

Differential Wi-Fi – A Novel Approach for Wi-Fi Positioning Using Lateration

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Key words: Wi-Fi, differential positioning, lateration

SUMMARY

For positioning using Wi-Fi either location fingerprinting or lateration is commonly employed. Fingerprinting is very labour consuming as a database with RSS (Received Signal Strength) scans from all visible access points (APs) measured on a large number of known reference points has to be established. Lateration requires the use of theoretical path loss models to convert the RSS measurements into ranges to all visible APs. To improve the applicability of RSS-based lateration methods in indoor environments and further provide feasible mathematical analysis for indoor localization, in this work we propose an improved lateration method based on the well-known DGNSS principle, which can outperform the original lateration methods in terms of performance significantly. The idea of the novel approach termed Differential Wi-Fi (DWi-Fi) is that positioning corrections can be deduced if reference stations are deployed at certain AP locations or in a network in the area of interest. They measure the RSS to all other visible APs similar as it is done on the mobile user's side. The RSS and the deduced range or coordinate corrections are obtained from a comparison with the known ranges between the AP reference stations. In addition, in a reference AP network area correction parameters (i.e., Flächenkorrekturparameter FKP) can be calculated similar as it is done in RTK-GNSS positioning in a CORS network. These corrections are then applied to the current RSS scans from the mobile user. The major advantage of DWi-Fi is that the RSS to range conversion is based on correction parameters and not only on standard theoretical path loss models. In this contribution the concept is discussed in detail and first promising results are presented.

ZUSAMMENFASSUNG

Für die Positionierung mit WLAN (Wi-Fi) werden meistens entweder das sogenannte Fingerprinting oder auch Lateration eingesetzt. Fingerprinting ist sehr arbeitsintensiv, da eine Datenbank von gemessenen Signalstärken (RSS) zu allen Access Points bestimmt und angelegt werden muss. Dafür sind eine Vielzahl von Messungen auf Referenzpunkten, die in der Regel in einem regelmäßigen Raster angeordnet sind, notwendig. Andererseits erfordert die Lateration den Einsatz von theoretischen Modellen für die Ableitung des Zusammenhangs zwischen der Signalstärke und der Distanz. Zur Verbesserung der Einsetzbarkeit der RSS-basierten Lateration und deren mathematischen Behandlung für die Positionierung in Innenräumen wird in dieser Arbeit ein neuer Ansatz vorgestellt, der auf dem Prinzip von differentiellen GNSS (DGNSS) Verfahren beruht. Das sogenannte DWLAN Verfahren erreicht eine entscheidende Verbesserung im Hinblick auf die Leistungsfähigkeit und die erreichbaren Positionierungsgenauigkeiten dadurch, dass wie bei

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DGNSS Strecken- bzw. Koordinatenkorrekturen durch gleichzeitige Signalstärkenmessungen auf Referenzstation und auf dem mobilen Endgerät des Nutzers ausgeführt werden. Aus einem Vergleich der von den RSS-Messungen abgeleiteten Distanzen an den Referenzstationen und den Entfernungen aus Koordinaten können die Korrekturparameter abgeleitet werden. Die Referenzstationen werden entweder bei den Access Points oder in einem Netz von Stationen im Interessensgebiet angeordnet. Im zweiten Fall können dann Flächenkorrekturparameter FKP wie in einem RTK-GNSS Referenzstationsnetz abgeleitet und an die Messungen der Nutzer angebracht werden. Der größte Vorteil von DWLAN ist, dass die bestimmten Entfernungen zwischen der Nutzerposition und den Access Points nicht nur alleine von theoretischen Modellen abhängen sondern durch die Anbringung von Korrekturparametern abgeleitet werden. In diesem Artikel wird das Verfahren vorgestellt und erste vielversprechende Ergebnisse gezeigt.

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1. INTRODUCTION

For indoor localization the use of ‘signals-of-opportunity’ has become increasingly popular. These refer to those radio frequency (RF) signals that are originally not intended for positioning but are freely available all the time. Examples of signals-of-opportunity are Wireless Fidelity (Wi-Fi; a.k.a. WLAN), Bluetooth, RFID, digital television, FM radio, and mobile telephony (Chen, 2012; Li and Rizos, 2014). Thus, the widespread deployment of wireless technologies in urban and indoor environments, in particular Wi-Fi, are resulting in a variety of location-based services, such as personal tracking and inventory control. Using the received signal strength RSS is an attractive approach to perform localization since it can reuse the existing wireless infrastructure (Yang and Chen, 2009). Hence, the use of signals-of-opportunity has the advantage that existing wireless network infrastructure can be used to determine a user location without deploying any localization-specific hardware in the environment. This results in tremendous cost savings. In this paper the focus is led on localization using Wi-Fi.

The paper is organized as follows: In section 2 the principles of Wi-Fi positioning are reviewed followed by a discussion of lateration techniques which use the measured RSS for distance conversion (section 3). In section 4 the novel differential Wi-Fi (DWi-Fi) concept is introduced. Experimental tests described in section 5 prove the applicability of this approach. Finally some concluding remarks and outlook on future work are given.

2. PRINCIPLES OF Wi-Fi POSITIONING

Wi-Fi is originally a technology for short-range wireless data communication and is typically deployed as an ad-hoc network in a hot-spot fashion in the areas where a wireless Internet access is needed. IEEE 802.11 is currently the most utilized Wi-Fi technology. Wireless networks are built by attaching a device called access point (AP) to the edge of a wired network. In the infrastructure topology APs are the central control point which forward traffic between terminals of the same cell and bridges traffic to wired LAN. Clients communicate with the AP using a wireless network adapter that is similar to a traditional Ethernet adapter. The modulation is Complementary Code Keying (CCK) that is based on the original Direct Sequence Spread Spectrum (DSSS) modulation of the 802.11 physical layer. The high rate radio is backward compatible with the DSSS radio. It operates in a portion of the ISM (Industrial, Scientific and Medical) band from 2.400 to 2.495 GHz which is attractive because it is license-free and available almost globally. IEEE 802.11 defines the maximum of 100 mW transmission power in Europe. This results into cell sizes of tens of meters indoors and over a hundred meters outdoors. Beacon frames are transmitted in IEEE 802.11 Wi-Fi for network identification, broadcasting network capabilities, synchronization and for other control and management purposes. In the infrastructure topology APs transmit beacons periodically

according to the beacon interval parameter. A synchronization function is defined that keeps timers of all terminals synchronized to the AP clock by using the timestamp information of the beacon frames. The IEEE 802.11 MAC (Media Access Control) protocol utilizes carrier sensing based contention. The carrier sensing is based on energy detection or signal quality. The standard specifies the RSS that measures RF energy by the radio. RSS of up to 8 bits (256 levels) are supported, but the absolute accuracy is not specified (Kotanen *et al.*, 2003). The transmission power is the major factor that has direct influence on the effective range. Hence, the RSSs and MAC addresses of the APs are location-dependent information that can be adopted for positioning purpose. An observable associated with a MAC address of an AP consist of the following information: (1) the unique MAC address of the RF transmitter, (2) the location of the RF transmitter, and (3) the effective range of the signal, or the size of the signal coverage area of the RF transmitter (Chen *et al.*, 2012).

Theoretically, the measurement of the Time-of-Arrival (ToA) of the Wi-Fi signals would result in the best performance for localization. As in GNSS positioning, this requires, however, synchronization of the transmitter and receiver clock. The timer resolution is too inaccurate for range measurement with ToA as it is 1 μ s which then results into 300 m error in distance estimate. Thus, ToA is not an existing observable in the standard Wi-Fi technology. Additional hardware and software would be necessary in order to facilitate those observations (Llombart *et al.*, 2008). Hence, the localization technique used for positioning with wireless APs is based on measuring the intensity of the received signal (RSS) where as a basis for positioning the relationship is used that the power of the received RF signal is a function of the distance between the user and the APs (Chang *et al.*, 2010).

The RSS can be easily accessed via the Application Programming Interface (API) in a standard Wi-Fi device. A mobile device, such as a smartphone or tablet, can obtain the RSS observables via a passive scanning because the APs emit periodically beacon frames which include the RSS information of the corresponding AP (Chen *et al.*, 2012). Hence, there is no need to establish a data communication with the wireless network but only the RSS to the surrounding ‘visible’ APs are measured on the mobile device. The most commonly employed Wi-Fi positioning method is location fingerprinting which involves a training and a positioning phase. During the training phase, a receiver periodically scans its environment to discover networks and record the RSS of APs. For that purpose the RSS scans are measured on known reference points (RPs) distributed throughout the area of interest. Then the RSS measurements define a so-called fingerprint on that particular RP. Once the training phase is completed the data is processed to build a radio-map and stored in a fingerprinting database. During the positioning phase, the RSS of APs at the receiver location is recorded in real-time and then the position of the receiver is determined through comparison of the readings from APs with the data stored in the radio-map (Chang *et al.*, 2010). In the fingerprinting database each AP is represented by its RSS and MAC address. For the establishment of such a database the RPs are usually distributed in a regular grid throughout the area of interest. To achieve acceptable results for localization determination with positioning accuracies on the few meter level or at least to locate the user in the correct room in a building the grid has to be rather dense (Retscher and Hofer, 2015). This is the main disadvantage of location fingerprinting as it is very labour consuming to establish this database. Furthermore, fingerprinting or other probabilistic

approaches (Bahl and Padmanabhan, 2000) are heuristic-based and do not have closed-form solutions, and thus are hard for mathematical analysis. Another problem of fingerprinting is the fact that the RSS observations in both phases cannot be performed at the same time. This results in relatively low positioning accuracies caused by high spatial and temporal variations of the RSS. Significant effects, for instance, can be seen if the environment changes after the training phase or a different current number of people is present in the area of interest. Thus, a novel approach is developed in which RSS observations for obtaining corrections are performed at the same time epoch as the current positioning measurements. This new approach is based on lateration. Localization using lateration has also the advantage that it is a closed-form solution for convenient mathematical analysis (Chang *et al.*, 2010). Hence, in this study the use of lateration in Wi-Fi positioning is investigated which is briefly discussed in the following section and then the novel approach is introduced in section 4.

3. LATERATION MODELS

Lateration is a conventional algorithm used in surveying, as well as in the RSS-based techniques. It is a common method for deriving location of wireless devices. The positioning method is based on the distance or distance-related observables. Location of a mobile device can then be found on intersection of three (or more) spherical surfaces. The centers of the spheres are the known AP positions and their radii are the distance between the corresponding AP and the mobile device obtained from RSS observations. If more APs are accessible, then redundant observables are available to locate the wireless device based on least squares methods. A propagation model estimates the relation between the RSS and distance. Theoretically, the power of the RF signals decreases when it propagates into space and therefore the RSS decreases with the transmitted energy (Feuerstein *et al.*, 1994; Rappaport, 1996; Ranvier, 2004). Hence, the nature of the RSS varies with the changes of distance between transmitters and receivers. In the following, models for RSS to distance conversion and the limitations and resulting challenges are discussed.

3.1 Models for RSS and distance relationship

A number of models, termed path loss models, have been developed to establish the relationship between the RSS and propagating distances. Thereby path loss is defined as the dB reduction in power from the transmitter to the receiver location, where the received power is spatially averaged around the location. Specifically, it is averaged over an area whose radius is several wavelengths, with the wavelength being that at the center frequency of the transmission. When the assumptions of the model can be accepted, the distances between the transmitters and the receiver can be calculated easily according to the RSS by inverting the model (Ghassemzadeh *et al.*, 2003). As mentioned above, in general, the power of the RF signals decreases when it propagates into space (Rappaport, 1996). The trend of this process can be mathematically modelled. The RSS values are converted to distance estimates by using a radio wave propagation model. One of the simplest models, which describe the decreasing trend without the effects from reflections and obstructions, is presented as the log-distance path loss model. The measured RSS readings and distances are then

used to fit the signal propagation model and the signal-to-distance relationship is derived from equation (1):

$$PL(d) = PL(d_0) + 10 \cdot \gamma \cdot \log\left(\frac{d}{d_0}\right), \quad d \geq d_0 \geq d_f \quad (1)$$

where d is the distance between the transmitter and the receiver, $PL(d)$ the path loss at d in [dB], d_0 the reference distance, d_f the Fraunhofer distance which defines the boundary of the region and γ the path loss exponent which describes the slope of the average increase in path loss with dB-distance (Retscher *et al.*, 2012).

By additional consideration of the shadow fading S , a more general path loss formula that incorporates reflection, diffraction and scattering for both line-of-sight (LOS) and non-line-of-sight (NLOS) paths can be stated. It has the form:

$$PL(d) = PL(d_0) + 10 \cdot \gamma \cdot \log\left(\frac{d}{d_0}\right) + S \quad (2)$$

The spatial variation S denotes a zero-mean Gaussian random variable with standard deviation σ . It can thus be written as $S = y \cdot \sigma$, where y is a zero-mean, unit-variance Gaussian random variable. The spatial variation of S is usually referred to as shadowing, and it captures the path loss deviation from its median value (Ghassemzadeh *et al.*, 2003).

An alternative method is to use regression models based on the previous measured RSS to establish the relationship between distance and RSS. This method considers the effects of the environment on RSS using statistical methods which apparently increases the accuracy of modeling the RSS trend in the specific areas where the RSS data were collected for the regression. By solving the distances, the mobile user's position can be calculated according to the APs coordinates and the measurements of ranges between the APs and the mobile users. If redundant observations are present a least squares adjustment can be applied to derive the users' positions. The measurement model is given by:

$$d_i = \sqrt{(p_{x,i} - p_{x,0})^2 + (p_{y,i} - p_{y,0})^2 + (p_{z,i} - p_{z,0})^2} + \varepsilon_i, \quad i = 1, \dots, n, \quad \varepsilon_i \sim N(0, R_i) \quad (3)$$

where p_0 is the 3-D position of the mobile user, p_i are the locations of the i transmitters with known positions, d_i are the estimated distances calculated by ranging models, R_i is the covariance matrix of the measurements and ε_i is the associated measurement noise with zero-mean normal distribution (Retscher *et al.*, 2012).

Figure 1 shows comparisons of RSS measurements in both outdoor and indoor environments. They indicate that the path loss pattern in the outdoor environment is close to the log-distance pattern and

in the indoor environment along a corridor it shows a linear pattern. This is mainly due to the differences in the environments. In the indoor environment, the walls, ceilings and floors can form a structure, called waveguide. This structure forces the RF signals to propagate in particular directions (e.g. the two directions along an indoor corridor) and, consequently, changes the path loss patterns of the signal propagation and increases the errors in distance estimation using RSS.

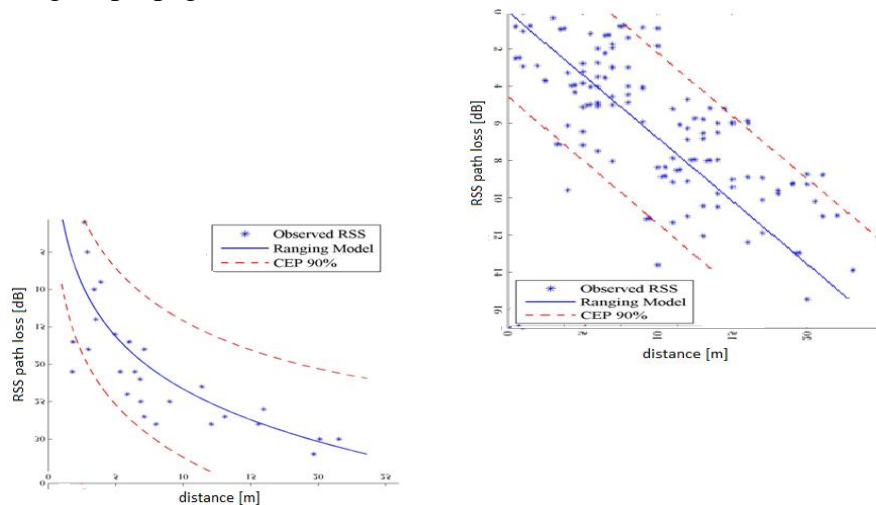


Figure 1: Examples of a log-distance path loss pattern outdoors (left) and a linear pattern indoors along a corridor (right)

Yang and Chen (2009) found in their experiments that regression-based methods can significantly improve the localization accuracy of original lateration methods. Apart from linear regression models different degrees of polynomial fitting may also be used. Additionally, they found that second, third and fourth degrees of polynomial regression achieve similar results indicating that they have similar localisation performance on both LOS and NLOS. Theoretically, the higher degrees of polynomial can obtain better curve fitting of the RSS observations, but often suffer from overfitting. Thus, high-degree polynomial regression may not result in better results in the RSS to range conversion. Moreover, compared to lower degree, the higher degree of polynomial regression involves more computational overhead.

3.2 Limitations and challenges for RSS to distance conversion

Wireless communication channels in indoor environments are generally noisy making the RSS a complex function of distance and environmental factors. The fluctuation of RSS reduces the accuracy of the location estimation considerably. For indoors, many factors such as NLOS propagation, multipath fading, absorption, signal obstruction, air temperature, interference from other wireless devices and presence of people in the area of interest make the modeling of the radio signal propagation much more complicated. Therefore the distances derived from RSS may contain large errors that will degrade the positioning accuracy. Furthermore, the contour lines of RSS of a single omni-directional antenna, however, are rarely forming the ideal circular pattern. This

directionality also causes errors in distance converted (Chen *et al.*, 2012). Multipath caused by reflections of the RF signals makes the received signals a combination of signals from both direct and indirect paths. The combination of the signals leads to an unpredictable variation of RSS in space since the paths are site-specific.

A common challenge for all RSS based positioning modes is the large temporal and spatial variations of the radio channel, especially indoors, where NLOS propagation and attenuation caused by walls, other structures, and even people cause significant fluctuations of the RSS measurements (Chen *et al.*, 2012). Signals of APs may be blocked or the RSS is lowered due to the body of the person to be localized. From the tests of Hu (2013) could be seen that typically Wi-Fi signals are affected when people are located physically between the APs and the mobile device. The main reason for this is that 2.4 GHz signals can be greatly attenuated by water and the human body consist of about 70% water.

Hence, lateration algorithms are highly dependent on the accuracy of distance measurements, but accuracy degrades significantly due to the inherent detrimental effects of the Wi-Fi indoor positioning technique. The limitation is that most of the theoretical models are subject to free space propagation or signal propagation in a simple environment. LOS and NLOS scenarios represent different signal propagation environment in indoors. Thus, under different scenarios, the propagation parameters are different, such as the path loss exponent γ and the shadow fading S in equation (2). In tremendously complex environments it is difficult to deal with through the assumptions or conditions listed in the physical or theoretical models. For example, in an office building, metal window frames and pipes passing through rooms can be reflectors of RF signals. Cabinets, timber walls and people can cause up to 10 dB extra path loss when the signals penetrate through them. These detrimental effects will degrade the accuracy of the distance estimated using the inversed path loss models. Some typical values of the path loss exponent γ are presented in the literature (see e.g., Rappaport, 1996). In free space, γ equals 2, which aligns the log-distance path loss model well with the free space propagation model. In lossy environments, such as outdoor and indoor NLOS areas, γ increases and its normal range is between 2 and 6. In the indoor LOS area, especially in corridors, this value can fall to less than 2. As seen from Figure 1 on the right this is caused by surrounding structures (waveguides) forcing the RF to propagate along the directions of the structures instead of propagating uniformly into the space (Retscher *et al.*, 2012). Thus, the parameters of the path loss models are often defined experimentally (see e.g. Kotanen *et al.*, 2003). To overcome the drawbacks and limitations for RSS to distance conversion an approach based on the well known DGNSS principle is developed. We term this novel technique DWi-Fi. In the following section this concept is introduced and discussed.

4. PRINCIPLE OF DIFFERENTIAL Wi-Fi POSITIONING

As conventional RSS-based lateration methods cannot achieve comparable performance in terms of location accuracy to other RSS-based algorithms such as location fingerprinting a novel approach termed differential Wi-Fi (DWi-Fi) is developed. The idea of this approach is based on the well-known differential GNSS (DGNSS) operation principle used in satellite positioning. To minimise

the inherent detrimental effects in Wi-Fi lateration, the RSS to distance relationship can be improved if range corrections are applied to the deduced ranges to the APs. They can be deduced if reference stations are deployed at certain AP locations or in the area of interest. Such a reference station measures the RSS to all other visible APs similar as it is done on the mobile user's side. The RSS and the deduced differential corrections are obtained from a comparison with the known ranges between the AP reference stations.

Figure 2 shows two different approaches for DWi-Fi. In the first case reference stations are deployed at certain Wi-Fi APs, i.e., at one AP as shown in Figure 2 on the left. This reference station measures continuously the RSS to all other visible APs $n-1$. These measurements are used to derive range or coordinate corrections. At the mobile user these corrections are applied to the current RSS observations of the corresponding AP for improvement of the localization. In the second case shown in Figure 2 on the right, a network of several reference stations is deployed. As an example three reference stations RS 1 to 3 are deployed at known locations as illustrated in the Figure. Then it is possible to derive area correction parameters (i.e., so-called Flächenkorrekturparameter FKP) in the reference AP network similar as it is done in RTK-GNSS positioning in a continuous operating reference station (CORS) network. The FKP are then applied to the current RSS scans from the mobile user. Depending on the environment a log-distance or linear regression model can be applied for the RSS to distance conversion (compare Figure 1).

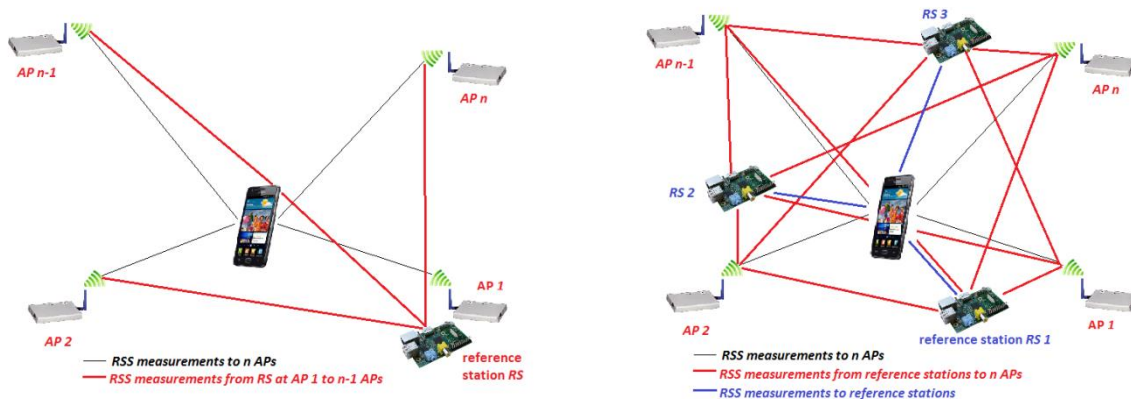


Figure 2: Two DWi-Fi approaches

A low-cost solution for these concepts is realized in using Raspberry Pi's for the reference stations. A Raspberry Pi is a low cost, credit-card sized computer which is operating similar to any other PC. Using an USB Wi-Fi adapter plugged into the Raspberry Pi RSS measurements can be performed similar as it can be done at the mobile client. A mobile App has been developed capable to scan the RSS to all visible APs. For identification of a particular AP the MAC address is used. Additionally the accelerometer and compass readings from the smartphone motion sensors are recorded with the App. Due to step counts using the accelerometers and heading measurement with the gyros and compass the trajectory of the user can be continuously obtained using dead reckoning (DR).

As pointed out above, the major advantage of DWi-Fi is that the RSS to range conversion is based on range or coordinate correction parameters in the first approach and FKP in the second and not only on standard theoretical path loss models. Thus, the positioning performance is significantly improved compared to conventional approaches. First test results are presented in the following section.

5. EXPERIMENTAL RESULTS

The DWi-Fi approach is tested for the first time in a multi-storey office building of the Vienna University of Technology (TU Wien), Austria. Figure 3 shows the test site on the ground floor of the building. In the selected area three reference stations RP 1 to 3 have been deployed. Their location has been purely selected to surround the study area and the 10 distributed test points MP 1 to 10 in this area. Some of them are located in the hallway, others in different rooms, such as MP 1 in the largest lecture hall in the building. RSS measurements to in total nine APs were performed. Their location, however, could not be selected under consideration of the geometry for lateration. Rather the predeployed APs had to be used for the tests. They are located to provide a continuous Wi-Fi coverage throughout the building and not to guarantee a good geometry for positioning. As mobile clients two different smartphones were used in the tests.

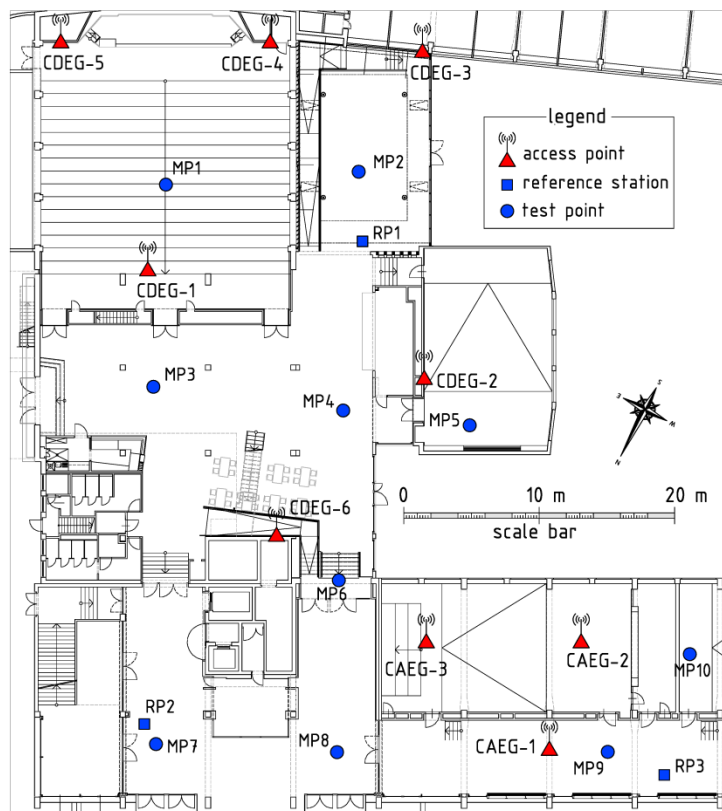


Figure 3: Test site on the ground floor of a multi-storey building

Figure 4 shows the relationship between the distance and the measured RSS on a straight line between the two APs CDEG-3 and CDEG-6 over a total distance of 40 m. Measurements were performed on the straight line in distance interval of 1 m. The top Figure shows the result for the first smartphone and lower for the second. The circles indicate the measurements from AP CDEG-3 and the triangles from AP CDEG-6. On each point five scans in four orientations were performed, i.e., at 0° , 90° , 180° and 270° in relation to the baseline between both AP's. They are indicated with different colours. The vertical error bars show the standard deviation of one sigma. As can be seen the relationship between the distance and the RSS is well described by a log-distance model with the coefficients a and b . When looking at the four different orientations it can be seen that the RSS is 5 to 10 dBm lower in the case if the user is located between the AP and the mobile device, i.e., at 180° orientation (blue line). The signal is shielded from the human body. The main reason for this is the in section 3.2 mentioned fact that the Wi-Fi signal is significantly attenuated by water which a human body consists. The other orientations correspond quite well. The red dashed line is an averaged log-function of these three orientations. Table 1 summarizes the numerical values for the mean deviations in [dBm] from the logarithmic function for the two smartphones.

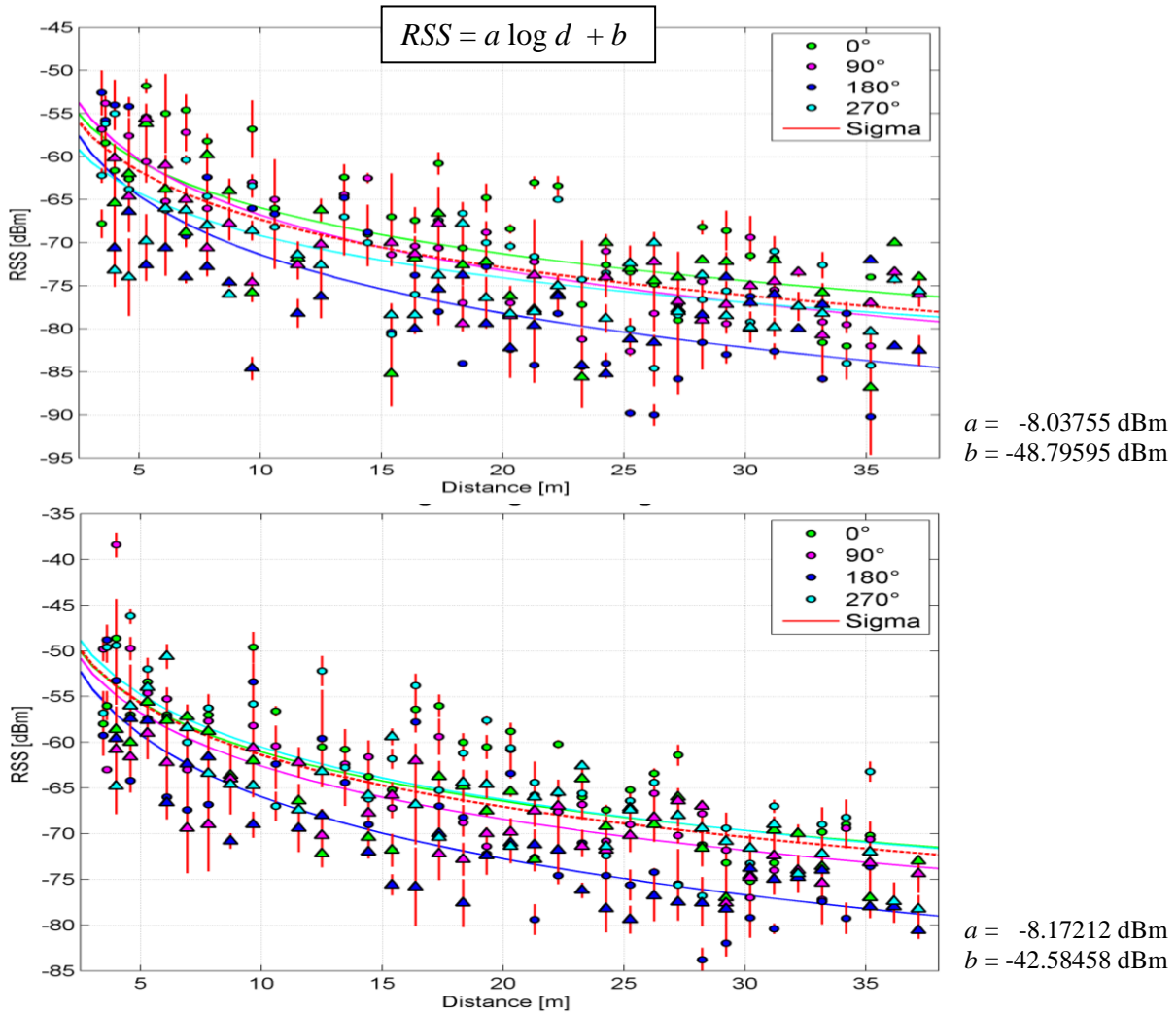


Figure 4: Relationship of the distance d to RSS for two smartphones

Table 1: Deviations from the logarithmic function for two smartphones

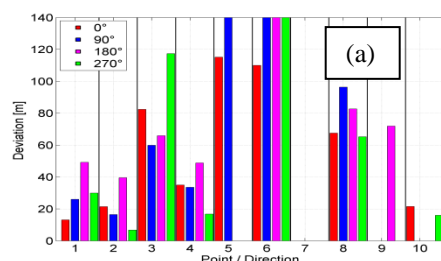
orientation	Smartphone 1		orientation	Smartphone 2	
	AP CDEG-3	AP CDEG-6		AP CDEG-3	AP CDEG-6
0°	5.305	4.122	0°	3.992	3.066
90°	3.452	2.776	90°	3.554	3.833
180°	6.487	6.264	180°	5.942	6.406
270°	3.814	4.250	270°	4.348	2.971

When comparing both smartphones it can be seen that they show similar behaviour for the RSS to distance relationship. For smartphone 2 (lower Figure 4) the function for orientation 180° is again

different than the one of the other three. This can also be seen again in Table 1 when looking at the numerical values for the mean deviations. Compared to smartphone 1, however, the offset b is smaller by a value of around 6 dBm for smartphone 2. This offset needs to be considered in the modeling of the RSS to distance conversion if different mobile devices are used.

Tests were also performed along other straight lines in the test area of this study. The measurements on these lines showed similar patterns and results. In Figure 4 the mean deviations are shown. A similar result is obtained if the median is calculated.

Figure 5 shows the deviations from the true positions for uncorrected measurements (Figure 5 (a)) and if differential corrections using reference station measurements (Figure 5 (b) and (c)) are applied. The deviation vectors are calculated from the true location and are given here rather than coordinate deviations in the local coordinate frame. To assign a reference station to the mobile devices an approximate position of their location is needed. As an approximate solution the determined location without applied corrections can be used. Then in an iterative process the differential corrections are calculated and applied to the raw measurements. For the calculation of the deviations the averaged log-distance relationship (red dashed line in Figure 4) of these three orientations is used. On the left (Figure 5 (b)) the resulting deviations are shown if the corrections are applied and on the right (Figure 5 (c)) with additional consideration of the user orientation. This orientation is obtained from the observation of the digital compass and magnetometer in the smartphone. Because of the high variation of the derived distances a robust adjustment method with the least median square is carried out for the estimation of the coordinates of the test points. The different colours of the error bars correspond again to the four measured orientations of the user in relation to the axes of the building. As can be seen from Figure 5 (a) the deviations reach several tens of meters from the true position (they even exceed more than 100 m in some cases) if no differential corrections are applied. A significant improvement can be seen if differential corrections are applied. Then in most cases the deviations are only a few meters. A few outliers, however, also exist in the data as can be seen in Figure 5 (b) and (c) respectively. When comparing both Figures it can be seen that a slightly improvement is achieved if an additional correction under consideration of the user orientation is applied.



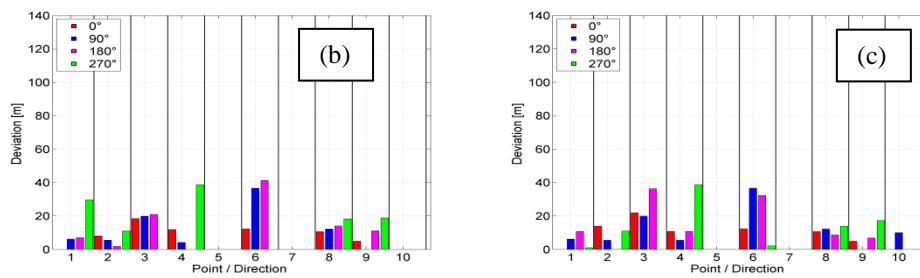


Figure 5: Deviations from true positions for uncorrected measurements (a) and applied differential corrections using reference station measurements (b) and with additional consideration of the user orientation (c)

One remarkable result of all tests is that it could be proven that the deduction of range corrections and determination of potential offsets between different mobile devices leads to a significant improvement for the RSS to distance conversion. Thus, a better result in terms of performance and positioning accuracy for Wi-Fi lateration is obtained.

6. CONCLUSIONS AND OUTLOOK

The IEEE 802.11b standard uses radio frequencies in the 2.4 GHz band, which is attractive because it is license-free, however, it does suffer from inherent disadvantages. In the 2.4 GHz band, microwave ovens, Bluetooth devices, cordless phones and other devices are sources of interference. Moreover, signal propagation suffers from severe multipath fading effects due to reflection, refraction, diffraction and absorption by structures and humans. As a result, a transmitted signal can reach a receiver through different paths, each having its own amplitude and phase. These different components are captured by the receiver and a distorted version of the transmitted signal is reconstructed. Furthermore, changes in the environmental conditions such as temperature and humidity affect the strength of the received signals to a large extent. Consequently, the RSS values received by a Wi-Fi card at a fixed location vary with time and physical conditions of the surrounding environment (Chang *et al.*, 2010).

To improve the performance of Wi-Fi lateration techniques a novel approach called Differential Wi-Fi (DWi-Fi) is derived from the well-known DGPS concept. In this approach the mobile client measures the RSS to all visible APs in the surrounding environment. Reference stations realised by Raspberry Pi's are deployed in the area of interest which measure also the RSS to all APs at the same time epoch. The major advantage of DWi-Fi is then that the RSS to range conversion is also based on area correction parameters FKP and not only on standard theoretical path loss models. From the first test results presented in this contribution it could be proven that the novel DWi-Fi approach is very promising in achieving a higher performance in terms of positioning accuracy and practicability.

In future work radio maps of RSS distribution for the whole test area in the study will be established to be able to deduce the FKP. For that purpose at least three reference stations are deployed.

Extensive data collection of RSS values in this area has been carried out recently. RSS scans were measured in a regular grid of reference points with a density of 2.5 m. This high density for RPs has been chosen in the tests to be able to determine the interpolation of the differential corrections at different reference grid distances. Additionally, temporal variations of the RSS are considered as measurements were performed over 24 hours. Then it is possible to analyze different time epochs with different conditions, e.g. different number of people in the building when measuring during the day and at night. The investigation will also concentrate on the derivation of the required density of reference points to be able to deduce the RSS radio map. Furthermore, a comparison with location fingerprinting will be performed.

The DWi-Fi approach is further developed and investigated in a project called InKoPoMoVer (Cooperative Positioning for Real-time User Assistance and Guidance at Multi-modal Public Transit Junctions). One aim of the InKoPoMoVer project is to provide assistance to persons in need of guidance in finding the shortest or the most convenient way between different lines and mode of transportation in a multi-modal transit situation. The concept is prepared to be established at a large multi-modal transfer station in the city of Vienna. For the guidance of users we consider additionally a cooperative positioning solution of several users. For further information on this project the interested reader is referred to the paper of Retscher and Obex (2015).

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BIOGRAPHICAL NOTES

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