Performance and Accuracy Test of the WLAN Indoor Positioning System "ipos"

Guenther RETSCHER[1], Eva MOSER[2], Dennis VREDEVELD[3] and Dirk HEBERLING[4]

[1,2]Vienna University of Technology, Vienna, Austria, e-mail: gretsch@pop.tuwien.ac.at, mosere@gmx.at
[3,4]IMST GmbH, Kamp-Lintfort, Germany, e-mail: (vredeveld, heberling)@imst.de

Abstract – Location based-services and personal navigation require the location determination of a user not only in outdoor environments but also indoor. For indoor location already established wireless infrastructure such as WLAN (Wireless Local Area Networks) can be employed. This approach has the advantage that no costly hardware installations are necessary inside a building if WLAN is already available. The IMST GmbH has developed a software framework called "ipos" for indoor positioning technologies. The principle of the developed platform and the performance of the location determination using WLAN in a localization testbed of IMST GmbH are presented in this paper.

1 Introduction

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

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

The IMST GmbH has developed a software platform as a basis for the realization of LBS applications. It consists of an efficient, freely parameterizable framework, which is suitable for multiple application architectures. Thereby signal strength measurements are performed on user terminals, while evaluations and visualizations can take place if necessary on user terminals. The developed positioning system "ipos" makes use of a standard WLAN infrastructure and no modification of the hardware is required.

In a study the performance and the achievable positioning accuracies of the positioning system "ipos" have been tested. This study was conducted in cooperation between the Vienna University of Technology and IMST GmbH. The tests were performed in a localization testbed in an office building of IMST. Currently, the testbed is based on WLAN and uses standard IEEE802.11x WLAN hardware.

With seven access points an area of over 1500 m^2 is covered where the tests have been performed in an area half of the total covered size. The results of this study are presented in this paper. It is possible to localize a user in the testbed with an accuracy of better than 3 metres at a 90 % significance level. Of course, the original WLAN services are also still available.
Extensions of the testbed to include other localization technologies, e.g. ultra-wideband (UWB) localization, are currently under development. Figure 1 shows the "ipos" system design and the software framework. The software framework supports multiple localization techniques. For example, in the WLAN case, the user terminal measures signal strengths, while calculations and visualizations can be performed within the network or at the user terminal. Once the post-processing step is reached, all data is independent of its underlying wireless technology. Using different processing steps, the estimation can be adapted to the application's needs. Data fusion allows then for a seamless handover between multiple localization techniques.

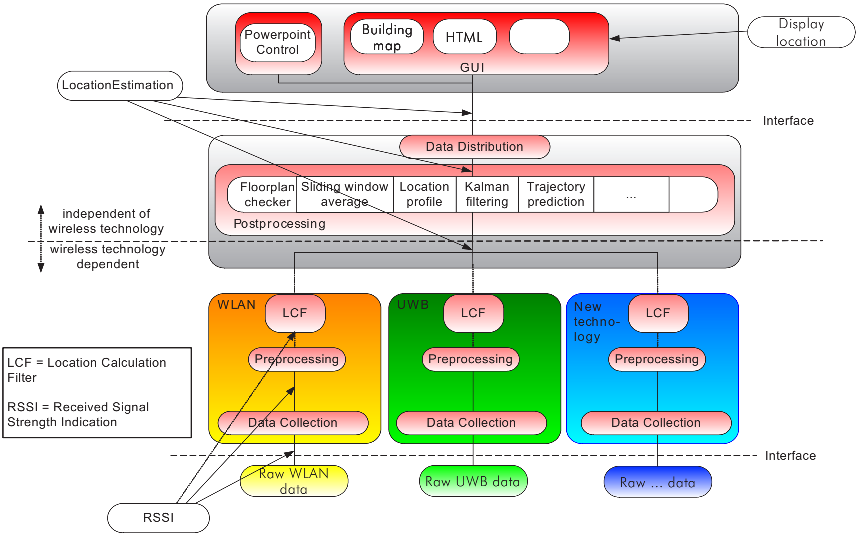

Fig. 1 The IMST *ipos* software framework

2 Principle of WLAN Positioning

The principle of WLAN positioning is based on the fact that the perceived signal strength of WLAN access points in the user's surroundings is a function of his position [2]. This location dependant information can be acquired from the WLAN device driver. A device driver may support two ways to obtain information that is relevant for our purposes: active probing and RF monitoring. During RF monitoring, which is also known as passive scanning, the WLAN device listens for beacon messages on assigned channels. These beacon messages are broadcasted periodically by an access point in order for a client to find potential access points in range to associate to. This is, for instance, necessary if the signal-to-noise ratio (SNR) of the signal from the client's current access point degrades and connectivity may be lost. The beacon messages received can then be used to initiate a hand-off to an access point with a better SNR. During active probing, which is also known as active scanning, the driver uses probe request frames on each channel where it is able to detect wireless activity. Every access point receiving this probe request will respond with a probe response frame. Both beacon and probe response packets contain the MAC addresses of visible[1] access points. The corresponding signal strength can be obtained through the services provided by the WLAN MAC-layer, see [3] for details. Once the scan command is completed, it results in a list of all visible access points with their current radio signal strength indicator (RSSI) for the current position. As the RSSI value is an indication on the relative position with respect to the corresponding access point, it is the main parameter the location calculation is based upon.

2.1 Location Calculation

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 RSSI values for visible access points at that particular location. This process is also known as *fingerprinting*. During the online phase, the calibration points are being used to calculate the most probable location of the user, whose actual location is unknown.

2.1.1 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 WLAN 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 [4][5].

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

2.1.2 Online Phase

As mentioned before, 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. The calculation is the central part of the *ipos* (Indoor Positioning) software framework, which will be explained in more detail in the following section. Details regarding the algorithms used can be found in [6].

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[1] In this context, visible means that the signal strength of this access points is larger than the noise level. The noise level is considered to be –97 dBm by default.

2.2 Software Framework

The methods described above have been integrated into a powerful software framework for indoor positioning technologies (see Figure 1). It represents a configurable, scalable, and open architecture for easy integration into third party applications on the one hand and adding more wireless localization technologies on the other hand. Running on Windows XP, Windows Mobile 2003, and Linux it supports a wide range of applications.

The framework can be divided horizontally and vertically. Horizontally, the different processing steps are displayed, while vertically different wireless technologies can be distinguished, e.g. WLAN and UWB. However, once a location has been calculated, there is no longer a difference between the wireless technologies and the vertical division no longer applies.

The different processing steps are organized as follows:

1. Data collection: this comprises the retrieval of the measured data from the device that is to be localized. In case of WLAN, this is a list of MAC addresses of access points with their respective RSSI values;
2. Preprocessing: contains any sort of preprocessing steps on the raw data obtained in the first step;
3. Location calculation (LCF): calculates the estimated location. The format of this location estimation is common to all localization technologies;
4. Postprocessing: contains any possible operation that may be performed on one (or more) calculated locations obtained from the previous step, e.g. a sliding average, trajectory prediction, etc;
5. Data distribution: receives the calculation locations and makes them available to client applications by means of a socket server;

For the test measurements that will be discussed in the following chapter, no pre- or postprocessing filters were used, as the aim of these measurements was to identify the accuracy of the location calculation as such.

3 Test Measurements

The WLAN positioning system "ipos" was tested in the localization testbed in the office building of IMST GmbH. Figure 2 shows the first floor of the building where 7 access points (● in Figure 2) are located that cover an area of approximately 1500 m^2. For the tests 7 office rooms (A, B, C, G, H, I and J in Figure 2) with an average space of around 25 m^2 each, two connecting corridors with about 15 m^2 each and a foyer with 100 m^2 (area D, E, F in Figure 2) were selected.

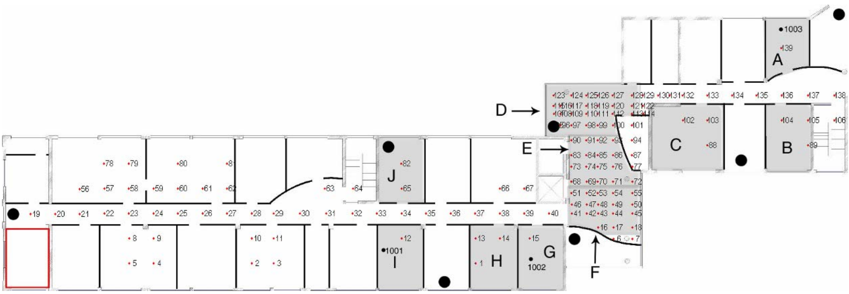

Fig. 2 Localization testbed in the office building of IMST GmbH

In the testbed standard IEEE802.11x WLAN hardware is used. For the measurements a tablet PC with a WLAN card was employed. The PC was put on a built trolley and was moved from each measurement to the next either in stop-and-go or kinematic mode. Figure 3 shows the measurements on a point in the corridor during the calibration of the system.

Fig 3 Measurement set up

3.1 Calibration Measurements

To use WLAN fingerprinting the signal strength values to all used access points have to be determined at certain locations in the building. These values are obtained during calibration measurements in the beginning and are stored in a database (see section 2.1.1). Thereby the result of the measurements depends on the orientation of the user. Usually the calibration measurements are performed in four directions (e.g. parallel or orthogonal to the main axis of the building). In addition, in some of the tests a fifth direction was used, i.e. the direction to the nearest access point.
Figure 4 compares the results of calibration measurements using 4 or 5 directions with the true location of calibration points in the building. It can be seen that there are only marginal differences between the use of 4 or 5 directions during the calibration. From this tests it can be concluded that the use of 4 directions in the calibration measurements is sufficient as the fifth direction does not improve the overall system performance but would require more time in the data acquisition.

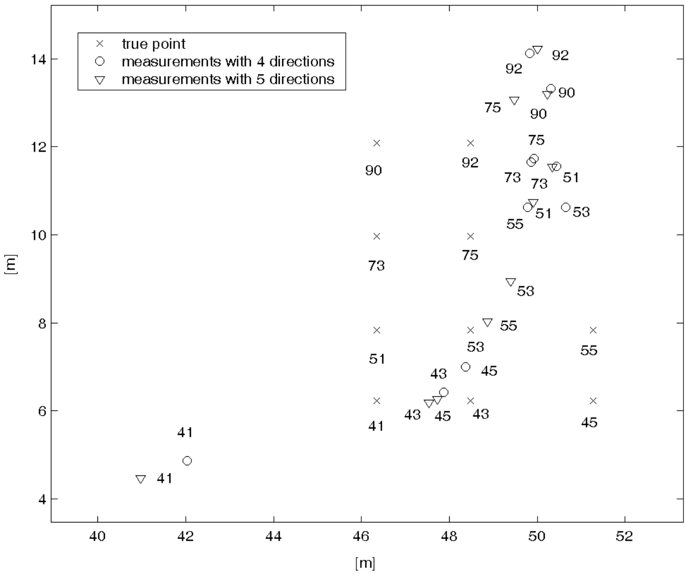

Fig 4 Calibration measurements with 4 and 5 directions

Furthermore different observation times on the points have been tested. For this purpose points in office rooms and the foyer were selected and observation times of 10 s, 20 s, 30 s, 40 s, 50 s, 60 s, 1 min 20 s, 1 min 40 s, 2 min were used. Figure 5 shows the standard deviations of the x and y coordinates of the measurements depending on the observation time (on the left the observations in an office room and on the right in the foyer are shown). Thereby the standard deviations in the x-coordinate are significant larger than of the y-coordinate for the observations in the office room. This is caused by the location of the calibration points, which results in a degradation of the x-coordinate. In addition, it can be seen that the standard deviations in the office room are larger than for the observations in the foyer. Reason for this is the larger number of calibration points in the foyer. In the office rooms, however, only one or two calibration points are used. As there is no significant difference for observations using 50 s and up to 1 min 20 s in both environments, usually an observation duration of 50 s was employed for the calibration measurements.

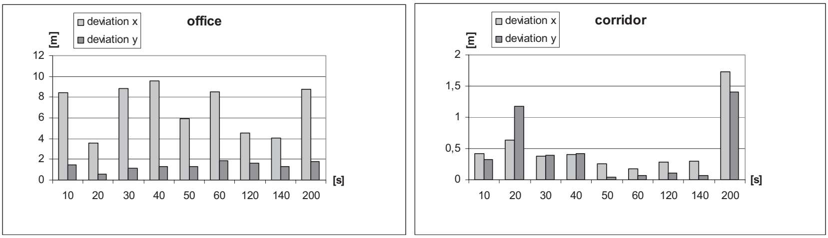

Fig 5 Standard deviations in x- and y-coordinates for calibration measurements with a duration of 10 s, 20 s, 30 s, 40 s, 50 s, 60 s, 1 min 20 s, 1 min 40 s, 2 min in an office room (left) and the foyer (right)

3.2 Location Determination of a User in an Office Building

In several tests the accuracy performance of the location determination of a user of the WLAN positioning system "ipos" was analyzed. In the following some tests results for the location determination of a user in an office room are presented. As the office rooms in the testbed have similar sizes apart from the foyer (i.e., 100 m^2), the foyer was divided into three areas (i.e., area D, E, F in Figure 2) of similar size to a standard office room. In the office rooms usually one or two calibration points are located. For the tests also a continuously moving user and a standing user were investigated. Exemplary Figure 6 shows the position fixes of a moving user in room A (for the location of the room see Figure 2) where on the left the position fixes using one calibration point and on the right the position fixes using two calibration points are shown. In both cases the majority of the observed points lies inside the room (86% in the case of 2 calibration points and 69% in the case of 1 calibration point). In addition, around the room a tolerance zone of double the room size was drawn. In this tolerance zone 98% of the position fixes are located if two calibration points are used and 82% if one calibration point is used.

Figure 7 summarizes all test results in the 7 office rooms and the 3 areas in the foyer (area A to J in Figure 2). Figure 7 shows the number of position fixes in % if one or two calibration points are used inside the room or defined area (Figure 7 left) or inside the tolerance zone (Figure 7 right). As can be seen from the diagrams, the probability that a position fix is located inside the room is higher if two calibration points are used. Thereby in 8 areas (out of 10) more than 50% of all position fixes are inside the room. If only one calibration point was used then only in half of the tested rooms more than 50% of all position fixes are inside. In room B and C only 10% of the position fixes were inside and in room I none of them. If the tolerance zone is considered the performance of the observations using only one calibration point is improved. The performance improvement is in average 22% (apart from room B). On the other hand, the performance improvement is in average 13% if two calibration points were used. It can therefore be recommended that two calibration points should be located in every room to have the majority of position fixes located inside the room. The tests have also shown that there is no significant difference between the observations in the standard office rooms and the foyer.

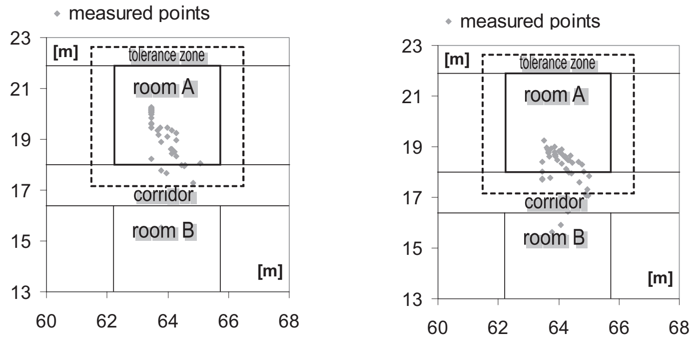

Fig 6 Position fixes of a moving user in room A using one (left) or two (right) calibration points inside the room

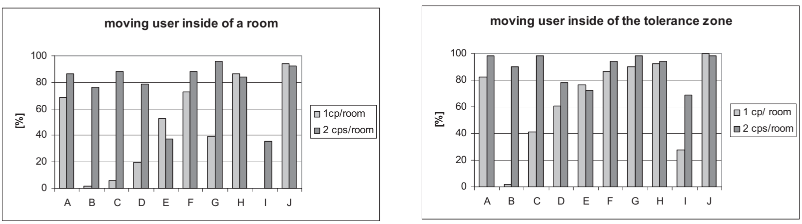

Fig 7 Position fixes of a moving user inside a room (left) or tolerance zone (right) where one or two calibration points (cps) are used

4 Outlook

For certain applications, an offline phase may be undesirable and/or more accurate positioning information may be required. Inherently, the radio channel between a transmitter (TX) and receiver (RX) contains information on the location of the one with respect to the other, which allows us to serve just these needs. To probe the channel, the TX has to radiate a pulse, such that the RX is able to measure the channel's response and obtain information on the radio channel and thus relative location. Typically, the radio channel consists of many multipath components, but the line-of-sight (LOS) component contains the most localization information. However, to isolate the LOS component from the rest, the pulse duration must be shorter than the typical delay difference between the LOS component and the first arriving multipath component. In indoor environments, the so-called rms-delay spread is typically (very) small, meaning that the delay introduced by individual radio path differs only slightly. As a result, pulse duration needs to be in the order of nanoseconds or smaller to avoid pulse overlapping[2]. The usage of short pulses inherently means that the bandwidth of the radio

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[2] In the case of WLAN, pulse-overlapping does occur, resulting in the distinct fading pattern as function of space, allowing us to do fingerprinting.

signal will be very large, i.e. in the order of several Gigahertz. In the past, no system was allowed to use such a large bandwidth, but after the legislation of UWB by the FCC in 2002 [11], and in the light of the upcoming legislation of UWB in Europe, industry and the scientific community quickly realized that accurate indoor localization can become reality, opening up a whole new application range.
To gather experience and to prepare for future developments, IMST initiated the project Puls-On [12] in August 2004, using a co-funding of the province of North-Rhine Westphalia. The goal of the project is to design an ultra wide-band localization system, able to localize in indoor environments. Furthermore, a fully functional demonstrator needed to be build using commercial-off-the-shelf (COTS) components.
To localize a single object or person, the Puls-On system uses three entities, mobile stations (MSs), base-stations (BSs) and a control station (CS). Each object or person to be localized has to carry such a MS, which periodically sends wideband radio beacons, which are used for both low rate but robust data communication and for localization. The base-station's function is to determine the angle of arrival (AOA) of the incoming radio beacons and to relay it to the CS.
To determine the AOA, the BS uses two patch antennas, separated by half a wavelength. The output of these antennas are processed by the modem to a) find the LOS component and b) to determine the related angle of arrival. Due to the large system bandwidth, the modem is able to distinguish individual radio paths. The CS is responsible for combining the AOA information in such a way that the location of all mobile-stations can be determined; and be visualized in a user-friendly form. For the computation of the location, the CS must receive the measured AOA from at least two base stations and needs to know the position and orientation of each BS. The usage of more BSs will inherently improve the accuracy/robustness of the localization.
In the Summer of 2005, the project was successfully completed, but the system is still under investigation and improvement. One of the upcoming tasks will be the integration of the Puls-On system with the ipos architecture. This enables the ipos software framework to benefit from increased accuracy and enables previously developed software components and algorithms to be re-used and applied on the Puls-On system.

5 References

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