Investigation and Testing of Location Systems Using WiFi in Indoor Environments

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Abstract

Many applications in the area of location-based services and personal navigation require nowadays the location determination of a user not only in outdoor environment but also indoor. To locate a person or object in a building, systems that use either infrared, ultrasonic or radio signals, and visible light for optical tracking have been developed. The use of WiFi for location determination has the advantage that no transmitters or receivers have to be installed in the building like in the case of infrared and ultrasonic based location systems. WiFi positioning technology adopts IEEE802.11x standard, by observing the radio signals from access points installed inside a building. These access points can be found nowadays in our daily environment, e.g. in many office buildings, public spaces and in urban areas. The principle of operation of location determination using WiFi signals is based on the measurement of the signal strengths to the surrounding available access points at a mobile terminal (e.g. PDA, notebook PC). An estimate of the location of the terminal is then obtained on the basis of these measurements and a signal propagation model inside the building. The signal propagation model can be obtained using simulations or with prior calibration measurements at known locations in an offline phase. The most common location determination approach is based on signal propagation patterns, namely WiFi fingerprinting. In this paper the underlying technology is briefly reviewed followed by an investigation of two WiFi positioning systems. Testing of the system is performed in two localization test beds, one at the Vienna University of Technology and the second at the Hong Kong Polytechnic University. First test showed that the trajectory of a moving user could be obtained with a standard deviation of about ± 3 m.

Keywords: Location determination of persons and objects, Indoor positioning, WiFi positioning, Signal strength observation, Location based services.

1. Introduction

The WiFi technology has won growing interest in recent years. In particular the comfortable and mobile access to the internet were here the driving factors. Access points can nowadays be found in our daily environment, e.g. in many office buildings, public spaces and in urban areas. Parallel to this development there is meanwhile substantial interest in offering the user information which refers to the current location of the user (so-called Location Based Services LBS). Such Location Based Services, however, will be accepted by the user only if the cost performance ratio is satisfactory. If existing infrastructure such as WiFi without additional hardware installation can be used for location determination, then the realization costs are small and the service can be offered under attractive conditions. Several systems are nowadays avaiable for location determination using WiFi signals. Their major application is the location determination of persons and objects inside buildings.

2. Principle of WiFi Positioning

A common approach for the localization of a handheld terminal or mobile device by means of WiFi is based on measurements of received signal strengths of the WiFi signals from the surrounding access points at the terminal. This information is available due to the beacon broadcast multiple times a second by every access points. An estimate of the location of the terminal is then obtained on the basis of these measurements and a signal propagation model inside the building. The propagation model can be obtained using simulations or with prior calibration measurements at certain locations. In the second case, the measured signal strengths values at a certain location in the building are compared with the signal strengths values of calibrated points stored in a database.

The calculation of the location of a user takes place in two phases: an offline and an online phase. During the offline phase, which has to be executed only once for each building, a so-called *radiomap* will be composed. This radiomap can be considered to be a collection of calibration points at different locations in the building, each with a list of radio signal strength indicator (RSSI) values for visible access points at that particular location. This process is also known as *fingerprinting*. During the online phase, the calibration points are being used to calculate the most probable location of the user, whose actual location is unknown.

2.1 Offline Phase

As mentioned before, the offline phase can be seen as a calibration. A certain amount of locations will be chosen, depending on the size and layout of the building. At each of these locations, a number of calibration measurements will be performed. This is due to the fact that the orientation of the user affects the RSSI value measured by the WiFi device. For example, if the user's physical location is between the access point and the mobile device, the measured signal strength will probably be smaller compared to the situation where the user positions itself on the opposite side of the device. This is due to the fact that the signal is attenuated by the human body. The difference between two orientations has been reported to be as much as 5 dB (Bahl and Padmanabhan, 2000; Ladd et al, 2002). Therefore four different orientations are usually performed on each calibrated point (see Retscher et al., 2006).

The goal of a single measurement is to determine the received signal strength of every visible access point at this location with this orientation. Due to the fact that the received signal strength is being influenced by many factors, a number of sequential measurements will be taken in order to collect statistically more reliable information on what average signal strength can be expected. Every measurement consists of a list of visible access points. For each access point, the received signal strength is measured. Once the measurements have been performed, a histogram is made with the measured data (see Figure 1). Each access point yields a separate histogram. These histograms are stored in the system database.

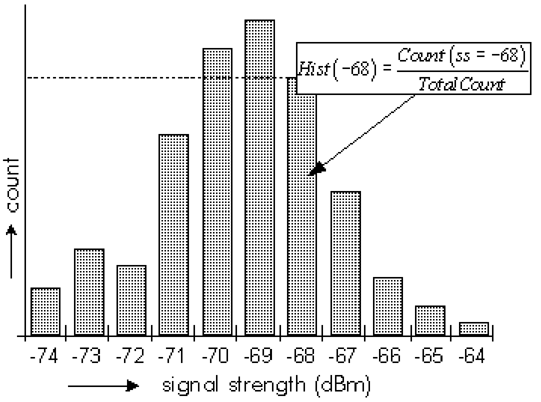

Figure 1. Histogram of the measured signal strength values for one acess point (where ss is the signal strength and Count is the number of the measured signal strength values)

2.2 Online Phase

The online phase is the phase where the calculation software periodically receives measurements from one or more mobile devices of different users. This information is compared against the values obtained from the offline phase, which yields a calculated position for each device. Once the received measurement has been parsed and found to be correct, it will be used as input for the calculation algorithm.

3. Performance of WiFi Positioning Systems

For the achievable positioning accuracy of WiFi location systems usually a value of 3 to 5 m for indoor positioning using signals from several visible access points is claimed by some system manufacturers. The positioning accuracy, however, depends very much on the surrounding environment. Radio signal propagation errors caused by multipath and other error sources and signal interference can degradiate the achievable positioning accuracies significantly. Therefore no general valid numbers for the achievable positioning accuracies can be given. In the following two different WiFi positioning systems are tested in different environments. One test bed was chosen in the Hong Kong Polytechnic University and the second in the Vienna University of Technolgy. Furthermore an approach for the conversion of the measured signal strength to the corresponding distance between the user's current location and the access point is presented.

3.1 Tests of the Ekahau Positioning Engine at the Hong Kong Polytechnic University

At the Hong Kong Polytechnic University the Ekahau WiFi Positioning Engine was tested in two projects at the campus in indoor as well as outdoor areas (see Chan, 2006; Yiu et al., 2006). The WiFi positioning system was developed by the Finish based company Ekahau for the location determination of persons and objects mainly in indoor arreas where WiFi access points are present. In the following selected test results for the location determination of a user are presented.

Before a user can be located, calbration measurements have to be performed in the area where the user has to be located. For that purpose a floor plan is loaded into the Ekahau positioning software and tracking rails must be drawn and placed on the map (see Figure 2). The objective of this is to indicate the possible travel paths of the user. Since the estimated locations determined by the software depend on the rails placed on the map, the rails drawn must be correct and accessible. After the tracking rails were drawn, an empty positioning model has to be created with no signal data. To combine different maps (floor plans) together for a multi-floor investigation, two adjacent maps must be connected by setting up common points which are points with the same horizontal position but with different levels or floors. For example, positions in front of the elevator or around the staircase are suitable for connecting the maps together.

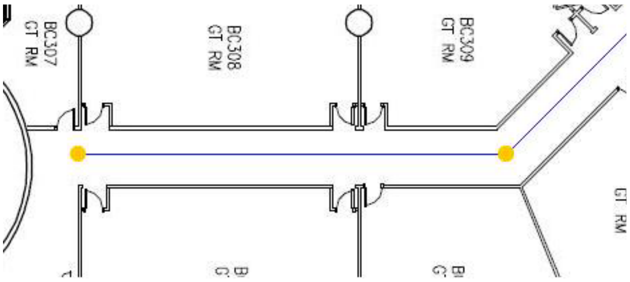

Figure 2. Definition of tracking rails for identification of the possible user's paths in the Ekahau software

After drawing the tracking rails, the calibration procedure can be started. In the presented tests calibrations were made only along the rails which were already drawn. In the calibration procedure any location on the rails in a distance of 3 to 5 metres may be chosen. On this point signal strength observations are performed while the notebook computer is rotated around 360°. This observations are then stored in the Ekahau database. After finishing the calibration a user can be located in the calibrated area.

Figure 3 shows performance tests of the system on the 3rd floor of core BC of the Hong Kong Polytechnic University. As can be seen from Figure 3 the achievable positioning accuracies vary quite significantly and range from ± 1.3 to 6.3 m with a few outlieres with even larger positioning errors. The best performance was achieved in the general teaching rooms which are equipped with an access point each. Table 1 summarizes the positioning accuracies in the teaching rooms. In the tests an average value for the positioning accuracy of ± 2.3 m could be achieved. For the points located on the corridor, however, the positioning accuracy was lower. A main reason for that could be that the average signal strength values were higher for the points located inside the teaching rooms than for those located on the corridor. The difference in the signal strength was in the range of 10 to 20 dB for at least three access points with the strongest signal.

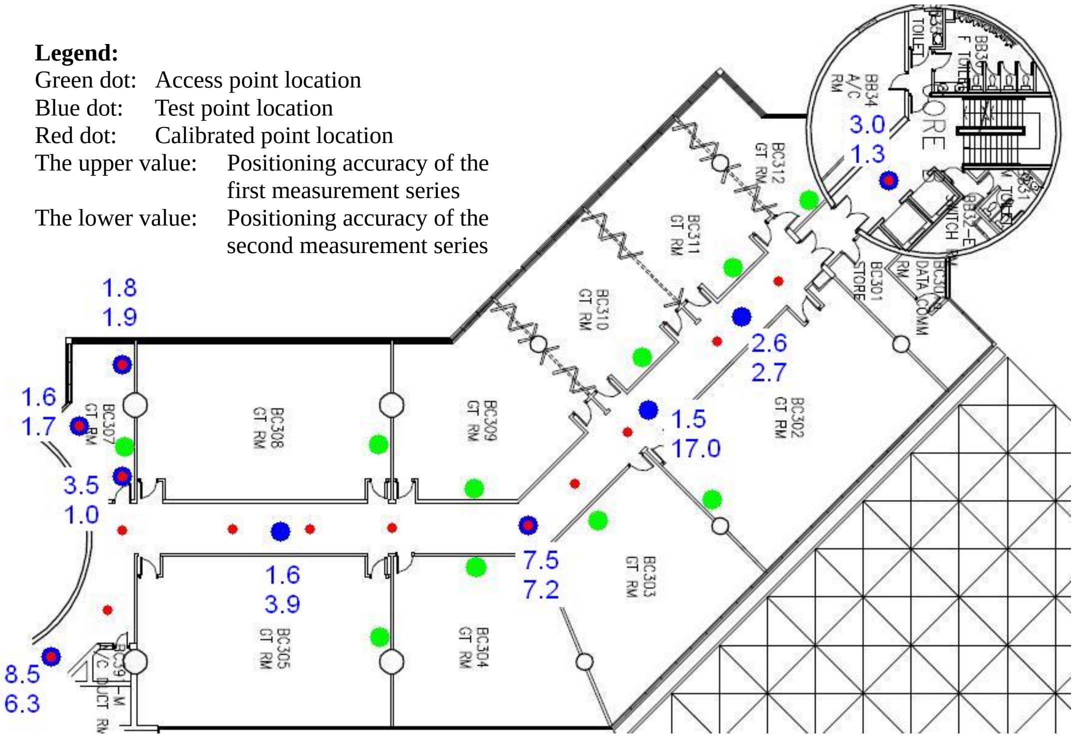

Figure 3. Performance tests on the 3rd floor of core BC of the Hong Kong Polytechnic University

Table 1. Acchievable positioning accuracies in the general teching rooms of core BC of the Hong Kong Polytechnic University

Floor of Core BC	Accuracy	
	1st	2nd
3/F	3.5	1.0
	1.6	1.7
	1.8	1.9
4/F	3.1	-
5/F	1.6	-
	2.2	-
	3.0	-
	0.6	0.0
	3.0	2.9
	3.8	4.8
6/F	3.0	-
Mean (GT)	2.3	
Mean	3.9	

where Mean (GT) (2.3 m) is the mean accuracy of the tested points in the general teaching rooms and the Mean value (3.9 m) represents the mean accuracy of all tested points in core BC.

A further interesting result was that the positioning accuracy was quite good in the lobby of the staircases (see Figure 4) where no access points are located and the average signal strength values are quite low. Generally, more than 10 access points could be seen and the average signal strength was around -40 to -80 dB along the corridor. However, if the notebook computer was placed at the lobby, then the signal strength dropped quite significantly by more than 20 dB. The achieved positioning accuracy, however, was in the range of ± 1.3 to 3.2 m.

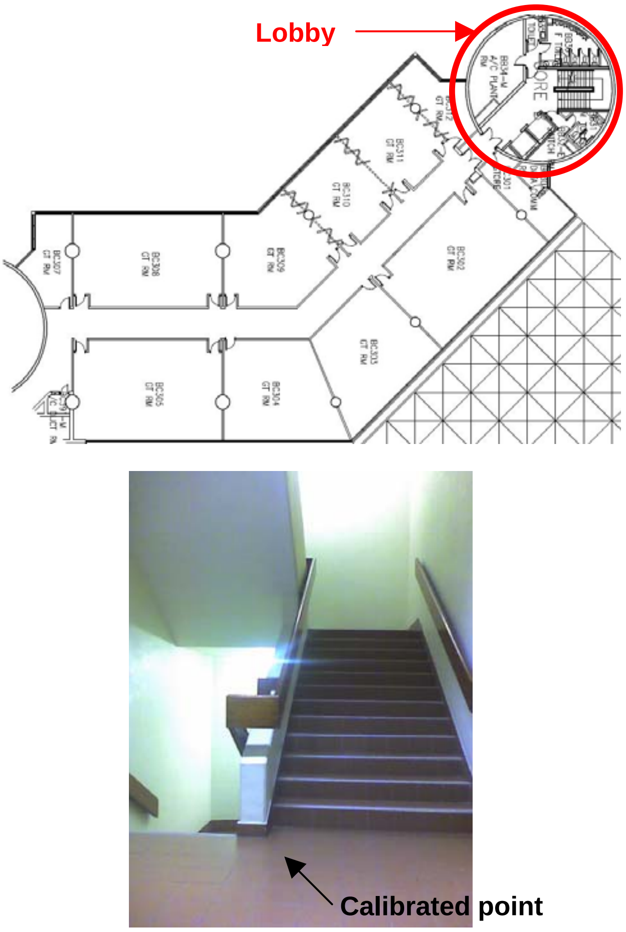

Figure 4. Location of the calibrated points for the performance tests in the staircase lobby of core BC of the Hong Kong Polytechnic University

In conclusion it can be said that an average positioning accuracy of around 3.9 m could be achieved in core BC and about 5.3 m in core PQ in indoor area in the performance tests at the Hong Kong Polytechnic University. Thereby the minimum number of used access points was always 5. Basically the results could confirm the achievable positioning accuracies using the Ekahau system obatined by other tests reported in the literature (see e.g. Teuber and Eisfeller, 2006).

3.2 Tests of the WiFi Positioning System ‘ipos’ at the Vienna University of Technology

The system ‘ipos’ was developed by the German company IMST GmbH. It is a software platform as a basis for the realization of LBS applications. It consists of an efficient, freely parameterizable framework, which is suitable for multiple application architectures. Thereby signal strength measurements are performed on user terminals, while evaluations and visualizations can take place if necessary on user terminals. The developed positioning system “ipos” makes use of a standard WiFi infrastructure and no modification of the hardware is required. In a study the performance and the achievable positioning accuracies of the positioning system “ipos” have been tested. This study was conducted in cooperation between the Vienna University of Technology and IMST GmbH. The tests were performed in a localization test bed in an office building of IMST (see Retscher et al., 2006). With seven access points an area of over 1500 m^2 is covered and the tests have been performed in an area half of the total covered size. It could be seen that it is possible to localize a user in the test bed with an accuracy of around 3 metres.

Further system testing was performed at an office building of the Vienna University of Technology where our institute is located. For this purpose a cooperation with the German company IMST GmbH was established and they provided the indoor location system ‘ipos’. First test results are shown in Figure 5. Figure 5 on the top shows the location of the calibrated points for a first system test on the 3rd floor of our office building and Figure 5 bottom the location test performed by students in our Practical Course on Location-based services moving along the corridor. Due to the small number of calibrated points and the location of the access points the trajectory of the moving user could be obtained with a standard deviation of about ± 3 to 5 m. Using the knowledge of the building model the trajectory can be matched to the corridor in a post processing step.

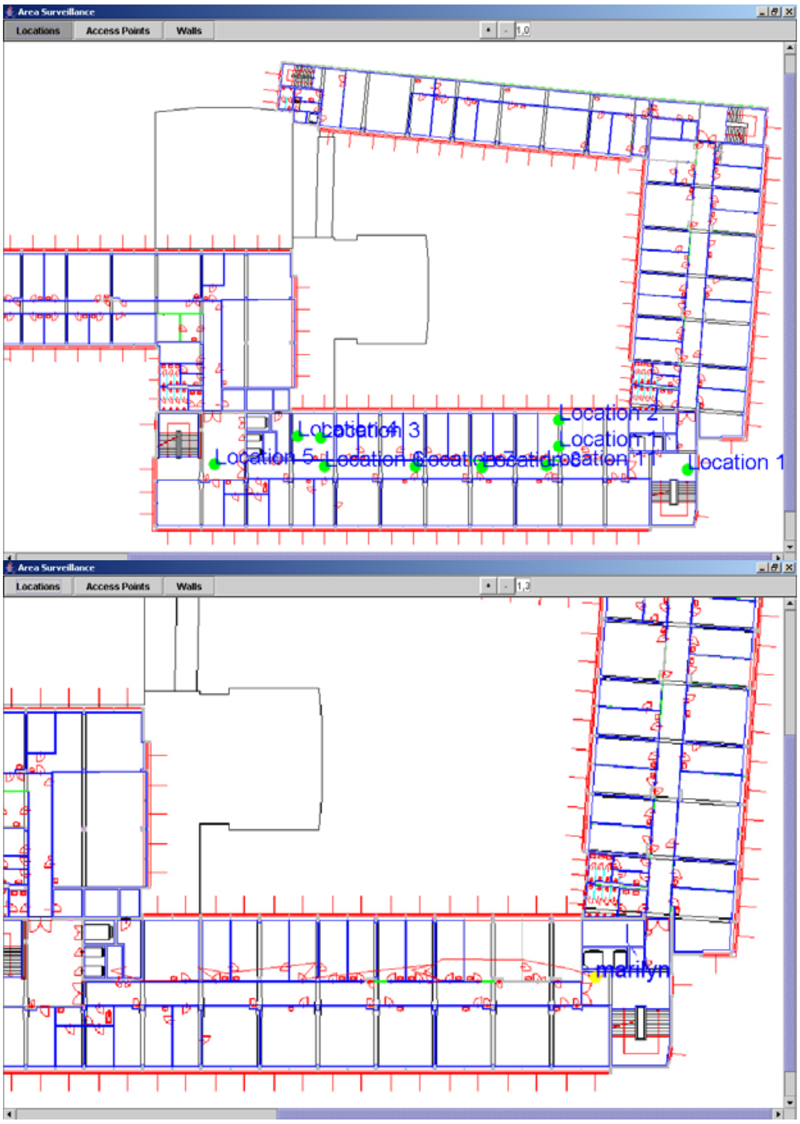

Figure 5. Indoor location determination using WiFi fingerprinting with the system ‘ipos’ on the 3rd floor of our office building (on the top the location of the calibrated points is shown and on the bottom the trajectory of a moving user along the corridor)

As the WiFi positioning systems usually provide only location capability in two dimensions, the augmentation of the indoor location system with a barometric pressure sensor for direct observation of the altitude of the user was also investigated. For that purpose the Vaisala PTB 220 pressure sensor was employed for the direct observation of the altitude of the user. This study was conducted in our research project NAVIO (Pedestrian Navigation for Combined Indoor/outdoor Environments) and the results are presented in Retscher (2005) and Retscher and Thienelt (2006). In the study it could be seen that we are able to determine the correct floor of a user in a multi-storey building. The maximum deviation of the determined height in our office building was less than ± 1 m for over 90 % of the oberservations.

3.3 WiFi Signal Strength to Distance Conversion

In order to integrate WiFi positioning determination with other location techniques it might be interesting to convert the measured signal strength values at one location to a range or distance to an access point. Then it would be possible to perform a trilateration using distances to several access points or radio transmitters. An approach for combined WiFi positioning and GNSS was presented in Mok and Xia (2005) and Mok et al. (2006). In this approach the distances to WiFi access points are combined with pseudorange observations to GPS satellites to determine the curent user's position. In the following the relationship between the measured signal strength and the distance to the corresponding access point is investigated.

Figure 6 shows the test site at the Podium level of the Hong Kong Polytechnic University. At one end of the 100 m long line either a Linksys or 3com access point was positioned. The signal strength was determined at 5 m intervals along the line. The observations were performed twice in both forward and backward direction. Figure 7 shows a graphical representation of the measured signal strength values on the top and the trend on the bottom. As can be seen from the Figure 7, the signal strength degrades with the distance from the access point. However, the ratio of decrease in signal strength is not the same along the whole straight line. In the first 10 metres the signal strength decreases very fast, followed by a slower decrease when the user moves away from the access points.

Figure 6. Test site at the Podium level of the Hong Kong Polytechnic University for the determination of the relationship between the signal strength and the distance

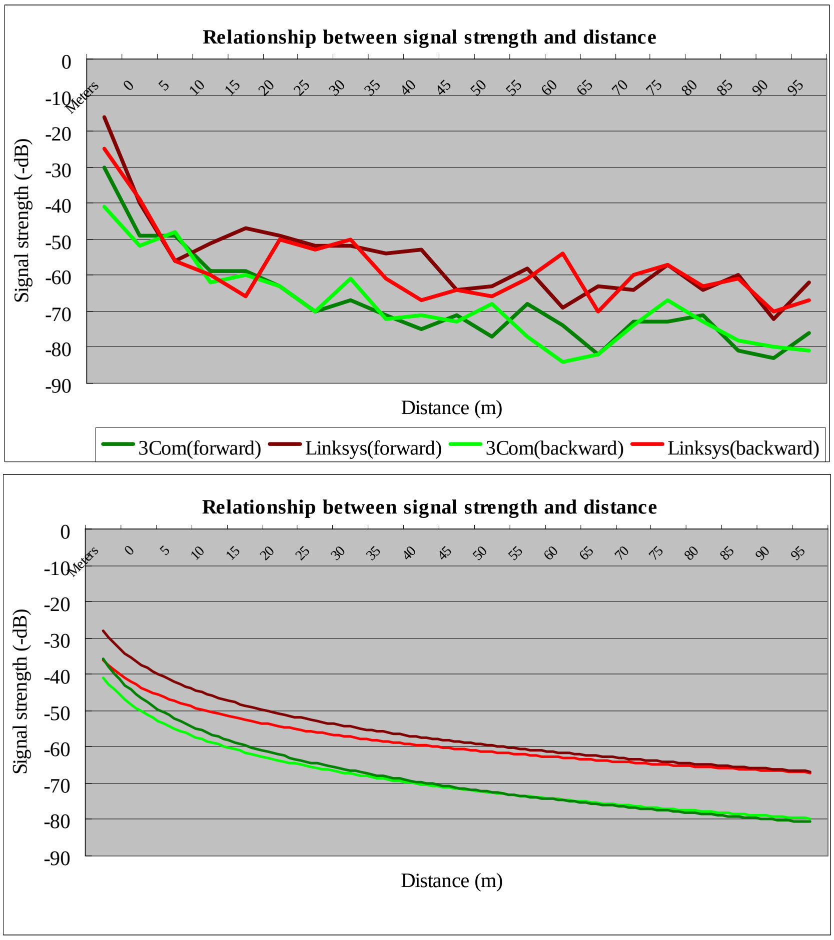

Figure 7. Relationship between signal strength and distance over a 100 m long straight line (measurements in the top, trend function in the bottom Figure)

Results of further tests reported by Mok et al. (2006) have shown that the signal strength can be converted successfully to a distance. The signal strength quality, however, varies significantly under different environmental conditions. Errors are mainly caused by radio interference and multipath effects. For environments with less environmental interference a least squares polynomial fitting may be able to establish a reasonable signal strength to distance conversion relationship. For more affected areas an approach was developed for the conversion of the signal strength to the corresponding distance. This algorithm has been verified in an unfavourable site condition and has proven to be successful with a 90 % success rate in a 20 m radius area around the access point with the accuracy threshold set to 5 m. If only the determined ranges to the access points are used in the location process, it would not be necessary to perform calibration measurements in the beginning as it is the case for the fingerprinting method (see section 2.1). This would be a major advantage of this approach.

4. Conclusions

The performed tests have shown that WiFi positioning systems based on fingerprinting are able to determine the current location of user inside a building with an average standard deviation of ± 3 to 5 m. To achieve this level of positioning accuracy observations of the signal strength values to at least 3 to 5 access points are required. The main disadvantage of the employed fingerprinting method, however, is the required calibration of the system in the beginning which is time consuming and very costly. The system requires the observation of the signal strenght values at known location inside the selected areas where the user has to be located. In this calibration usually signal strength values for at least four directions on each calibrated point are measured and stored in a database.

If the signal strenght is converted to a range or distance to the corresponding access point and the location of the user is determined using trilateration, no calibration of the system would be required. Therefore the relationship between the measured signal strength values and the corresponding distance was investigated and a new approach for conversion of the signal strength to the distance was investigated. In future an integration of different location techniques using radio signals with GNSS will be achieved if the range to the access point or radio transmitter is determined. This would lead to an ubiquitous location method where the signals of different radio transmitters can be used to obtain an optimal location determination of the user.

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