

Multiple Signal Direction of Arrival (DoA) Estimation for a Switched-Beam System Using Neural Networks

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Abstract— A new Direction of Arrival (DoA) estimation method based on Neural Networks (NNs) is presented. The proposed NN-DoA procedure is especially designed for a Switched-Beam System (SBS), whose basic component is an 8×8 Butler Matrix (BM). The technique is simple and appropriate for real time applications. Simulations of DoA estimation tests show accurate results even for a big set of simultaneously incident signals.

1. INTRODUCTION

DoA estimation for signals impinging on an antenna array is a very important issue for wireless communications. Several methods have been proposed and developed concerning DoA finding in wireless systems [1–3]. The most widespread methods are the so-called subspace ones and the most popular algorithms amongst them are the *MUSIC* [4], the *ESPRIT* [5] and their variants. The implementation, [6], of the above super resolution algorithms is quite complicated and computationally intensive. Also, the signals have to be uncorrelated and there is a need for many signal snapshots. A faster DoA estimation algorithm is proposed in [7]. It is based on a pseudocovariance matrix and a small number of signal snapshots. In all the aforementioned techniques, for an N element array, the relation $M \leq N$ should be satisfied for the discrimination of M incident signals. Recently the *Matrix Pencil* (MP) method, [8,9], has been introduced for DoA estimation purposes. Its main advantage is that it uses a single snapshot of the input signals, and therefore the computational time is reduced. However, accurate DoA finding can be made only for $M \leq (N + 1)/2$ simultaneously incoming signals. Neural Network (NN) DoA estimation methods constitute a new sort of DoA finding procedure, [10–12]. The NN methodologies are based on the mapping between the signal autocorrelation matrix and the angles of arrival. Since they do not perform eigen-decomposition processes, they are found to be faster than the conventional super-resolution techniques. The majority of DoA estimation algorithms concern adaptive array systems, which perform either digital or analog beamforming. In most works digital beamforming is applied. However, in [13, 14] analogue beamforming architectures are presented proposing DoA finding for parasitic arrays. In this paper, a NN based DoA estimation method for a SBS system is presented, called the **NN-SBS** method.

2. BRIEF DESCRIPTION OF THE SWITCHED-BEAM SYSTEM

A smart antenna system that relies on a fixed Beam Forming Network (BFN), instead of a series of adaptive array processors, is called Switched-Beam System (SBS) [1]. In a SBS, a switch is used to select the best beam of receiving a particular signal, from a number of fixed beams. Such systems are quite popular, because they offer many of the advantages of the fully adaptive systems at less expense and complexity.

The radiating part of the SBS used in the present work is a linear array of eight, $\lambda/2$ spaced, microstrip patches structured on a single dielectric layer with substrate of $\epsilon_r = 2.2$ (λ is the carrier wavelength). The array is fed by an 8×8 Butler Matrix, [15], and the entire system operates at 2.4 GHz. The input ports of the BM are connected to a switching network that performs beam switching using SPDT (Single Pole Double Throw) switches. The simulated radiation pattern of the described structure is shown in Figure 1.

3. DOA ESTIMATION METHOD AND NEURAL NETWORK TRAINING

The proposed DoA estimation method is based on the application of strict power control at the mobile stations and on the a priori knowledge of the number of simultaneously incoming signals. Due to power control, all signals are received at the base station with the same power level. Therefore,

the contribution of each signal to the total measured power depends only on its angle of incidence. The input power coming from each beam is measured through an appropriate meter connected to the switching network.

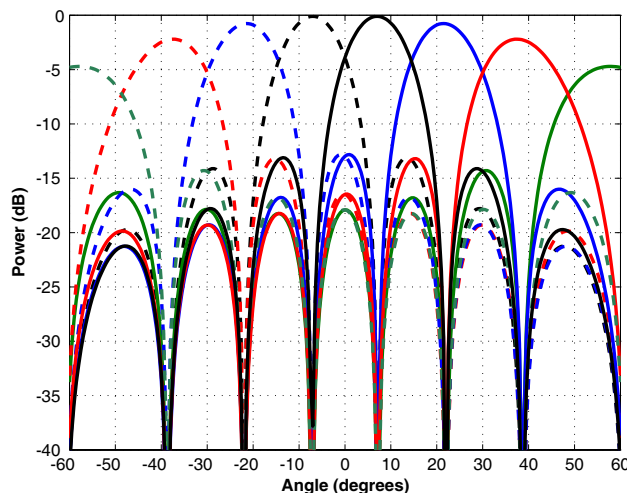


Figure 1: Radiation pattern of an eight patches SBS.

Consider a random set of N signals arriving in a 120° sector from angles φ_i , $i = 1 \dots N$, $-60^\circ \leq \varphi_i \leq 60^\circ$. The angles compose a vector $\boldsymbol{\varphi} = (\varphi_1, \varphi_2, \dots, \varphi_N)$. If beam switching takes place, each one of the eight beams P_j gives a total power P_{tj} , $j = 1 \dots 8$, where:

$$\begin{aligned}
 P_{t1} &= P_1(\phi_1) + P_1(\phi_2) + \dots + P_1(\phi_N) \\
 P_{t2} &= P_2(\phi_1) + P_2(\phi_2) + \dots + P_2(\phi_N) \\
 &\dots\dots\dots \\
 P_{t8} &= P_8(\phi_1) + P_8(\phi_2) + \dots + P_8(\phi_N)
 \end{aligned} \tag{1}$$

Equation (1) gives a power vector $\mathbf{P} = (P_{t1}, P_{t2}, \dots, P_{t8})$, thus a mapping between \mathbf{P} and the corresponding vector $\boldsymbol{\varphi}$ is established. Our aim is to utilize this mapping to accomplish DoA estimation, based on neuro-computational techniques. A set of M angle vectors $\boldsymbol{\varphi}_m$ is created, each one composed by randomly selected N angles of arrival. The index m denotes the m th angle vector. The random angle values are equal to integer multiples of $\Delta\varphi$, within the prespecified angular range. The value of the step angle $\Delta\varphi$ was defined equal to 0.5 degrees. A collection of randomly created pairs $(\boldsymbol{\varphi}_m, \mathbf{P}_m)$ is generated that is used as training set for the NNs. The number of pairs is $M = 3000$ or $M = 4000$. Considering the entire set of different possible vectors $\boldsymbol{\varphi}_m$, the training set volume is very small. This shows the effectiveness and the generalization capabilities of a properly trained NN.

Multilayer Perceptron (MLP) NNs are used, [16], composed by: 1) an input layer of eight nodes which is fed by the vectors \mathbf{P}_m , 2) an output layer of N nodes that gives the corresponding vectors $\boldsymbol{\varphi}_m$, and 3) one or two hidden layers. The number of hidden layers and the number of each layer's nodes depends on the value of N . The criterion of their choice is the better NN training convergence and the results' accuracy. The activation function of the hidden layers is the hyperbolic tangent function and the activation function of the output layer is linear. The NNs' training has been performed to MATLAB using the learning algorithm Levenberg-Marquardt (LM) [17]. The LM algorithm provides a relatively fast numerical solution to the minimization of the performance function, which is the Mean Square Error (MSE) (i.e., the averaged squared error between the network outputs and the target outputs during the training). The training stops when the MSE minimization reaches a plateau. Since the training of the NNs is over, the DoA estimation procedure is summed up to the following four steps: a) Simultaneous arrival of N signals. b) Beam switching and measurement of the total power for each beam. c) Feeding of the trained NN with the measured power vector. d) NN calculation of the DoA estimation vector.

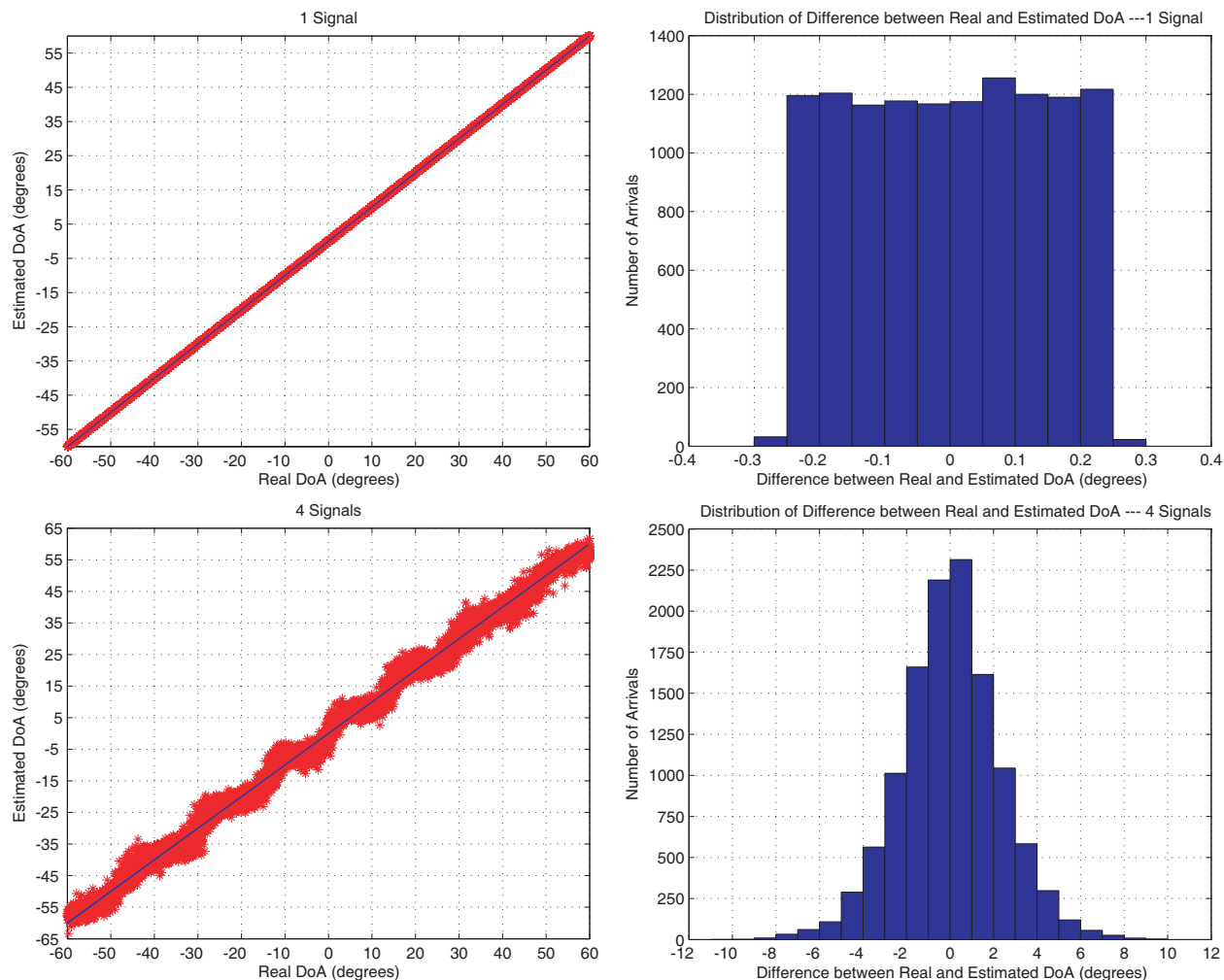
4. DOA ESTIMATION SIMULATIONS

In this section the results of simulated DoA estimation tests using the proposed NN-SBS method are presented. The simulation procedure has been performed to MATLAB, following the steps mentioned in the end of Section 3. Vectors φ_m are randomly generated and from Equation (1) the vectors \mathbf{P}_m are calculated. These power vectors correspond to the power that would be measured in a real DoA estimation problem. The vectors \mathbf{P}_m are fed to the proper NN that instantly gives as output the DoA estimation vectors. The accuracy of the technique is tested by comparing the estimated DoA vector with the initial vector φ_m , which is considered as the real DoA. In Figure 2, DoA estimation simulation diagrams are shown, for 1, 4, 8, and 15 incoming signals. The number of random arrivals tested for each case is 12000, so as to obtain uniform angle of arrival distribution.

Table 1: DoA estimation simulations results.

Number of Signals	Mean Value $\Delta\varphi_{\text{DoA}}$	Standard Deviation $\Delta\varphi_{\text{DoA}}$	$\Delta\varphi_{\text{DoA}} < 5^\circ$ (%)
1	0,13	0,07	100,00
4	1,77	1,46	96,42
8	2,34	1,87	90,68
15	2,41	1,98	89,84

The absolute difference between real and estimated DoA, $\Delta\varphi_{\text{DoA}}$, is statistically processed over the sample of 12000 arrivals, and the results are shown in Table 1. The table gives the mean value and the standard deviation of $\Delta\varphi_{\text{DoA}}$, and the percentage of $\Delta\varphi_{\text{DoA}}$ that is less than 5 degrees. The simulations results and diagrams show a robust behavior of the NN and achievement of accurate



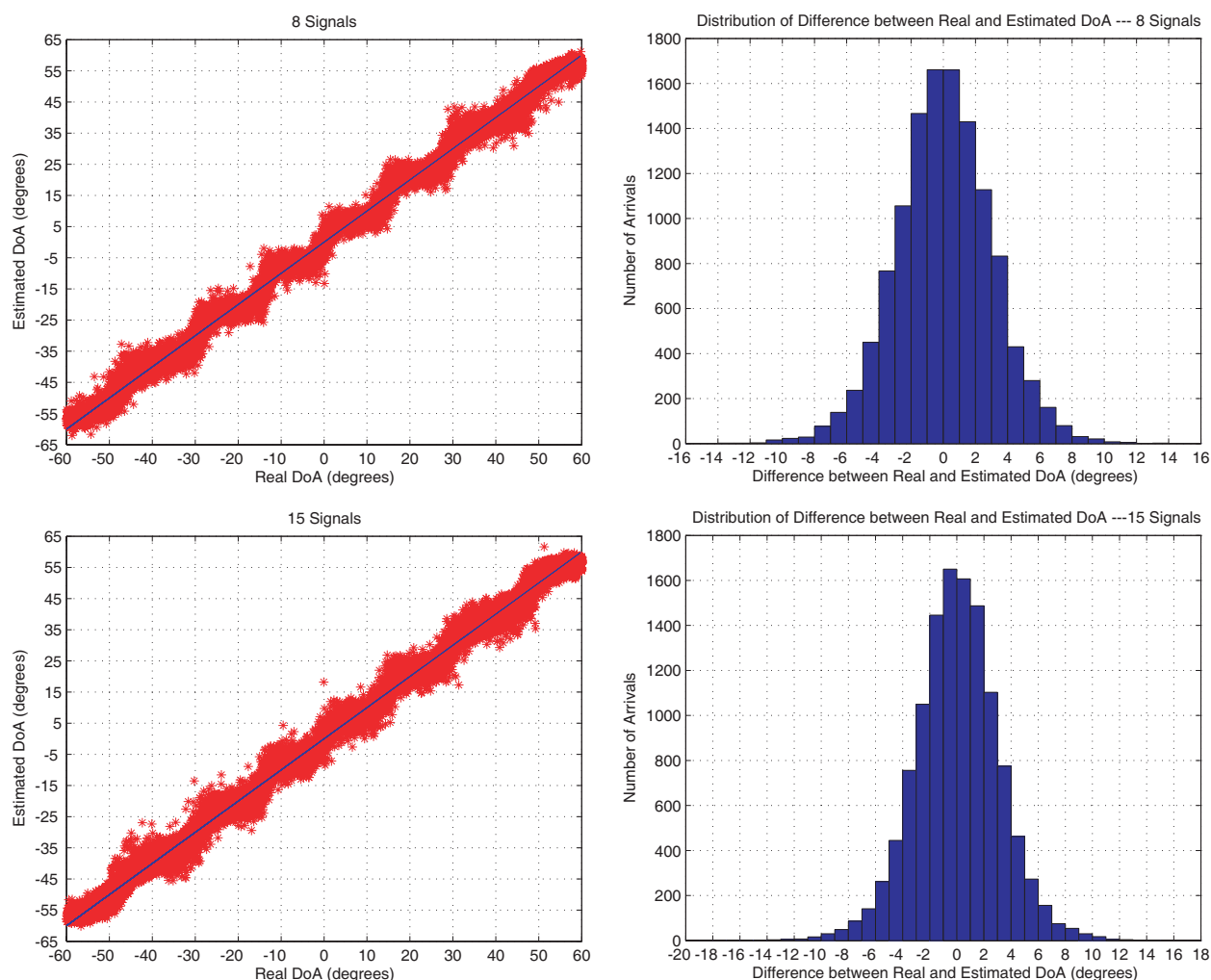


Figure 2: DoA estimation simulations diagrams.

DoA estimation, even if the number of incoming signals is greater than the number of the antenna elements.

5. CONCLUSION

A new DoA estimation method (NN-SBS) for a switched-beam system using neural networks was described. The synthesis, the requirements and the accuracy of the proposed method provide some interesting advantages. The most widespread super resolution algorithms (MUSIC, ESPRIT, Matrix Pencil etc.) need measurements at every antenna element and intensive signal processing in order to perform eigen-decomposition processes. Other NN based techniques require at least the calculation of the signal autocorrelation matrix. In the proposed method only power measurements at a single point of the system is needed, saving cost, complexity and time. Additionally, due to the simplicity of the technique and the speed of NNs, real time applications can be easily served into existing base stations. Finally, contrary to the majority of DoA estimation algorithms, accurate results are obtained even for a big set of incoming signals.

ACKNOWLEDGMENT

This work is implemented in the framework of Measure 8.3 through the O.P. Competitiveness 3rd Community Support Programme and is co-funded by: 75% of the Public Expenditure from the European Union — European Social Fund, 25% of the Public Expenditure from the Hellenic State — Ministry of Development — General Secretariat for Research and Technology, and Private Sector (INTRACOM S.A.).

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