The accuracy of algorithms for WLAN indoor positioning and the standardization of signal reception for different mobile devices

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Abstract: *Often mobile devices like mobile phones or personal digital assistants (PDA) are equipped with IEEE 802.11 WLAN adapters. Furthermore, within many buildings a WLAN infrastructure is available. The aim of this work is to investigate the quality of different indoor positioning methods based on values of WLAN received signal strength index (RSSI) using commercially available devices (mobile phones, PDA). Three positioning algorithms were considered: minimal Euclidian distance, intersections of RSSI-Isolines and a stochastic model based on Bayes' theorem. Two measuring testbeds, a museum's exhibition room and an empty seminar room, four different types of PDA (Dell, Fujitsu, HP, T-Mobile) and two types of access points (Netgear, Lancom) were used.*

Results show that positioning can be achieved with an average accuracy of approx. 2-3 metres. WLAN capable mobile devices behave differently in receiving RSSI values of a base station. For reasons of standardization a linear correlation between different receiving levels of PDA was investigated.

Keywords: *WLAN, RSSI, Positioning, Bayes, Euclidian distance, Triangulation, Isoline*

1. Introduction

Location based services (LBS) will be one of the most exiting features of the next generation wireless systems. Location based services are already established in the area of mobile phone networks using the global positioning system (GPS) as outdoor positioning component. Since GPS is not working indoors, establishing LBS within buildings needs an indoor wireless network, for instance WLAN, together with an positioning system [1].

The aim of the activities presented in this paper was the investigation of different WLAN positioning algorithms for indoor position based applications. The increase of existing WLAN infrastructures inside of buildings and the commercial availability of WLAN capable mobile devices leads to the question, whether an indoor positioning using such infrastructures and devices would be accurate enough for mobile indoor applications.

Beside other methods some are based on values of received signal strength index (RSSI) of several access points. Several mathematical methods exist for calculating the current position. We investigated the accuracy of determining the current position using three different algorithms.

Commercially available mobile devices like personal digital assistants (PDA) with WLAN capability show different reception quality of RSSI-values. We investigated the correlation between recorded RSSI-values of different PDA.

Several measurements were carried out in two testbeds over the period of a year's time. Methods, testbeds, measurements and results are presented below.

2. Related Work

Several groups are working on WLAN-RSSI based indoor positioning methods using different algorithms and different mobile devices.

Ladd et al. [2] used a Bayesian inference algorithm for comparing histograms of calibration and positioning phase. Experiments were conducted by a human operator carrying a Hewlett Packard OmniBook 6000 laptop with a PCMCIA LinkSys wireless Ethernet card. They modified the standard Linux kernel driver to support new functionalities, including the scanning and recording of hardware MAC addresses and signal strengths of packets and the automatic scanning of base stations. Sampling times ranged from ten seconds to about a minute. A total of 1307 packets on 11 different positions were measured. Neighbouring positions are located in 3 meters distance from each other. The algorithm reported calculated positions with a deviation of up to 1.5 meters from the measuring position.

Retscher et al. [3] developed the IPOS system using RSSI-fingerprints as well. Their testbed was an office building and a tablet-pc was moved from each position to the next either in stop-and-go or kinematic mode. They focussed on determining wether a user is located inside a room or not and wether one or two calibration points within one room are sufficient.

Teuber et al. [4] used a method of minimal Euclidian distance together with Fuzzy logic postprocessing. Their testbed was an empty airport hangar. Accuracy of positioning was 4.47 m using Euclidian distance alone. With Fuzzy logic postprocessing the accuracy decreased to 3 m.

The Ekahau Positioning Engine (EPE) [5] is a commercially available Software for RSSI-WLAN indoor positioning. The engine combines according to the manufacturer's instructions signal strength pattern recognition together with an attempt to include the user's history (boundary conditions like allowed paths and speed). Determination of the current position is possible depending on the environment with an accuracy of 1-5 m.

The authors developed a method identifying intersections of lines of constant RSSI-values (isolines) of several base stations within interpolated radio maps based on a Delaunay triangulation [6]. A slightly modified method was used by Röhrig et al. [7] focussing on a triangulation with larger mesh widths.

3. Lines of constant received signal strength index (RSSI-Isolines)

The Isoline method proposed here belongs to the group of fingerprint methods, i.e. measured RSSI values of several base stations (access points) are compared with RSSI values previously recorded during a calibration phase.

A network of triangles not overlapping each other with grid nodes representing the triangle nodes is developed using Delaunay triangulation [8]. The triangle nodes are represented by the calibration points. Fig. 1 shows the triangulation of one of our testbeds, an empty seminar room of size 15m x 7m.
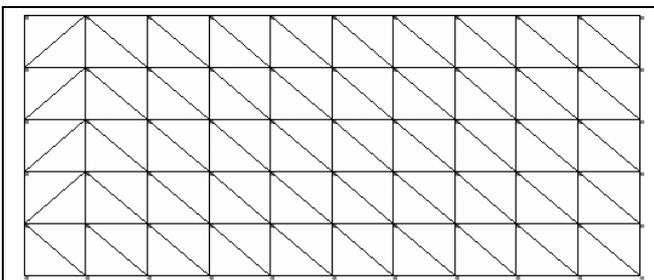

Fig. 1 - Triangulation of testbed 1 ('seminar')

Every node of the triangulation in Fig. 1 represents a calibration point, i.e. RSSI-values are recorded at every point from four access points located at the four corners of the room. Having recorded RSSI-values of an access point at every calibration point linear interpolation between node values within one triangle delivers a detailed radio

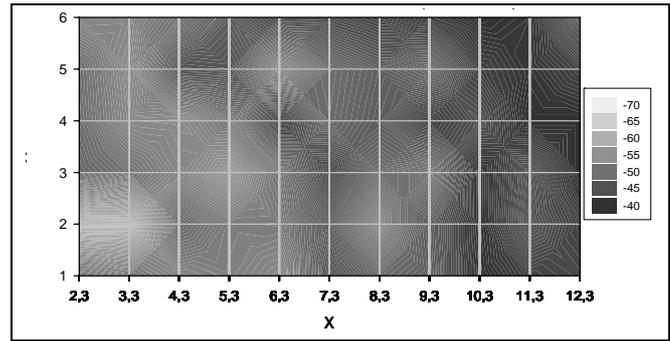map consisting of a surface of interpolated RSSI values over the entire area of triangulation. (Fig. 2).

Fig. 2 - Interpolated radio map of one access point (right upper corner)

Given a RSSI-value of one access point recorded during positioning phase we can select triangles whose nodes have RSSI-values recorded during calibration phase, which are higher and lower than the RSSI-value recorded during positioning phase. Within such a triangle it is possible to calculate an interpolated line of constant RSSI-value (isoline). These isolines build continous trajectories through the whole area of triangulation.

Given two RSSI-values of different access points measured simultaneously at the same location we are now able to select triangles whose interpolated radio maps include the according isolines. Fig. 3 shows a triangulation with triangles including one or two isolines of different access points. If there is an intersection of the two isolines, we can calculate the intersection point within the triangle. A first idea takes the intersection point as estimated position.
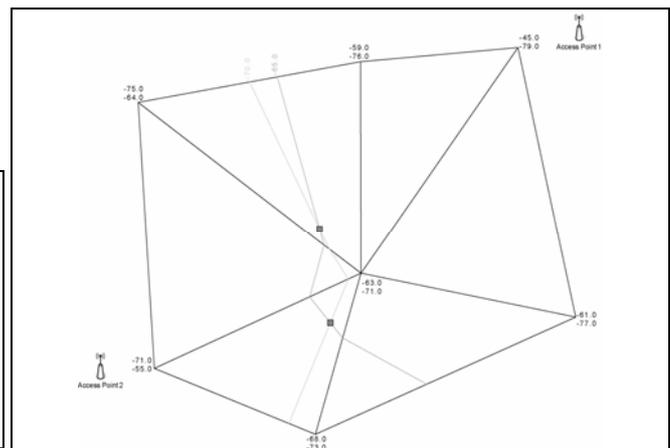

Fig. 3 - Triangles with isolines of two access points

Using small sized triangles with mesh width up to 1m the balance point of the triangle itself can be used as the estimated position.

Usually we will select several triangles including isolines of several base stations. We rank all triangles of the entire triangulation according to the number of isolines they include. The secondary

ranking parameter is the number of intersections within one triangle.

The "best" triangle is assumed to be the triangle with the largest number of isolines and the largest number of intersections. The estimated position is assumed to be the balance point of the "best" triangle or the average of all intersection points within this triangle. For our evaluation we used the average of the balance points of the five "best" triangles.

As an example Fig. 4 shows the result of the ranking process. Isolines of RSSI-values recorded from all four base stations are drawn and marked by different grey scale values. The shaded areas show five triangles selected as "best" triangles. They contain at least three different isolines and one intersection. The original measuring position is marked by the black square.
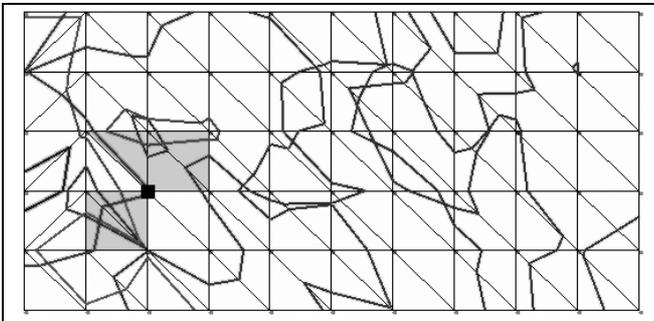

Fig. 4 - Radio map including isolines of 4 access points

4. Accuracy and comparison of three positioning algorithms

One aim of our measurements was to investigate and compare the accuracy of three algorithms used for WLAN-RSSI indoor positioning: the Bayes inference algorithm (Bayes) [2], the algorithm of minimal Euclidian distance (Euclid) [4] and the algorithm using Isolines within a triangulation (Isolines). All three algorithms were implemented in C# resulting in corresponding positioning programs, which deliver a position within the area covered by the triangulation resp. a grid of calibration nodes. Knowing the original measuring position we are able to calculate the deviation between the original and the estimated position.

5. Testbeds and measurements

Measurements were carried out within two different testbeds: testbed 1 ('seminar') and testbed 2 ('museum'). Testbed 1 represents an empty seminar room (scale: approx. 15m x 7m) in a building of Dortmund University of Applied Sciences. As testbed 2 an exhibition room of the museum "Strom und Leben" at Recklinghausen (scale: approx. 30m x

11m) was used. Both locations had been equipped with four access points at the outer corners below the room's ceilings. In two series of measurements Netgear and Lancom access points were used as base stations.

Fig. 5 shows the triangulation of testbed 2 ('museum'). Some triangles of the original triangulation had to be eliminated, because they cover areas with large exhibits or areas people are not able to enter. Such triangles contribute misleading data, so they had to be removed from the triangulation
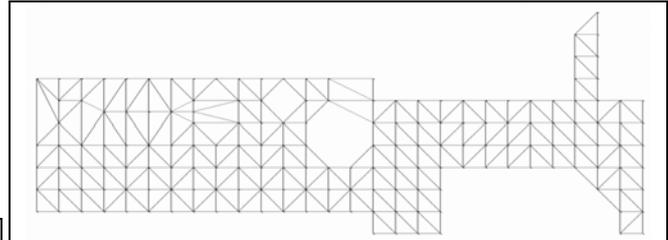

Fig. 5 - Triangulation of testbed 'museum'

For measuring WLAN RSSI-values personal digital assistants (PDA) with Windows Mobile OS and with inbuilt WLAN adapter were used. Recordings were carried out using devices of the manufacturers Fujitsu-Siemens (Pocket Loox 720), Hewlett Packard (hx4700), T-Mobile (MDA III) and Dell (Axim X50v).

For simultaneous recording of WLAN RSSI-values of four access points with a PDA a software tool was developed. The tool was implemented in C# using the OpenNetCF framework. The framework offers methods for recording data like SSID, Mac address and RSSI values of neighbouring WLAN access points.

Both testbeds were provided with a 1 metre rectangular grid covering the ground floor. Measurements were carried out during calibration phase at each of these points in four directions (0, 90 180, 270 degree). RSSI-tuples of all 4 access points had been recorded simultaneously over a period of 50 seconds (one recording per second).

Fig. 6 shows a radio map of testbed 2 ('museum'). The access point is positioned in the left lower corner below the room's ceiling.
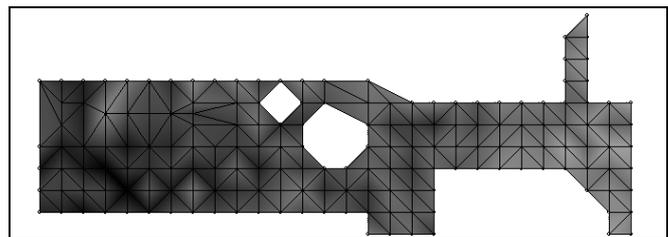

Fig. 6 - Radio map of testbed 'museum' (access point at the left lower corner)

All recordings were carried out by a person keeping the PDA horizontally in front of him in his left hand. Recording was started by the person by clicking on a button on the touch screen with his right hand.

During positioning phase measurements were carried out under the same conditions as in the calibration phase at known grid points and with known orientation. The recorded data had been stored in a database.

Between August 2005 and November 2006 several test series were carried out in both testbeds. There was one series in testbed 2 ('museum'), a tour through the exhibition room and three series of measurements in testbed 1 ('seminar'). Within the latter there was one series called 'exhibit', where the measuring person stands close to the wall with orientation to the wall like observing an exhibit at the wall. Another series ('strolling') was a loop through the room with orientation parallel to the walls and the third series ('random') consists of measurements at calibration points randomly selected.

6. Standardization of reception quality of different types of PDA

Another aim of our measurements was the analysis of receiving quality of different types of PDA. During our measurements we observed significant differences of different PDA concerning their WLAN reception quality. The following two figures will illustrate this.

Fig. 7 shows a radio map based on RSSI-values recorded from access point 1 (AP1) with a Dell PDA within testbed 1 ('seminar'). The access point is located at the upper right corner.
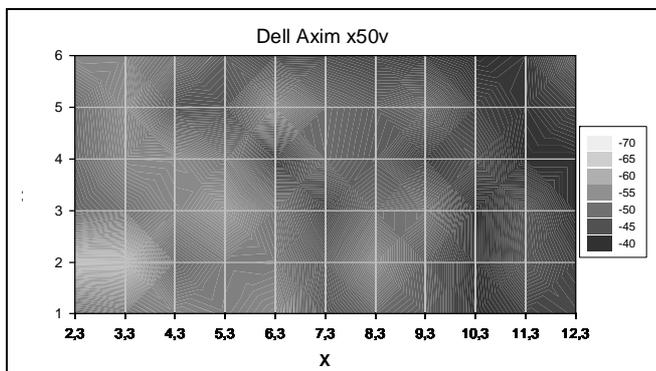

Fig. 7: Radiomap recorded by a Dell PDA (testbed 1, AP1, orientation 0 degree)

Fig. 8 shows a radio map based on RSSI-values recorded from AP1 analogously with Fujitsu-Siemens PDA again within testbed 1 ('seminar').
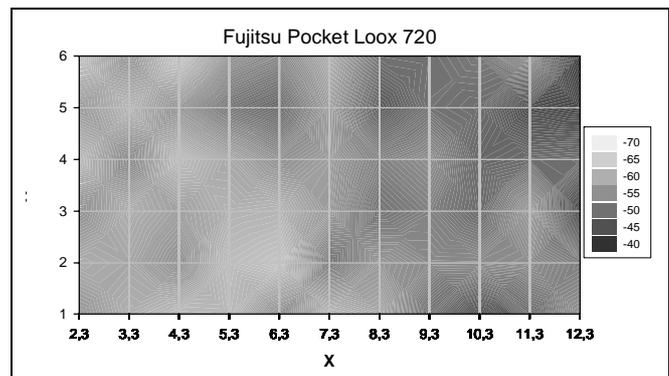

Fig. 8: Radiomap recorded by a Fujitsu PDA (testbed 1, AP1, orientation 0 degree)

During both measurements the parameters of the testbed, particularly the transmitting power of the base station (AP1), were not changed. The difference between the two radio maps is obvious. Especially, when using fingerprint methods this represents a major problem, because calibration has to be repeated for every different type of PDA resulting in a multiplication of workload.

One reason for the difference of radio maps could be the influence of the measuring person, who did not perform both measurements along the same lines. To exclude this we tried to make sure, that the measuring process was always carried out along the same strict specifications. There were guidelines for keeping and positioning the PDA. Moreover, the measurements were carried out by the same person.

Another reason for this phenomenon may be due to different receiving capabilities of the mobile devices' inbuilt WLAN adapters and their antenna layouts. One possibility to overcome this problem and to reduce calibration amount is to find a function, which correlates the RSSI-values of two different types of PDA. If there are such functions, calibration can be carried out by one PDA, and during positioning phase 'correlated' PDA may be used.

Table 1: RSSI-values recorded by four PDA under identical conditions

BS	MP	Dell	Fujitsu	HP	MDA
AP1	MP 001	-46,23	-54,97	-44,95	-49,70
AP1	MP 002	-43,60	-49,38	-42,82	-49,12
…					
AP2	MP 001	-49,95	-52,60	-45,75	-52,05
AP2	MP 002	-50,35	-55,72	-50,00	-53,15
…					
AP3	MP 001	-58,35	-61,78	-56,53	-61,68
AP3	MP 002	-55,47	-61,63	-54,43	-63,27
…					
AP4	MP 001	-57,87	-63,42	-59,63	-63,90
AP4	MP 002	-56,53	-65,58	-58,48	-65,43
…					

Within testbed 1 ('seminar') we recorded RSSI-values from all base stations at all calibration points with all available PDA along the same lines (identical transmission power, orientation etc.).

Table 1 shows recorded RSSI-values of four PDA. The RSSI-values in one row correspond to the same base station, the same calibration point, the same transmission power and the same orientation.

The idea is to find out, wether RSSI-values recorded under identical circumstances from one base station by two PDA are linearly correlated.

Using regression analysis [9] parameters for a linear correlation between the RSSI-values recorded by the Dell-PDA and the three other PDA were calculated with Microsoft EXCEL.

The Dell PDA was selected as reference device, since it has shown the most stable behaviour of all used mobile devices during the measurements. For every combination (Fujitsu-Dell, HP-Dell, T-Mobile-Dell) separate calculations were carried out. The result of each calculation is a linear equation:

$$RSSI_{Dell} = A_x * RSSI_x + B_x;\qquad(1)$$

$RSSI_x$ means a RSSI-value recorded by one of the other PDAs. A_x and B_x are the parameters calculated by regression analysis for PDA_x. $RSSI_x$-values will be transformed to $RSSI_{Dell}$-values and may than be compared to RSSI-values recorded by the Dell-PDA during calibration phase.

For visualization the values of HP, Fujitsu and T-Mobile were plotted on the x-coordinate (abscissa) against the values of Dell on the y-coordinate (ordinate). Fig. 9 shows the result.
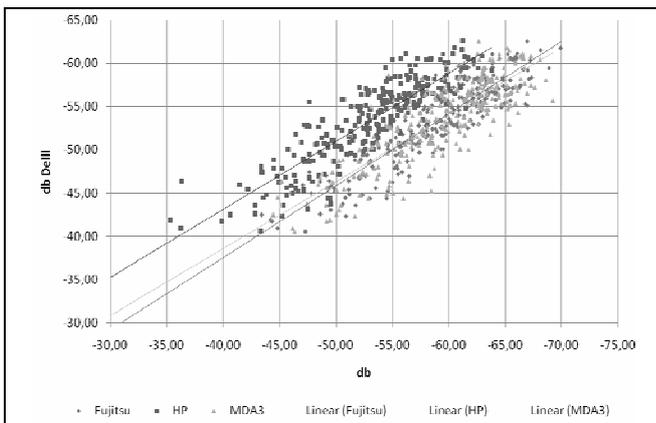

Fig. 9 - Scatter-plot of correlated RSSI-values

7. Results

The results of measurements concerning the accuracies of the three algorithms 'Bayes', 'Euclid'

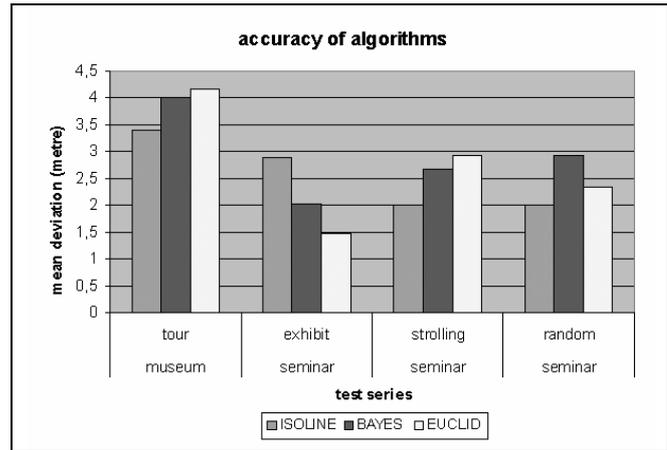and 'Isolines' arranged according to the different series are shown in Fig. 10.

Fig. 10 - Comparing the accuracies of three algorithms

Table 2 shows more precisely the average distance between measuring position and estimated position together with the corresponding standard deviation of a test series rearranged according to the different algorithms.

Table 2: Average difference between measuring and estimated position

	test series		mean (m)	standard deviation (m)
BAYES	Museum	tour	4,01	2,27
	Seminar	exhibit	2,03	2,34
	Seminar	strolling	2,67	1,40
	Seminar	random	2,91	1,56
EUCLID	Museum	tour	4,16	2,51
	Seminar	exhibit	1,47	1,27
	Seminar	strolling	2,91	1,15
	Seminar	random	2,33	1,51
ISOLINE	Museum	tour	3,40	1,71
	Seminar	exhibit	2,90	0,48
	Seminar	strolling	2,00	0,58
	Seminar	random	2,00	1,04

Table 2 and Fig. 10 show ambiguous results. There is no definite best algorithm. The isoline method has an advantage, since regarding the mean deviation it is three times on the first position, but after all at least once on the last position. Standard deviations seem to be significantly smaller for the isoline method in comparison to those of the other algorithms.

The measurements within testbed 2 ('museum') result in larger average deviations than those in testbed 2 ('seminar'). This may be due to the more inhomogenous environment of testbed 2. Testbed 1 is an empty room, testbed 2 a room containing several large exhibits.

In testbed 2 ('museum') we observe an average deviation between 3,4m and 4,16m depending on the selected algorithm, in testbed 1 an average deviation between 1,47m and 2,91m again depending on the algorithm.

The results of the regression analysis are presented quantitatively in Table 3. As shown qualitatively in Fig. 9 we can observe rather linear correlations between the RSSI-values measured by the Dell PDA and the other PDA.

Table 3: Regression analysis of RSSI-values

PDA	Correlation Coefficient	Correlation
Fujitsu-Dell	0,9036	y = 0,834x - 4,164
HP-Dell	0,8677	y = 0,787x - 11,648
T-Mobile-Dell	0,8252	y = 0,774x - 7,612

A good positive linear correlation between the signal level indices of the Fujitsu PDA and the Dell PDA is found. The correlation coefficient was calculated as 0,9036. The corresponding coefficients of the correlations HP-Dell and T-Mobile-Dell are calculated as 0,8677 and 0,8252.

8. Conclusion

The results of this paper show, that WLAN-RSSI based positioning can be achieved with commercially available Personal digital assistants without modification of hardware and software.

For the time being WLAN-RSSI-based fingerprint positioning technologies seem to be not accurate enough for disposal in position based indoor applications using personal digital assistants in all environments. In small and medium sized rooms the accuracy of positioning is not sufficient. Moreover, obstacles preventing line of sight transmission cause further detoriation of accuracy. Within larger rooms and a required accuracy of not less than 2-3 m WLAN-RSSI based indoor positioning can be used.

The comparison of the different PDA and their receiving capabilities shows a distinctive linear correlation. Correlation coefficients values of 0.9 (Fujitsu), 0.86 (HP) and 0.82 (T-Mobile) suggest a good positive linear correlation. This will lead to a considerable decrease in calibration workload and make fingerprint methods more applicable.

There are improvements possible by refining measuring technology. By using the framework OpenNETCF some series of measurements over time showed an unusual behaviour. RSSI-values did not change over a period of several seconds, whereas a change within a range of 3-5 db every second was observed usually. There is some evidence, that the used framework's methods are not mirroring instantly (within a period of a second or less) RSSI-value changes. The framework OpenNETCF has to be reexamined.

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