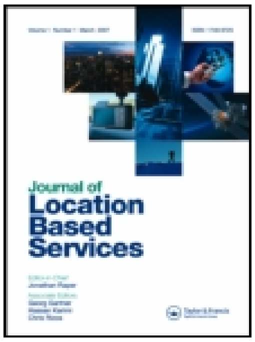

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Location determination using WiFi fingerprinting versus WiFi trilateration

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Many applications in the area of location-based services and personal navigation require nowadays the location determination of a user not only in an outdoor environment but also an indoor. Typical applications of location-based services (LBS) mainly in outdoor environments are fleet management, travel aids, location identification, emergency services and vehicle navigation. LBS applications can be further extended if reliable and reasonably accurate three-dimensional positional information of a mobile device can be determined seamlessly in both indoor and outdoor environments. Current geolocation methods for LBS may be classified as GNSS-based, cellular network-based or their combinations. GNSS-based methods rely very much on the satellite visibility and the receiver-satellite geometry. This can be very problematic in dense high-rise urban environments and when transferring to an indoor environment. Especially, in cities with many high-rise buildings, the urban canyon will greatly affect the reception of the GNSS signals. Moreover, positioning in the indoor/outdoor transition areas would experience signal quality and signal reception problems, if GNSS systems alone are employed. The authors have proposed the integration of GNSS with wireless positioning techniques such as WiFi and UWB. In the case of WiFi positioning, the so-called fingerprinting method based on WiFi signal strength observations is usually employed. In this article, the underlying technology is briefly reviewed, followed by an investigation of two WiFi-positioning systems. Testing of the system is performed in two localisation test beds, one at the Vienna University of Technology and another one at the Hong Kong Polytechnic University. The first test showed that the trajectory of a moving user could be obtained with a standard deviation of about ±3–5 m. The main disadvantage of WiFi fingerprinting, however, is the required time consuming and costly signal strength system calibration in the beginning. Therefore, the authors have investigated if the measured signal strength values can be converted to the corresponding range to the access point. A new approach for this conversion is presented and analysed in typical test scenarios.

Keywords: GNSS; WiFi-positioning; seamless indoor and outdoor positioning; signal strength to distance conversion

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1. Introduction

Current geolocation methods for location-based services (LBS) may be classified in satellite-based (GNSS), wireless network-based (cellular phone networks, WiFi or UWB) or their combinations. LBS provides wireless users with different applications in the field of vehicle navigation and fleet management, location identification and emergency services. These services are widely recognised as a value added service and due to the diversity of user requirements research efforts are needed to improve the location determination capability and its accuracy and reliability. Recently, the mobile device development has mainly concentrated on system integration of GPS, WiFi and cellular wireless networks to cater for different LBS applications. For the integration of all sensor observations, an optimised model is required for optimal estimation of the current user's location (Mok and Xia 2005, Xia *et al*. 2006).

In the area of satellite positioning, a lot of research efforts are put in the development of the new European satellite navigation system Galileo. Having seen the importance of the synergy between navigation services and communication facilities for a wide spectrum of LBS market demand, the navigation and communication integration is in fact one of the architecture requirements in the design of Galileo. Additional data or information from the so-called local elements (LE) can be integrated into the Galileo core system through communication networks to improve service performance. Suggested categories of the LE include cellular network positioning, network assisted navigation (Assisted GNSS) and indoor positioning such as WiFi or UWB. This fusion lays a very sound foundation for future development of a high accuracy and seamless three-dimensional indoor and outdoor positioning system. Research on establishment of an optimised model and method to accommodate location under complex conditions is of practical significance under such a development trend.

For indoor location determination, WiFi positioning techniques based on Wireless Local Area Network (WLAN) or Wireless Personal Area Network (WPAN) is commonly employed nowadays. Recent tests have shown that indoor positioning with WiFi systems can generally achieve 1–4 m indoor and 10–40 m in the outdoor environments (Cheng *et al*. 2005, Retscher *et al*. 2007). Although WiFi positioning can fulfill the general geolocation positioning requirements in the indoor and some outdoor environments, positioning accuracy for different LBS can be further improved with the emerging Ultra Wideband (UWB) technology, to enable more reliable, accurate and efficient emergency decisions. The increasing demand for high-speed wireless transmission of multimedia information and precise geolocation positioning in indoor environments have led to specific interests on UWB; a radio-communication technology originally developed for military applications in 1960 (see, e.g. Barrett 2000). Using UWB, it is claimed by product vendors that a positioning accuracy of 0.3–0.6 m can be achieved for indoor location determination (Alabacak 2002, Eshima *et al*. 2002). It is not difficult to predict that, the fusion of UWB, GNSS and wireless networks will be the trend for providing sub-metre level (or less) ubiquitous 3-D positioning services. To enable successful development of such a system, it requires investigations into an optimised location model for UWB in indoor and outdoor environments, and ground network (like UWB, WiFi) and GNSS integration algorithms. The principle of the integration algorithm for location determination using different data sources was presented in Mok and Xia (2005). As a first stage, WiFi observations can be integrated with GNSS. It should be noted that WiFi observations are received signal strength (SS), which in some studies the signal power in terms of decibel (dB) or decibel-milliwatt (dBm) are presented, while in some other studies, the Signal Strength Indicator (RSSI) is adopted for analysis. To allow SS data integrated into the optimised location model based on derived range data, effective SS-to-distance conversion is to be considered. In the following sections the fundamentals of WiFi positioning, its performance, and studies on SS-to-distance conversion are discussed.

2. Principle and performance of WIFI fingerprinting

A common approach for the localisation of a handheld terminal or mobile device by means of WiFi is based on measurements of SS 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 point. 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 SS values for visible access points at that particular location. This process is also known as *fingerprinting*. During the online phase, the SS values at calibration points are measured for deriving a database of radiomap of SS values to determine the most probable location of the user, which can be expressed mathematically as

$$\mathrm{MIN}(i=1,\ldots,m)\left|\sqrt{\sum_{i=1}^{m}[\mathrm{SS}_{\mathrm{RM}}(i,j)-\mathrm{SS}_{\mathrm{MEAS}}(i)]^2}\right|,\quad j=1 \text{ to } n \tag{1}$$

where $\mathrm{SS}_{\mathrm{RM}}\ (i,j)$ is the SS value of the signal transmitted from access point (i) at radiomap point (j), and $\mathrm{SS}_{\mathrm{MEAS}}\ (i)$ is the measured SS of the signal transmitted from access point (i). The radiomap point (j) having the minimum norm is considered to be the most probable location.

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).

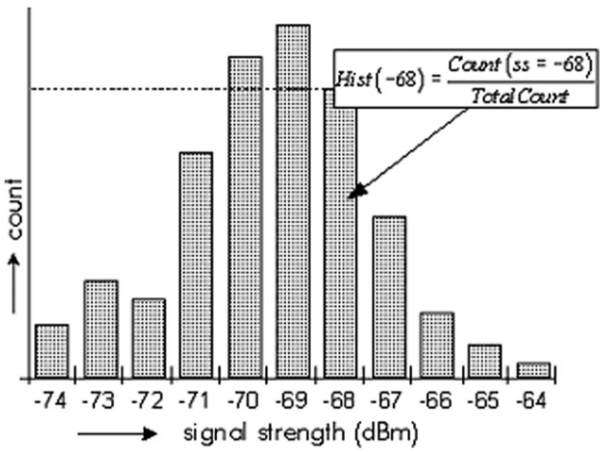

Figure 1. Histogram of the measured signal strength values for one acess point (where SS is the signal strength and count is the number of the measured signal strength values).

Therefore, four different orientations are usually performed on each calibration point (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 statistically collect 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 (Figure 1). Each access point yields a separate histogram. These histograms are stored in the system database.

2.2. *Online phase*

The online phase is the phase where the calculation software periodically receives measurements from one or more mobile devices. 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 (Retscher *et al.* 2007).

2.3. *WiFi fingerprinting positioning performance*

For the achievable positioning accuracy of WiFi location systems usually a value of 1–3 m is claimed by the 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, the performance of two different WiFi positioning systems is tested in different environments. One test bed was chosen in

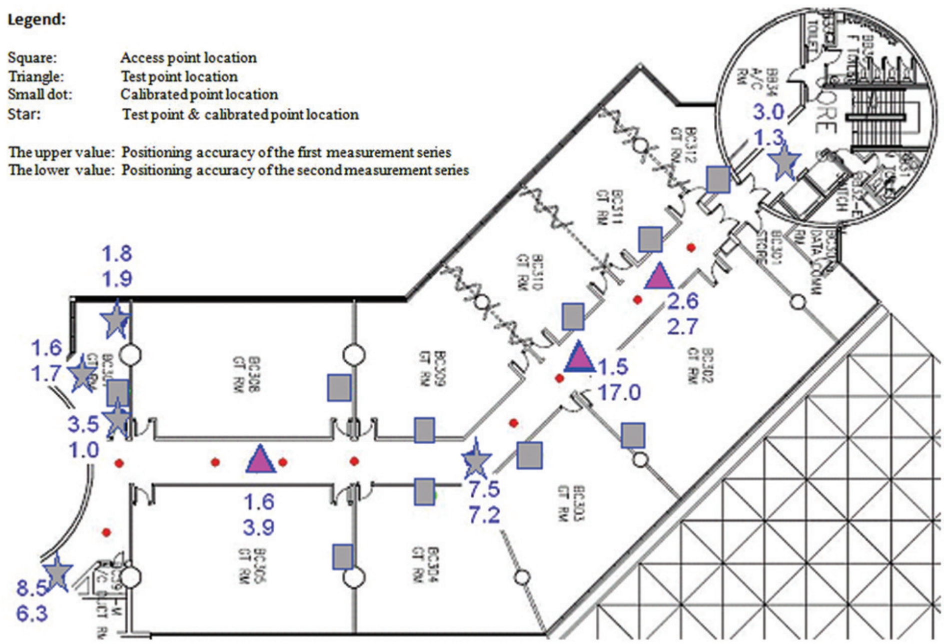

Figure 2. Performance tests of the Ekahau WiFi positioning engine on the 3rd floor of core BC of the HKPolyU.

the Hong Kong Polytechnic University and the second in an office building of IMST GmbH in Germany.

Figure 2 shows performance tests of the 3.1 version of Ekahau WiFi positioning engine on the 3rd floor of core BC of the Hong Kong Polytechnic University (HKPolyU). As can be seen from Figure 2 the achievable positioning accuracies vary quite significantly and range from ± 1.3 to 6.3 m with a few outliers 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 summarises 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 10–20 dB for at least three access points with the strongest signal.

In a further study, the performance and the achievable positioning accuracies of the positioning system 'ipos' of the German company IMST have been tested. This study was conducted in cooperation between the Vienna University of Technology and IMST GmbH. The tests were performed in a localisation test bed in an office building of IMST (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. Figure 3 shows the trajectory of the user from one side of the test area to the other along the corridor and the foyer. The width of the corridor is approximately 1.8 m. In this case a sliding window average of the position fixes taking into account the previous three position fixes

Table 1. Achievable positioning accuracies in the general teaching rooms of core BC of the HKPolyU.

Floor of core BC	Accuracy (m) 1st	Accuracy (m) 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	

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

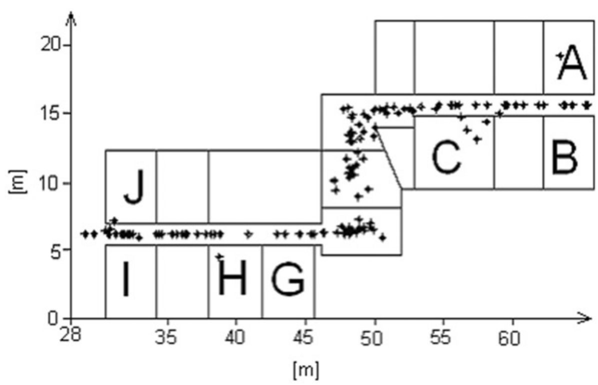

Figure 3. Position fixes of a moving user along the corridor from rooms I and J to A and B using the WiFi positioning system 'ipos' in an office buidling of IMST GmbH in Germany.

has been performed. As can be seen from Figure 3, the system is able to position the user with a high accuracy along the corridor. Using the system we are able to locate a person or object in an office room or the corridor with a standard deviation of around ±3 m.

3. WIFI signal strength to distance conversion

In order to integrate WiFi positioning determination with other location techniques not only on the coordinate level it is necessary to convert the measured signal strength values

Figure 4. Set up of the field test carried out at the HKPolyU.

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 other range data such as pseudorange observations to GPS satellites and range data from an ultra-wide band (UWB) system, to determine the current user's position. This article discusses the investigations undertaken on the relationship between measured signal strength and the distance to the corresponding access point, and their integration with other techniques using trilateration in the range varying between 15 and 35 m, which interval is considered to be possible for successful conversion from the WiFi signal strength.

3.1. *Field test sites for the WiFi signal strength to distance conversion*

The relationship between RSSI and distance may be expressed mathematically as the logarithmic function of distance. However, in real practice, this mathematical relationship may be seriously distorted by radio interference and multipath effects, particularly in indoor environments. In order to integrate signal strength data from WiFi systems with other range data such as from GNSS and UWB, it is important to investigate how well this mathematical relationship can be maintained in the indoor–outdoor transition and outdoor environments; how distances can be best estimated with provision of signal strength data; and the quality of the estimated distances. To answer these questions, field tests were respectively carried out at the Hong Kong Polytechnic University (HKPolyU) and Vienna University of Technology (TU Vienna).

Figure 4 shows the set up of the field test carried out at the HKPolyU, with a 40 m baseline established at the podium of the university campus. A Linksys WiFi access point, supported by a tripod and about 1.5 m in height from the ground was located at the 'zero' mark of the tape. A PC computer installed with an external WiFi PC card was used to collect the signal strength data at 1 m intervals, in 0° and 180° directions.

Further field testing was carried out on the roof of a University building of the TU Vienna, with equipment set up similar to that of the HKPolyU's field test. Signal strength data were collected at 1 m intervals over the 25 m baseline, at directions 0°, 90°, 180° and 270° (refer to Figure 5).

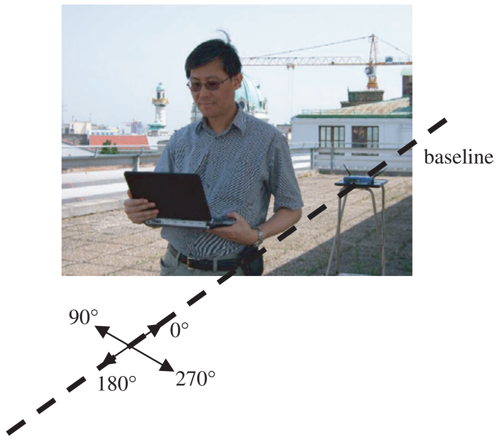

Figure 5. Signal strength observations in four directions referenced to the baseline alignment carried out on the roof of an office building at TU Vienna.

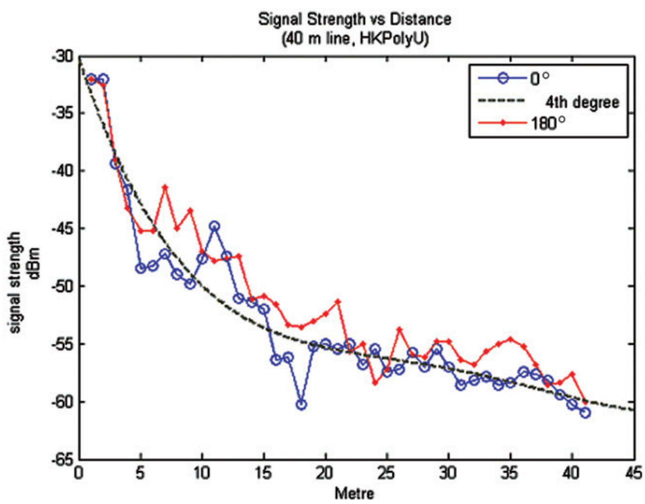

Figure 6. Test result of signal strength versus distance over a 40 m baseline in HKPolyU.

3.2. *Test results in the different localisation test beds*

3.2.1. *HKPolyU test result*

Figure 6 shows the result of the test carried out in the HKPolyU campus. The SS varies between −30 and −60 dBm. Both the 0° and 180° plots are in general very similar, indicating that the signal strength of the area under test has no significant difference in the two directions. However, it is noted that the discrepancy of signal strength between the two directions can be as big as 10 dBm at around 7 and 17 m. Using a 4th degree polynomial curve fitted to the data an obvious change in signal strength from 0 to around 20 metres can be seen; in addition the signal strength fluctuates between −53 and −60 dBm for distances longer than 20 m.

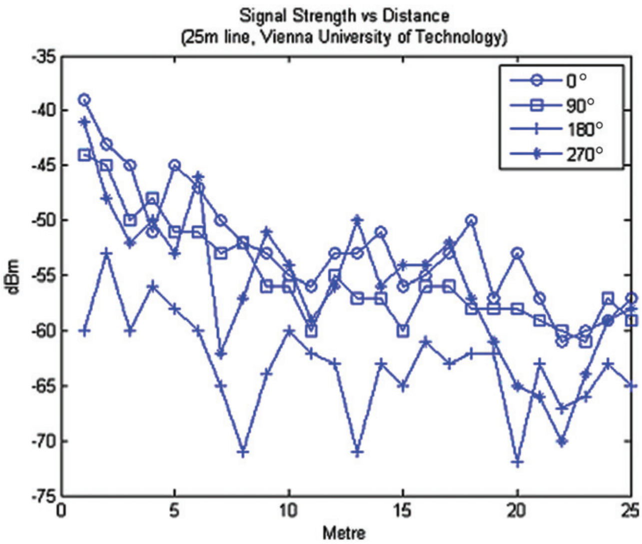

Figure 7. Test result of signal strength versus distance over a 25 m baseline at TU Vienna.

3.2.2. *TU Vienna test result*

Figure 7 shows the result of the test carried out at TU Vienna. The trend is similar to that of the HKPolyU result for the directions 0°, 90° and 270°, with signal strength varying between −38 and −60 dBm; but showing stronger fluctuations. It can be seen that the 270° data set is extremely noisy, although a general downward trend of signal strength to distance relationship can be traced. No obvious trend can be seen in the 180° curve. The significantly higher signal strength over the 25 m distance indicates that the WiFi signal is more susceptible to noise in this test site.

3.3. *Analysis of test results*

The previous results have shown the dramatic change in site conditions in the indoor–outdoor transition, and the outdoor environments which would give rise to very different distance to signal strength relationship at different directions. For areas having less interference to WiFi signals, a least squares polynomial curve fitting may be able to establish a reasonable mathematical relationship between signal strength and distance. However, for areas with WiFi signals susceptible to radio interference and multipath effect, a curve fitting model may filter out the useful signal strength characteristics at particular distances. Purely a substitution of the signal strength values by a polynomial curve model may result in incorrect distance estimation, as can be seen in an example illustrated in Figure 8. A point P about 7 metres from the access point has a signal strength of −60 dBm at direction 270°. According to the calibration data, there is a fluctuation in signal strength in the range of −45 dBm to −65 dBm (A–B–C in Figure 8) between 6 and 8 m. Substituting the −60 dBm into the mathematical model would give an incorrect answer of P′, which results in a distance of around 17.5 m. Furthermore, the WiFi signal reception direction changes

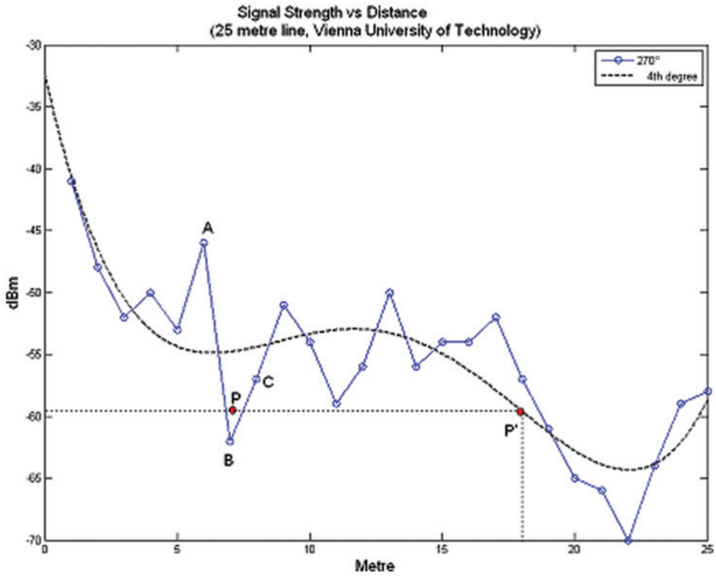

Figure 8. Illustration of incorrect signal strength to distance conversion based on curve fitting.

dynamically with respect to location and orientation between the access point and signal reception antenna. Therefore, in formulating a signal strength to distance conversion algorithm, the signal strength characteristics at different ranges and at different orientations should be considered. A distance conversion algorithm taking into account these two important site condition related factors are proposed in Mok *et al.* (2006). This algorithm was verified using signal strength data collected in an area having high interference of RSSI. Within the effective distance of 25 m from the access point, over 90% of the RSSI-to-distance conversion were successful with RMSE of 3.1 m. For areas with less interference such as the test data shown in Figure 6, better RSSI-to-distance conversion results are expected. This investigation results form a basis for further analysis of the trilateration with RSSI derived distance, which will be discussed in Section 4.

4. WiFi trilateration

Investigations discussed previously have shown that, the effective RSSI-to-distance conversion is about 20 m, with the error ranging from 1 to 3 m subject to site conditions. Therefore, trilateration may be an alternative approach for position determination using WiFi signals. In order to compare the fingerprinting and the trilateration techniques, a WiFi trilateration accuracy analysis was performed. Figure 9 shows the configuration of the Access Points (APs) inside a 20 m times 20 m area, with known coordinates. The height (*Z*-coordinate) of all APs are set at 10 m level. It is assumed that a mobile device (unknown point) is to be positioned inside this area.

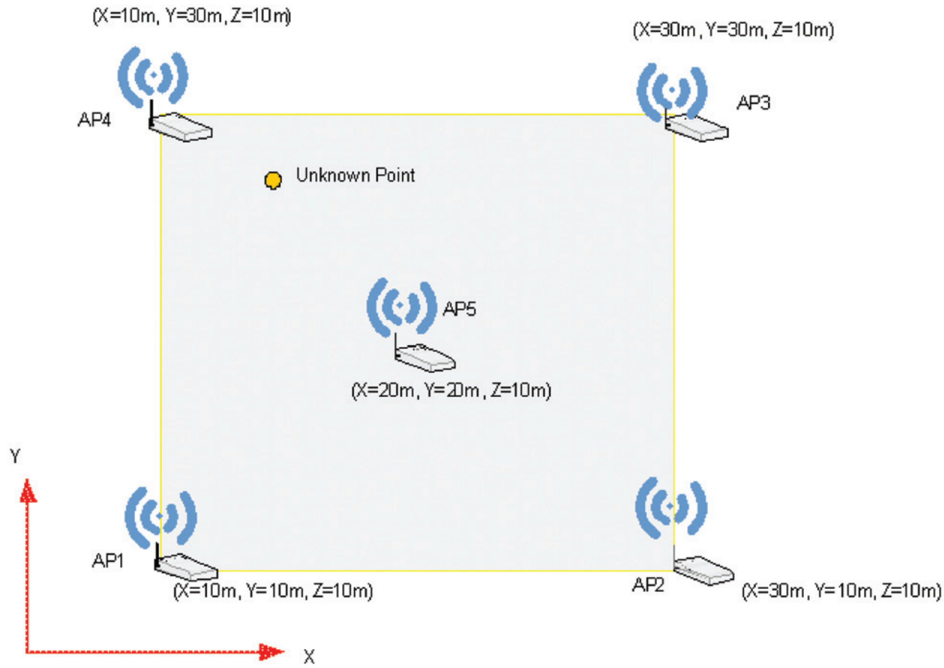

Figure 9. Configuration of APs for WiFi-trilateration analysis.

Accuracy analyses were carried out with the following scenarios of mobile device's positions:

(1) The X and Y coordinates of the following two points fixed, the Z value varies by 1, 3 and 7 m

$$X^0 = 29\,\text{m}, \quad Y^0 = 29\,\text{m}, \quad Z^0 = 1, 3, 5, 7\,\text{m}, \quad \sigma_0 = \pm 3\,\text{m}$$

$$X^0 = 15\,\text{m}, \quad Y^0 = 25\,\text{m}, \quad Z^0 = 1, 3, 5, 7\,\text{m}, \quad \sigma_0 = \pm 3\,\text{m}$$

(2) The X, Y and Z coordinates of the following four points fixed and the measurement error (σ_0) varies between 1 and 3 metres

$$X^0 = 29\,\text{m}, \quad Y^0 = 29\,\text{m}, \quad Z^0 = 7\,\text{m}, \quad \sigma_0 = \pm 1, 2, 3\,\text{m}$$

$$X^0 = 15\,\text{m}, \quad Y^0 = 25\,\text{m}, \quad Z^0 = 7\,\text{m}, \quad \sigma_0 = \pm 1, 2, 3\,\text{m}$$

$$X^0 = 20\,\text{m}, \quad Y^0 = 29\,\text{m}, \quad Z^0 = 7\,\text{m}, \quad \sigma_0 = \pm 1, 2, 3\,\text{m}$$

$$X^0 = 20\,\text{m}, \quad Y^0 = 11\,\text{m}, \quad Z^0 = 7\,\text{m}, \quad \sigma_0 = \pm 1, 2, 3\,\text{m}$$

Because of the mirror effect, the design matrix would be the same for coordinates such as ($X=29$, $Y=29$, $Z=7$) and ($X=11$, $Y=11$, $Z=7$), therefore the above selected scenarios are sufficient to represent different geometrical relationships between the mobile device and the APs.

Let (X^i, Y^i, Z^i), $i = 1, 2, \ldots, N$ be the 3-dimensional coordinates of the i-th access point location and (X^0, Y^0, Z^0) be the approximate position of the point to be determined, then the least squares solution for the unknown position can then be expressed as

$$\begin{aligned} A\hat{X} - L &= 0 \\ Q_{XX} &= (A^T A)^{-1} \\ D_{XX} &= \sigma_0^2 Q_{XX} \end{aligned} \tag{2}$$

with

$$A = \begin{bmatrix} -\left(\frac{X^1 - X^0}{R_{0,1}}\right) & -\left(\frac{Y^1 - Y^0}{R_{0,1}}\right) & -\left(\frac{Z^1 - Z^0}{R_{0,1}}\right) \\ -\left(\frac{X^2 - X^0}{R_{0,2}}\right) & -\left(\frac{Y^2 - Y^0}{R_{0,2}}\right) & -\left(\frac{Y^2 - Y^0}{R_{0,2}}\right) \\ \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet \\ -\left(\frac{X^N - X^0}{R_{0,N}}\right) & -\left(\frac{Y^N - Y^0}{R_{0,N}}\right) & -\left(\frac{Y^N - Y^0}{R_{0,N}}\right) \end{bmatrix} \tag{3}$$

where

- A is the design matrix,
- Q_{XX} is the cofactor matrix of the unknowns,
- D_{XX} is the variance covariance matrix of the unknowns,
- σ_0 is the standard deviation of the unit weight and
- $R_{0,i}$ is the slope distance from access point i to the unknown point.

The positioning accuracy can therefore be estimated by extracting the σ_X, σ_Y and σ_Z from D_{XX}. Tables 2–4 summarise the results of the trilateration accuracy analysis in the different scenarios.

In the following the analysis results are discussed.

It is obvious from the previous analysis that the accuracy of the WiFi trilateration depends on the geometrical strength between the unknown point and the APs' location as well as the standard deviation of the unit weight σ_0. With the σ_0 estimated to be in the range of 1–3 m by adopting the proposed RSSI-to-distance conversion algorithm, the positioning accuracy is estimated to be in the range of 2–6 m at the 95% confidence level.

Table 2. Accuracy estimation of WiFi-trilateration with X- and Y-coordinates of unknown point fixed and the height value Z varies between 1 and 7 m.

	$X = 29$ m, $Y = 29$ m, $\sigma_0 = \pm 3$ m			$X = 15$ m, $Y = 25$ m, $\sigma_0 = \pm 3$ m		
Z (m)	$2\sigma_X$ (m)	$2\sigma_Y$ (m)	$2\sigma_z$ (m)	$2\sigma_X$ (m)	$2\sigma_Y$ (m)	$2\sigma_z$ (m)
1	±5.6	±5.6	±5.4	±5.2	±5.2	±4.8
3	±5.2	±5.2	±5.6	±4.8	±4.8	±5.4
5	±5.0	±5.0	±5.8	±4.4	±4.4	±6.6
7	±4.8	±4.8	±6.2	±4.2	±4.2	±10.0

It should be noted that the 3 m distance error may only occur in adverse interference site conditions. In areas where more stable RSSI signal can be collected, more accurate RSSI-to-distance conversion is expected, and hence smaller σ_0 would lead to more accurate positioning results.

Another observation is regarding the Z-coordinate (or height). The Z-coordinate can be as big as more than 10 m, therefore although the Z-coordinate could be determined by the WiFi-trilateration approach, such value is not accurate enough to estimate the correct floor level in a multi-storey building in indoor positioning. If the Z-coordinate is considered to be known, then the Z-coordinate component would not be included in the design matrix, hence matrix A would become a N by 2 matrix. Analysis results have shown that there are slight improvements in the X- and Y-coordinates by considering known Z-coordinates of the unknown point. The height can be determined directly using a barometric pressure sensor for instance (Retscher 2006).

Finally, Table 2 shows an accuracy improvement in both X- and Y-coordinates, and the opposite effect for the Z-coordinate when the height difference between the unknown point and the APs is decreasing. In indoor positioning applications, the APs are normally set 2–3 m above the mobile device, such height difference is suitable for horizontal position determination. However, further investigations for optimum mobile device and APs relationship is needed if the WiFi-trilateration approach is used for outdoor positioning applications.

5. Concluding remarks and outlook

An algorithm for converting the WiFi signal to the corresponding distance is essential that the WiFi signal strength data to be successfully incoporated into the integrated

Table 3. Accuracy estimation of WiFi-trilateration with unknown point fixed and σ_0 varies between 1 and 3 m.

	$X=29$ m, $Y=29$ m, $Z=7$ m			$X=15$ m, $Y=25$ m, $Z=7$ m		
σ_0 (m)	$2\sigma_X$ (m)	$2\sigma_Y$ (m)	$2\sigma_z$ (m)	$2\sigma_X$ (m)	$2\sigma_Y$ (m)	$2\sigma_z$ (m)
±3	±4.8	±4.8	±6.2	±4.2	±4.2	±10.0
±2	±3.2	±3.2	±4.2	±2.8	±2.8	±6.6
±1	±1.6	±1.6	±2.1	±1.4	±1.4	±3.4

Table 4. Accuracy estimation of WiFi-trilateration of the two unknown positions having the same design matrix A (in relation to the access point locations are the same).

	$X=20$ m, $Y=29$ m, $Z=7m$			$X=20$ m, $Y=11$ m, $Z=7$ m		
σ_0 (m)	$2\sigma_X$ (m)	$2\sigma_Y$ (m)	$2\sigma_Y$ (m)	$2\sigma_X$ (m)	$2\sigma_Y$ (m)	$2\sigma_z$ (m)
±3	±4.0	±4.6	±13.2	±4.0	±4.6	±13.2
±2	±2.6	±3.2	±8.8	±2.6	±3.2	±8.8
±1	±1.4	±1.6	±4.4	±1.4	±1.6	±4.4

processing model. For the deduction of a conversion algorithm field tests have been carried out at the Hong Kong Polytechnic University and Vienna University of Technology. Results have shown that the signal strength quality varies significantly under different environmental conditions where radio interference and multipath effects are present. For environments with less environmental interference a least squares polynomial fitting may be able to establish a reasonable signal strength to distance conversion relationship. However, for site conditions where signal strength is susceptible to radio interference and multipath effects it is unlikely that polynomial fitting will provide the correct solution in the signal strength to distance conversion. The authors have proposed an algorithm by making full use of the signal strength propagation characteristics to estimate the distance from the measured signal strength data. 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, where the achievable accuracy generally is in the range between 1 and 3 m. Although the algorithm used is successful using one calibration baseline in our test, some other site conditions may have different signal strength propagation characteristics which may require more than one calibration baseline. Therefore further investigation has to be caried out.

The main advantage of the conversion of the signal strength observation to ranges to the corresponding access points and calculation of the current user's position with trilateration compared to the WiFi fingerprinting method is that, once the SS-to-distance conversion has been calibrated in an area, simple trilateration positioning technique can be applied. Hence no database searching and comparing processes are needed. It should be noted that the above discussed SS-to-distance conversion algorithm is based on the mean value of the four direction SS measurement values. In real practice, the moving platform can be in any direction. Hence, further refinement of the method would be needed to cater for an arbitrary WiFi card signal reception direction. On-going research results have shown that the highest SS value sampling at a particular position may be more suitable for the calibration, and other SS-to-distance conversion methods such as parametric modelling to cater for different site conditions are being investigated. The discussion of the investigation results would be worthly of another paper.

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