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Abstract

Building Informational Modeling (BIM) is very popular in the construction industry in Norway today, and Omega 365 has created a suite of tools for BIM, including a 3D visualising tool for 3D models of buildings, called a BIMViewer. This tool exists in multiple forms, and one of them is an app for mobile phones, which construction workers carry with them on construction sites. When determining one's own position in the BIMViewer, it may take time to find and select the correct position. This study aims to create a feature for the BIMViewer using new technology, IEEE802.11mc and comparing it with an old method, Wi-Fi received signal strength (RSS) with the Log Distance Path Loss model. In addition, GPS was tried in order to prove it was not usable for this use case and in order to compare it with the other two methods. The main goal is to find a method that is cheap for clients to implement in regards to equipment and installation, but is precise enough to provide a good user experience.

Three experiments were conducted for this study, one using only GPS and two for the other two methods. One experiment used only a single floor and the other used two floors. Both of these experiments used only 6 access points and were conducted at NyeSUS, the new hospital in Stavanger which was an active construction zone during the experiments.

The experiments showed that GPS was a bad choice for the use case and that both the other methods were usable. The round trip time (RTT) method, which used the IEEE802.11mc measurements was more precise than the RSS method, however suffered from the need for more access points than the RSS method.

This study concludes that both the RTT and the RSS methods may be usable, however some improvements would be needed for a truly good user experience. The study also suggests that a mix of the two methods may be beneficial.

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Acronyms

AP	Access Point
BIM	Building Information Modelling
FTM	Fine Time Measurement
GNSS	Global Navigation Satellite Systems
GPS	The Global Positioning System
IFC	Industry Foundation Classes
LDPL	Log Distance Path Loss
LOS	Line-of-Sight
MD	Mobile Device
NN	Neural Network
PLE	Path Loss Exponent
RFID	Radio Frequency Identification
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
RTOF	Round-Trip Time of Flight
RTT	Round Trip Time
TDOA	Time Difference of Arrival
TOA	Time of Arrival
UWB	Ultra Wide Band

1 Introduction

1.1 Motivation

Positioning, also sometimes called localization, is the act of determining the coordinates of some person or object. For the sake of this thesis, indoor positioning will refer to the act of determining the position of some mobile device inside a building. The traditional ways of doing this include using audio waves or radio waves to determine the distance or angle from some fixed points to the device, estimating the position based on the signal strength of radio waves and a pre-made signal strength map, or assuming the position based on the strongest signal from an access point or tag with a known position. What differentiates indoor positioning from general positioning is that the indoor environment introduces some challenges to signal propagation that makes it significantly more difficult than outside, where there is generally line-of-sight (LOS) and much less obstruction. Well-known systems like the Global Positioning System (GPS) and Galileo are not usable inside as they are designed to send signals that do not penetrate the walls and roofs of most buildings. [22]

Building Information Modelling (BIM) is the process of creating and managing a digital representation of a building or any other construction. This digital representation, or model, contains data needed to build the construction and can also be used for management after finished construction. Projects that might use BIM include office buildings, hospitals, roads, train tracks or oil rigs. The model will usually include a 3D representation of the construction which can be viewed and interacted with using software that is often called a BIM viewer. Other than the 3D model, the BIM model will include data about systems and objects e.g. dimensions, names, descriptions etc. and the BIM model may contain documents or links to documents relating to the project e.g. contracts, specifications, receipts, etc.

Omega 365 provides BIM services to customers, which include a 3D viewer. The Omega 365 BIM system is based around the Industry Foundation Classes (IFC) format, which is an open, non-proprietary standard format, for digital representations of a construction. This specific tool is used by construction companies, mainly in Norway, and is integrated with the Omega 365 tool suite, which is one of the main products developed at Omega 365, along with PIMS R4 and Pims365, both of which also have versions of the BIM tools.

A typical usage of the BIM 3D viewer specifically is with a mobile device, a user will enter the building to inspect it, then mark on the BIM model where they find any issues. This use case involves the user finding their position in the BIM model based on their physical location. Omega 365 wishes to make this positioning part as simple as possible, since it can be cumbersome to first select a BIM model, then select a floor, find their approximate position in the floor plan, and then move the virtual camera to a place they can see and select the object they want to mark. Instead, it is desirable if the user could open the BIM viewer and automatically be positioned in the right model, on the correct floor, at approximately the position that reflects where the device currently is.

1.2 Goals

This process of positioning the user device can be separated into multiple smaller goals: finding the correct model, the correct floor, and the correct position. All of these goals will eliminate one step for the user when they want to use the 3D model, while the first goal is easier than the next and the last one should be the most difficult. In this paper, the focus will however be in the opposite order, where positioning will be attempted first, as solving this would eliminate the need for figuring out the floor separately, and can be used to eliminate the need for selecting a model. It cannot be expected to find the position with 100% accuracy, however if the method used finds some arbitrary position in the building, that is not usable. A user expects to be positioned in approximately the same place in the model as their device is relative to the real building, and this approximation may be better or worse, depending on the building and other factors. One might assume that the user would find it frustrating, detracting from the experience, if the approximation misses the real target by more than a few meters. Finding a more accurate tolerance of failure is also a minor goal of this paper, with the further goal of determining what techniques are appropriate for the use case of indoor positioning in the context of BIM.

The main goal of this paper is to determine if there is an approach to positioning that provides adequate precision for the users to find it an improvement to the BIM experience while keeping the cost as low as possible for the clients. This necessitates some comparison between different technologies, which means it is necessary to have some criteria and measures to compare them on. The measures that are immediately apparent are price, precision, reliability, and complexity. Complexity should be evaluated with respect to both the implementation and the work needed to install the feature. The price must be viewed from the perspective of the client, so the price of any additional equipment that is needed for the feature to function must be included.

1.3 Outline

1 Introduction Introduces the thesis.

2 Background Explains theory necessary to understand later experiments, and presents different methods that have been used to solve the indoor positioning problem.

3 Implementation Shows the chosen approaches that will be evaluated in the experiments and explains the code briefly for these approaches.

4 Experiments Presents the setup for the experiments.

5 Results Lists the results of the experiments

6 Discussion Interprets the results and aims to understand which approaches work and what the limitations are, as well as the limitations of the experiments themselves. This section also looks to the future and will briefly give recommendations for future studies on the topic.

7 Conclusion Concludes the thesis and summarizes the results in terms of the goals set in the introduction.

2 Background and Theory

This section will examine the problem in more detail and give perspective on the different possible approaches to positioning. It will also explain some of the key concepts that are necessary to understand the experiments and implementations in section 3 and 4.

2.1 Coordinate System

Positioning requires coordinates, and in the case of BIM, there must be a relationship between the coordinates of the BIM software and the actual physical location of the device that is localized.

2.1.1 Model Coordinate System

The BIM model has an internal coordinate system which is used by the BIM software. This system is always in meters, however, the origin point and orientation are set by the creator of the model. The Omega 365 BIM viewer provides options to rotate the model, and it also provides the option to relate the origin point to a real-world global coordinate in the geographic coordinate system (GCS) WGS84. These must all be set by a user, however, and the tools provided do not have any guarantees about precision. A single model will typically span at most a kilometer in any direction if it is a building, however, this does not necessarily apply to roads or train tracks etc.

2.1.2 Global Positioning

For some positioning approaches, the result returned to the BIM application will be in some form of global coordinates [2]. For these, the simplest software implementation requires fixing the origin point and a direction in the model in the same coordinate system as the returned result. The models for buildings will never be large enough that the curvature of the earth distorts the translation of the coordinates much when translating along the model coordinate system.

2.1.3 Local Positioning

Some of the positioning approaches use fixed devices that are inside the real-world space that the model represents. In this case, we can instead include these devices in the model and regard them as single points in the model coordinate system for the purposes of positioning the user device. These techniques measure the distance or angle between the device and the fixed points, and since those fixed points are in the model coordinate system, we can calculate the position of the device in that same coordinate system directly.

2.2 Environment

The 3D viewer is used in multiple environments including outdoors for road construction, bridge construction, oil rigs, train tracks, etc., or indoors in a variety of buildings ranging from small houses to large concrete office buildings. This thesis focuses on the use of the viewer in large buildings. These buildings have some significant limitations due to their building mass and floor plans. Some of these challenges are multipath propagation, path loss, and the position of transmitters or receivers.

2.2.1 Multipath Propagation

Multipath propagation, or just multipath, is the phenomenon that makes a radio signal arrive at a destination at multiple different times [25]. This usually happens because the signal is reflected on surfaces and may reach the receiver using multiple different paths, that may take different times. The same phenomenon exists for auditory signals, which is commonly called echo. This happens because of walls, floors, furniture, or other obstacles the signal encounters, especially reflective surfaces. In addition, this phenomenon can lead to interference and phase shifting [24]. The indoor environment will rarely offer line-of-sight paths to all the receivers needed. This can lead to both differences in time and signal strength, which are the two most used measures to estimate the distance between the device and the receiver [3].

2.2.2 Path Loss

Because the signals will travel in an environment with many walls, and potentially floors, roofs, windows, or doors, it can be expected that whatever signal is used will lose some energy while it propagates. For a device to receive a signal, the signal must have some amplitude that is above a certain threshold. The signal may not be able to go through many walls while remaining above the threshold, and floors, which are generally thicker than walls may lead to more loss of energy.

There is also regular path loss, where the energy is lost while the signal travels through the air normally. This path loss has been shown to be logarithmic, and the signal strength can generally be estimated using a formula called the Log Distance Path Loss (LDPL) model. [31, chapter 10]

$$\overline{PL}(dB) = \overline{PL}(d_0) + 10\lambda log(\frac{d}{d_0}) \tag{1}$$

Equation 1 shows the Log Distance Path Loss formula where $\overline{PL}(dB)$ is the received signal, $\overline{PL}(d_0)$ is the received signal at some distance d_0 and λ is an environmental constant.

2.2.3 Position of Receivers

When creating a WLAN for a building, it is common practice to have devices spread out in a manner that provides a minimum of a certain signal strength to most of the building. This means that a room might be served by a single access point (AP), which would mean that there could be big differences between the different APs in the signal strength and travel time between the AP and the mobile device. In addition, having APs too close, or within line of sight of each other may lead to increased interference.

2.3 Triangulateration

A common way to position a device is to use the properties of triangles, which is called triangulateration, which is a combination of the words trilateration and triangulation.

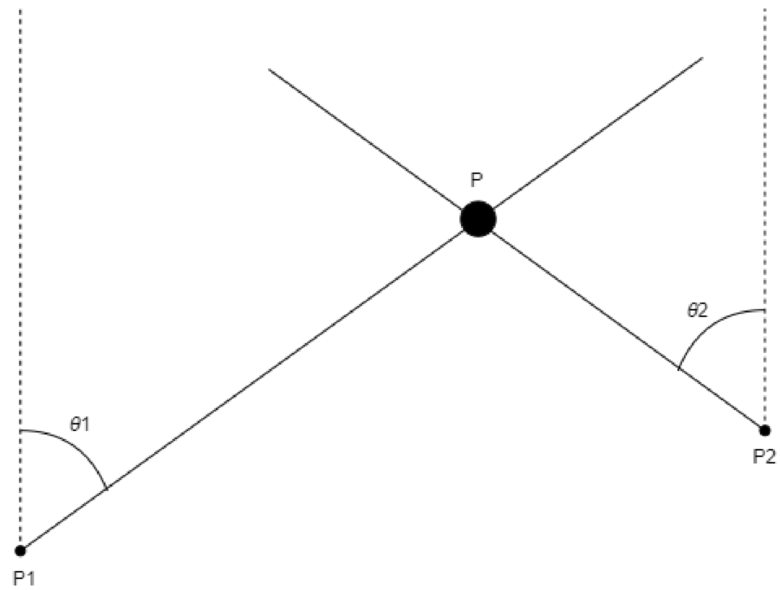


Figure 1: Angle of arrival based positioning of point P.

2.3.1 Triangulation

Triangulation, also called angulation, uses the properties of angles in order to pinpoint a location [11]. For it to work, the angle between some fixed points and the movable device needs to be known, and it can find a position in two dimensions with as few as two known angles using a technique called Angle of Arrival (AoA), which is shown in Figure 1. The disadvantage with AoA is that it often requires specialized equipment and small errors may have a great negative impact on the precision compared to other techniques [21] [8, p. 252].

2.3.2 Trilateration

Trilateration, also called lateration, uses distance instead of angles. The most common ways to measure the distance are using the time a message takes to travel from the fixed node to the mobile device or the round trip time or using the difference in time for a signal to travel from the mobile device to multiple fixed nodes (or from the nodes to the device). One major disadvantage with the travel time from mobile device to fixed nodes is that it requires time synchronization, either between the nodes or between the nodes and the mobile device.

Time of Arrival (TOA) is a technique to estimate the distance from a sender to a receiver, by using the time it takes for a signal to travel from one to the other and the speed at which the signal travels. This method requires strict time synchronization and relies on a timestamp at the time of sending.

Round-Trip Time of Flight (RTOF) is similar to TOA however it tracks the time it takes for a signal to travel from sender to receiver plus the time it takes for a signal to travel back to the original sender. This reduces the need for strict time synchronization. A challenge with this method is the time it takes for the responder to process and emit the response, which is not known by the original sender. This time can be ignored if it is assumed to be very small in relation to the transmission time, however, for radio signals that travel at the speed of light and for short ranges of only a few meters, this is not possible.

Time Difference of Arrival (TDOA) is another timing-based technique, but for this method it is normal for the mobile device to send the signal. The time difference of arrival between the different receivers is used to calculate the position. This removes the need for any time synchronization with the mobile device, however, there is still a need for time synchronization between the receivers.

Received Signal Strength Indicator (RSSI) is a technique where we estimate the distance based on the attenuation of a signal. The actual method for estimating the distance differs based on signal type and there are multiple theoretical models used for calculating it. This method has the advantage of not needing any time synchronization, however, it is regarded as not very accurate due to being affected by multipath propagation, and because it can be affected easily by obstacles in the environment.[23].

Once the distance is found, we can use for example the Least Squares Method (LSM) to find the coordinates. This method requires at least 3 fixed points with known distances to the mobile device in order to position the device in two dimensions (see Figure 2), while 4 points are needed for three dimensional positioning [8, p. 253]. LSM is described in detail in [8, p. 253], [12] and [3].

2.4 Positioning Technologies

As mentioned earlier, there are multiple methods of determining the position of a device, and those methods usually use either radio signals or audio signals. These include GPS, Wi-Fi, Bluetooth, RFID and ultra-sound-based techniques, but it is also possible to determine position using a camera and an algorithm or a trained machine learning model.

2.4.1 GPS

The Global Positioning System (GPS) is a system that uses satellites and atomic clocks in order to position a device somewhere on earth. GPS was developed by the U.S. military, but is in wide use today by civilians all over the world, and there are as of February 2022 4 different such systems, collectively called Global Navigation Satellite Systems (GNSS) [29]. It is one of the most widely used technologies for positioning, provides several different levels of accuracy, down to centimeter precision, and almost all mobile devices support it. For most civilian use the accuracy is 7 meters. However, for the purposes of indoor positioning, it has the challenge that it uses satellites far away from the building, and the signals have a hard time penetrating through layers of walls and roofs. GPS generally requires LOS from four of the satellites to the device to function properly [30].

2.4.2 Wi-Fi

Wi-Fi is the most used technology for digital wireless communication today. A huge advantage of using a Wi-Fi-based positioning system is that almost all buildings can be expected to have Wi-Fi APs already installed, and all mobile devices that support the BIM viewer also have Wi-Fi capabilities.

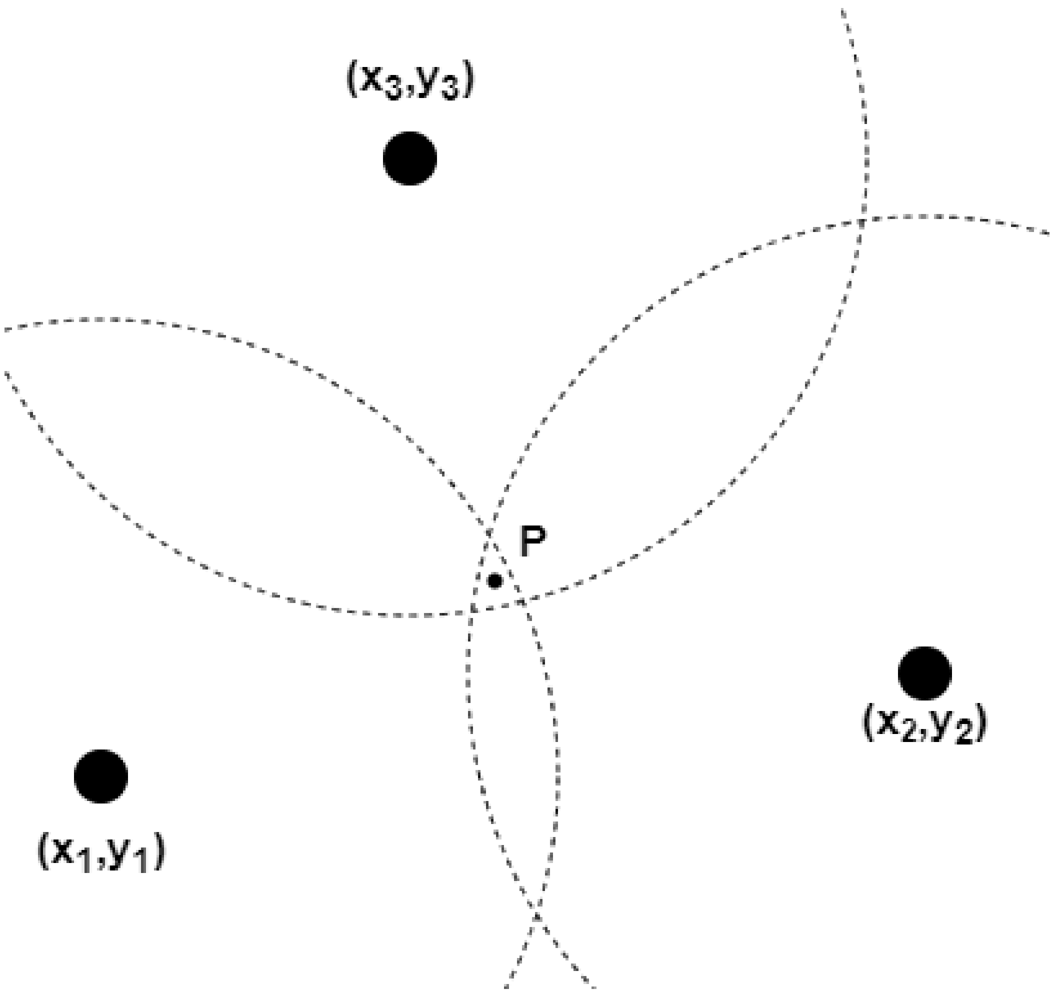


Figure 2: Trilateration in two dimensions. The actual point is assumed to be at the point that best matches all three circles defined by the measured distances.

Received Signal Strength (RSS) is a technique that uses the signal strength from different APs felt by a mobile device to estimate the position of the device. In order for this technique to work, there needs to be some preliminary work to record samples of the signal strength in different locations inside the building. This is called the *offline phase* and is done to create a radio map over the area. The *online part* is where the actual positioning of a device happens, and this is done by having the device sample the signal strength, then comparing the samples with the radio map to estimate the position. [20]

The position estimation can be done in multiple ways, which can be categorised into deterministic or probabilistic approaches. For a deterministic approach, an algorithm that runs a comparison with the samples or radio map can be done using interpolation where no data is found or assuming the nearest data point to be the position. A probabilistic approach can use a probability distribution function for each AP, merge these functions, then compare where the device most likely is based on the received signal strength of the device and the probability functions [20]. It is also possible to use a Neural Network (NN) in order to calculate the position using the radio map and received signal strength [37].

This approach has several disadvantages, in addition to needing manual work in order to create the radio map, this map may also be outdated after a change in the environment. Furthermore, the approach is very sensitive to the multipath effect as well as device heterogeneity (different types of devices perceive different signal strengths at the same position) [20]. This method, like any RSS-based method, may also be affected by furniture or obstacles and even the person holding the device if they are standing between the mobile device and the access point.

Fine Time Measurement (FTM) is a newer addition to the IEEE802.11 standards. It was outlined in IEEE802.11-2016 in 2016 and has not seen widespread adoption yet, however, some devices support it. It is being worked on still, as of February 2022 [16], with the amendment IEEE 802.11az [33] [1]. This is a ranging technique that estimates the distance between an AP and a mobile device based on only the time a signal takes to travel between them. It claims precision of typically one to two meters for distance measurement from an AP to a mobile device, however, this is assuming ideal conditions[9].

FTM is also called Wi-Fi RTT, short for Round Trip Time. The protocol uses one AP and one receiver device and uses only the time of the AP, so no time synchronization is needed. As a ranging technique, it only requires a Wi-Fi AP and a mobile device that supports IEEE802.11mc, so as long as this becomes standard in new APs and mobile devices, no additional equipment will be needed. As of February 2022, only Android mobile devices have an API to allow developers to use Wi-Fi RTT, while many commercial APs do not support it. Some APs support it but do not advertise this fact, and many require some configuration in order to respond to FTM ranging requests [12].

2.4.3 Bluetooth

Bluetooth is generally similar to Wi-Fi, except that it is designed to be shorter range and to have a lower power consumption. This also means that RSS-based techniques are possible with Bluetooth as well [32]. Bluetooth is also used to enhance the use of Wi-Fi when positioning with an RSS technique [20], as described in [7] and [19]. Bluetooth technologies can also use angle of arrival techniques to position a device [15] and have been shown to have very high accuracy [4].

Bluetooth is also comparable to Wi-Fi with respect to how widespread it is. Almost all smartphones and tablets have Bluetooth capabilities, and Bluetooth beacons are fairly affordable. Bluetooth-based positioning is often used in the healthcare industry already, which is one of Omega 365's core markets for their BIM solution. A Bluetooth-based approach requires specialized equipment, however, this cost may be reduced in cases where the building already uses Bluetooth for other positioning needs.

2.4.4 Imaging

It is possible to estimate a position using imaging techniques, especially when used together with machine learning algorithms. Training a neural network to associate images taken from a smartphone to a position in the BIM model is conceivable. This would require the device to have a camera, and has the advantage of not needing any other equipment on-site. A drawback to this method is the training cost for the machine learning algorithm and the computation cost when estimating the position. This estimation may be too computationally expensive to be done on the device itself, however, this could be solved by shifting the computation over to a server.

Another way of using imaging to position a user is to have cameras installed inside the building and then use a machine learning algorithm to detect users and their positions. This requires cameras in every part of the building where the user might want to traverse, and it requires that the user gives up their right to privacy in any part of the building where they wish to be positioned. This is clearly infeasible for most applications.

2.4.5 Others

There are many other positioning technologies that are worth mentioning but are not quite relevant to this study other than for comparison, because they require specialized equipment.

Sound can be used in much the same way as radio signals for BlueTooth or Wi-Fi. The signals are easier to block than radio signals and travel much slower. It is possible to use both ultrasound and audible sound. Because it travels slower, the variations caused by the processing of the signal when transmitting or receiving are much smaller, which improves accuracy.

Ultra Wide Band (UWB) is a technology that uses short pulses of radio signals with high bandwidth. This has the advantage of being more resistant to multipath problems since it is easier to filter out the first arrival time of the pulse, and it does not suffer from interference from BlueTooth or Wi-Fi because of the different bandwidth[21].

Radio Frequency Identification (RFID) uses tags installed in a building along where people or robots are assumed to move and antennae for the positioning target called readers. The signal does not travel far, and this allows the system to use proximity or RSSI-based approaches with high accuracy. [5][28]

2.5 Omega 365 BIMviewer Application

The BIMviewer mobile application has multiple layers. The app is primarily developed using Flutter[13], however, the actual viewer portion is using a web view to show a web article built using JavaScript. The viewer consists of a core part, which is shared between all versions of the viewer, including the desktop version. The viewer then has extensions which are separate modules that add features, like measuring objects, rotating the model, or controlling the camera. The extensions communicate with the user interface using scrips called plugins. The plugins are different between desktop and mobile versions, and for the mobile version, they are responsible for the web portion of communication between the web view and the Flutter application. The flutter app also has dependencies on many packages built in either Swift or Kotlin for iOS and Android respectively. Another thing of note is that the app is designed to function with no access to any network because the app is also used during the construction of buildings before any access points are installed.

2.6 Related work

Positioning is a well-researched field, and there have been many studies about positioning in general. Most of these studies focus on only a single method of positioning, while some studies specifically compare multiple methods. Some of these include [20] and [21], both of which collect and compare many other studies for different positioning approaches, with a focus on performance and precision, but also on cost. [20] separates the positioning approaches into either passive or active, and further separates it still based on method instead of technology, while [21] examines the positioning techniques based on the underlying technology, and looks more at specific implementations.

This thesis will mainly focus on Wi-Fi-based techniques, and there are many articles detailing most of the different methods Wi-Fi is used for positioning. The most common method for this is using fingerprinting and there are numerous studies into different ways to use fingerprinting such as [37], [17], [14], and [34]. The latter two also use machine learning to enhance usability and accuracy.

In this study, there will be implemented two methods of positioning relying on Wi-Fi, an RSS-based method and an RTT-based one. There have been studies into the use of RSS for measuring distance, by using the tendency of the signal strength to decrease logarithmically. Studies that explore this are for example [18] which combined the log distance path loss model with fingerprinting, and [36] which proposes methods for improving the accuracy with the log distance path loss model.

There are still very few studies properly exploring the RSS approach using IEEE802.11mc, however, there are some. Both [12] and [10] both make an attempt at determining how accurate Wi-Fi RTT is, however they come to very different conclusions, while neither of them attempts to use their measurements for 2D or 3D positioning. There have been some complex solutions to 2D and 3D positioning using Wi-Fi RTT as shown in for example [6] and [35].

There are also some papers which evaluate the metrics and measurement methods used when comparing different positioning approaches. An opinion on this is found in [26], where the authors criticise the practice of using only Euclidean distance between the real and estimated position to measure the usefulness of a positioning approach. They also write about the difficulty of comparing different approaches when they are tested in different environments and under differing conditions.

3 Implementation

All code can be found on Github, see apendix B.

3.1 Choice of method

As stated in 1.2, the main goal is to have a positioning technique that is both accurate and cheap. It should be cheap both in terms of equipment and in terms of implementation. Looking only at the techniques that are feasible to test for this paper, we have only the techniques relying on Wi-Fi and GPS. Since we can expect the building to have Wi-Fi when it is finished, and even to some degree when it is under construction, we can use existing Wi-Fi access points for the purpose of positioning, lowering the cost of the feature to near zero for the client. GPS comes standard with every mobile device the users will use when accessing the BIM model, so this can also be used at no additional cost for the client, however, this is expected to provide very low precision.

The users will also have access to Bluetooth technology with their devices, as well as speakers and microphones, and usually RFID technology. In order to use any of these for positioning, the project must have beacons or tags installed in the building first. This would be additional equipment needed for the feature, in addition to requiring substantial time and effort for installation. It additionally limits the use of the feature to finished projects, as installing beacons that need to be moved during construction is not an option. Wi-Fi-based techniques might also suffer from this, however, the construction workers may need internet access while the project is under construction, and convincing them to place access points in a manner that is usable for the positioning feature may be feasible.

Because of the reasons given above, the techniques implemented for this paper are GPS and Wi-Fi-based techniques. Specifically, we will look at Wi-Fi RTT and Wi-Fi RSS-based ranging techniques, and then use trilateration to find the position. We will not be implementing an RSSI fingerprinting-based method for positioning, because this method requires a significant time investment when collecting samples, and it suffers even more than any other from the problem of changing environment. Since this will be used while the building is under construction, we can expect the access points to be moved frequently, and the environment around them to change even more often. The fingerprinting would need to be redone every time the environment changes significantly, and we should not require this of a client.

3.2 Code

The Omega365 BIMViewer app is made using Flutter, while more platform-specific code is implemented in either Kotlin for Android or Swift for iOS. The app also contains a webview which renders a web app, written in HTML, CSS and JavaScript. The server is written in C# and runs on a server provided by Microsoft Azure. There is also a Transact SQL database and a file storage system where the BIM models are stored. The mobile app stores the geometry of the model locally, however, it must have access to the internet in order to access any other information.

3.2.1 GPS

GPS is the simplest method to implement because the technology is mature and in wide usage. Flutter has a package for retrieving and manipulating geolocation. The app must first ask for location permission, using the Permissions package, and then it can directly ask for the current position in geolocation coordinates. This will return the latitude and longitude coordinates, as well as an estimated error margin. If the error margin is larger than 10 meters, the result is regarded as not sufficiently accurate.

The project itself will have coordinates in latitude and longitude entered by a superuser, which is retrieved when the app starts. The geolocation package can find the distance and bearing between two points given by latitude and longitude, and this can be converted into a vector by making a unit vector in the x-direction, multiplying it by the distance between the points, and then rotating it around the y axis with the bearing between the two points. If the superuser set the point correctly, this vector should point to the user's location in the xz-plane. This however means that the y-direction, or elevation, is forgotten about. The GPS method has no way of determining elevation, so this must either be entered by the end-user or determined using a different method.

3.2.2 Wi-Fi RTT

iOS does not allow any app to access information about the Wi-Fi without special privileges from Apple, and iOS platforms do not support 802.11mc. Android is the only major platform that supports 802.11mc, and there is no flutter package for this yet (as of May 2022). The Wi-Fi RTT method was therefore implemented mostly in Kotlin for Android devices in a Flutter plugin.

The plugin provides methods for checking whether the device supports 802.11mc, getting the Wi-Fi access points the device has access to, getting the signal strength of the access points, running a ranging request, and trilaterating with a given set of points and distances. A scan of the network must always be run before running a ranging request for correct results. After the scan, the available access points are collected in a list, which is then used to run the ranging request. This part must be run asynchronously because there is no synchronous way to run the scan of the network and use the results. For the RTT ranging, all APs that are not 802.11mc responders are discarded.

The access points are stored in the database with Mac address (BSSID) and position. This position can be changed by using the BIMViewer web app on a computer or mobile device. When using the RTT method, the app will retrieve the positions of the APs using a stored procedure. It will then run the ranging request which returns the distances, standard deviation, and a status code. For each measurement where the status is a success, the position of the AP and the measurement to that AP are combined and used to trilaterate the position of the mobile device.

3.2.3 Wi-Fi RSS

Much like the Wi-Fi RTT method, the Wi-Fi RSS method does not work on iOS, and it uses the same plugin to get the received signal strength of the APs. In general, everything is the same as the Wi-Fi RTT method, except the way it finds the distance. Instead of sending an FTM request, it will use the RSS to mathematically estimate the distance, using the Log Distance Path Loss model [31, chapter 10]. The mathematical formula is

$$RSSI = A - 10 \times n \times log(d) \tag{2}$$

where RSSI is the received signal strength measured in dB, d is the distance we are interested in, A is the RSS at 1 meter distance from the AP (this is stored together with the position and MAC in the database), and n is a constant determined by the environment[31, chapter 10]. The constant n can either be selected based on known environments or it can be measured for each AP with the formula

$$n = \frac{A - RSSI}{10 \times log(d)} \tag{3}$$

Changing the unknown for d we have

$$d = 10^{\frac{A-RSSI}{10n}} \tag{4}$$

3.2.4 Trilateration

The trilateration method that was used is a version of the Levenberg-Marquardt algorithm, which is a least-squares algorithm based on combining the Gauss-Newton algorithm and gradient descent. Multiple methods of calculating the weights have been proposed, and [12] proposes these two:

$$\frac{1}{\sqrt{stdDevDistance^2 + stdDevPosition^2}} \tag{5}$$

$$\frac{1}{distance^2} \tag{6}$$

A third method, which is a combination of the other two has also been implemented:

$$\frac{1}{\sqrt{stdDevDistance^2 + stdDevPosition^2} \times distance^2} \tag{7}$$

stdDevDistance is the reported standard deviation which is provided for any measurement using the FTM protocol, while stdDevPosition is an estimate for the accuracy of the position of the device and the access points. For RSS, only the inverse squared distance weights were used.

3.2.5 Measurements

In order to analyse the implementations, the measurements were stored in a database through stored procedures. Measurements were taken of distances recorded with FTM and the RSS along with the position of the mobile phone and the identity of the access point it was measuring to. Additionally, an estimated position was recorded immediately, using GPS and the two Wi-Fi-based techniques, where all three methods of weighting the measurements were tried only for the Wi-Fi RTT method.

In order to take measurements, the position of the mobile device must also be stored with the measurement. This was done by pretending the device was an access point with the mac address of 00:00:00:00:00:00. This way, the same code used for repositioning an access point could be used for giving the position of the mobile device.

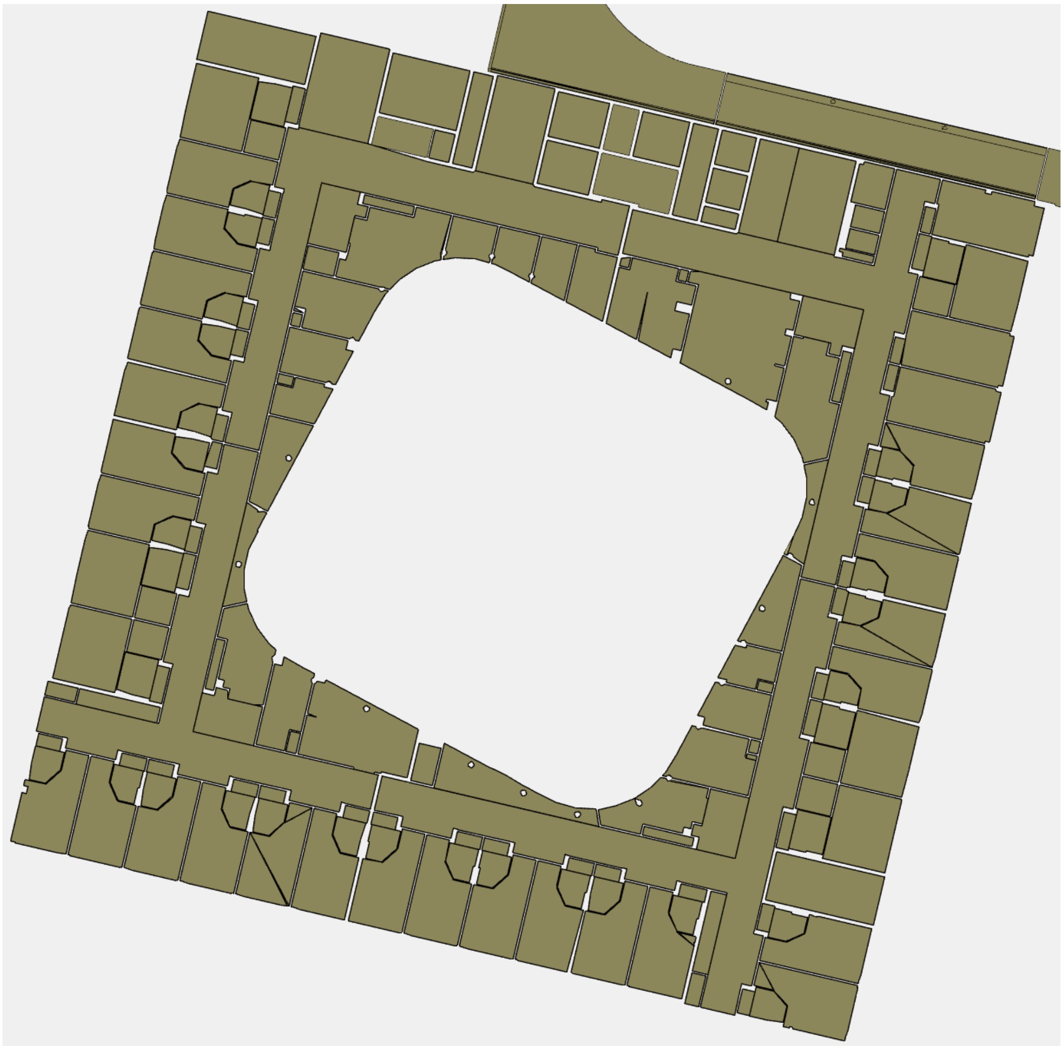


Figure 3: Floor plan of building 71

4 Experimental Setup

The experiments were run using the BIMViewer app with the modifications detailed in 3.

4.1 Location

The tests were run at the construction site for NyeSUS, a hospital under construction in Stavanger. It took place between May 2nd and May 13th, the year 2022. At this time, it was an active construction site and only the reinforced concrete, windows, cladding, and some of the ventilation were done. There was no insulation or any furniture, and most walls were not yet present. The tests were run on the third and fourth floors, which have similar floor plans, which can be seen in 3

Figure 4: One access point on the floor connected to a power outlet.

4.2 Equipment

For these experiments, the access points used were six Google Wi-Fi routers and the mobile device was a Samsung Galaxy S21. Google Wi-Fi can either be set up as access points or routers and will normally be in a mesh configuration where one is in router mode while the rest are only access points. For this experiment, all the access points were set in router mode, because otherwise the RTT feature will not work without access to the internet, and there was no internet access at the testing location.

4.3 Limitations

- No fully offline implementation of the tests was made. This means that in any place where there was no cellular network, no measurements could be taken.

- Using only 6 of the google Wi-Fi access points does not cover 2 floors of this building adequately, even for regular internet use.

- The power outlets were limited in number and stationary. Some cable extensions were used, but in general, the access points were placed very close to the power outlets.

- Access points could not be attached anywhere and were only placed on the floor or on top of blocks of materials that were spread around the building.

4.4 Placement of access points

The access points were placed in 2 configurations, one where they were all on the same floor, and one where half were on the fourth floor and the other half on the third.

4.5 Running the experiments

Data was collected over a period of two weeks, in combination with testing and troubleshooting parts of the app. The app was improved substantially during the two-week period, and many of the early results were inaccurate. The experiments that produced trustworthy results are limited to two days for the RSS and RTT-based methods.

The app has a method for collecting estimations of the path loss exponent, which one would use to find the appropriate average to use when estimating distances based on the Log Distance Path Loss model. Because of bugs that were discovered after the experiments, these path loss exponent estimates had to be discarded, and the results for the RSS method had to be recreated from raw measurements of signal strength. This used the same method to determine the path loss exponent as initially planned but used only the measurements for the two days where raw data was collected, instead of calculating the path loss exponent ahead of time and then estimating the position during the experiments. Using these calculated constants, the distances were calculated using the same trilateration as the RTT method. This method uses all 3 dimensions for positioning.

Most of the RTT-based position estimates use only two dimensions and then infer the elevation based on the average floor of the access points used for the position estimate. In the same way the RSS measurements were recreated there were also created three-dimensional estimates for the RTT method. These measurements were taken by first running the RTT ranging 5 times, then selecting the measurement which reported the lowest standard deviation out of the 5, for all distance measurements.

4.5.1 Position of the mobile device

The mobile device was placed by using the BIMViewer app, placing the 3D camera approximately where the real-world device is, then sending that position to the database where the mobile device is modelled as an access point. This process is not extremely precise, but by using objects in the environment and a laser meter in the real world combined with a measuring tool in the app, it is possible to make it quite accurate.

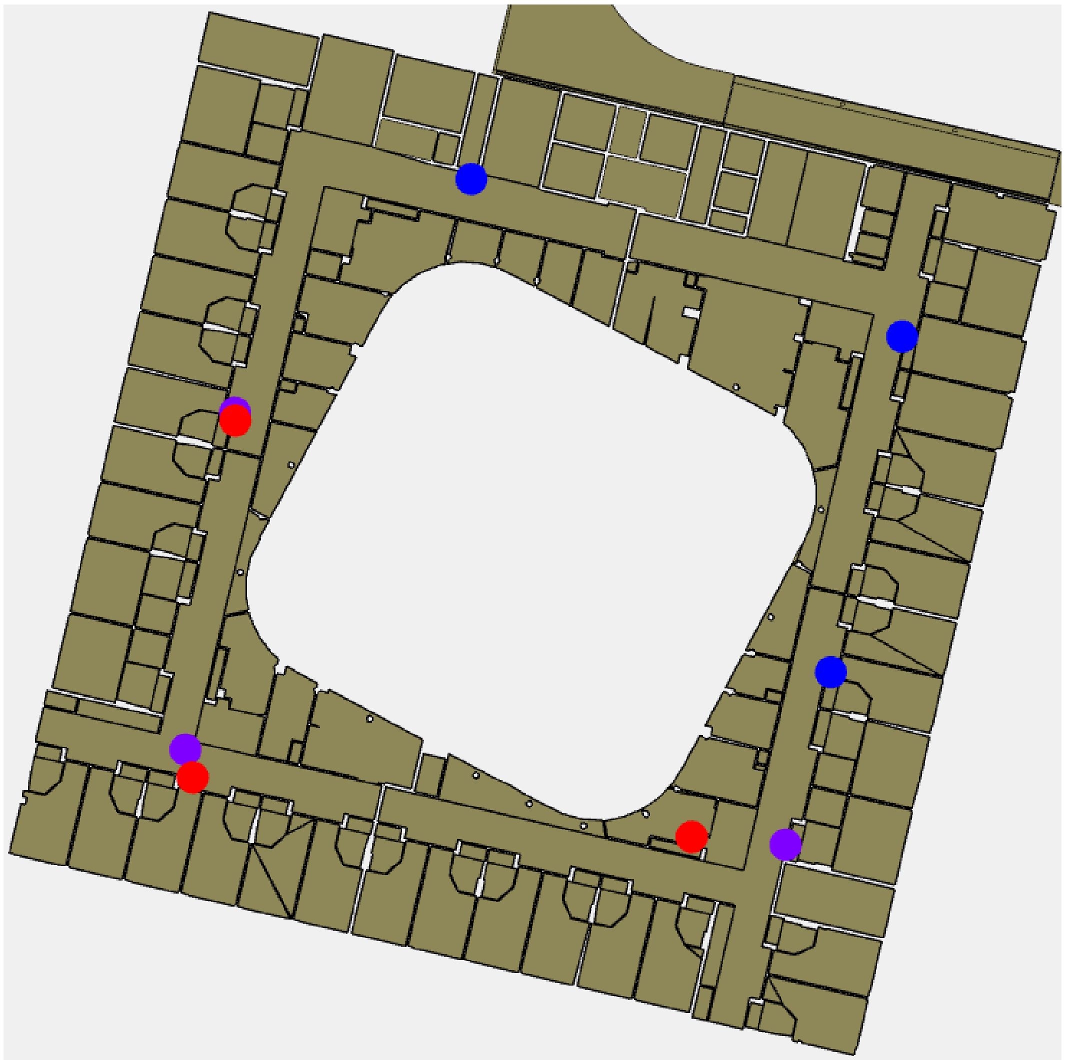


Figure 5: The positions of the access points on floor 3 and floor 4 of building 71. Blue dots are for access positions used only in the single-floor experiments, red dots are for the positions of access points on the upper floor of the two-floor experiments, and purple dots are for access point positions used in all experiments on the lower floor.

5 Results

The full data can be found together with the code on Github, see appendix B.

5.1 RSS method

5.1.1 Path loss exponent

Experiment	Statistic	AP 1	AP 2	AP 3	AP 4	AP 5	AP 6
Using only one floor.	Average	2.285	2.793	2.792	2.869	2.500	2.416
	Median	2.382	2.978	2.803	2.911	2.460	2.519
	Min	1.631	1.468	2.099	1.756	1.842	0.911
	Max	2.950	3.687	3.961	4.026	3.521	3.292
Using two floors.	Average	2.408	3.432	3.566	3.180	3.309	2.553
	Median	2.383	3.177	2.508	2.751	2.822	3.098
	Min	1.596	2.346	2.021	1.023	1.230	0.000
	Max	3.325	5.818	6.462	5.445	6.158	4.130

Table 1: Path loss exponent experiments.

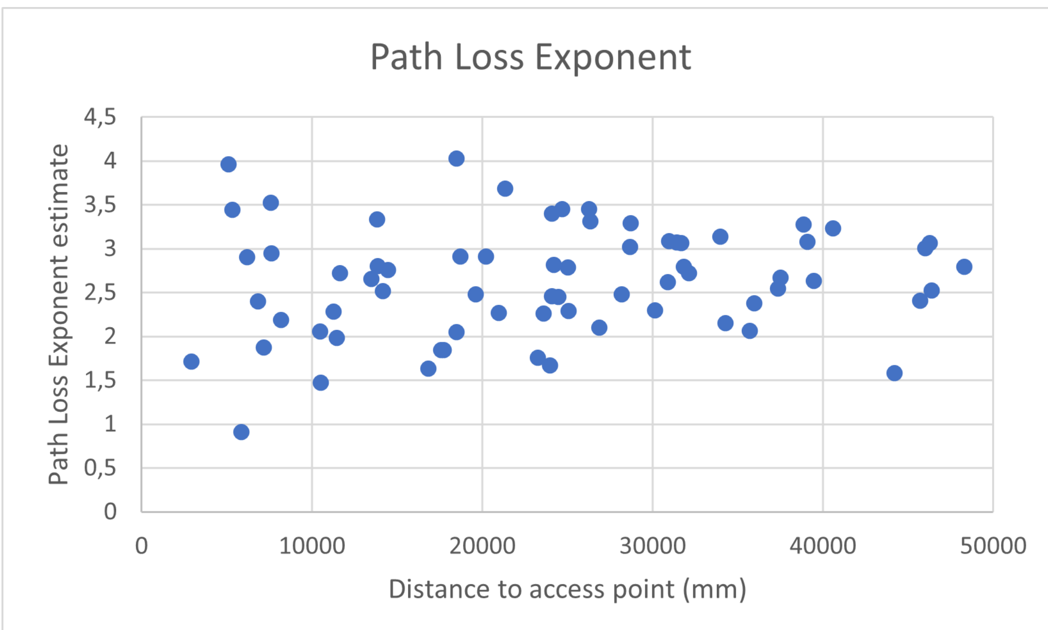


Figure 6: Path loss exponent over distances for the one floor experiment.

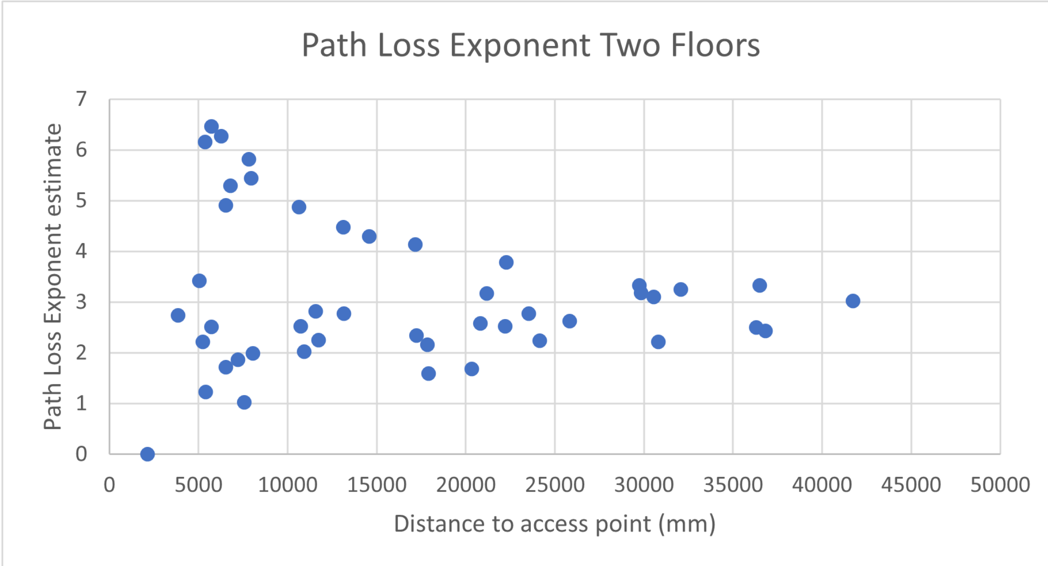


Figure 7: Path loss exponent over distances for the two floor experiment.

5.1.2 Distance estimates

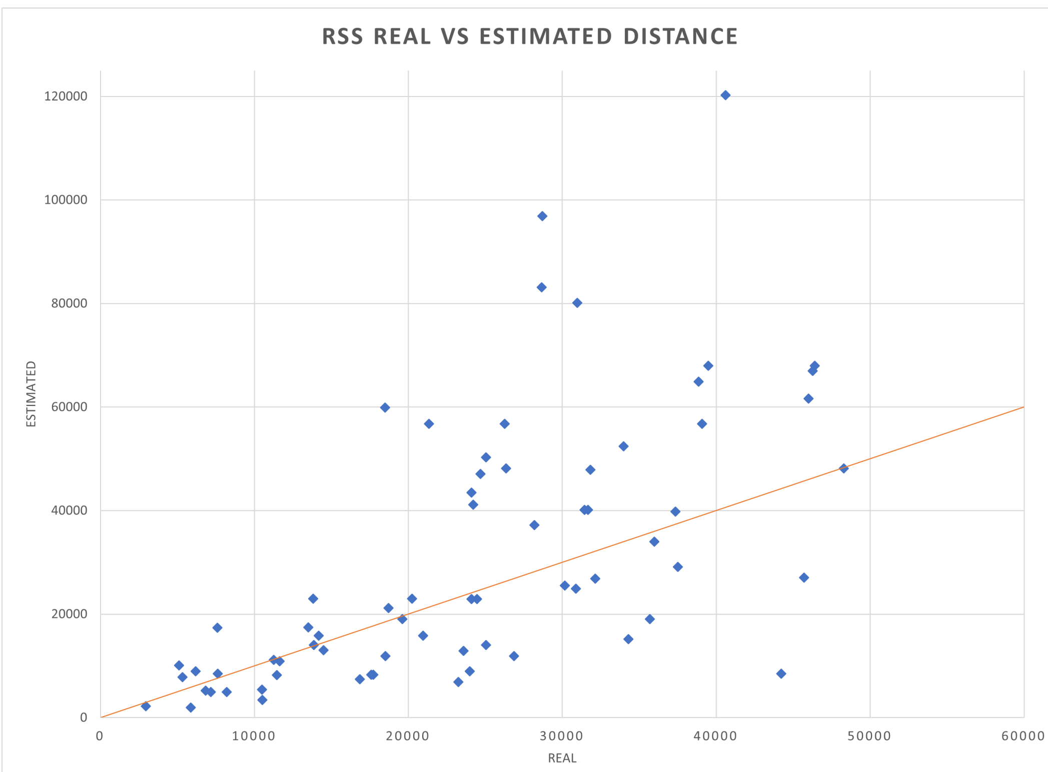


Figure 8: Estimated distance against real distance (in millimeters) using the RSS method for the single floor experiment.

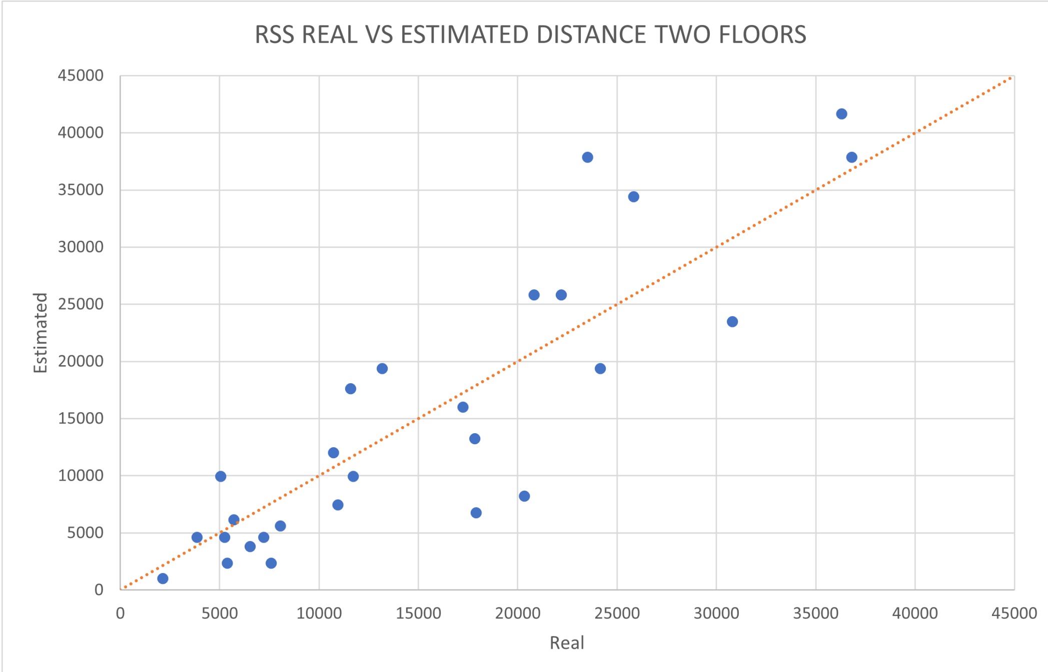


Figure 9: Estimated distance against real distance (in millimeters) using the RSS method for the two floor experiment.

Experiment	Average error	Median error	Best	Worst
Single floor	13832	9156	38	79673
Two floors	38259	7953	432	136604

Table 2: Statisitcs for error in the distances measured using the Log Distance Path Loss model. All measurements are in mm.

Experiment	Under 1m	Under 2m	Under 3m	Under 5m	Under 10m
Single floor	10.14%	18.84%	27.54%	36.23%	57.97%
Two floors	6.52%	17.39%	23.91%	39.13%	52.17%

Table 3: Percentage of measurements where error is lower than 1m, 2m, 3m, 5m, and 10m using LDPL.

5.1.3 Position estimate errors

Experiment	Average	Median	Min	Max
All	10563	8548	1517	33259
Only one floor	13872	10852	3656	33259
Two floors	5982	4971	1517	15209

Table 4: Statistics for error in positioning (in millimeters) for the RSS based method.

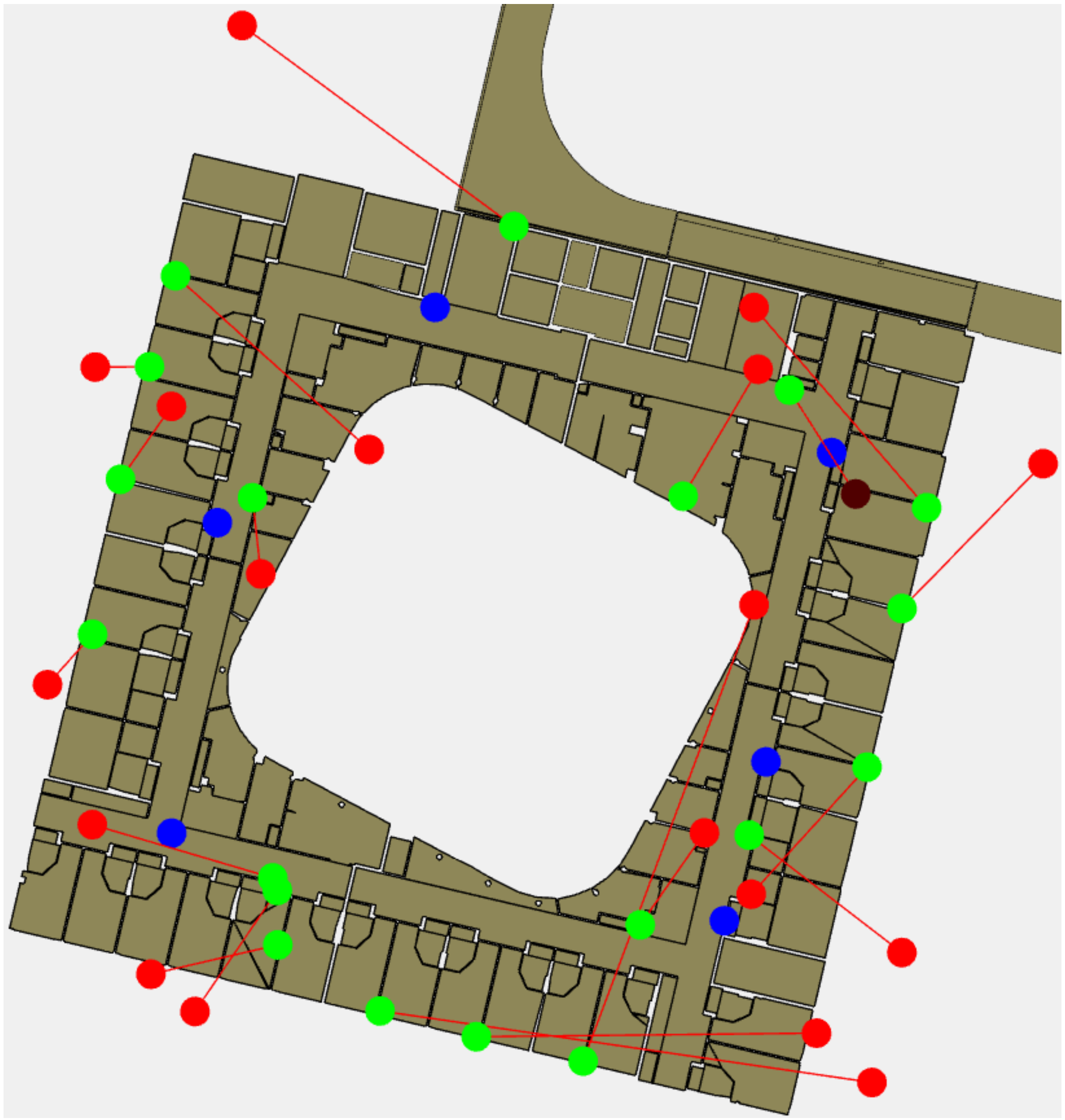


Figure 10: Visualization of positioning estimates using the RSS method for the single floor experiment. This experiment uses three dimensions for positioning.The green dots are real positions, the red dots are estimated positions, these have red lines between them. The blue dots are the AP positions.

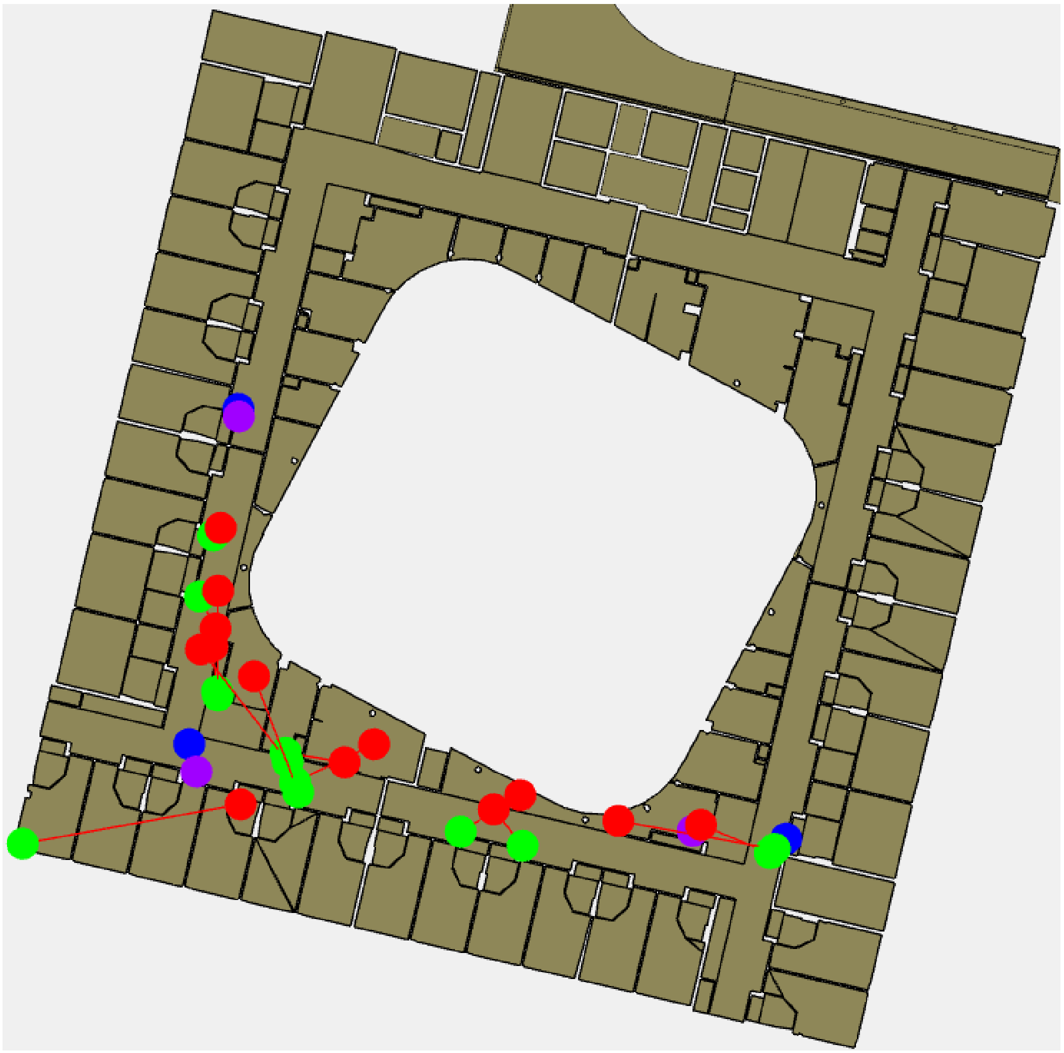


Figure 11: Visualization of positioning estimates using the RSS method for the two floor experiment. This experiment uses three dimensions for positioning. The green dots are real positions, the red dots are estimated positions, these have red lines between them. The blue dots are the AP positions for the lower floor and purple dots are the APs on the upper floor.

5.2 RTT method

5.2.1 Distance estimates

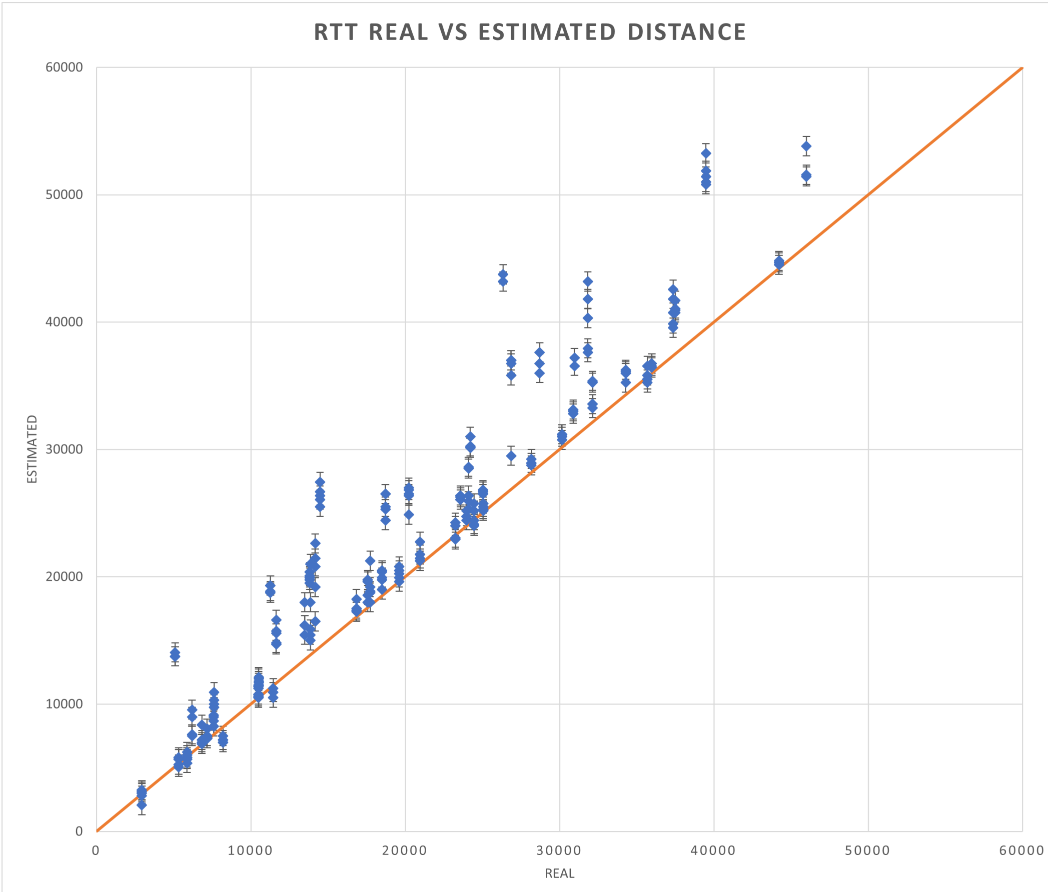


Figure 12: Estimated distance against real distance (in millimeters) using the RTT method for the single floor experiment.

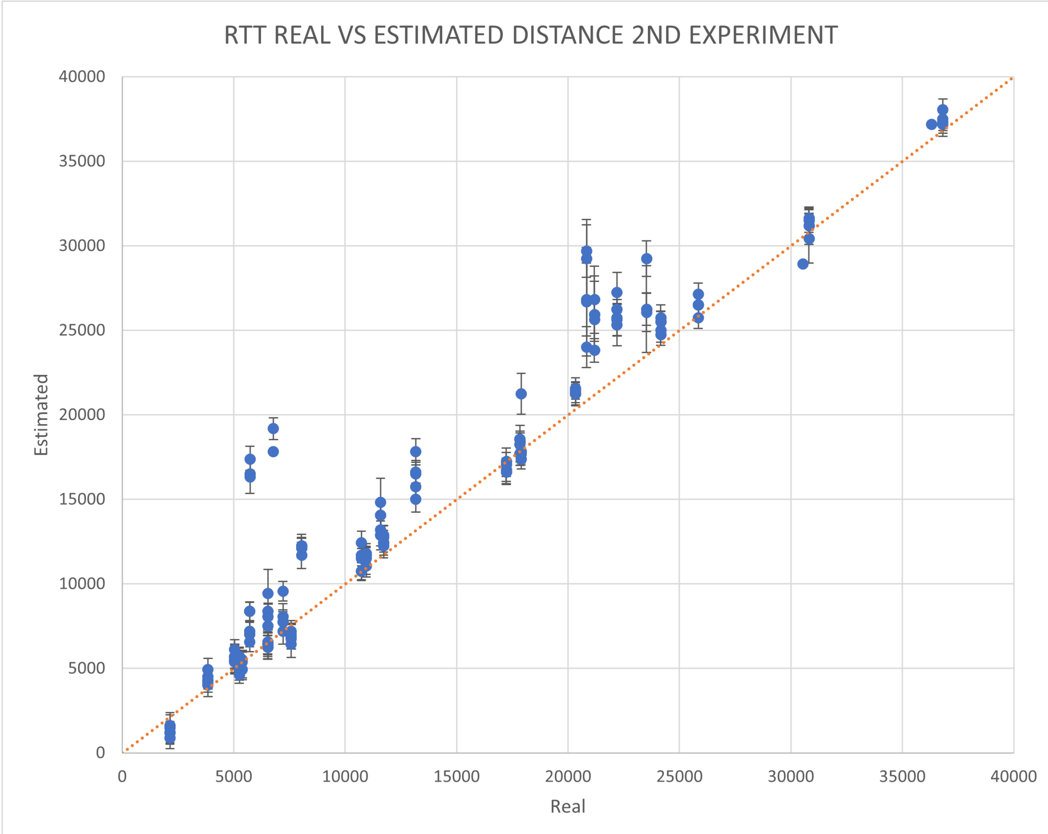


Figure 13: Estimated distance against real distance (in millimeters) using the RTT method for the two floor experiment.

Experiment	Average error	Median error	Best	Worst
Single floor	3364	1838	14	17403
Two floors	2301	1185.5	16	12404

Table 5: Statisitcs for error in the distances measured using FTM. All measurements are in mm.

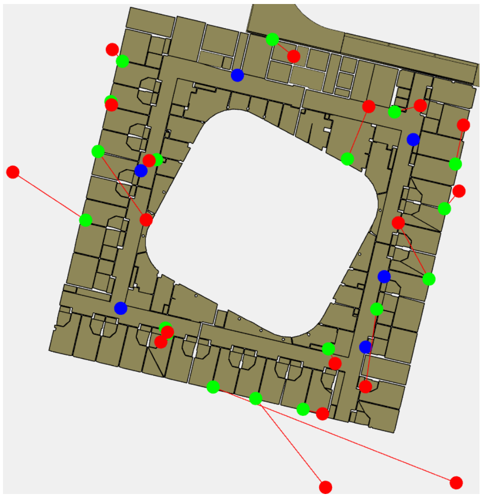
Experiment	Under 1m	Under 2m	Under 3m	Under 5m	Under 10m
Single floor	32.03%	52.81%	63.20%	72.29%	93.51%
Two floors	45.45%	62.73%	72.73%	89.09%	95.45%

Table 6: Percentage of measurements where error is lower than 1m, 2m, 3m, 5m, and 10m using FTM.

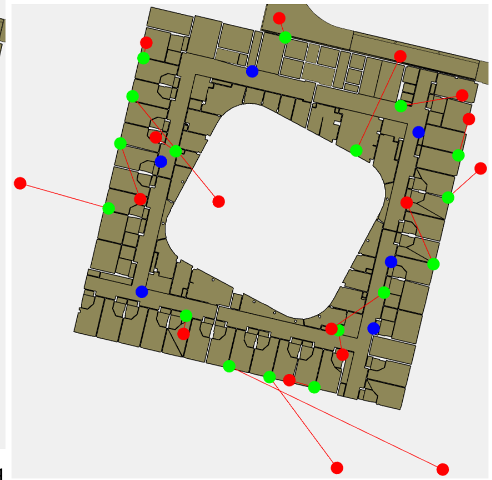
Experiment	Success rate	Max failed RSS	Min success RSS	Min failed distance	Max success distance
Single floor	72.19%	-71db	-90db	13489mm	45999mm
Two floors	62.34%	-78db	-90db	5379mm	36821mm

Table 7: Not all RTT measurements succeeded. M̈ax failed RSSïs the best signal where a measurement failed, while M̈in success RSSïs the worst signal where a measurement succeeded. Note that RSS is negative. M̈in failed distanceïs the closest distance a measurement failed, while M̈ax success distanceïs the furthest distance a measurement succeeded.

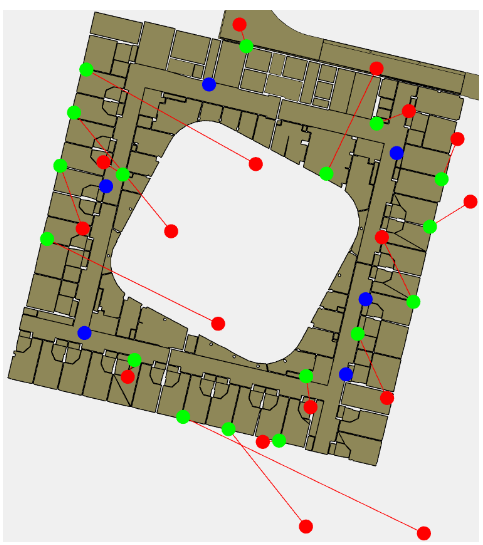
5.2.2 Position estimate errors



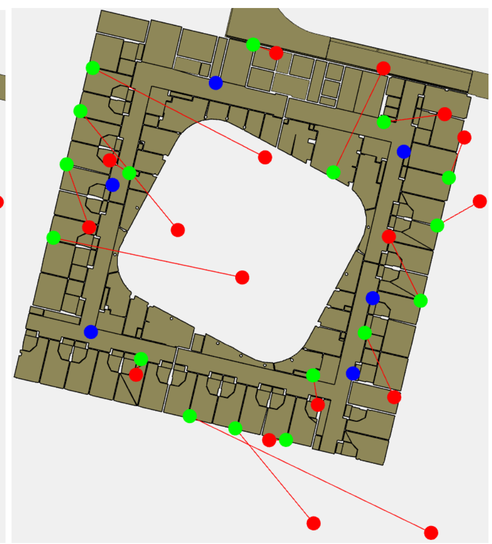
(a) Three dimensions, weights are calculated from distance. These estimates use the best of 5 measurements for each AP.



(b) Two dimensions, weights are calculated from distance.

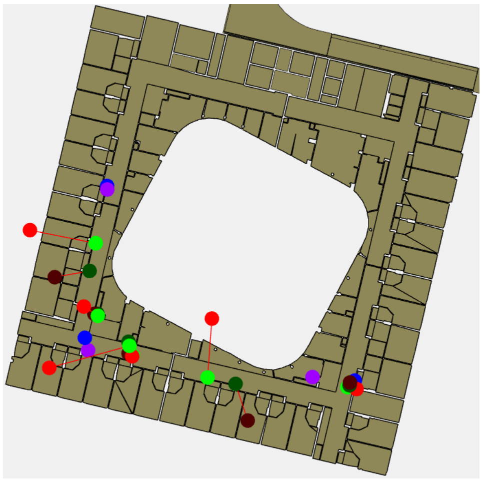


(c) Two dimensions, weights are calculated from reported standard deviation from the RTT API call.



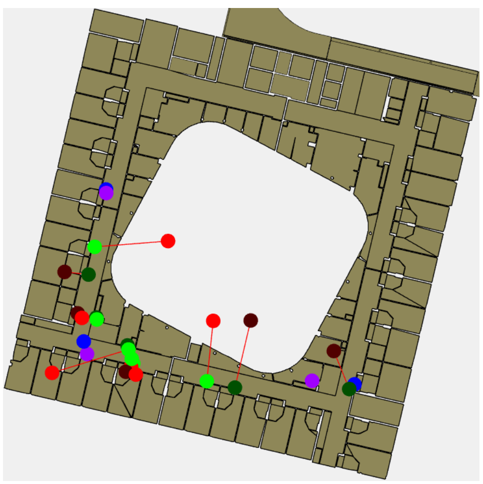
(d) Two dimensions, weights are calculated from based on a combination of the distance and standard deviation.

Figure 14: Real VS estimated positions for the single floor experiments, using different weightings with the RTT method. The green dots are real positions, the red dots are estimated positions, these have red lines between them. The blue dots are the AP positions.

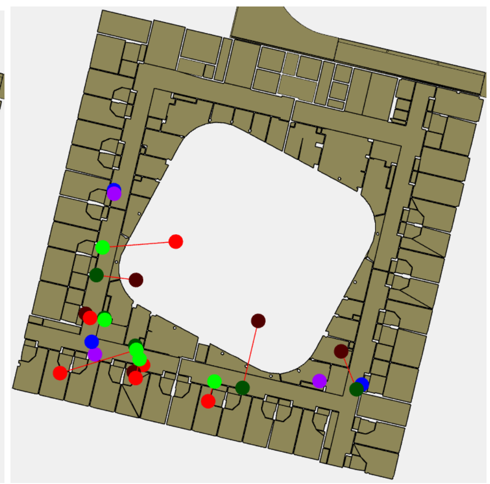


(a) Three dimensions, weights are calculated from distance. These estimates use the best of 5 measurements for each AP.

(b) Two dimensions, weights are calculated from distance.



(c) Two dimensions, weights are calculated from reported standard deviation from the RTT API call.



(d) Two dimensions, weights are calculated from based on a combination of the distance and standard deviation.

Figure 15: Real VS estimated positions for the two floor experiments, using different weightings with the RTT method. The green dots are real positions, the red dots are estimated positions, these have red lines between them. The dark green and red are on the upper floor or higher, while the lighter green and red dots are positions on the lower floor or lower. The blue dots are the AP positions on the lower floor, while the purple dots are APs on the upper floor.

Experiment	Weights	Average	Median	Min	Max
Single floor	Distance	10808	**9489**	2525	**38025**
	Standard deviation	12488	**9489**	2328	**38025**
	Combination	12697	**9489**	2370	**38025**
With 3 dimensions	Distance	**9534**	9684	**763**	39654
Two floors	Distance	6321	**5653**	1842	**10973**
	Standard deviation	6210	6433	1738	**10973**
	Combination	**5928**	**5653**	1665	**10973**
With 3 dimensions	Distance	6065	5795	**834**	11525

Table 8: Statistics for error in positioning (in millimeters) for the RTT based method.

5.3 GPS

Average	Median	Min	Max
1917034	579707	22210	4038612

Table 9: Statistics for error in positioning (in millimeters) for the GPS based method.

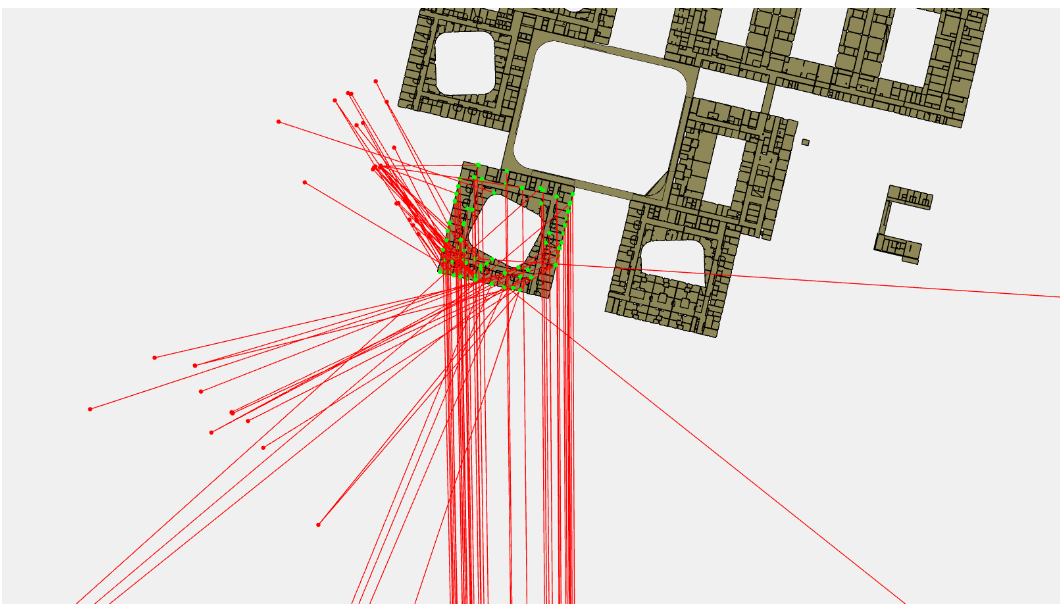


Figure 16: Estimated and real positions for the GPS method. The green dots are real positions, while the red lines point to red dots which are the estimated positions. The image is cropped in order to show more accurately the closer estimates.

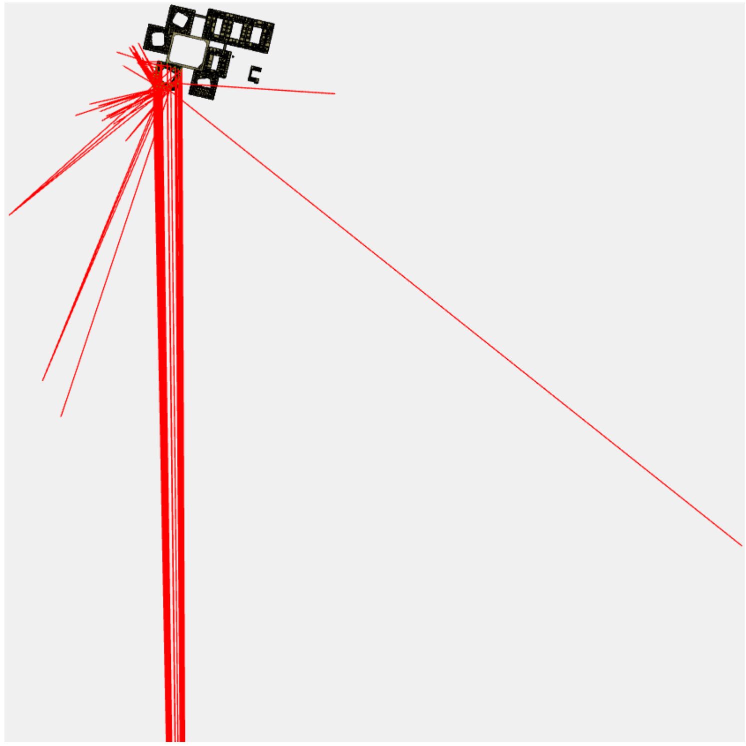


Figure 17: Estimated and real positions for the GPS method. The green dots are real positions, while the red lines point to red dots which are the estimated positions. Some estimates were too far away to be included in the image.

6 Discussion

These experiments were, as stated, performed with an active construction site in mind, and were conducted at such a site. They can however also tell us something about positioning for a project in daily operations. The results of the experiments can tell us about the environment for this location, the accuracy of the ranging techniques, and the precision of the positioning method in total, and this can be used to tell us whether any of these methods are adequate for use during the construction phase, and to what degree. As stated earlier, even determining only the current floor is a major benefit to the clients.

6.1 Findings

6.1.1 Signal propagation and environment

An accurate measurement of distance using the Log-distance path loss model requires an accurate estimate of the path loss exponent. The first experiment in 5.1 shows the estimation of the path loss exponent for all the access points, where the average is later used to estimate the position in other experiments.

Although we see from figure 8 and figure 9 that there is more variation for the path loss exponent estimates when the access points are closer, the average seems to be consistent over distances.

The path loss exponent can be assumed from the type of environment, and [27, page=104] shows that for the indoor of a building we should expect between 1.6 to 1.8 when unobstructed and between 4 and 6 when obstructions are present. The results show more similarity to what [27, page=104] expects from a factory environment. This makes sense in many ways because the location has no furniture and is almost an open space with few walls and some pillars.

6.1.2 Distance measurements

As stated in 2.4.2, Google promises a precision between one and two meters for the FTM protocol in ideal conditions. We already see from 6.1.1 that the environment is not ideal, however, table 5 shows that the average is not very far away from this, while the median error is within this estimate. Table 6 shows that around two-thirds of measurements for FTM will be under 3meters, while around 6% will be over 10meters.

The Log Distance Path Loss model is expected to perform worse than the newer FTM protocol, and we see from 2 that this is indeed the case. Both the average and median are significantly worse, and the variation is much larger, visualized in figures 8 and 9.

Comparing the RSS and the RTT methods, it is clear that the RTT method is significantly better for determining a precise distance. While the median error for RTT is less than two meters, the median for the RSS method is almost 8 for the two-floor experiment, and over 9 for the single-floor experiment. This is made worse by the fact that the outliers for the RSS method are much more pronounced, and even more common. Table 3 shows that only around 50-60% of measurements using LDPL were within 10 meters of the real distance, while table 6 shows that FTM has the same precision over 90% of the time. We can also see from table 2 that the worst estimate had an error of over 130m, while the worst error by the RTT method was 17m, a difference of more than 700%.

However, the downside for RTT when it comes to distance measuring is that it sometimes fails. When there was a signal between the mobile device and an access point, only around two-thirds of the measurements delivered valid results. This was more common when the access point was further away and the signal weaker, but we see from table 7 that even a measurement as close as within 5 meters of the access point failed. The data (included in the github) shows that this was caused by the access point being on another floor than the mobile device, and in fact, this was the case for all measurements that failed with a real distance of less than 10 meters.

6.1.3 Positioning estimates

For both the RSS and the RTT methods, the errors in distance measurements should in theory compound into larger errors in the position estimate. We see from table 8 that this is the case for the RTT method, where the average and median error are around 10 meters for the single-floor experiment and 6 meters for the two-floor experiment. The RSS method however shows a less significant decrease in precision after trilateration on average and is even equally good as the RTT method for the two-floor experiment on average.

The GPS method performs much worse than either of the two other methods. Even the best positioning attempt with GPS is over 20 meters off, shown in table 9, and that is of course ignoring elevation. Figure 17 shows that not even a single of the positioning attempts estimated a position within the building.

From table 5 and from figures 14 and 15 we can see that the three weights have no clear winner. Using the 3D positioning where all inputs to trilateration were selected from the best of five measurements seems to provide more precision in some cases, however, it also produced the worst estimate for both the single-floor experiment and the two-floor experiment. Looking at the averages and medians, this method seems to produce the most consistent results however.

6.2 Interpreting the results

6.2.1 User experience

When users, including the author, tested the feature it was clear that the feature can be both useful and a detriment. It becomes a detriment to the overall experience when the position estimate is inside an object or wall, on the wrong floor, or outside the building entirely. An estimate that was on the wrong side of the outer walls, even if it missed by only a meter, was worse than an estimate that missed the mark by 10 meters, simply because of how disorienting it is when the app shows a camera position outside the building with no reference points to use for correction.

6.2.2 GPS

Not only does the GPS method perform much worse than the other two, it does not approximate the position well enough to determine reliably which section of the building the mobile device is in. This is in addition to not being usable for determining elevation. It is well known that GPS is not accurate inside concrete buildings, and this study shows that it does not help with determining any more than which building the device is in. This does meet the first goal, of determining which project to open when using the BIMViewer app, but fails to meet the more advanced goals.

6.2.3 RTT

Although the distance measurements are very good when using FTM, the compounded error when trilaterating means the position is still not very accurate most of the time. We see some estimates that are within a meter of the real position, which would meet all the goals of this study, however this is not the case for most of the estimates. We can see from figure 14b and figure 15b that most of the position estimates are within the building, and for the two-floor experiment the position estimates selected the correct floor. Although there are some outliers, and the average error is close to 10 meters for the single-floor experiment, this is still good enough to be usable for clients, however some improvements may be desired.

6.2.4 RSS

From a preliminary look at 10 and comparing to 14b, the RSS method has fewer estimates that provide a good user experience. Many of the estimated positions are outside the building, and even when that is not the case, they are more likely to be in the wrong room or wrong hallway. This method performed well for the two-floor experiment, and almost all of the estimates were on the correct floor, while the distance between the estimated and the real positions is also within acceptable levels. One reason the RSS method might do well compared to the RTT method is that it has more measurements to use for trilateration, as some of the FTM measurements fail while it is still possible to use LDPL.

6.2.5 Amount of access points

There are only used 6 access points in the experiments done for this study. A typical configuration for this building would have either 3 or 4 access points, which would most likely reduce the precision and reliability of both the RSS and RTT methods for positioning. Specifically RTT would be heavily affected by this since it requires a stronger signal for successful measurements than the RSS method. For a completed building like this, we can assume there to be many more access points, but also more walls. The walls are a larger hindrance for the RSS method than the RTT method, which would reduce the precision of the RSS method.

6.2.6 Compared to other methods

Compared to some of the methods shown in [21], we see that neither the RSS method nor the RTT method are close to the accuracy of some of the other options on the market. Some of the low-cost solutions in that study report an accuracy of within a meter. This is not achievable for any of the approaches tested in this study, without major improvements. It seems to be generally better to use a fingerprinting technique or other technologies than Wi-Fi if the purpose is to get the most accurate position estimates.

6.2.7 Goals

The goals for this feature are first to position the mobile device in the BIMViewer application, and if this is not achievable to determine at least the correct building and floor. The GPS method only manages to determine the correct BIM project, and even that is only if there are no other projects close by. NyeSUS is one large project consisting of multiple buildings that are connected, and if the different buildings were in separate projects, the

GPS method would not alone be able to reliably determine which building the mobile device is in. The RSS method is sufficient to figure out the general area of the mobile device, specifically, it is able to reliably tell which floor the device is on, and it can to some degree determine the actual position of the device. The RTT method works approximately as well as the RSS method, however it is slightly more reliable when there are enough measurements, and may therefore require more access points.

6.3 Limitations

There are many flaws with this study and in this section, we acknowledge some of them, as well as discuss the possible effects these flaws may have on the conclusions.

6.3.1 Inaccurate measurements

All of the measurements are compared to some real position or distance which is entered manually. The access points are also positioned manually, using a laser meter to improve accuracy. This can never be perfectly accurate, and this study assumes the position is within at least 30cm of the real position. These inaccuracies may have an effect on any comparison made between estimated distance or position with what the study calls "real" positions and distances.

6.3.2 Sample size

A study like this can never gather enough data to examine every use case, and must therefore consider a narrow set of use cases. This study has enough data to conclude some things about the use of the three methods tested in the environment that was tested, however drawing conclusions about the wider usage of the methods is difficult. Even within this narrow use case, the amount of data collected is not much, and it is all limited to positions that were simple to translate from the real world to the BIMViewer. This may have skewed the results somewhat, however based on the expected usage of the positioning feature these positions should be close to the positions we would expect users of the feature to have when using the feature.

6.3.3 Number of devices

For these experiments, only one mobile device was used for testing. It is known that different mobile devices may report differing signal strength from the same location, which could change the result of measuring with the RSS method. In theory, the RTT method and the GPS method should work as well across different models of devices.

The experiments also use six access points. This means that for the two-floor experiments, only three access points were placed on each floor. This is rather unrealistic for any real use scenario and may have reduced the accuracy of results. Even for the single-floor experiments, six access points may be realistic during construction, but would not be realistic for post-construction operations. In order to fully test the methods, a larger number of access points would be required.

6.3.4 Insufficient experiments

The study consists of multiple experiments, however not enough. An important aspect to test when evaluating the RSS and RTT methods is to run experiments with different configurations of access points. Especially important is to consider how workers would require internet and how they would deploy the temporary network. The experiments were conducted in a location where no work was scheduled, and therefore had no access points deployed, hence the positions of the access points were based only on speculation by the author.

It would also benefit the study to have experiments in other locations, at other times, or using other methods. There was insufficient time and budget to do any of this however. Specifically, testing the Wi-Fi RSS fingerprinting method discussed in 2.4.2 together with some calculated radio maps (requiring little to no manual sampling work) would be very beneficial, as it would be equally viable to the RTT method.

6.3.5 Plans and data

Although Omega 365 has access to the 3D models and much of the general plans regarding the construction of NyeSUS, there are some notable documents absent. Among these are the plans for the deployment of Wi-Fi or network infrastructure. We did not have access to any calculated radio signal map or spectrum analysis maps, which could have made it possible to try Wi-Fi RSS fingerprinting. We also did not have access to the planned positions of Wi-Fi access points, thus we can say little about how the situation will look for both the RTT and the RSS-based methods when the hospital is in operation.

6.3.6 Locations

We did not have access to more than a single building for any of the experiments. This means we did not have the ability to test the solutions in a variety of environments, nor in similar environments during different phases of construction. This is possibly the largest of the limitations because all conclusions will be based on the assumption that this is a representative environment.

6.4 Future research and implementation

It was already well known that GPS would not work well, and this study has proved this assumption true, while both the Wi-Fi methods have shown themselves to be usable to some degree. When implementing this feature in any real project, a mix between the two should probably be used, depending on the access point configuration. Future research on this topic should focus more on how many access points would be needed, and it should probably look at a completed building with more walls and furniture or a building with more open space like for example a hall or stadium. In addition, a study comparing the RTT-based method with more access points and some methods using another technology with comparable price and complexity should be done.

This positioning feature can provide some usefulness to clients, however, a more sophisticated algorithm for avoiding estimated positions inside walls or objects and positions outside the building would be much better. This may be implemented in the web client using the already existing 3D model and coordinate system. It is also possible that a more statistical approach would be beneficial, using either machine learning or giving some values to sections of the building where it is expected that a person might want to use the feature.

6.5 Cost and impact

This study used 6 access points costing a total of 4980 NOK and a mobile phone costing 9390 NOK, however a full-scale implementation of the feature would require many more access points, at least 4 for every floor and for every building of this specific project. For larger projects, it would require even more. This feature also requires all users to have a mobile device running Android OS 9 or newer. For a client, this may not mean much, as they would need every potential user to have a mobile device for other reasons, and would therefore not require additional expenses for mobile devices. Because the feature requires more access points than is strictly necessary for internet access it may require some additional expenses in order to install the necessary access points. Any future research on this topic should have a larger budget and use more access points.

This feature would have a limited impact on the environment, seeing as all the equipment would already be required and used for other reasons. The use of a BIMViewer itself however does require the clients to have mobile devices they would not need if they did not use BIM, which negatively impacts the environment.

7 Conclusion

This study aims to find a method for positioning that is both cheap and reliable for clients using the Omega 365 BIMViewer app inside large buildings. The main focus of this thesis is the construction phase, however, some considerations have been given to post-construction operations. Based on the results of the experiments conducted we can conclude that using either of the Wi-Fi-based methods presented it is possible to position a mobile device with somewhat adequate precision.

The study concludes based on the experimental results that GPS does not meet the goals for the feature, while the method based on IEEE802.11mc FTM measurements, and the method based on the Log Distance Path Loss model with Wi-Fi signal strength can be used to some degree. The RTT method is more accurate given enough successful measurements but suffers from the fact that it requires more access points to function properly. Determining which floor a mobile device is on is already useful, and this is easily achievable for a building with thick concrete floors. Full 3D positioning is possible but may in some cases provide a poor user experience, and a better algorithm for estimating the position than what was shown in this thesis should be implemented.

Lastly, this study can not conclude how precise the position estimates need to be for the feature to be useful for clients, and neither can it predict how much different configurations of access points and different environments affect the positioning. This will be left to future studies.

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Appendices

A Poster

The poster was created before major bugs were found, so most of the data shown is invalid.

Indoor positioning in BIM

By Tor Haakon Andersen

Problem

Omega 365 wishes to have a positioning system for their BIMViewer tool, a visualization tool for 3D models of building and road construction. A standard for measuring distance between a mobile device and a WiFi access point, IEEE 802.11mc, has been considered for this purpose. Omega 365 wishes to implement this, test it, and compare it to other possible technologies, both in terms of usability, but also cost of implementation. Most conventional positioning techniques may not be viable for an active construction site.

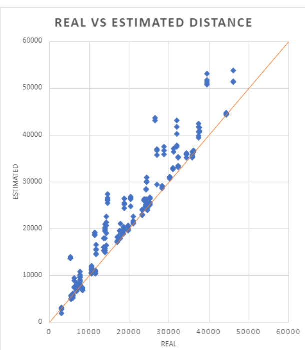
Methods

The most widely used positioning technique is GPS, however GPS is well known to be unreliable for indoors positioning. We would usually use either tags and beacons, with NFC or bluetooth technologies, or WiFi-RSS(Received Signal Strength) fingerprinting for indoors positioning. Both of these are unsuited for a construction site, the first one due to needing many beacons that would get in the way of construction and need to be moved often and the second one because the environment changes often and the fingerprinting would need to be repeated often.

Even though the workplace may be lacking in furniture, the construction sites often need to have internet access, and therefore will ensure there are at least a few access points around. There will rarely be as many access points as the finished construction, however it may still be enough to be used for positioning with WiFi. This can be done by finding the distance between the mobile device and some number of access points, then using trilateration to determine the coordinates.

For the experiments, 3 methods were compared. The first method is GPS, which was used to prove that it is insufficient. The second method is an RSS based ranging technique that uses Log Distance Path Loss model to estimate the distance between the mobile device and access points. The last method is a newer protocol in WiFi supported only by some access points called Fine Time Measurement or Round Trip Time, which promises much more accurate estimation of distance than the RSS method.

All the methods were tested at NyeSUS, the new hospital in Stavanger, which is currently under construction, since this project is currently using Omega 365 software and is a prime target for the positioning feature.

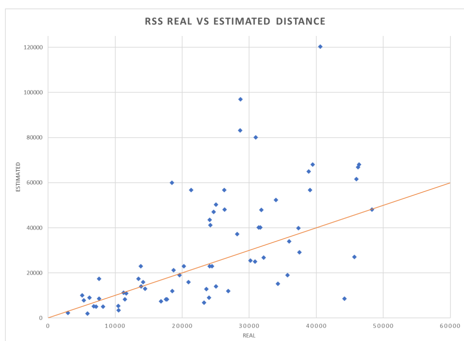


Distances estimated by WiFi-RTT (in millimeters). The protocol clearly overestimates the distance most of the time.

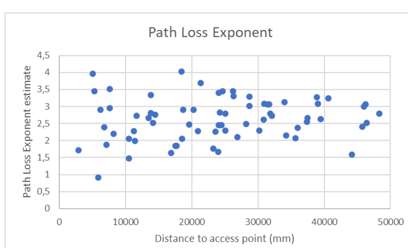
It is worth mentioning that measuring with RTT can sometimes fail to give any measurement, even when there is signal between the access point and mobile device.

$$d = 10^{\frac{A-RSSI}{10n}}$$

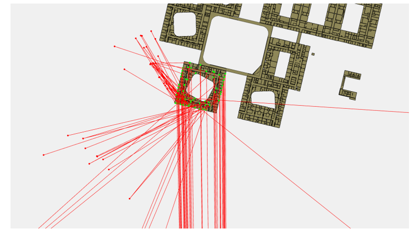
The Log Distance Path Loss model uses the above formula to calculate the distance d. A is the RSSI at 1 meter distance while n is the path loss exponent, which can be estimated based on many measurements done manually. Samples of estimates for the path loss exponent can be seen on the graph to the right.



Distances estimated by RSS and the Log Distance Path Loss method (in millimeters). This method varies a lot more than the WiFi-RTT method. The largest error is almost 80 meters.



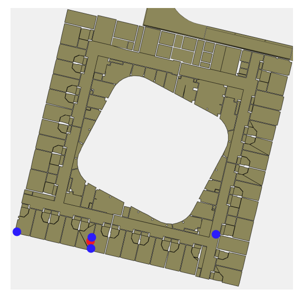
The green dots are the actual position of the device, while the red lines and dots show the app estimated position.



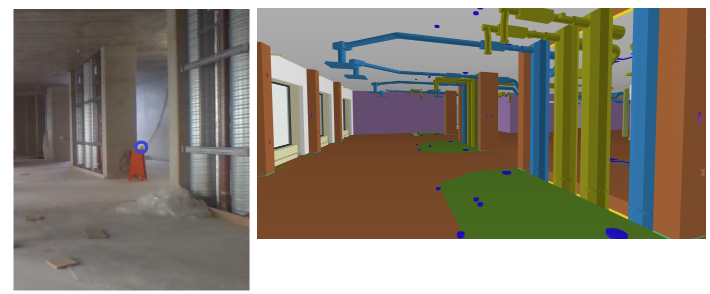
Above is an attempt at using GPS for positioning. It is hard to see the green dots, and some of the estimates are off by kilometers.

Left shows the positions of the access points during the experiments. The blue ones are used only for experiments contained in a single floor, the red ones are only on the upper floor, while the purple ones are on the lower floor and used for all experiments. The placement of the access points was severely limited by the placement of power outlets on site.

From the left, the first figure shows positioning using RTT where all access points are on the lower floor and all samples are collected from the same floor. The second image shows the same experiment but using the RSS measurements. The third figure shows an experiment where half of the access points are on the lower floor and half are on the upper, and the same is true for the measurements themselves, half are from the upper floor and half from the lower floor, and this experiment also uses RTT based measurements.



Some of the measurements failed, but only a few positioning attempts had too few measurements to trilaterate. The blue dots in the figure shows where RTT failed but the RSS method succeeded, while the red dot is an attempt where both failed to get enough measurements.



A side by side comparison of the same location between a photo taken on site and a render from the Omega365 BIMViewer. The building has almost no internal walls and is lacking all furnishing. The photo has a blue circle showing where one of the access points were placed.

Conclusion

None of the methods that were implemented show precision enough to be used as is, however RTT does show some promise compared to the RSS and Log Distance Path Loss model based measuring. GPS is as expected, not useful for this purpose, as not even a single measurement estimated the position inside the building at all.

Both the RSS method and the RTT method work for determining the correct floor, and correct section of the building. This is already a large improvement.

RTT does not work with very long ranges or with many obstacles, even when there is a signal.

B Code and experimental results

All code except for Omega 365 proprietary code can be found at https://github.com/torhaakon/indoor-positioning-for-bim. Here you can also find experimental results, including raw data collected during the experiments.