An Indoor Localization System Based on DTDOA for Different Wireless LAN Systems

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Abstract - Location awareness is a basic need for future wireless systems. In this paper we use the time measurement principle DTDOA and discuss a solution of time measurement based on an add-on correlator module in an IEEE 802.11a receiver. Furthermore, we investigate the performance of an indoor localization system for a Gbit/s, 60 GHz high-performance wireless LAN, currently under development. Simulation results demonstrate that carefully selected patterns and small modifications of the OFDM receiver would allow the implementation of the entire localization procedure using existing hardware.

1 Principles of differential time difference of arrival (DTDOA)

The localization is based on distance measurements between a point at an unknown position of a mobile transceiver (MT) and points at known positions (access point, receiver base station BS). In practice, the propagation time of an electromagnetic wave is measured to calculate the distance. It requires the knowledge of the starting time at the transmitter and of the time of arrival (TOA) at the receiver. Our setup consists basically of at least four base stations and one or more mobile transceivers. Fig. 1 gives an impression of the setting. By using the DTDOA scheme the base stations do not need a costly synchronisation in time. The master base station sends a request using a pseudo noise (PN) data sequence, the mobile transceiver react with a response using the same PN sequence. Afterwards the host PC collects the measured time differences of the arrival of the request and the response data of all base stations to calculate the position of the mobile transceiver.

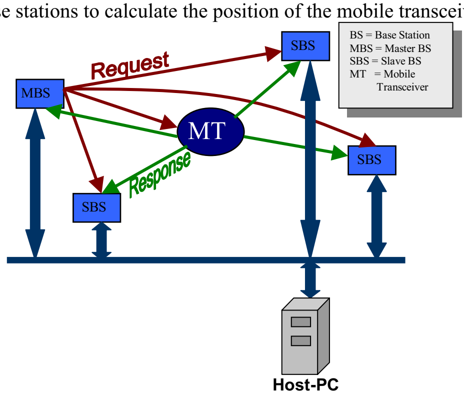


Fig. 1 Localization architecture

The DTDOA measurement method, error terms, the effects of clock accuracy and multipath propagation were previously discussed for a Bluetooth scenario [1] and an OFDM scenario [2]. Carefully selected positions for the access points (i.e. corners or edges) and directed antennas can reduce multipath errors, resulting in an accuracy <2 m for a Bluetooth localization based on DTDOA.

2 Measuring of time of arrival in OFDM systems

2.1 TOA detection with a dedicated time-domain correlator chip

A high resolution cross-correlator is necessary to achieve time resolution adequate for the localization procedure. Such a complex cross-correlator requires a large number of complex multipliers and large adder trees. If only the time information of a maximum correlator peak is sought an important simplification can be applied – the usage of binary samples, calculated by a signum function. A MATLAB simulation was used to determine the advantages and disadvantages of such simplifications. The simulation is based on 802.11a PHY parameters. We use a carrier frequency of 5 GHz and a sample frequency of 20 MHz. The correlator uses a four times oversampled sequence (80 MHz sample frequency), which corresponds to a time resolution of 12.5 ns (3.75 m). A QAM-64 modulation was used for transmission. The 802.11a forward error correction (FEC) and scrambling has been omitted. In a first simulation, using a best case scenario with 6 base stations, a room size of 4x3x2 m (Fig. 2), and an ideal transmission channel, we achieved an accuracy of <2 m in about 70% of the simulated cases.

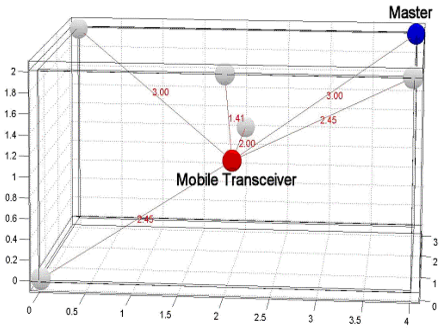


Fig. 2 MATLAB simulation test scenario, room size either 4 x 3 x 2 m³ or 20 x 15 x 10 m³

Ideally, a localization system should calculate positions accurately and consistently from measurement to measurement. For example, a simple base station can identify positions within an accuracy of 2 m for approximately 50% of the measurements. More complex systems usually provide much better results, reaching 1 m accuracy at 75% of the measurements. As described in [4] the distance denotes the accuracy for a single measurement and the percentage denotes the precision, i.e. how often we can expect that accuracy. The following simulation experiment is to obtain statistical results about the precision and accuracy.

Some impact on the precision is caused by the algorithm, that is used to solve the set of equations. Depending on the optimisation task to be performed, the algorithms are quite sensitive to the chosen initial values. For this reason the precision decreases in a simulation for a five times bigger room, as shown in Fig. 3. In our simulation environment the best results were achieved by the Levenberg-Marquardt method from the MATLAB optimisation toolbox.

In this simulation an additive white gaussian noise (AWGN) channel was used and the positioning algorithm has been applied 50 times for each of the four different SNR levels from –10 dB to +50 dB. As a result we get a precision of around 50% at an accuracy of less than 2 m and a SNR of >10 dB (see Fig. 3).

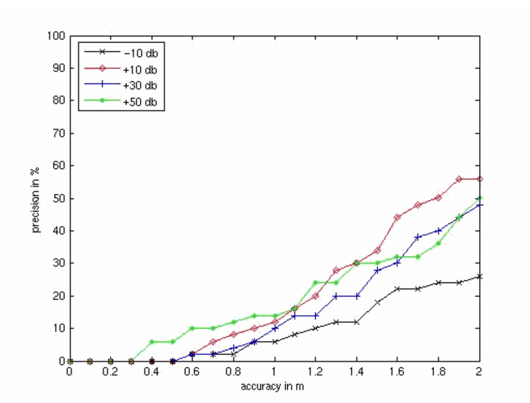


Fig.3 SNR-dependent precision of the localization system in a room of 20x15x10 m

For some indoor applications this performance may be not sufficient. To further enhance the precision and accuracy, multiple position measurements can be combined. Under the assumption, that all time stamps of multiple measurements are equally distributed around the real TOA, we can improve the time resolution and hence the position accuracy by averaging those time stamps. The SNR has been constantly set to +10 dB. The result of this simulation is shown in Fig. 4.

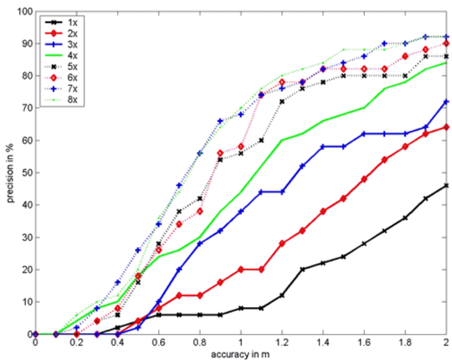


Fig. 4 Precision vs. accuracy for multiple accumulated measurements in a room of 20x15x10 m

It can be seen, that the accumulation of multiple measurements can enormously improve the localization performance. In over 90% of the cases the accuracy of 2 m can be achieved for the 8x

measurement. Even 1 m accuracy is possible with around 75% precision. Fig. 4 also shows, that the impact of additional measurements decreases with the number of measurements performed. E.g. the advantage of 8x measurements over the 5x measurement is insignificant.
Finally, the accumulation of multiple measurements turns out to be a very flexible tool to adapt the localization performance on the users requirements independent of the available bandwidth of the underlying radio technology.

2.2 Reducing the influence of frequency and phase shifts

The oscillator's phase noise and the missing synchronization between the modulation and demodulation clock have an important effect on the received signal quality. Normally, the frequency offset will be corrected during the synchronization procedure in the receiver. However, since the time synchronization is often coupled to the frequency synchronization, we have to sample the data stream before the synchronization process to feed the correlator. This has severe consequences for the correlation. In simulation experiments, the cross correlation yields no useful results for frequency offsets of more than 50 kHz. For a 5 GHz oscillator this is equivalent to a phase stability better than 10^{-6}. This is difficult to achieve and hence, would be very costly. That's why, we decided to omit the signal phase as information carrier and place all the data of the correlation pattern in the signal amplitude. From that point of view a binary 0/1 PN sequence would suit very well, but because the mean value is not zero like a +1/-1 PN sequence, it isn't suitable for data transmission over the wireless channel. Using a ternary +1/0/-1 PN sequence for transmission and its absolute value for correlation is the best compromise, that combines the advantages of both binary sequence types. Let X_n and Y_n be two different equally distributed 0/1 PN sequences. Then a ternary sequence T_n, that consists of 25% +1, 25% -1 and 50% 0 can be generated as follows:

$$T_n = X_n \cdot (2Y_n - 1)$$

Fig. 5 shows the results of a series of 50 position estimations per curve for the scenario with a room size of 20x15x10 m for an ideal transmission channel.

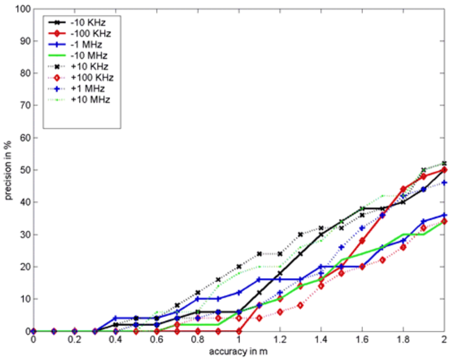


Fig. 5 MATLAB simulation results for 802.11a PHY parameters and different frequency offsets

This estimation is very robust to frequency variations of the receiver's oscillator. Even a very high offset of +/- 10 MHz doesn't significantly deteriorate the correlation result and thus, the localization performance. In all cases an accuracy of 2 m or better was achieved with a precision between 35% and 50%. As simulation shows, ternary sequences can be used for the cross-correlation to eliminate the need for a preceding frequency synchronization. To be able to deal with ternary sequences in hardware, special window comparators must be used for A/D conversion. The resulting ternary output will be converted to the absolute value and then fed to the correlator as illustrated in Fig. 6.

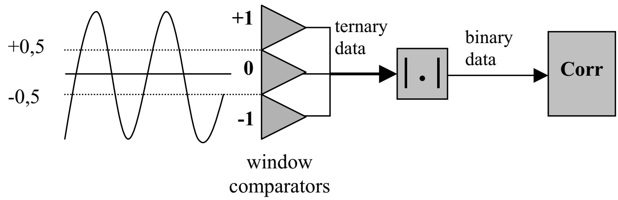
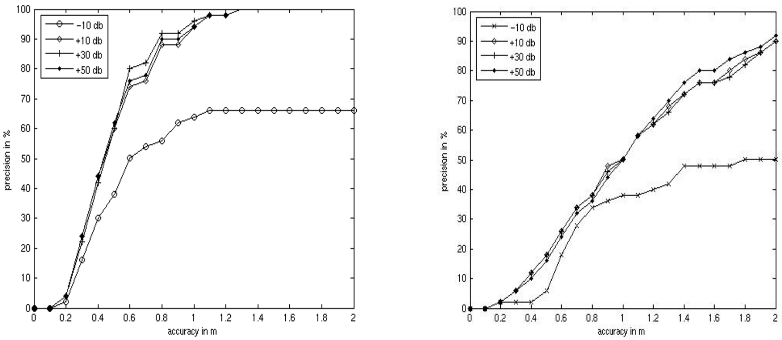


Fig.6 Window comparators for the computation of ternary correlation patterns

2.3 MATLAB Simulation model for localization in high-performance OFDM Systems

Prospective OFDM systems with data rates up to 1 Gbit/s require high sampling frequencies. We used a MATLAB model to find out the benefits of this approach. Two scenarios with six base stations (Fig. 2) were used for the simulation model of the 60 GHz OFDM baseband system as outlined in [5]. In our simulation model the position of the mobile transceiver was changed randomly and the localization was measured. We get the percentage of localization results that do not exceed a given accuracy. As shown in Fig. 7 a SNR of –10 dB reduces the precision to 60 %. Comparing Fig. 7b to the results at Fig. 3 we can expect an obvious better localization precision. This can be improved further on using multiple measurements as described in 2.1.



a) b)

Fig. 7 Precision depending on the required accuracy for different SNR in different scenarios: (a) in a small room (4 x 3 x 2 m³) and (b) in a bigger room (20 x 15 x 10 m³)

3 Improvements

Normally, the calculation of the position of the mobile transmitter is a set of spherical equations. Missing clock synchronization of all base stations causes a bad conditioned equation system. For reliable results an efficient equation solver (e.g. Levenberg-Marquardt) is essential. We suggest to solve this problem by reducing the measured time stamp values. This can be done by using the initial conditions from a formerly calculated position of the mobile tranceiver or from the maximal distance in a room (e.g. the diagonal line). With this initial condition, the standard method of least squares can be used to calculate the position. Furthermore, using more than 4 base stations gives an overdetermined set of equations which increases the accuracy.

Further improvements can be achieved using a position prediction. A suitable simple position prediction was presented in [3]. Depending on the parameters for position update and position prediction the precision can be enhanced up to 85 %.

Combining all presented methods – difference time measurements, suitable patterns for a robust and fast correlation, wireless LAN with increased bandwidth, numeric simplification position prediction – we can perform indoor positioning at a quality sufficient for most applications.

4 Conclusion

For the definition of future wireless LAN standards, localization aspects should be taken into consideration at an early stage. It has been demonstrated, that a position estimation based on IEEE 802.11a wireless LAN with an accuracy of <2 m is possible using the DTDOA principle. This can even be further improved by accumulation of multiple measurements. The problem of missing frequency synchronization can be solved using a ternary correlation pattern. In particular, localization-friendly training sequences can significantly enhance the performance of the algorithms. The simulation results yield localization accuracies of about 2 m (IEEE 802.11a) and 0.5 m (60 GHz OFDM) for indoor purposes. This can be achieved without the use of the unreliable receive signal strength indicator (RSSI).

5 References

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