Study and Simulations of an Angle of Arrival Localization System for Indoor Multipath Environments

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Abstract. Present-day RF indoor localization systems generally underperform due to multipath propagation. This paper presents a new localization method based on Angle of Arrival estimation and ray tracing. This system exploits the reflections that are generally considered as a burden in conventional systems. In order to design the proposed system, a virtual test bench is created that enables adjusting all parameters. This test bench is then used to evaluate various antenna array elements. Also the Beamscan, MVDR, MUSIC and ESPRIT angle of arrival estimation algorithms are being tested and the effect of spatial smoothing is studied for each of these algorithms. The tests demonstrate that directional microstrip patch antennas result in the best array response for the proposed system and that spatial smoothing is indispensable in multipath environments.

Keywords. Angle of Arrival, Antenna array, Localization, Multipath

1. Introduction

In modern network applications, information on the location of persons and objects is very valuable. Several indoor positioning systems are commercially available, but they generally underperform and require expensive installations that need ad hoc tuning (Hui et al. 2007). Most of these systems are based on Received Signal Strength (RSS) measurements of electromagnetic signals, relying on the decreasing signal strength with increasing distance. Other systems use Time (Difference) Of Arrival (T(D)OA) technology, measuring the travelled time of the signal. However, these technologies suffer from reflections, scattering, diffraction and fading in indoor multipath environments, where line-of-sight connections are scarce

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(Sayed et al. 2005, Seybold 2005). In this paper, a new kind of indoor positioning system is proposed that exploits the reflections of electromagnetic waves in indoor environments. The considered system consists of a phased antenna array at a fixed location in a room and a mobile omnidirectional transmitter. The array is used for Angle Of Arrival (AOA) estimation of the received signals with beam forming techniques (Munoz et al. 2009). With this information and a detailed map of the environment with its reflecting obstacles and the position of the antenna array, ray tracing algorithms can determine the actual position of the mobile transmitter. Unlike T(D)OA or RSS techniques, the proposed technique could even enable accurate indoor positioning in non-line-of-sight situations.

In order to develop the proposed system, the influence of all design parameters on the system performance should be evaluated in a reference environment. This paper presents the first results of this evaluation with a virtual test bench in computer simulations.

This paper is organized as follows. Section 2 details the system setup and all the configurable parameters. Section 3 explains the tests that were carried out and the performance of the system in different configurations. Section 4 contains the conclusions and future work.

2. System setup

2.1. Proposed system

Figure 1 represents a basic configuration of the proposed system. It consists of a rectangular room with a mobile omnidirectional transmitter. A receiving antenna array is positioned in a corner of the room. It is positioned under an angle of 45°, so all signals impinge under an angle of -45° to +45°. Due to this restriction of the field of view, a higher accuracy and/or resolution can be achieved, as discussed in (Van Trees 2002). Figure 1 depicts a situation in which a line of sight signal is received by the array, together with two first order reflections. In order to detect D signals, the array should consist of M elements, with M>D (Chen et al. 2010). When the directions of these signals are determined with an AOA estimation algorithm, the location of the transmitter can be traced back with ray tracing techniques. In order to dimension this system, a virtual test bench was designed as detailed in section 2.2.

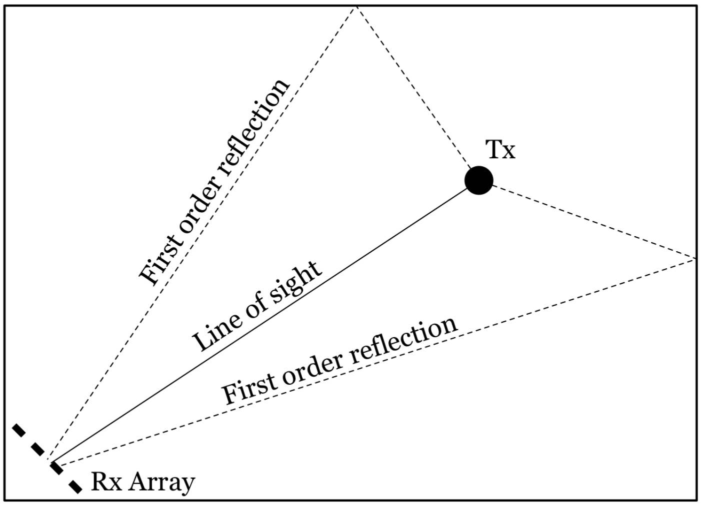

Figure 1. Proposed system architecture

2.2. Virtual test bench

In the first phase of testing and dimensioning the system, the antenna array and AOA estimation algorithms are simulated in order to evaluate their behavior in different configurations and for different incoming signals.

The model of the antenna array features a uniform linear array with an adjustable number of array elements and adjustable inter-element spacing and operation frequency. In standard configurations, frequencies of 2.4 GHz or 5.8 GHz are chosen because this simplifies future hardware implementations, given the commercial availability of components for these frequencies. Furthermore, this results in a feasible array size for indoor use. Standard inter-element spacing is λ/2 to prevent grating lobes (Van Trees 2002). However, inter-element spacing can be adjusted if a smaller field of view is allowed. The elements themselves can also be defined by inserting their radiation pattern. Currently tested options include an isotropic radiator, a half-wavelength dipole, a wavelength dipole and a directional microstrip patch antenna.

Apart from setting these array parameters, it is also possible to define multiple impinging signals by their angle of arrival, signal strength and delay. These inputs can be coupled with the outputs of a ray tracing algorithm, but this is considered as future work. In standard simulations, the signal is defined as a carrier with a certain signal power, attenuated by a free space loss that is calculated from the travelled distance, and an extra loss due to reflections at material boundaries. Apart from these signals, a noise source with selectable noise power (standard −75 dBm) is included. The resulting signals are combined and sampled at each array element, taking the radiation pattern of the elements into account. The data that is obtained in this way, can then be processed by an AOA estimation algorithm. The implemented algorithms include non-parametric methods, such as the Minimum Variance Distortionless Response (MVDR) or Capon method, and the Beamscan method (Munoz et al. 2009, Van Trees 2002). Parametric methods that were implemented, include the Multiple Signal Classification (MUSIC) algorithm (Spielman et al. 1986) and the Estimation of Signal Parameters via Rotational Invariance Techniques (ESPRIT) algorithm (Roy & Kailath 1989). In order to improve the performance of these algorithms, a technique called spatial smoothing was implemented for these algorithms. This technique improves AOA estimation of correlated sources, which is useful in multipath environments where reflected signals are highly correlated.

3. Simulation results

In order to develop the proposed system, the influence of the design parameters is investigated with the help of the developed virtual test bench. This paper shows how various array elements influence the array's response. Also the performance of the AOA algorithms is investigated, as well as the influence of spatial smoothing.

3.1. Array elements

In the virtual test bench, standard simulations are performed with isotropic radiators as array elements. The response pattern in the 0° elevation plane for such an array with 10 elements, steered at 0° azimuth, is shown in figure 2. It is clear that the array response is symmetric along the -90° ... 90° azimuth axis, which means that no distinction can be made between signals arriving on the front and the backside of the array. This is a very unfavorable situation, since all signals impinging on the front of the array will also reflect against the wall and impinge again on the backside, given that the array is located in a corner of the room, as visualized in figure 1. The same response pattern is obtained in the 0° elevation plane when the isotropic radiator is replaced by a (half) wavelength dipole.

In order to solve this problem, the array elements are defined as directional microstrip patch antennas. The resulting array response in the 0° elevation plane is depicted in figure 3. This configuration is not sensitive to signals arriving on the backside of the antenna. Also, the array is less sensitive to signals arriving at more than 45° from the 0° azimuth axis. This characteristic is not disadvantageous in the given configuration, since the field of view is defined from -45° to 45° azimuth.

We can conclude that the use of directional microstrip patch antennas is the best of all considered options, given the insensitivity to signals arriving on the backside of the array.

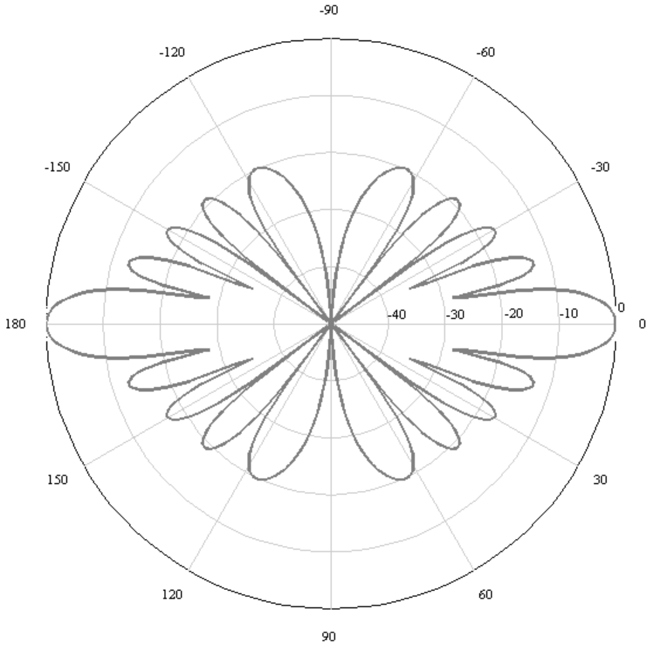

Figure 2. Response at 0° elevation for array with isotropic elements, steered at 0° azimuth

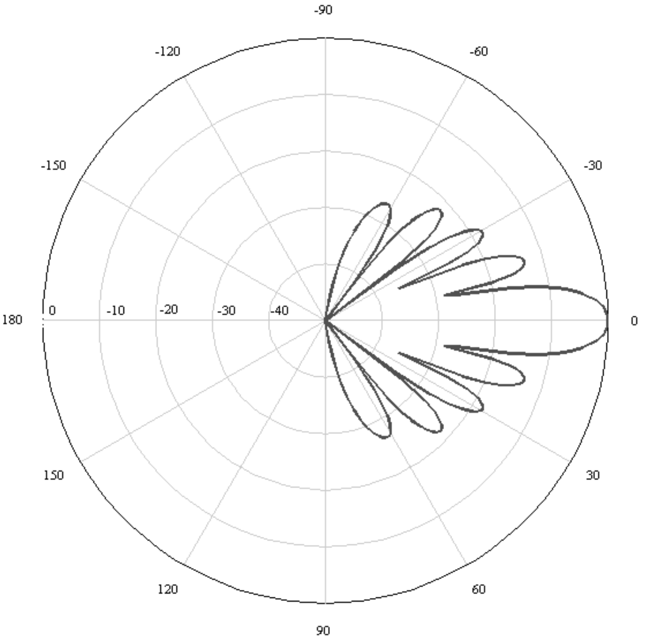

Figure 3. Response at 0° elevation for array with directional microstrip patch antenna elements, steered at 0° azimuth

3.2. Performance of AOA algorithms

The test bench includes 4 AOA algorithms in order to determine the directions of incoming signals. However, the performance of these algorithms degrades when signals are correlated (Van Trees 2002), which is the case in indoor environments, where multiple (reflected) signals descend from the same source. Spatial smoothing can be applied in order to decorrelate the signals, but one has to remark that every decorrelation is equivalent to reducing the array with one antenna element. This results in one less signal that can be distinguished.

In order to test the AOA algorithms, a setup was configured in the test bench, with a direct signal impinging at 10° azimuth and a reflection at -30° azimuth. The goal of this test is to compare the performance of the AOA algorithms, with or without spatial smoothing.

Table 1 displays how much the reflected signal can be attenuated, compared to the direct signal, while still enabling a correct AOA estimation.

	Beamscan	MVDR	MUSIC	ESPRIT
No spatial smoothing	-5.2 dB	-5.5 dB	-	-
Spatial smoothing	-6.6 dB	-53 dB	-63 dB	-55 dB

Table 1. Attenuation of the reflected signal that still results in a correctly estimated AOA

The table shows that the MVDR algorithm performs best of all when no spatial smoothing is applied. A reflection can be attenuated up to 5.5 dB and still be detected. The parametric methods (MUSIC and ESPRIT) exhibit a different behavior. When no spatial smoothing is applied, they cannot correctly determine the AOA of as well reflected as direct signals.

When spatial smoothing is applied, the performance of the algorithms is generally increased dramatically. The high resolution parametric methods function precisely, even with strongly attenuated reflected signals. Only the Beamscan algorithm shows a minor performance improvement.

These results are further demonstrated in figures 4 and 5. These figures display the spatial spectrum for the Beamscan and MVDR algorithm, without and with spatial smoothing. The largest peaks in these spectra represent the AOA and should therefore be located at -30° and 10°. Parametric methods are not represented because they don't use spatial spectra.

Figure 4 shows that a 5.2 dB attenuated reflection is nearly undetectable without spatial smoothing. But when spatial smoothing is applied, the -30° peak becomes more pronounced. Figure 5 shows a more apparent influence of spatial smoothing for the MVDR algorithm. Not only do peaks in the spatial spectrum become more pronounced, they also narrow, enabling more precise AOA estimation.

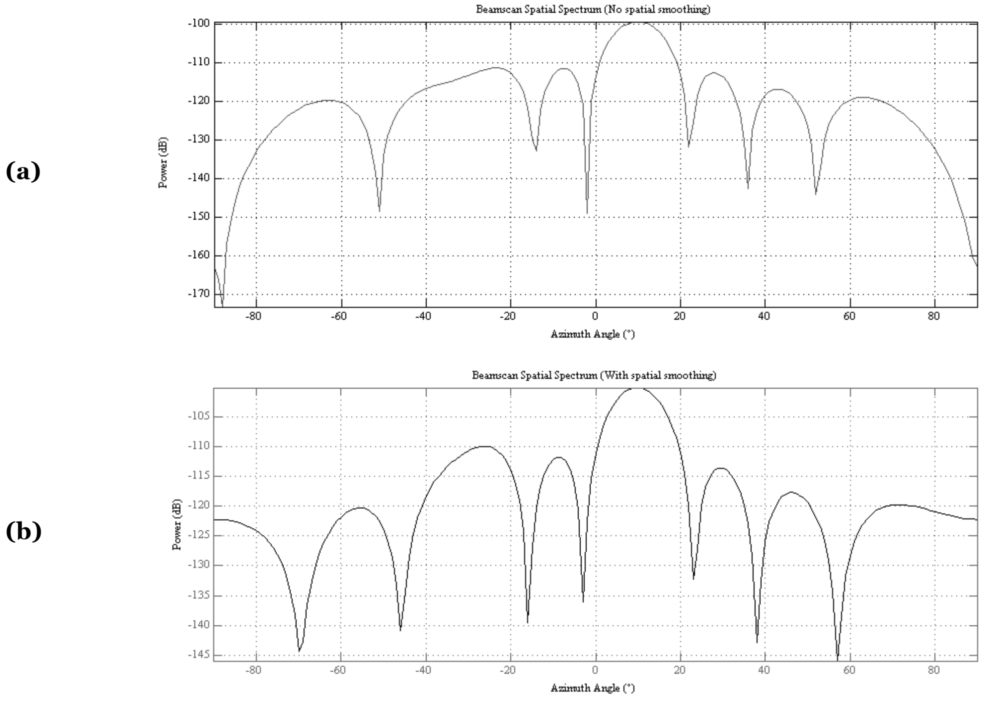

Figure 4. Spatial spectrum for Beamscan algorithm without (a) and with (b) spatial smoothing

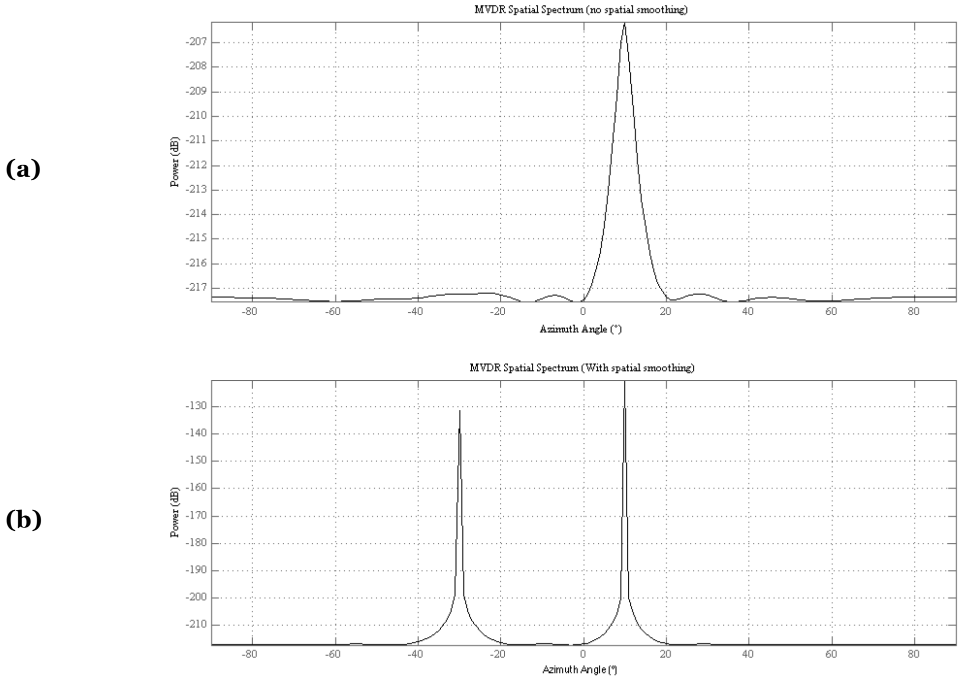

Figure 5. Spatial spectrum for MVDR algorithm without (a) and with (b) spatial smoothing

4. Conclusions and future work

A new type of indoor localization system that exploits reflections in multipath environments was proposed. A virtual test bench was created in order to evaluate and lay down system parameters. This test bench was then used to evaluate various antenna array elements. A directional microstrip patch antenna showed to be the most appropriate option, since it eliminates the array response at the backside of the array. Also the performance of different AOA algorithms was investigated, with or without spatial smoothing. It was shown that MUSIC and ESPRIT underperform in multipath environments when spatial smoothing is not applied. MVDR performs well with spatial smoothing and without this technique, it still exhibits the best results. Furthermore, the value of spatial smoothing in combination with the Beamscan algorithm appears limited.

Future work involves the investigation of other design parameters (e.g., the operation frequency, inter element spacing, signal waveform,...). Afterwards, the current test bench will be coupled with a ray tracing algorithm, enabling total system simulations. These results can then be verified in practical tests. Also the integration in existing wireless networks will be investigated.

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