*Progress In Electromagnetics Research Letters, Vol. 54, 101–105, 2015*

# Angle-of-Arrival Estimation in Multipath Environments Using Sliding Antenna Arrays

**Mirel Paun[1, *], Razvan Tamas[2], and Ion Marghescu[1]**

**Abstract**—This paper presents a method for improving Angle-of-Arrival estimation accuracy in multipath environments using a sliding antenna array consisting of only two antennas. The proposed method is then experimentally validated by means of a dual channel Software-Defined Radio receiver and a wireless microphone.

## 1. INTRODUCTION

In the context of the increasing number of wireless devices used indoors, the necessity for improving the accuracy of locating methods in the presence of multipath interference produced by reflections on walls becomes imperative [1].

One of the most extensively used methods for implementing Angle-of-Arrival estimation uses antenna arrays and the Multiple Signal Classification (MUSIC) algorithm [2], which exploits the eigen-structure properties of the covariance matrix of the antenna array measurements [3]. However, in the presence of multiple correlated sources, such as in multipath environments, the MUSIC algorithm looses accuracy since the measurements covariance matrix becomes singular. In order to circumvent this limitation, the so called Spatial Smoothing method [4] has been developed. The idea behind this method is to partition the total array into sub-arrays and then average the covariance matrices of the sub-arrays in order to obtain a smoothed covariance matrix.

Although effective, this approach needs a lot of antennas and RF channels, which increases the costs of the implementation.

Our approach is based on the spatial smoothing technique and reduces the number of antennas and RF channels to only two, significantly lowering the hardware costs.

## 2. PROPOSED METHOD

The proposed method exploits the fact that spatial smoothing closely resembles the effect of physically moving the array along the direction of the array between the successive snapshots [5, 6]. The effect of this movement is the fact that the secondary propagation paths, those created by reflecting objects, are phase-shifted due to their varying lengths, so that their contribution to the final averaged result becomes null. In the same time, the primary, desired, line of sight propagation path remains almost unmodified, if the signal source is far enough from the receiver array. Obviously, the proposed method is intended only for slowly varying environment scenarios, where the multipath pattern does not change during the measurement process, like the Synthetic Aperture RADAR (SAR) technology [7] from which it is inspired.

*Received 23 June 2015, Accepted 23 July 2015, Scheduled 29 July 2015*
* Corresponding author: Mirel Paun (miricip@gmail.com).
[1] University Politehnica of Bucharest, Romania. [2] Maritime University of Constanta, Romania.

The proposed hardware implementation consists of a USRP N200 platform fitted with a TVRX2 RF daughterboard. This configuration provides two input channels, each channel connecting to a Vivaldi antenna. The choice for this particular antenna is motivated by its wide-band and ease of fabrication [8].

The two antennas are placed on a sliding platform and moved to a specific position for each measurement, as depicted in Figure 1. Every measurement consists of a recording of the received radio signals with a length of 1 second.

The other components of the proposed system are the RF transmitter acting as a calibration source and a computer, as depicted in Figure 2.

Figure 3 presents the practical implementation of the proposed system hardware.

The TVRX2 board provides two down-converter chains, implementing a low-IF architecture. The local oscillator signals for both channels are derived from the same on-board reference oscillator using two fractional-$N$ synthesizers. Therefore, after each retune, a random phase offset between the two channels will occur. As a consequence, this random phase offset has to be measured and compensated in order to implement the direction-of-arrival algorithm. For this purpose, a RF transmitter is used as a calibration source and a calibration procedure is performed after each retune.

The algorithm for estimating the Angle-of-Arrival of the radio waves emitted by the target source relies on the Cross-Spectral Density (CSD) function of the signals received by the two antennas. This algorithm was successfully applied for direction-finding of spread-spectrum signals [9, 10]. It relies on the ability of the CSD to provide the phase-shift between the two input signals, as follows:

$$\mathrm{CSD}(f) = |X_1(f)||X_2(f)|e^{j(\theta_1-\theta_2)} \tag{1}$$

where $X(f)$ is the Fourier Transform of $x(n)$ and $\theta$ its corresponding phase.

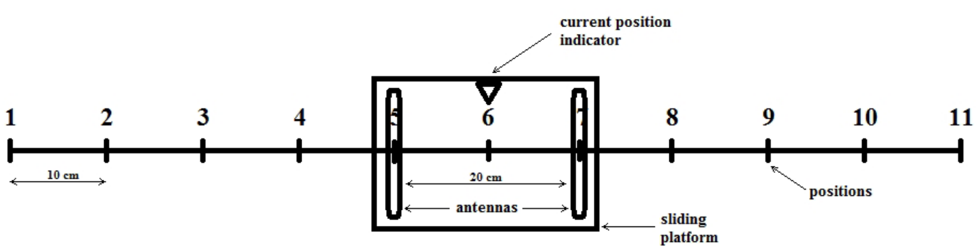


**Figure 1.** Sliding antenna array.

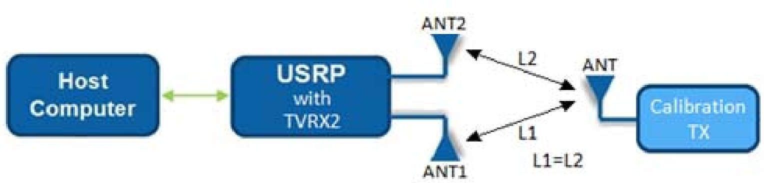


**Figure 2.** Direction finding system — block diagram.

**Figure 3.** Direction finding system — practical implementation.

In order to implement the Spatial Smoothing, the antenna array moves from left to right through all the 11 positions indicated in Figure 1.

The direction of the source is determined with the following relation:

$$\varphi = \sin^{-1}\left[\frac{\lambda}{2\pi d}E\left(\theta_i\right)\right], \quad i = 1:11 \tag{2}$$

where $\theta_i$ is the phase of the CSD at the target source frequency with the array placed at position $i$, $\lambda$ is the wavelength, $d$ the distance between the two receiver antennas and $E$ signifies the expectation operator or mean value.

## 3. EXPERIMENTAL RESULTS

In order to test the proposed implementation, a wireless microphone, employed as target source, is used to generate a narrow band radio frequency signal with a central frequency of 626 MHz. The selected frequency lies in the TVRX2 frequency range, extending from 50 to 860 MHz. In order to acquire the received signal, both channels of the TVRX2 board are configured with the same central frequency value, 625.8 MHz. Antennas are separated by a distance of 20 cm, nearly half a wavelength. The experiments are performed indoors, in a room with highly reflective steel reinforced concrete walls.

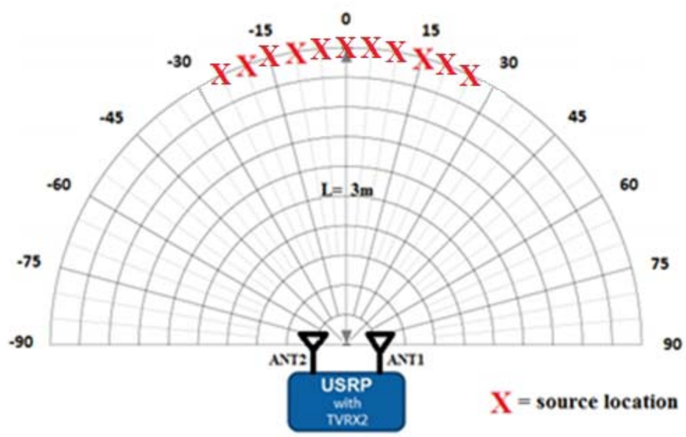


**Figure 4.** Target source locations.

**Table 1.** Results with and without the application of the Sliding Antenna Array Method.

| True angle [°] | Sliding Antenna Array Method<br>Estimated angle [°] | Sliding Antenna Array Method<br>Absolute error [°] | Fixed antenna array<br>Estimated angle [°] | Fixed antenna array<br>Absolute error [°] |
|---|---|---|---|---|
| −25 | −22.89 | 2.11 | −30.70 | 5.7 |
| −20 | −20.51 | 0.51 | −25.59 | 5.59 |
| −15 | −17.80 | 2.80 | −2.20 | 12.8 |
| −10 | −10.24 | 0.24 | −5.55 | 4.45 |
| −5 | −2.46 | 2.54 | 0.00 | 5.00 |
| 0 | 1.15 | 1.15 | 16.78 | 16.78 |
| 5 | 10.88 | 5.88 | 11.52 | 6.52 |
| 10 | 13.09 | 3.09 | 8.43 | 1.57 |
| 15 | 11.48 | 3.52 | 18.71 | 3.71 |
| 20 | 16.31 | 3.69 | −46.19 | 66.19 |
| 25 | 21.04 | 3.96 | 33.51 | 8.51 |

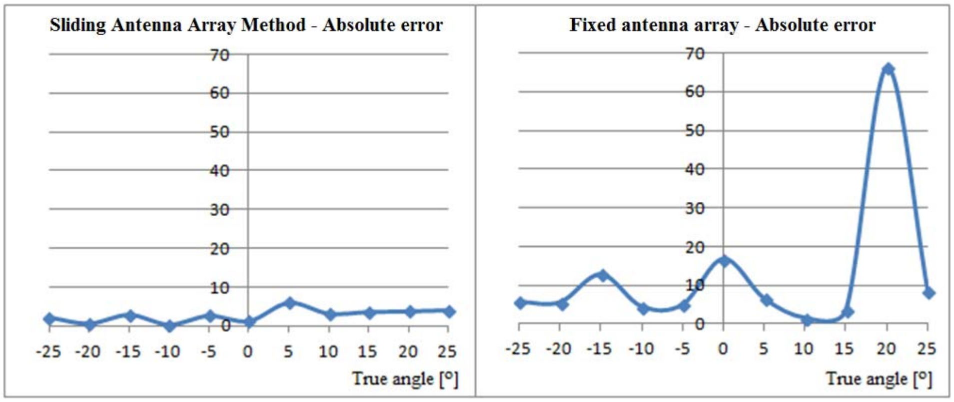


**Figure 5.** Estimation absolute error with and without the Sliding Antenna Array Method.

Eleven measurements were made with the target source placed at the bearings shown in Figure 4.

The choice for testing the system only for small incidence angles is determined by the antennas, which are not omnidirectional, so that the sensitivity of the antenna array decreases with increasing the incidence angle.

Table 1 summarizes the results issued from the experiments, providing a comparison between the proposed, Sliding Antenna Array Method and the results obtained without movement.

For each source position one complete measurement procedure was performed, meaning that the two antennas platform was moved through all the 11 measurement points depicted in Figure 1 and 11 pairs of waveforms were acquired. All these waveforms were used for computing the estimated Angle-of-Arrival using the proposed methodology. The issued results are presented in the 2nd column of Table 1. In order to prove that our method improves the accuracy of the estimation as intended we also computed the angle using only the waveform pair acquired by the antennas when placed in the central, number 6, position. These results are presented in the 4th column of Table 1.

Figure 5 shows a graphical depiction of the results presented in Table 1. The absolute error of the estimation is plotted versus the true value of the angle.

It can be observed that the error of the estimation is not symmetric with respect to 0°. This asymmetry of the error is determined by the asymmetry of the environment, which was intentionally selected to contain multiple and randomly distributed reflecting objects, similar to the real world situation encountered inside a building.

It can be noted that in the case of the proposed, Sliding Antenna Array Method, the mean absolute error of the estimation reduces from 12.430 to 2.680. Also, the variance of the absolute error of the estimation is significantly reduced, the method providing a more stable result by reducing the source position dependence of the estimation accuracy.

## 4. CONCLUSIONS

In this paper we propose a method for increasing the accuracy of the angle-of-arrival estimation in multipath environments.

We also prove experimentally that the proposed method is able to successfully determine the direction of a target source with reasonable accuracy in a multipath environment, acting as expected.

For the future, we intend to explore the effect of the number of measurement points on the accuracy of the estimation.


## ACKNOWLEDGMENT

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/132395.

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