

## Chapter 3.17

# Robust Algorithms for DOA Estimation and Adaptive Beamforming in Wireless Mobile Communications

**R.M. Shubair**

*Etisalat University College, UAE*

**K.O. AlMidfa**

*Etisalat University College, UAE*

**A. Al-Marri**

*Etisalat University College, UAE*

**M. Al-Nuaimi**

*Etisalat University College, UAE*

### ABSTRACT

This paper presents a tool for the modelling, analysis and simulation of direction-of-arrival (DOA) estimation and adaptive beamforming needed in the design of smart antenna arrays for wireless mobile communications. The developed tool implements the Minimum Variance Distortionless Response (MVDR) algorithm for DOA estimation and the Least Mean Squares (LMS) algorithm for adaptive beamforming. Performance of each algorithm is investigated with respect to the variation of a number of parameters that re-

lated to the signal environment and sensor array. Results of numerical simulation are useful for the design of smart antennas systems with optimal performance. Hence, the developed simulation tool can be used to improve and accelerate the design of wireless networks. It can also be used for computer-aided learning of modern communication systems utilizing smart antenna arrays.

### INTRODUCTION

The demand for mobile communication resources has increased phenomenally over the past few

years. Adaptive, or smart, antenna techniques have emerged as a key way to achieve the ambitious requirements introduced for current and future mobile systems. Examples of these requirements are the ability to support broadband data, maximize spectral efficiency and support new location-based services (AlMidfa, 2000,2003).

A smart antenna is commonly defined as a multi-element antenna where the signals received at each element are intelligently and adaptively combined to improve the overall performance of the wireless system, with the reverse performed on transmit. The benefit of smart antennas is that they can increase range and capacity of systems while helping to eliminate both interference and fading.

Most wireless systems such as Wi-Fi, WiMAX, UWB and GPS can benefit from the addition of an adaptive array antenna. Since Wi-Fi systems are time-division-duplex (TDD) systems, the received weights can be used for transmission to obtain the same gains in both directions with the use of smart antennas on one side only. As an example, Winters (1998) showed that a four-antenna array can provide up to a 13 dB signal-to-noise ratio gain (6 dB array gain plus a 7 dB diversity gain), or the possibility of data rates as high as 500 Mbps (as considered for IEEE 802.11n). Similar gains can be achieved in WiMAX systems (particularly those using TDD) (Winters, 1998).

One way in which adaptive antennas can be exploited is by Direction Finding (DF), where algorithms are used to estimate the direction-of-arrival (DOA) of the received signals at the Base Station (BS). These are used to improve the performance of an antenna array by controlling its directivity to reduce effects such as interference, delay spread and multipath fading (Godara, 2003).

In addition to estimating the directions of the signals from the desired mobile users, adaptive antennas are used to estimate directions of interference signals. The results of DOA estimation are then used to adjust the weights of the adaptive beamformer so that the radiated power is maxi-

mized towards the desired users, and radiation nulls are placed in the directions of interference signals (Shubair, 2004; 2005). Hence, a successful design of an adaptive array depends highly on the choice of the DOA estimation algorithm, which should be highly accurate and robust.

This paper investigates the Minimum Variance Distortionless Response (MVDR) algorithm for DOA estimation and the Least Mean Squares (LMS) algorithm for adaptive beamforming. The theory of each algorithm is developed using a realistic model for the signal environment surrounding the sensor array. The performance of each algorithm is then analyzed using a simulation tool developed along with a graphical user interface (GUI). This includes investigating the effect of parameters related to the signal environment such as the number of incident signals and their angular separation. It also investigates effect of parameters related to the design of the sensor array itself including number of array elements and their spacing.

## **DOA ESTIMATION USING MVDR ALGORITHM**

The MVDR algorithm involves estimating the noise subspace from the covariance matrix on which the  $M$  array steering vectors are projected. These steering vectors are also known as direction vectors and they represent the response of an ideal array to the signal sources. The signal sources can be derived from the direction vectors which are orthogonal to the noise subspace (Al-Ardi, 2003; 2004; 2005).

The algorithm starts by constructing a real-life signal model. Consider a number of plane waves from  $M$  narrow-band sources impinging from different angles  $\theta_i$ ,  $i = 1, 2, \dots, M$ , into a uniform linear array (ULA) of  $N$  equi-spaced sensors, as shown in Figure 1.

At a particular instant of time  $t$ ,  $t=1,2, \dots, K$ , where  $K$  is the total number of snapshots taken,

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