Using Calibration in RSSI-based Location Tracking System

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Abstract: - This paper describes an enhancement method for location tracking system based on Received Signal Strength Indicator (RSSI)-values and Extended Kalman Filter (EKF). The enhancement is based on pre-calibration of measurement vectors and individual position block usage in final estimation of the target's position. The EKF and the described enhancement methods are used on a standard Wireless Local Area Network (WLAN) by software computing, thus omitting the need for hardware component additions. The paper will in addition to the enhancements review the effects of an office environment to the RSSI-values and present information concerning the effects of base station placement.

Key-Words: - WLAN, Positioning, Navigation, Tracking, Extended Kalman Filter, Calibration, RSSI

1 Introduction

The possibility of gaining additional value from pre-existing infrastructural components such as the WLAN by introducing only software computing blocks is both intriguing and easily implemented. Software calculated tracking in an indoor environment is possible using a set of Base Stations (BS) to pinpoint the location of a Mobile Station (MS). This is done by converting the readily available RSSI-values from each BS into range estimates. If the range estimates intersect each other in a common plane, it is possible to point out the most probable location for the MS in the intersection point. This triangulation method relies on continuous measurements from each BS, and that the measurements intersect each other. More often than not, the estimates do not intersect due to noise corrupted measurement vectors. The problem in RSSI-based tracking and positioning is the erratic behaviour of the 2.4 GHz frequency in an indoor environment. These inaccuracies in the perceived RSSI-values makes it virtually impossible to use any kind of closed form solution model to triangulate the position of the MS. Hence a recursive method capable of maintaining a position estimate must be used to guarantee state estimates even when no measurement vectors are available or they are highly corrupted by noise. The EKF is used to maintain the state estimate even when no measurements are available, and to cope with the inaccuracies of the RSSI-values. The state estimate obtained from the EKF is presented on a 2D map of the monitored floor [4]. In this paper we will introduce calibration as an enhancement method for the positioning system. The Implementation as well as obtained results will be presented.

2 RSSI behaviour in an office environment

The RSSI-values are measured in WLANs to monitor the signal link quality and transmission efficiency. It is a highly averaged indicator for distance approximations. Furthermore, it is slow in responding to sudden changes and occasionally fails to produce a measurement value at a given point of time.

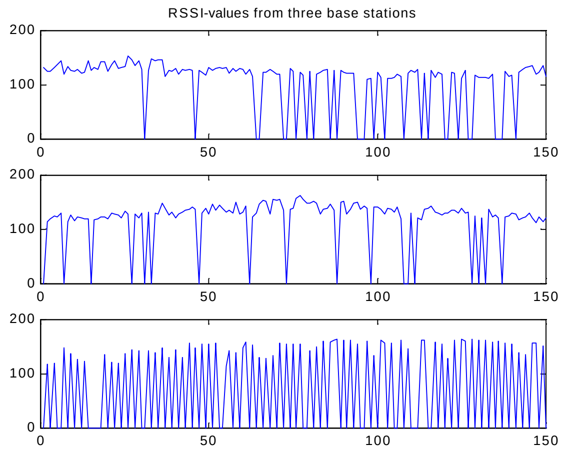

Figure 1. RSSI-behaviour in a test run.

Figure 1 shows the behaviour of RSSI-values in an office environment. The RSSI-values are gathered from three base stations. X-axis represents the number of requested RSSI-value and y-axis represents the strength of the measured signal. As can be seen in the figure, it is not always possible to get RSSI-values from the BSs. This is due to environmental facts and due to the nature of the 2.4 GHz frequency. At certain time instances, great fluxuations in the measured values were noticed due to human traffic in the office environment. As the tracking system used in this application is based on gathered RSSI-values, the characteristics of the signal strength relative to the distance from its source is of uttermost significance.

The used WLAN environment consists of Proxim's RangeLAN2 network interface cards (RL2 NIC). We used RL2 Access Point model 7520 as BSs and a RL2 6100 adapter in a laptop computer as MS. The antenna we used with the BS is a standard omnidirectional directly-connected antenna which is delivered with the basic RL2 package. RL2 NICs use Frequency Hopping Spread Spectrum technology (FHSS) and communicate with each other at 1.6 Mbps. To determine the effect of our office environment to the RSSI-values, we placed our BSs in static locations and ran a site survey program in our MS. By the means of the site survey program, we measured the RSSI-values between BS and MS. The measurements were made of the BSs signal strength differences, as the MS signal strength depends on several functions related to WLAN functionality. [1][4]

Between the measurements, we changed the location of MS in order to map out the effect of different materials and distances between the stations. The signal strength behaviour was as undeterministic as was expected. Due to multipath propagation, we got at times even stronger values when the distance between the stations was longer.

2.1 Different distances

Figure 2 shows a chart describing the results of our test. In the tests we measured the effect the distance has to the RSSI-value. We made the measurements in two different ways: first by keeping a clear line of sight (LOS) between BS and MS, and then another test where the BS was behind one concrete wall. The values presented in the figure are the averaged values from a measurement of 4 minutes. In this test, we noticed that when there is a clear LOS between the MS and the BS, the RSSI-values are fading so slowly that we can not use them to calculate distances.

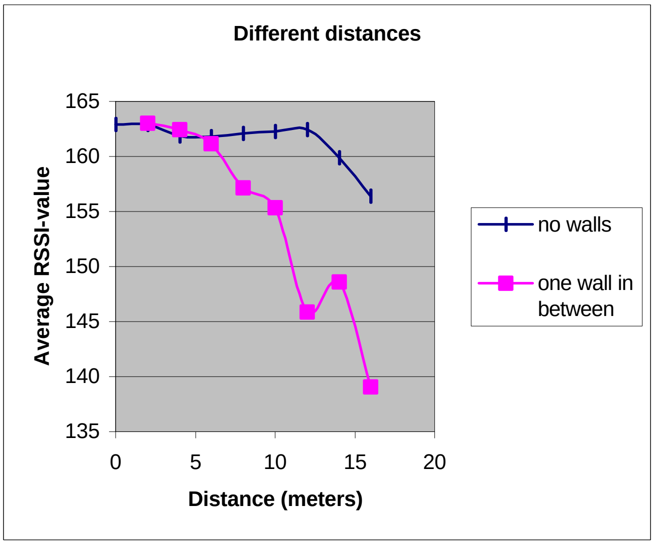

Figure 2. Different distances

Instead, there is a possibility to use this information in adding value to map based tracking possibilities. With relative sureness it is possible to state when a BS has a direct LOS to the MS. This information is useful only if each environment where tracking is performed is modeled accurately concerning the adjacent walls. The second test method where one wall was used between the stations proved out to be more interesting. The attenuation of the BS signal is following a near linear function. This information is used in pre-Kalman calibration.

2.2 Other observations

We performed also tests to find out how much height differences between BS and MS has relevance to the measured RSSI. We set the BS 1.5 meters above the floor level and then did our measurements 8 meters away from the BS. Three different measurements were performed: on the floor level, 1 meter above the floor, and 2 meters above the floor level. We found out that it has a great significance how high we keep the antenna of the MS. At the floor level the average RSSI was about 12 units weaker than the average RSSI at the highest position (2m). At one meter level, the measured RSSI was close to the value we got at the two meters level (2 units weaker).

The effect that multiple similar walls have to the signal attenuation was found quite linear. Depending on the wall material, one wall weakened the signal from 5 to 15 RSSI-value units. When we added another wall and about three meters of free space, the signal weakened another 5 to 15 units. Still, it must be noted that it is impossible to generalize the overall behaviour of the RSSI values, as there are several aspects that bias the attenuation. For example, when setting BS and MS on different sides of a corner, the situation isn't necessarily as clear as with one or two walls. We also found out that MS's different antenna positions don't have much effect on the perceived RSSI-values.

3 Extended Kalman filter

Due to the shortcomings of the RSSI-values, they can not as such be used for direct triangulation of the MS location. This is why a state-maintaining method must be used. We chose the Kalman filter to do this task. Kalman filter is a computational algorithm that provides a recursive solution for the optimal Linear Minimum Variance (LMV) of error estimation for system states. It processes measurements to deduce an optimum estimate of the past, present, or future of a linear system by using a time sequence of measurements of the system behaviour and a statistical model that characterizes the system and measurement errors. Furthermore, it needs information of the system in an initial state. The purpose of the Kalman filter is to assign the confidence levels of its own measurement estimation and measurement vectors. The assigned confidence levels depend on how many recent samples are available and how well they conform to estimated next turn measurements. The Kalman filter is a very versatile filtering technique which can be applied to estimation, prediction, noise filtering, and stochastic control. It has been proven to provide an optimal stochastic solution to these kind of problems [2][3]. Kalman filters have also been widely used in a different kind of tracking applications. When the corrupted measurements are averagely distributed around the true position (white noise assumption), the Kalman filter is able to find the true values.

The basic Kalman filter assumes a linear relationship between state-vector and measurement-vector. However, this is not the case in our system. In order to utilize Kalman filter equations in the non-linear case, we have to linearize these non-linear equations. The linearization is accomplished using Taylor series expansion. This linearized form of the filter is called extended Kalman filter(EKF). [4]

Although the Kalman filter is able to use all the information about the movement including speed and acceleration, we have decided to use only the position information. This is because we are dealing with human targets and we trust that they move with relatively slow speeds and acceleration is virtually of no consequence.

The Kalman filter is very good in establishing a reasonably sensible location estimate for the target. Great care must though be given to minimize the systematic error of the measurement vectors in order to gain the most from the Kalman filter. Methods for accomplishing the minimization will be treated in the next section.

4 Calibration

It was found in the tests that the quality of the position estimations could be significantly enhanced by means of a simple calibration operation. The calibration must be performed whenever the tracking system is installed in a new environment or whenever the environment is considerably altered. Several possible alternatives were considered to be used.

One potential calibration method considered was a "wall count" –method, where we use the information we gain from the predefined floor plan and latest location estimate. Knowing the number of walls between the latest location estimate and a BS, we could correct the RSSI-value in a way that it could be rightfully compared with RSSI-values gained from the other base stations. This method could also be reversed in a way that the correlation between the measured RSSI-values and the true location on a predefined map is sought. The location on the map could be sought with help of the information on the signal attenuation caused by walls. Such map matching algorithms have been used in other kind of systems [5]. The greatest advantage of this kind of calibration method is that no additional test run or environment configurations are needed after the floor plan for the location tracking environment is drawn. However, due to the varying signal attenuation that we measured for different walls in our test runs, we decided not to rely on this method as the main calibration system. The "wall count" – method is not valid without more specific floor plans. Such more specific floor plan should also consider all different wall materials, windows, doors and different metallic objects as cabinets or bookcases etc. [6]

The second alternative method we tested was to derive an alteration function between the measured and the real distance between the MS and BS. The obvious problem in this kind of approach is the presumption of homogeneous wall material and formation placement. As such these results were greatly location bound and gave poor results. The alteration function gave good results in some part of the building while at the same time resulted in non-intersecting reception estimates in another part. It became evident that a location based adaptive filter was required.

The building floor used for tracking is divided into different blocks. Figure 3 shows floor plan with 5 blocks drawn with dashed line. The numbers below the picture show the dimensions in meters. These blocks are manually selected in a calibration tool designed for this purpose.

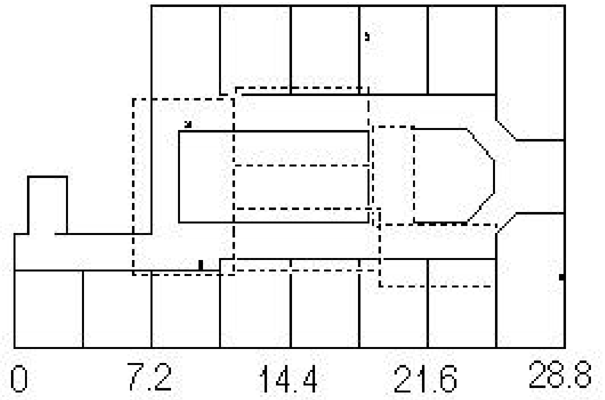

Figure 3. Floor plan divided to blocks.

Method **A** is based on selecting one point in each block and calculating the alteration function based on the measured and the real distance from that point to BSs. This solution model suffers from the same kind of accuracy problems as a general alteration function. If an infinite amount of processing power was available, the best results would be obtained by creating a filter for every 2D point in the environment. As this is not the case, alternative approaches had to be considered. In method **B,** a testpath is walked in the tracking environment, and the alteration function in each block is calculated with the information of the real and measured vectors. Basically, this method interpolates between the measured points in each block to obtain a continuous alteration function. To use this method effectively, the timing must be precise, but the results surpass the results obtained with other methods.

The function used to describe the relationship between the measurement and real vector is parametrized as a first order linear function. This was deemed to be an adequate accuracy concerning the overall accuracy of the RSSI-values. During the calibration, the alteration functions are calculated from each block to each BSs. When the actual tracking and positioning is performed, the system selects the appropriate alteration function based on the Kalman filter's current position estimate, i.e., the block. If the position estimate is outside all defined blocks, a common alteration function is used. After the usage of the alteration function, the converted measurement vectors are inputted into the Kalman filter. The accuracy of the overall system has doubled since the introduction of the block calibration system giving us a mean absolute error of 1.5 meters in an office environment. The accuracy can be emphasized further by reducing the size of the calibration blocks and thus focusing the preciseness of the used alteration function. Table 1 describes the different steps in the tracking system.

Table 1: Tracking steps

System initialization	Generation of the floor plan. Selection of the proper blocks.
System calibration	Test runs in each block. Adaptive filter function derivation in each block.
Obtaining RSSI-values from the BS	Measurement of RSSI-values and propagation to the central unit.
Converting of RSSI-values to distances	Depending on the previous position estimate determine which function is to be used for conversion.
Kalman filter calculates next estimate	Distance measurements are inputted to the Kalman filter and depending on these measurements and the previous estimates the Kalman filter gives the next position estimate.

5 Conclusion

The RSSI-based tracking system is easily implemented on any existing WLAN environment and offers as such additional value to pre-existing infrastructural networks. By using the described calibration method, the accuracy is high concerning the reliability of the measurement vectors. An mean absolute error of 1.5 meters in an indoor environment is enough to pinpoint the corridor or room, where the target is located. The calibration method is required for successful tracking in a new environment. The value of the block method is emphasized in heterogeneous environments, even though benefits from its usage can be observed in any environment.

This project is done in collaboration with Datex-Ohmeda Instrumentarium. It aims to introduce a tracking system to be used in conjunction with a telemetric device. The focus of the tracking system is to be able to track human targets within a rooms accuracy.

References:

[1] Proxim. *”Proxim RangeLan2 OEM Developer Design Guide”*, May 30, 1997.

[2] Houles A., Bar-Shalom Y.”Multisensor Tracking of a Manouvering Target in Clutter”, *IEEE Transactions on Aerospace and Electronic Systems*, Vol. AES-25, No. 2,March 1989.

[3] Bar-Shalom Y., *”Tracking and Data Association”*, Academic Press Inc., 1988.

[4] Latvala J., Syrjärinne J., Ikonen H., Niittylahti J. ”Evaluation of RSSI-based Human Tracking”, *European Signal Processing Conference*, 2000, pp. 2273 – 2277.

[5] Saab S. S. ”A Map Matching Approach for Train Positioning Part I: Development and Analysis”, *IEEE Transactions on Vehicular Technology* , Vol. 49, No. 2, March 2000, pp. 467 - 475.

[6] Tarng J.H., Liu T.R., ”Effective Models in Evaluating Radio Coverage on Single Floors of Multifloor Buildings”, *IEEE Transaction on Vehicular Technology* Vol. 48, No. 3, May 1999, pp. 782 – 789.