving it disappears.

Volley is a library that provides Android apps with faster and easier networking, [29]. It is an easy way of sending HTTP requests and updating information when a response is received.

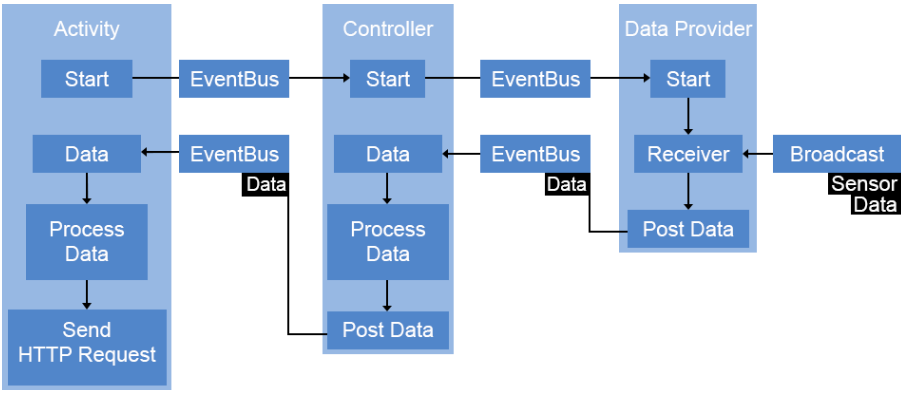

Fig. 20. This figure shows a flowchart of the data on the client side during the online phase, from a broadcast received to an http request sent to the server.

The data provider is the first and lowest layer of data processing in the client. It is mainly used to collect raw data from a receiver listening for Wi-Fi or Bluetooth data. The data provider then posts the formatted data on the event bus to be received by a controller.

The controller belongs to the second layer of the chain. This is where the data is processed and filtered if needed. It also controls the data provider by receiving commands from the top layer. The processed data is then posted on the EventBus yet again, this time to be received by the activity, the third and top layer. The top layer is the last step in the chain of processing the data before it is sent to the server. The activity works on a layer that uses the processed data to build packages, such as paths of magnetic samples, containing data from the controller. When the activity is done treating the data, it is sent to the server using Volley together with a command telling the server what to do with the data.

There is a small difference in structure between the online phase and the offline phase of the smartphone application, as seen when comparing Fig. 20 with Fig. 21. The offline phase allows the user to contribute with information by interacting with the screen, such as giving start- and end point for a path or choosing the position of a reference area. This results in a communication channel between the fragment and the controller and a controller that processes the data differently.

The filter used at layer two, in the controller, is a mean value filter trying to filter out the noise from incoming signals.

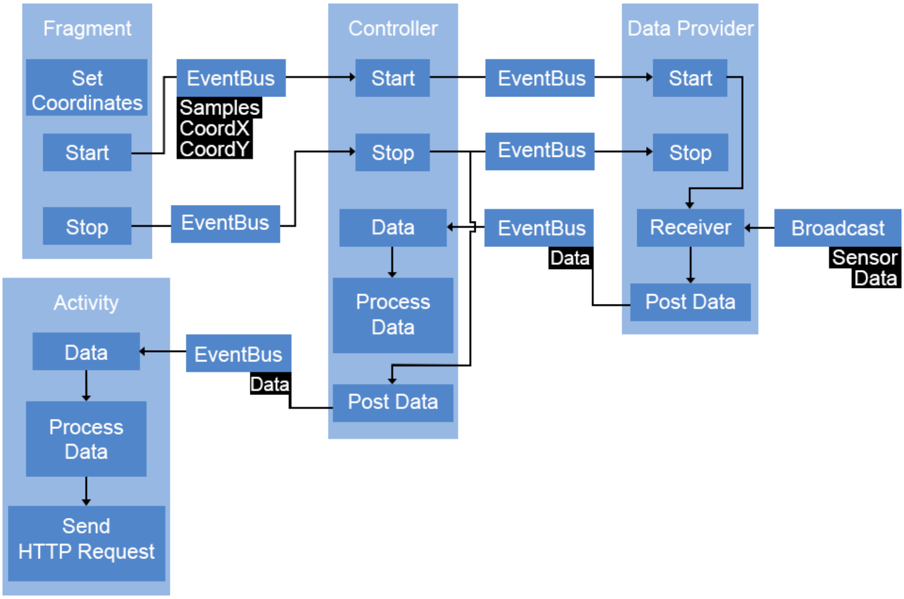

Fig. 21. This figure shows a flowchart of the data on the client during the offline phase, the creation of the radio map.

6.1.6. Web page

The web page consist of two parts, an HTML interface providing a visual map together with all positioned devices and a JavaScript that performs all of the background work such as obtaining data via the servlets and updating the interface.

The purpose of the web page is to visualize data in a context that is perceivable to the user. This is done using a HTML (HyperText Markup Language) page containing a map and JavaScript to provide real time discrete updates of the positions of all connected devices. The web page is also important in terms of testing as it is implemented with the option to display particles and fingerprint matches, this gives a good visual illustration of how the system behaves.

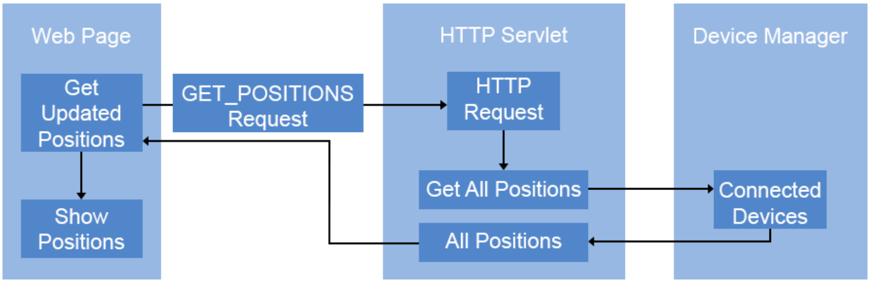

Fig. 22. This figure shows a flowchart of the data when the web page pulls positioning data from the server.

The web page is a stand-alone component, of the server side, requesting data from the server via HTTP Requests. The response from the server is a list of all the devices together with related coordinates relative to the image of the map. The server contains a device manager, which basically manages the list of devices that exists. The flow can be seen in Fig. 22 starting with a frequently sent request from the web page to the server requesting all of the connected devices positions which is visualized on the webpage.

The map provided in the web page is based on the Cybercom building's architectural sketch, seen in Fig. 23.

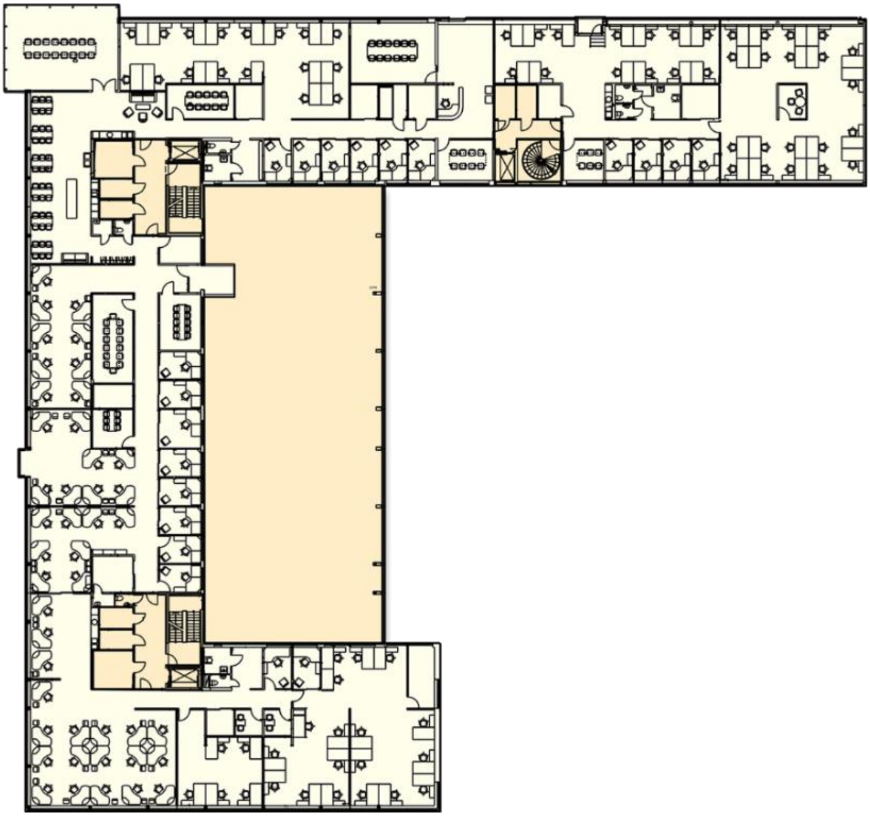

Fig. 23. This figure shows the map of the building as to be the basis of the devices positions.

6.2. Experiments & Reflection

Several experiments were performed during this master thesis project. The first experiments described, in chapter 6.2.1, were performed in order to determine which technology performed in the office environment and should be used as a fingerprint data. Then the focus turned towards testing the software, in 6.2.2. This test was to determine how the magnetic readings could be used and interpreted. Then in chapter 6.2.3, some experiments were performed in order to provide a working particle filter adapted to the environmental situation.

This chapter will describe these experiments that were performed and some discussion based on them.

6.2.1. Fingerprinting experiments

Fingerprinting was chosen mostly due to the high required precision and since it is appropriate to the scale of the area that the system is applied to. The solution focuses heavily on magnetic field strength due to its stability compared to Bluetooth and Wi-Fi, which needs to be filtered extensively in order to distinguish near positioned points.

This was proven during the experiments 1, 2 and 3.

Experiment 1: Test of Wi-Fi signal strength stability

Environment: Cybercom office in a non-isolated area

Method: A smartphone Samsung Galaxy s3 was placed at a given spot recording the received signal strength from one randomly chosen access point in the environment. A total of 100 samples were recorded.

Result:

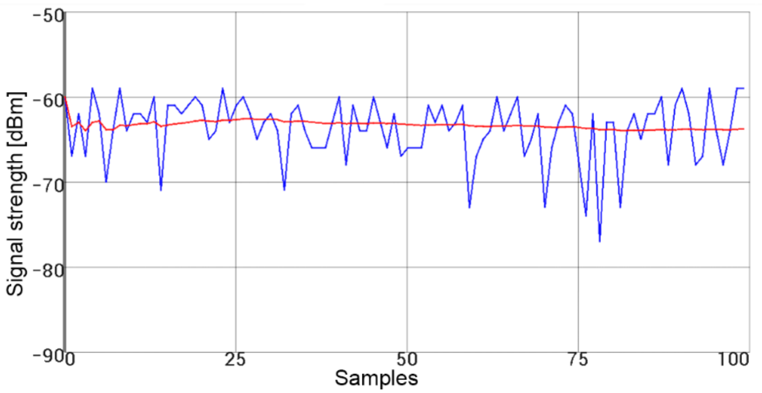

Fig. 24. This figure shows how the unfiltered (blue) and the mean value filtered (red) behaves during 100 samples of measurements of the signal strength of the transmitted signals from a Wi-Fi access point.

Scanning nearby Wi-Fi access points turned out to be a slow process on a smartphone, since it takes approximately four seconds in an active mode to detect nearby APs. This is due to the wide spectrum of channels and frequencies that need to be covered during the broadcasting of the requests. The offline phase using Wi-Fi would get too expensive, especially with the data presented Fig. 24. This figure reveals that the signal variates a lot, which in order to be smoothen out could need a large number of samples.

Experiment 2: Test of Magnetic field sensor stability

Environment: Cybercom office in a non-isolated area

Method: A smartphone Samsung Galaxy s3 was placed at a given spot recording the magnetic field strength in the environment. A total of 1000 samples were recorded.

Result:

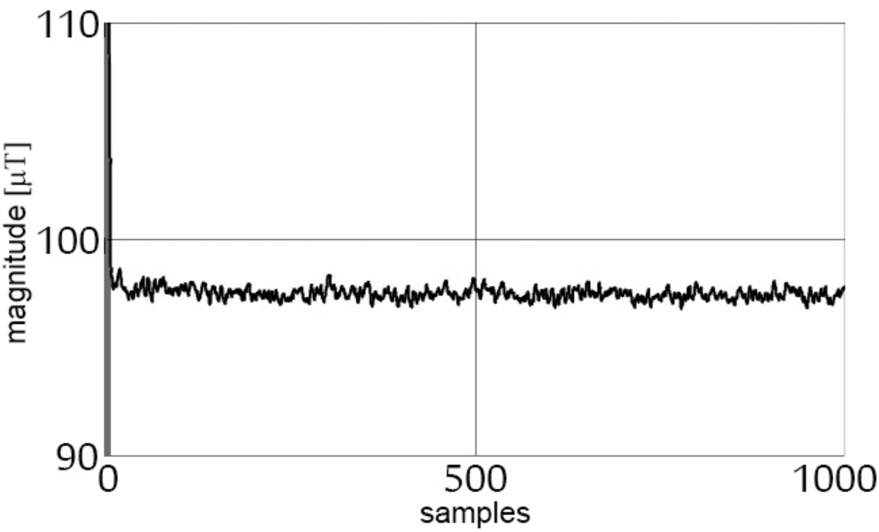

Fig. 25. Showing the variance of the magnetic field strength during 1000 samples of readings.

Experiment 3: Test of Estimote Bluetooth beacon signal strength stability

Environment: Cybercom office in a non-isolated area

Method: A smartphone Samsung Galaxy s3 was placed at a given spot recording the received signal strength from one randomly chosen Bluetooth beacon in the environment. A total of 100 samples were recorded.

Result:

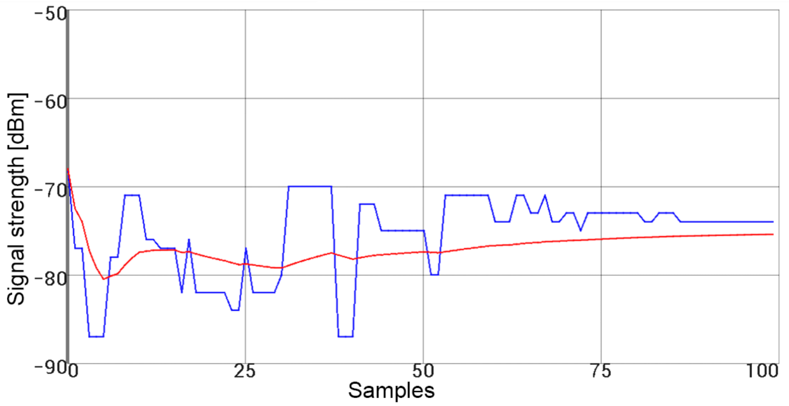

Fig. 26. This figure shows how the unfiltered (blue) and the mean value filtered (red) behaves during 100 samples of measurements of the signal strength of the transmitted signals from an Estimote Bluetooth beacon.

The Fig. 25 and Fig. 26 presents the stability of the signals received from the magnitude of the magnetic field and a Bluetooth beacon. It can be observed that the magnetic readings have a clear advantage in terms of stability. The main disadvantage with using magnetic field properties as fingerprint is the lack of data parameters. The test shows that after 1000 samples of gathering magnetic measurements, the magnitude of the magnetic field is still stable. Some noise is appearing, however, the variance is still very low in comparison. Meanwhile the 200 samples of collected Bluetooth data appears to be very sensitive. This is partly due to interference, reflections and absorptions by walls and other materials, meanwhile the magnetic field strength is not affected by materials not producing its own magnetic field.

Due to the high stability of the magnetic field strength and the smartphone sensor an additional experiment was performed revealing the magnetic field anomalies of the office. The idea of this experiment was to conclude if there was enough variation in the magnetic field between different locations in the experiment environment for a fingerprinting solution to be plausible.

Experiment 4: Test of the magnetic field strength anomalies

Environment: Cybercom office

Method: A smartphone Samsung Galaxy s3 was placed in a front pocket of a user carrier while walking a predefined path through the office at normal walking speed. A total of 1000 samples were recorded.

Result:

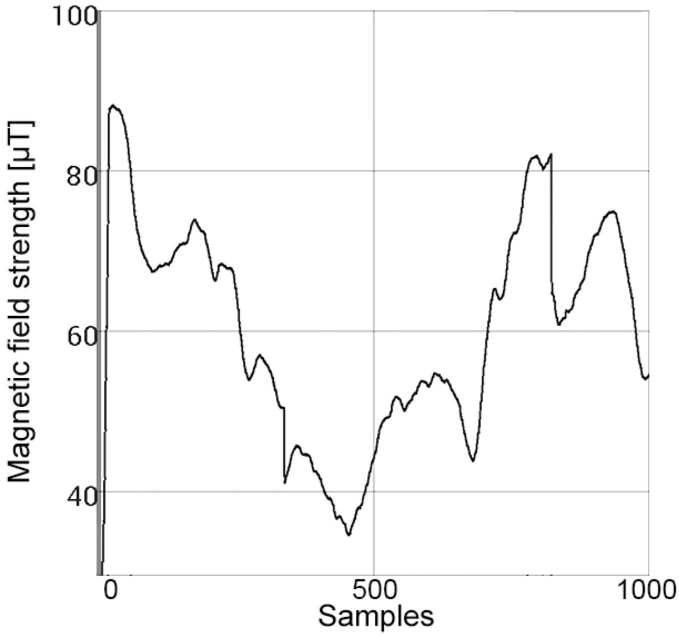

Fig. 27. This figure shows the magnetic field magnitude measurements when sampling while moving through the Cybercom building. Revealing the magnetic field anomalies of the magnitude at different positions in the building.

The resulting figure Fig. 27 shows that there is difference in magnetic field strength at different locations of the office. It is also possible to see that the readings are not unique for every location. The uniqueness could be increased by limiting the amount of possible locations.

When creating an indoor positioning solution it is important that the solution works for different types of smartphones. A test was performed exposing the difference in interpretation of the magnetic field strength by two different smartphones.

Experiment 5: Test of the magnetic field sensor stability difference between two smartphones

Environment: Cybercom office

Method: Two smartphones, a Samsung Galaxy s3 and a Samsung Galaxy s4, were placed at a given spot recording the magnetic field strength in the environment. A total of 200 samples were recorded by each smartphone.

Result:

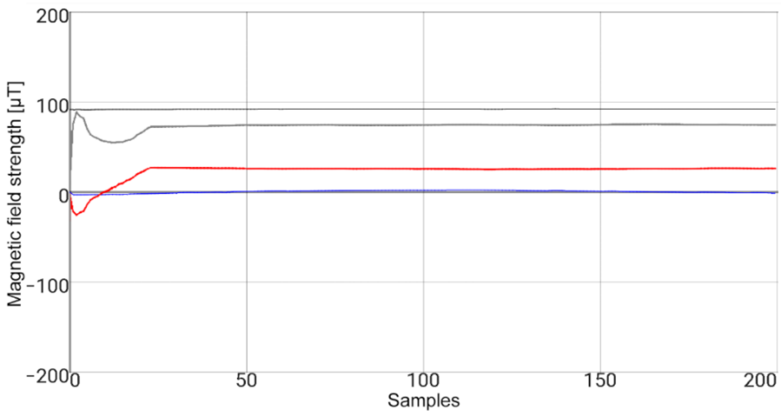

Fig. 28. This figure shows the difference in magnetic field strength magnitude between a Samsung galaxy s3 (gray is magnitude and red is field strength in z-axis) and a Samsung galaxy s3 (black is magnitude and blue is field strength in z-axis)

The result presented in Fig. 29 reveals that there is a constant difference in the readings.

6.2.2. Reference areas

The identification of reference areas could also be done using Wi-Fi fingerprints. Using Wi-Fi fingerprints mean that no beacons with known location need to be placed in the building as the system would rely on already existing APs. During development several tests using this approach have been performed, however, Bluetooth beacons proved to be the more reliable option.

When using Bluetooth proximity the risk that one area is mistaken for another is reduced since the beacon itself acts as a reference to a known location. This is not the case with fingerprinting, where the locations of the APs are unknown and therefore could lead to severe positioning errors if the fingerprint-matching suggests the wrong reference area. Such an error can take some time to repair as well since the system will have to wait for the next Wi-Fi scan to calculate a new reference area.

Another serious concern discovered when using Wi-Fi was that scanning for access points and at the same time switching between access points within the building often caused connection problems. This issue left the system useless in some parts of the building.

Magnetic field strength fingerprinting, which was used in this solution, was discovered to work better for smaller areas with fewer fingerprints due to the lack of parameters. This resulted in the idea of dividing the building into smaller sub areas which resulted in a radio map that could have the appearance of Fig. 29, where the green circles represent sub areas and the black points represent the magnetic fingerprints.

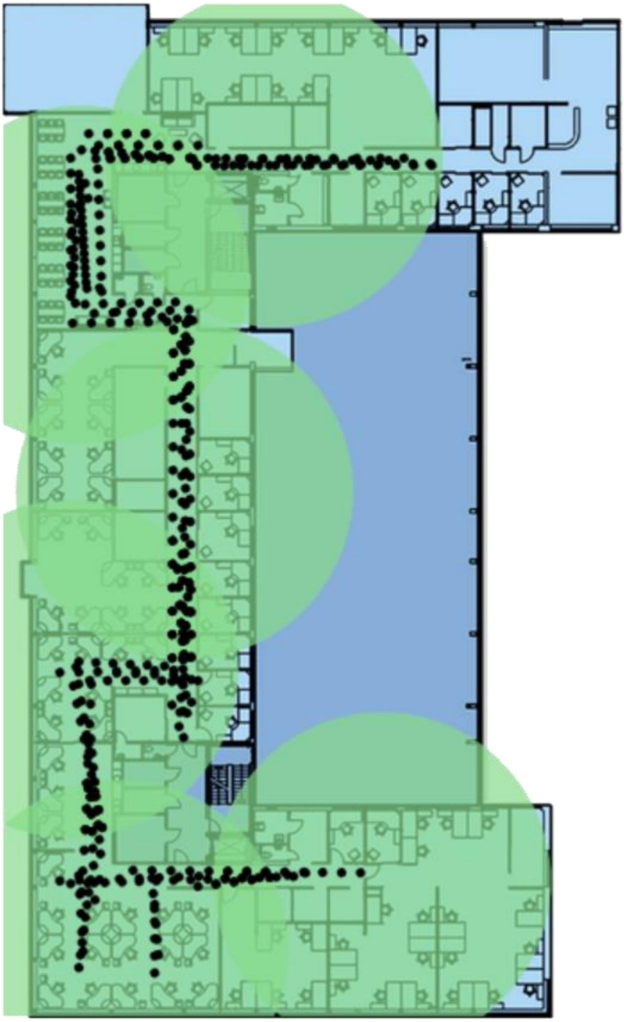

Fig. 29. This figure shows the implemented reference areas (green) with attached magnetic points (black).

6.2.3. Magnetic measurements in global coordinates

The usefulness of the magnetometer in terms of magnetic fingerprinting can be improved by calculating the magnetic field strength in z-axis into earth-fixed coordinates. This allows us to identify the magnetic properties of a location using two variables instead of one, magnitude and z-axis instead of magnitude only. This is a good way to reduce the lack of data parameters issue, stronger location identification means higher location prediction accuracy.

It was discovered that the z-value varied significantly between different mobile phones. The reason why this is the case is probably due to the fact the accelerometer and the magnetometer behave differently on different devices. The problem could probably be solved with an offset, however, this was out of this master thesis scope. Furthermore, when testing this on one device the increase in performance was barely noticeable.

6.2.4. Algorithms

Euclidean distance is commonly applied when comparing two vectors of data. Another option would be to use Manhattan distance, however, results would be very similar compared to Euclidean distance.

Particle filters have proved to be very useful in fingerprint based positioning applications due to its ability to make high accuracy estimates based on probability. Particle filters are also relatively easy to implement and understand.

The particle filter is used to achieve a more smooth position estimation. Instead of setting the position to the best magnetic point the use of “candidates” and a particle filter means that good magnetic matches that are far away from the previous estimated position are filtered. The idea is that at least one candidate will correspond to the actual user location and that particles eventually will form around this point.

6.2.5. Web page

The advantage of presenting the map on the web is the reachability. It can be reached from all around the world, from any type of device with an Internet connection, and there is no need for adapting it to the different type of devices. The JavaScript pulls data by sending HTTP requests to a servlet which will verify the request and provide a response containing all connected devices with corresponding positions.

6.2.6. Offline phase

In this master thesis project a significant amount of work have focused on finding different ways to reduce the cost of the offline phase. This is a very important aspect of work in order to improve the solution in terms of cost and scalability.

In the proof of concept application that has been developed the user interface provides tools for construction of the radio map. This means that the mobile phone where the application is installed is the only hardware required during the mapping process.

The magnetometer sensor is very stable, which means that there is no need to take several measurements at the same location when generating fingerprints. This property is of great importance since it allows fingerprints to be generated at a fast rate and while the mobile device is moving. In the application the user can interact with the map by tapping on the screen to place a start point and an end point, see Fig. 30. The user then presses start and moves along the specified path. The application will then take magnetic samples at rate of about 2 samples/sec. The samples are, together with the length and the angle of the specified path, used to automatically generate fingerprints and place them on the map. Assuming that the user walks with a constant speed, this allows several fingerprints to be placed very accurately and at a fast rate. This feature allows rooms and corridors to be mapped in seconds.

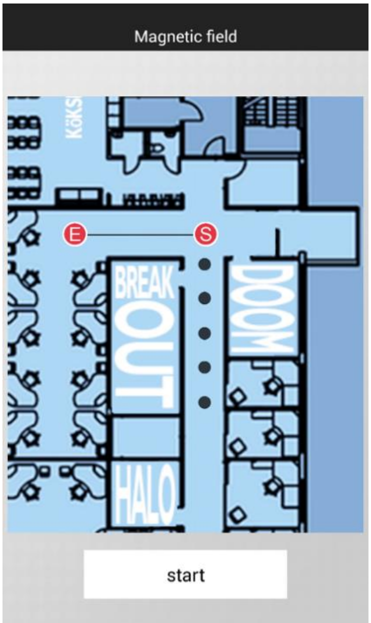

Fig. 30. This figure shows the construction of paths of magnetic points. It works by applying a start point and an end point, then pressing start before moving from point “S” to point “E” resulting in the creation of a path (black dots).

Due to the lack of uniqueness of the magnetic fingerprints, the area of mapping was divided into sub areas, called reference areas. This means that each magnetic fingerprint is added to a reference area that is identified by a Bluetooth beacon. By first determining in which area the user is located the fingerprint search space can be limited.

A reference area can be created by placing the phone close to a beacon and tapping on the screen where the beacon is located. When pressing start the application will scan for the strongest BLE beacon signal and send the SSID of that beacon to the server. The graphical interface when adding a reference area can be seen in Fig. 31.

Reference areas can also be identified using Wi-Fi. The user can easily switch between Bluetooth and Wi-Fi in the application. Placing a reference area on the map works the same way for both technologies.

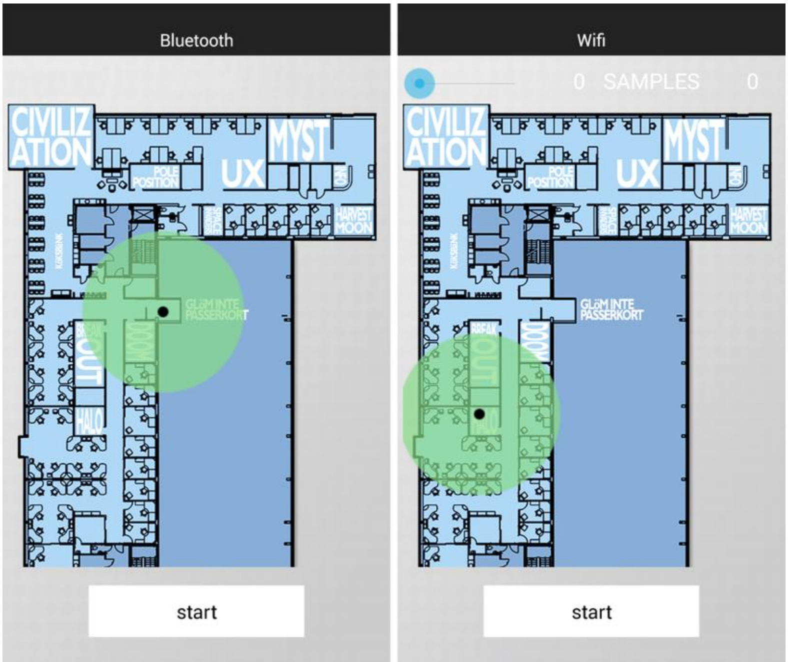

Fig. 31. This figure presents the creation of a reference area on the smartphone application. This done by using Bluetooth proximity, to the left, or by using Wi-Fi fingerprints, to the right.

6.2.7. Online Phase

The online phase client is shown at the following Fig. 32 – Fig. 35. At an initial state the particles are spread out as seen on the map at Fig. 32. Were each particle is given a randomly generated set of coordinates and is placed somewhere on the map. This is due to the true position being unknown and could be somewhere in the building. When the device senses a reference area, a Bluetooth beacon, the algorithm will start matching the measurement towards the fingerprints in this area. The current state of the algorithm is that a reference area has been located and good fingerprints has been found, the white dots, and the particles are about to propagate towards them and form a cluster of particles as seen in Fig. 33.

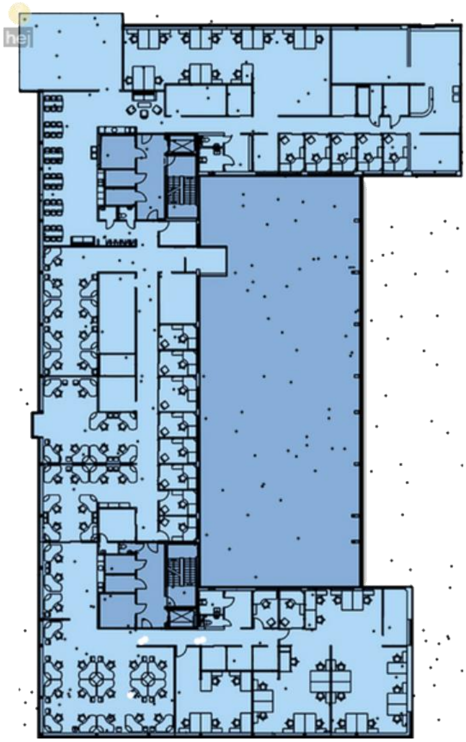

Fig. 32. This figure shows how the proof of concept scatter all of the particles (black dots) at the initial moment of positioning. The filter has found a reference area also resulting in candidates (white points) of magnetic points matching the thresholds of the proximity.

Then while moving measurements will be registered and the particle will propagate towards the matches closest in Euclidean distance as seen in Fig. 33.

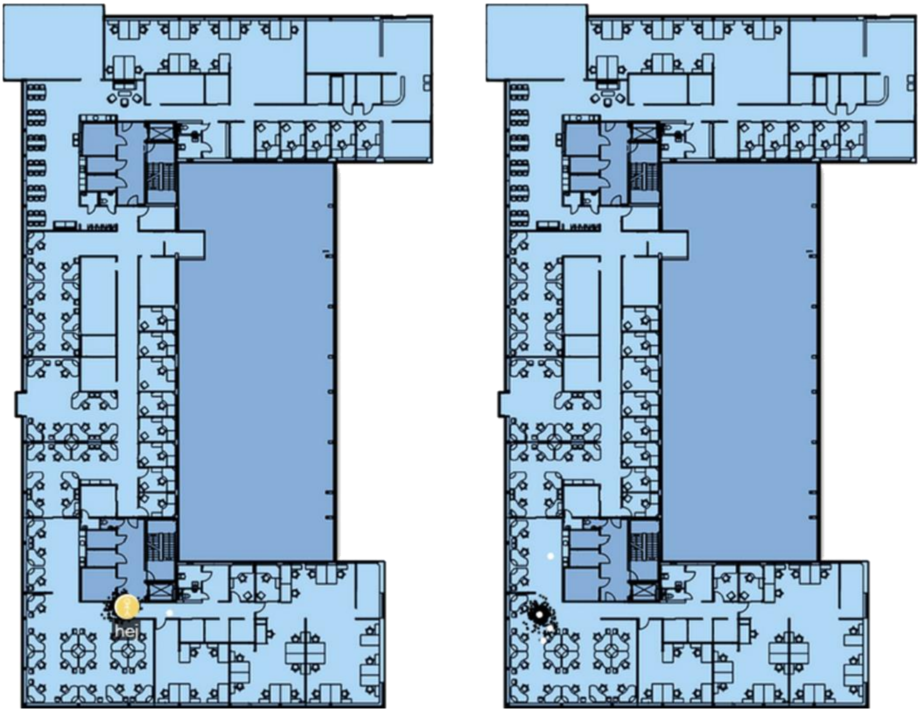

Fig. 33. This figure shows how the particle filter of this proof of concept works, a particle's (black dots) position is set regarding to the best matches (white points) of the magnetic magnitude. The left image also shows a more usability adapted token of a device together with a chosen name.

This system uses a threshold value that should be exceeded in order for a fingerprint to be considered as a match, meaning that sometimes a match cannot be found if the threshold is not reached. This type of event is managed by letting the particles scatter until the filter finds a match, meanwhile the device symbolizing a user turns faded to signal the lack of matches. This event is seen in Fig. 34.

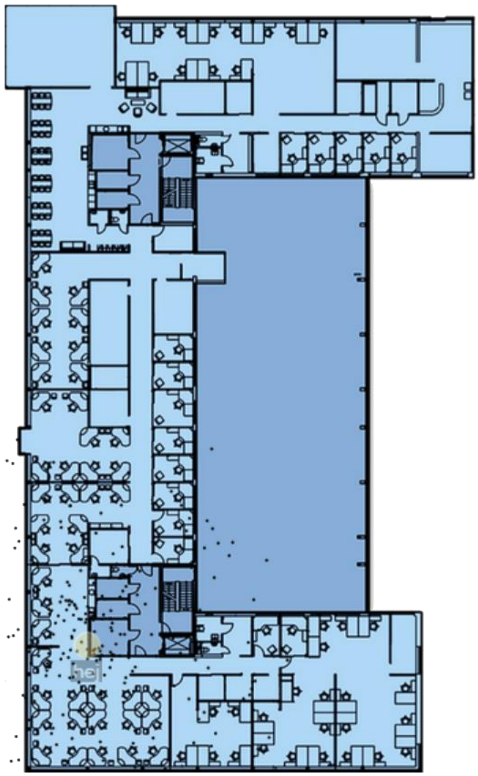

Fig. 34. This figure shows how this proof of concept handles a situation where the magnetic magnitude measurements behaves in such a way that no matches are found. Resulting in the particles scattering in order to easier find a future position meanwhile the user device token opacity is lowered.

This master thesis solution is also able to handle multiple users simultaneously, as seen in Fig. 35, since each device uses its own particle filter stored together with a unique device id.

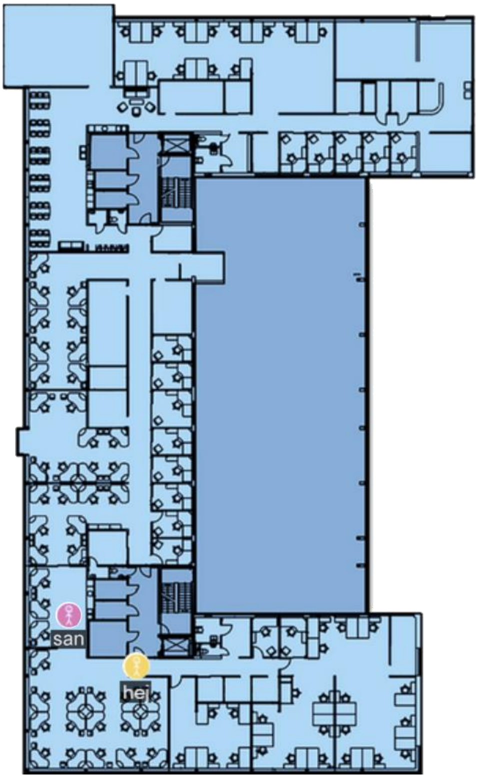

Fig. 35. This figure shows how this proof of concept handles multiple users connected at the same time. Each user receives a random color which the token uses as background and is shown together with a chosen name.

6.2.8. Sensors

There were some experiments performed on two of the smartphone sensors. The first experiment was to see if the accelerometer could be used as a step detector. The second experiment was to see how a simple application, presenting the walked path of a user carrier, would perform. The application was implemented using the gyroscope. The idea of using the sensors in this master thesis was to enhance the solution by obtaining more data.

Step detection using the accelerometer

Detecting if the device is actually moving is very helpful when a predicting and estimating a position. Step detection will be used as fundamental data when estimating the distance that the device has been moved. It is also possible by this method to estimate the velocity in which the device is moving.

The values from the accelerometer is presented in three different dimensions, x, y and z. The values are generated due to the device's movement in each dimension. The acceleration is measured, including the gravity that is generated by earth. This means that when the smartphone lies still on flat area, the only force applied to it was due to the gravity, resulting in an acceleration approximately $9.81 m/s^2$.

An experiment was performed in order to collect and observe and collect data generated by the accelerometer. This was done by programming a software application in Android, which only purpose was to collect 200 samples of data from the accelerometer. The data was then plotted and examined in order to see how the component performed and to actually get a graphical representation of the collected data.

The experiment was based on a smartphone placed in the front pocket of a user carrier.

The accelerometer collected data when the user was walking around. Data was then transferred to a computer software to get a graphical representation. Since the smartphone was placed in a front pocket making the front/backside of device facing the direction of movement, considerable stronger measurements were expected in the z-direction. The z-direction is as seen in Fig. 36 the axis that represents the accelerated direction while moving.

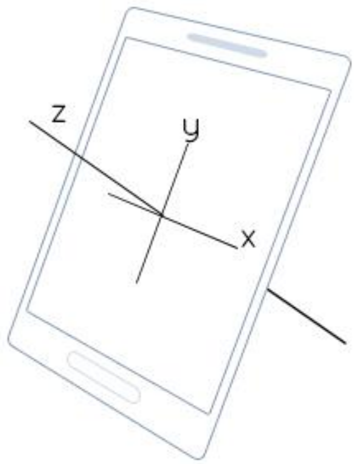

Fig. 36. This figure illustrates the three directions of acceleration that were measured.

The collected acceleration data was then linearized meaning that gravity was removed, which resulted in data produced only by the user applying a force to the smartphone.

The accelerometer data could be examined further, but it was out of the scope of this thesis.

It is also obvious that the magnitude in the z-direction was superior, resulting in a larger aim of focus towards that direction.

As mentioned, each graph represents each of the dimensions of the space. When observed, they contain a large amount of high frequency movements, which can be considered as noise. Since the data was not smooth enough, a low pass filter was implemented resulting in three new graphs with more useful values.

Experiment 6: Using a smartphone accelerometer as a step detector

Environment: Cybercom office

Method: A smartphone, Samsung Galaxy s3, was placed in a front pocket of a user carrier, while walking at a normal walking speed. A total of 100 samples were recorded.

Result:

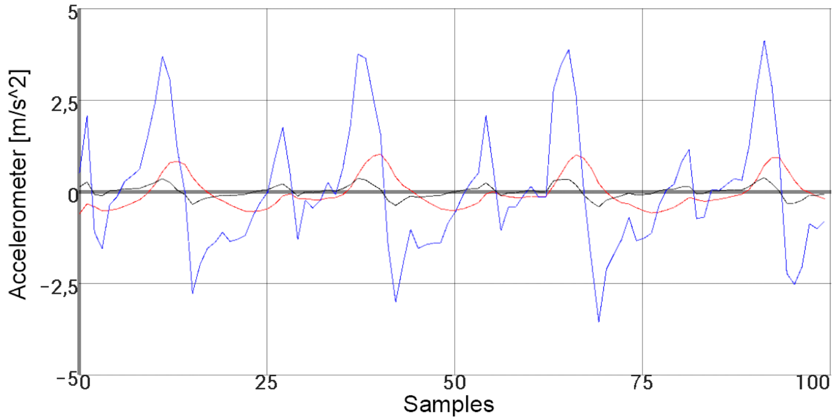

Fig. 37. This figure shows the raw linearized accelerometer data (blue line), the low pass filtered linearized accelerometer data (red) and the derivative of the low pass filtered linearized accelerometer data. All data was generated by a smartphone placed in front pocket of a user carrier, while walking. All data is estimated based on the values in z-direction, since the screen is either pointing forwards or backwards.

As presented in Fig. 37, the low pass filter removed the high frequent noise resulting in a smooth repeating curve that is more useful. The number of steps is clearly visible, and there is also some inaccurate values in the beginning of the sampling due to the learning phase of linearizing of the data.

Overall, the experiment was successful resulting in a beginning of an algorithm to detect steps.

To count the steps, an algorithm was applied to calculate the derivative between each measurement, searching for peaks where the derivative was zero or went from positive to negative due to the time discrete samples. This method of approach seemed to work with a consequent way of walking. When switching speeds or by generating some low frequent movements while performing a step, the graph showed multiple peaks at a step. This was interpreted as multiple steps by the algorithm making it rather inaccurate.

After some testing, the best approach seemed to be to detect the intersection between the obtained curve and the x-axis after exceeded a threshold. This was more sustainable and produced accurate step detection. Using the threshold was to eliminate noise that could be interpreted as a step.

The algorithm works by registering accelerometer data due to the user carrier moving. This acceleration exceeds the applied threshold, meaning that user carrying the device is actually moving his or her leg. Then when the user putted down the leg the other one is in movement making the device register a negative acceleration which will be interpreted as a taken step. This was to be the final implementation of the step detection algorithm, since it performed well.

Angle detection using the gyroscope

It is fully possible to base an indoor positioning solution on just detecting movement and directions and presenting these on a map of the building.

A test application was created by implementing an open source android library containing everything needed for determine the direction of a device. It was developed by Kaleb Kircher, Kircher Engineering, LLC [30]. The application listens to the gyroscope, obtaining rotation samples in each of the three dimensions. These are used to calculate the angular speed of the specific sample, then they are normalized and used to calculate a delta rotation vector which is needed in order to obtain the wanted rotation matrix. Obtaining a rotation matrix requires an initial rotation matrix, which is provided by using multiple sensors: gyroscope, accelerometer and the magnetometer. The application then plots a red dot in the corresponding direction the smartphone is pointing, when sensing a step.

Fig. 38 shows the application that was developed in order to register how a person was moving in a room, seen from above. It performed well in short scenarios but tended to provide values that drifted. Drifting means that the sensors emit very small values all the time, adding them up would result in a rotation.

Fig. 38. This figure shows a pedestrian dead reckoning (PDR) solution based on gyroscope and accelerometer. It recognizes when the user has taken a step and the smartphones current angle. The step button simulates a step. The red curve represents the path which the smartphone experienced while the user walked around. The white area represents the floor of a room.

7. Evaluation

When developing the indoor positioning solution, the main focus was on three important aspects; usability, scalability and precision. In this chapter the developed solution is evaluated based on these three aspects.

7.1. Usability

The developed solution consists of a smartphone application. This means that the solution does not require the user to carry any extra hardware except a smartphone, which most people carry around anyway. It is also important to mention that the solution works independently from phone orientation, this is important from a usability perspective as it allows the user to carry the smartphone in its pocket.

A disadvantage with developing applications that focus on a potentially full day usage is the battery consumption. This is taken in consideration while developing the application, which can be used in both active and passive mode, meaning that the user can see his or her position or the application can run in the background allowing the user to perform whatever the user do on the phone every day.

The solution supports multiple users and smartphones being simultaneously connected and positioned. Each and every smartphone is provided with the position of every connected smartphone, which is visually presented by the application. The visual presentation of every connected smartphone can also be provided by visiting a webpage, which can be reached from any computer in the world.

The application is easy to use and building a radio map is very easy due to the simple graphical interface. A user simply clicks the screen when placing a Bluetooth beacon or when creating a path with magnetic points, as seen earlier.

7.2. Scalability

The application allows the radio map to be created very easily and in a short amount of time due to the use of magnetic readings. The time invested in the offline phase of the system is comparable with the time required to walk through the building. Mapping the Cybercom building, all the rooms and corridors, takes just a few minutes. The application currently does not support to display multiple levels.

7.3. Precision

In order to evaluate the precision we performed two tests, one to estimate the positioning error and one to reveal how the solution behaves during a walk through the office.

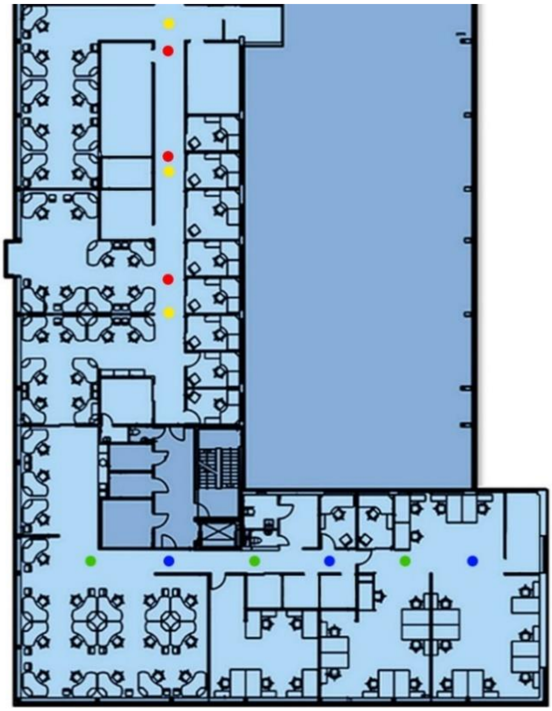

Fig. 39. This figure presents the two corridors used when estimating the final precision. Each three circles of the same color represents a test walk, resulting in the total of four test walks.

The precision of this proof of concept solution was estimated using a test that was performed in two different corridors of the Cybercom office. The test was to measure the positioning error towards the real position at three specific points of the corridor. This was done as mentioned in two different corridors with two test walks for each one. The different points of each test can be seen in Fig. 39, where each color represents a test walk.

The precision of this solution was estimated to 2,6m in average and the accuracy was estimated to be below 2m at 63% of the time at presented in Fig. 40.

The other test was performed to reveal the behavior of the positioning filter where a user walked through the Cybercom office following a marked path trying to reveal the behavior of the positioning. The test was performed twice, one while walking in one direction of the map, and the other while walking back.

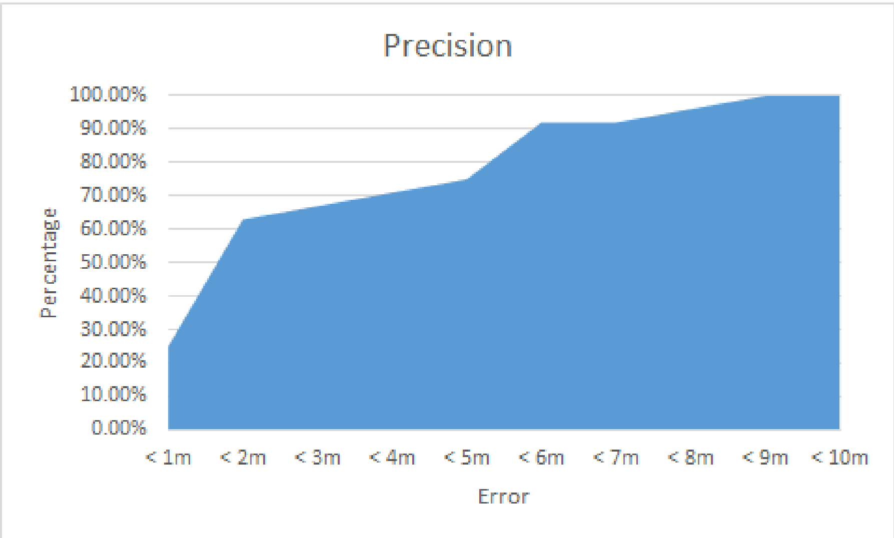

Fig. 40. This figure shows the resulted precision of this master thesis solution, concluded from a set of tests.

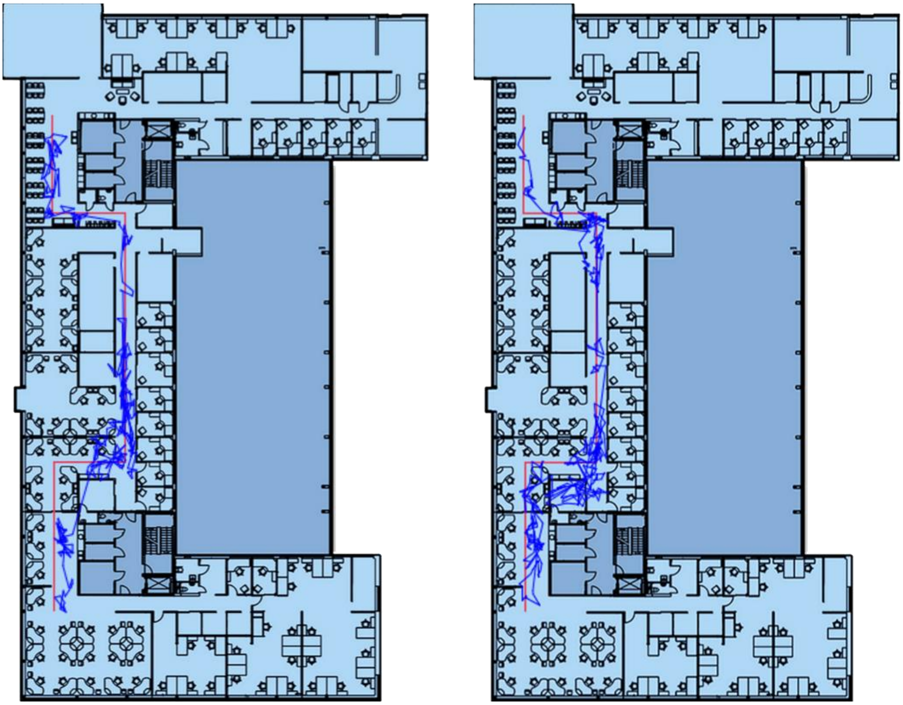

Fig. 41. This figure presents the resulting precision of this master thesis solution using Bluetooth proximity with magnetic fingerprint points. The left image shows a smartphone walking the red, true path, from the bottom to the top of the map. Meanwhile the right image shows the same but starting at the top and moving towards the bottom of the map.

8. Conclusion

This master thesis has resulted in an implementation of a proof of concept in order to evaluate the chosen solution for this problem. The application performs fairly well, as illustrated in Fig. 41, even though there is room for improvement in several areas. The filter implementation is very simple and could be vastly improved by for example taking advantage of sensors such as gyroscope and accelerometer.

The number of particles is chosen based on a few tests and needs to be further investigated. Too many particles will result in more demanding calculations and too few will result in poor precision. This must be overviewed and adapted to suit a desired number of simultaneous mapped devices and increase the number of particles thereafter to maximize the precision. There might even be ways to simplify the matching algorithm and the particle filter in order to lower computational load, but still obtain the same result.

Time could also be invested into researching the possibility of creating artificial magnetic anomalies using coils, in order to easier distinguish fingerprints. This could result in magnetic anomalies becoming even more stable and with a higher contrast.

The idea of letting the website pull data from the server can be improved, resulting in unnecessary server calls and potentially very many of them. The server should instead be pushing the information out to the website when there is new information available.

There are certain areas that could need some improvement due to the limitations in time and desired focus aiming towards, for example, a visually attractive solution. When the algorithm successively performs better it should be tested with larger reference areas. Ideally it would work without reference areas using only magnetic points and sensor readings.

In this master thesis project the option of implementing an algorithm that automatically updates the radio map has also been investigated. Such an algorithm would allow the radio map to be created once without requiring additional maintenance in the future as the system would automatically adapt to, for example, small changes in the magnetic field. However, implementing the algorithm properly would be very time consuming and difficult to fit within the scope of this master thesis. Considering the fact that the proof of concept supports tools that make the mapping process quick and easy to effectively reduce the time required during the offline phase, it is also debatable if an automatic mapping algorithm is actually necessary. When studying how such an algorithm could be implemented it became apparent that the adaptability of the solution will probably be limited to very small changes in the magnetic field, larger changes would still require a new offline phase.

As previously mentioned, a specific magnetic threshold is calculated for each reference area. This feature allows the system to adapt the threshold to different areas of the building. This is important if, for example, there are specific areas of the building where the fluctuations in the magnetic field are very low. In that case a lower threshold is needed for the system to remain accurate. However, since the reference areas have a fixed size and are circle shaped regardless of the magnetic field and the fact that the threshold is calculated in a very simple way it is safe to say that this feature could be improved further. More extensive testing of the performance of the adaptive threshold as well as a smarter way of calculating the threshold will be needed to further improve this feature, however, the idea definitely has potential.

In terms of usability we believe that this solution is a good choice. The solution consists of a client-side which is simply a smartphone application. This means that a user do not need any extra hardware in order to be positioned which is very preferable. Making each and every user carry an extra device could be devastating. It would not be appreciated.

The application is also very simple to understand and to use. The server-side consists of a server and some Bluetooth beacons, which is relatively cheap.

In terms of scalability we believe, even though fingerprinting is not the most scalability friendly, that this is a good approach. This is due to the fast mapping and building of the radio map and the magnetic sensor implemented in the smartphones. As mentioned in the evaluation, an office/building can be mapped in a few minutes, which is very fast. Fingerprinting results in a potentially higher precision which should be taken in consideration.

The resulting precision of this proof of concept was beyond our expectations. It should be mentioned that the test was performed using the same smartphone during the mapping of the building and the positioning. We believe that the resulting average precision 2,6m is very good, especially since this is a proof of concept and there is so much to improve.

The performance of the positioning system could be vastly improved by using sensors (accelerometer and gyroscope), unfortunately there was not enough time to implement the improvements we had in mind. The particle filter could be made more accurate by an improved user movement model. Sensors could be used to improve particle movement.

A solution where the mobile phone utilizes the accelerometer and the gyroscope sensors could spread the particles in a direction that is relevant, in the direction which the user actually is moving. This would result in an elimination of particles finding matches in directions which the user is not moving. This, of course, implies that we find a way to use sensors to determine when the user makes a turn.

A more simple way to improve the particle filter using sensors would be to implement a step detector. A step detector would allow us to register if a user is moving or not, as well give some information of how fast the user is moving. Knowing if the user is moving or not would allow us to eliminate much of the unnecessary transmissions of data while the user is not moving, as there is no need to update the user position. Information regarding walk speed of the user could be used to set the speed of particles.

A pedometer would register the actual movements making the particle filter adapt better to movements and behave more natural. A combination of the accelerometer and the gyroscope would correct most of the particle filter's insufficiencies by offering supplying more data about how the user acts in its environment, it would result in each particle acting as qualified guesses instead of random ones based on nothing. This would also allow this solution to work much better with smaller rooms by not moving through walls and by entering a room along a corridor would only be done when for example the sensors register a 90 degree turn and together with magnetic fingerprints matching the ones in the room.

The problem with the smartphone sensors is the reliability of the values, the gyroscope turned out to be drifting. Meaning that if the phone registered angular changes even if the phone was to be laying still on a table. These changes were insignificant in a short run, but would turn into an issue after a while.

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