

Modeling and Simulation of Adaptive Beamforming for Mobile Communication

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Abstract—This paper presents importance of beamforming technique for next generation broadband wireless mobile systems. Beamforming is a powerful means of increasing capacity, data rates and coverage of the cellular system. In this paper two beamforming techniques, Minimum Variance Distortionless Response (MVDR) and Linear Constraint Minimum Variance (LCMV) are presented. These techniques form radiation beams based on the received weight vector of the desired signal. Simulation has been carried out for two algorithms in MATLAB environment. The uniform linear array (ULA) and Uniform Rectangular Array (URA) smart antenna are used to receive the signal. The ULA contains 10 isotropic antennas. The element spacing is half of the incoming wave's wavelength and the operation frequency is 9MHz. The URA consists of 10 rows and 5 columns of isotropic antenna elements. The spacing between the rows and the columns are 0.4 and 0.5 wavelengths, respectively.

Keywords— Beamforming, ULA, URA, Minimum variance distortion, Linear constraint minimum variance Introduction

I. INTRODUCTION

Next generation mobile communication is not only limited to voice communication, but it also supports dynamic business and social applications such as internet access, video streaming etc. To achieve high data rates and high capacity it is needed to reduced interferences and noise which greatly affects the performance of cellular system, while have to increase the desired signal power. With limited spectrum availability, achieving this goal is difficult due to cochannel and adjacent channel interferences. So more advanced technologies are desperately needed to fulfill the need of next generation wireless mobile communication.

In recent decades, beamforming antennas for mobile wireless communications have received enormous interest. Beamforming is a promising technology which reduces interferences and noise. This makes mobile wireless operators to provide high speed data services as per the demand in affordable price to subscribers by supporting large number of users over limited available spectrum.

Beamforming is a form of spatial filtering. Beamforming pass signals originating from a specific direction. Attenuate signals arriving from other directions. There are two categories of beamforming as described in Table 1. Adaptive beamforming is superior to fixed beamforming.

Adaptive Beamforming is a technique in which an array of antennas is exploited to achieve maximum reception in a specified direction by estimating the arrival of signal from a desired direction (in the presence of noise) while signals of the

same frequency from other directions are rejected. This is achieved by varying the weights of each of the sensors (antennas) used in the array. It basically uses the idea that the signals originating from different transmitters, occupy the same frequency channel and they still arrive from different directions. This spatial separation is exploited to separate the desired signal from the interfering signals.

TABLE I
TWO CATEGORIES OF BEAMFORMING

Fixed beamforming	Adaptive beamforming
Data-independent	Data-dependent
Fixed weights	Adjustable weights

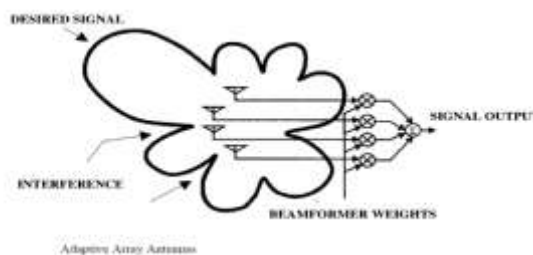


Fig. 1. Beamforming [1]

Beamforming is a signal processing technique used in sensor arrays for directional signal transmission or reception. This spatial selectivity is achieved by using adaptive or fixed receive/transmit beam patterns. The beam pattern is formed by adjusting complex weights of the antenna elements so that the beam is directed in the direction of interest [3].

In Fig. 1 the outputs of the individual sensors are linearly combined after being scaled with the corresponding weights optimizing the antenna array to have maximum gain in the direction of desired signal and nulls in the direction of interferers. For beamformer the output at any time n , $y(n)$ is given by a linear combination of the data at M antennas, with $x(n)$ being the input vector and $w(n)$ being the weight vector[3].

When receiving, the information from different sensors is combined in such a way that, the expected pattern of radiation is preferentially observed. Thus receive beamforming increases the sensitivity in the direction of desired user than that of interferences. A beamformer controls the phase and relative amplitude of the signal at each transmitter when transmitting and produces a high directional beam in the

direction of desired user and null in the direction of interferences, thereby increasing SINR of the desired user and reducing the wastage of transmitted power in the undesired direction. The reception beamforming is achieved independently at each receiver while in the transmit beamforming, the transmitter has to consider the all receivers to optimize the beamformer output.

The paper mainly aims to find the direction of the desired user and the interference in order to steer the main beam towards the desired user and null along the interference. Two methods of adaptive beamformer design namely Minimum Variance distortionless response (MVDR) and Linear constraint minimum variance (LCMV) are tested in MATLAB.

II. PROPOSED ALGORITHM

A. Linear Constraint Minimum Variance (LCMV) Beamformer

Beamforming is used for enhancing a desired signal while suppressing noise and interference at the output of an array of sensors [1]. The linear constraint minimum variance (LCMV) beamformer is one of the most popular. It selects the weight vector to minimize the array output power subject to the linear constraint that the signal of interest (SOI) does not suffer from any distortion. The signal received by a uniform linear array (ULA) with M sensors can be represented by an M-by-1 vector [3, 10]:

$$y(t) = s(t)a(\theta_0) + \sum_{j=1}^J \beta_j(t)a(\theta_j) + n(t) \tag{1}$$

Where, t is the index of time, J is the number of interference sources, s(t) and $\beta_j(k)$ (for $j = 1, \dots, J$) are the amplitudes of the SOI and interfering signals at time instant t, respectively, θ_j (for $l = 0, 1, \dots, J$) are the Direction of the SOI and interfering signals. n(t) is the additive white Gaussian noise (AWGN) vector at time instant k.

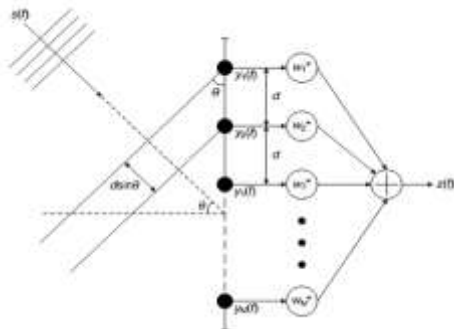


Fig. 2. Uniform Linear Array (ULA) Beamforming [2]

The output of a beamformer for the time instant t is then given by

$$z(t) = w^H y(t) = s(t)w^H a(\theta_0) + \sum_{j=1}^J \beta_j(t)w^H a(\theta_j) + w^H n(t) \tag{2}$$

where w is the M-by-1 complex-valued weighting vector of the beamformer. Based on the above goal, the weight vector can be chosen as

$$\begin{aligned} &\text{minimize } w^H R w \\ &\text{subject to } w^H a(\theta) = 1 \end{aligned} \tag{3}$$

where R is the M-by-M covariance matrix of the received signal vector y(t), and $w^H a(\theta) = 1$ is the distortionless constraint applied on the SOI.

B. Minimum Variance Distortionless Response (MVDR) Beamformer

When beam former has constant response in the direction of useful signal, the LCMV algorithm turns out to be MVDR algorithm. The MVDR beam former does not require the knowledge of the directions of the interferences for weight vector calculation. It requires only the direction of the desired signal. MVDR weight vector is given by [12],

$$w = \frac{R^{-1} a(\theta_d)}{a(\theta_d)^H R^{-1} a(\theta_d)} \tag{4}$$

That mean we will get ten weights for 10-elements:

$$w_{MVDR} = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \\ w_5 \\ w_6 \\ w_7 \\ w_8 \\ w_9 \\ w_{10} \end{bmatrix} \tag{5}$$

These weights are the solution of the following optimization problem

$$\begin{aligned} &\text{minimize } w^H R w \\ &\text{subject to } w^H a(\theta_d) = 1 \end{aligned} \tag{6}$$

Steering vector a(θ) is:

$$a(\theta) = \begin{bmatrix} 1 \\ \exp\left\{j \frac{2\pi}{\lambda} (\sin \theta_i) d\right\} \\ \exp\left\{j \frac{2\pi}{\lambda} (\sin \theta_i) (m-1) d\right\} \end{bmatrix} \tag{7}$$

Where d the space between elements of antenna, θ_i desired angle, M number of element.

Thus, the beamformer weights are selected by minimizing the mean output power while maintaining unity response in

the look direction. The constraint ensures that the signal passes through the beamformer undistorted. Therefore, the output signal power is the same as the look-direction source power. The minimization process then minimizes the total noise, including interferences and uncorrelated noise. Minimization of total output noise, while keeping the output signal constant is same as maximizing the output SINR. For the optimal beam former to operate as described above and to maximize the SINR by canceling interferences, number of interferences must be less than or equal to $L-2$, as an array with L elements has $L-1$ degrees of freedom and one has been utilized by the constraint in the look direction. As MVDR beamformer maximize sensitivity only in one direction, this beamformer is not suitable for multipath environment where desired signal get scatter in many directions. Multipath occurs in the non-line-of-sight (NLOS) environments such as populated urban area where there are many scatterers close to the users and the base station. Thus, MVDR nullifies the desired signal coming from different directions due to multipath fading and not suitable for in such environment. Thus it can be implemented for rural environment where multipath signals do not exist.

III. SIMULATION RESULTS

In the simulations, firstly a ULA with 10 half-wavelength spaced antennas is considered. We have assumed that the noise power is 0.5 watts, which corresponds to a 30 dB Signal-to-Noise Ratio (SNR) at each antenna element. From the received signal, we have applied MVDR and LCMV to calculate the weight. These two algorithms depends on the steering vector and covariance matrix to get the optimum weight, interference (null) and the direction of desired signal (main lobe).

We define the incoming signal. The signal's baseband representation is a simple rectangular pulse. Firstly, MVDR beamformer is tested for the signal arriving at the array from 60 degrees in azimuth and 0 degrees in elevation. Weights are calculated using Eq (4). The three interfering signals are set to be 20°, 50°, and 70°, respectively. The interference to noise ratios (INRs) is set to be 50 dB respectively. Fig. 3 shows power spectrum for MVDR beamformer output.

In this case, the desired signal is at 60° in azimuth. The MVDR beamformer preserves the signal arriving along a desired direction and suppresses the signals coming from other directions (20, 50 and 70 degrees). We see three deep nulls along the interference directions, (20, 50 and 70 degrees). The beamformer also has a gain of 0 dB along the target direction of 30 degrees. Thus, the MVDR beamformer preserves the target signal and suppresses the interference signals.

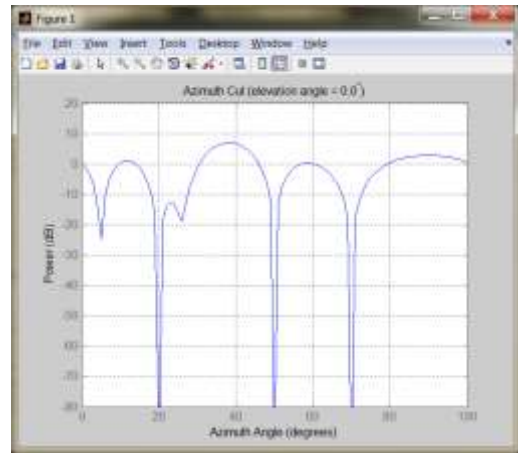


Fig. 3. Power Spectrum of MVDR Beamformer

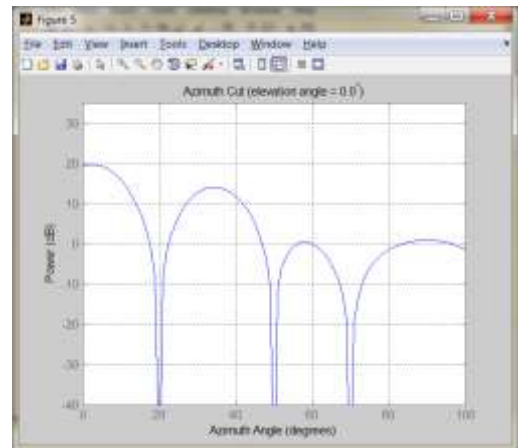


Fig. 4. Power Spectrum of LCMV Beamformer

Secondly, LCMV beamforming algorithm is applied to the received signal. A single desired source is considered in direction 60° in azimuth and 0° degrees in elevation. Weights are calculated to produce a beam in the direction of desired user and null in the direction of interferences (20°, 50°, 70°). LCMV beamformer is also maintain the signal arriving along a desired direction and suppresses the interference signals as shown in Fig. 4.

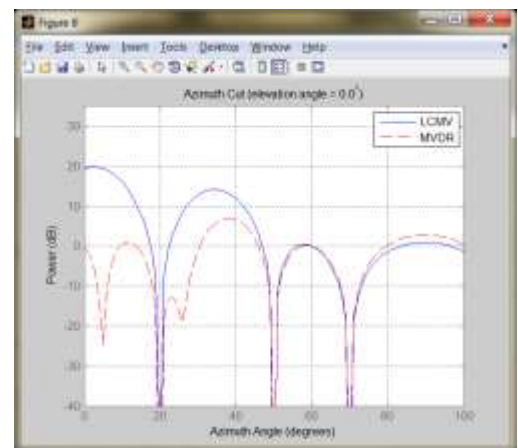


Fig. 5. Comparison of Response Pattern between LCMV and MVDR

The comparison of the LCMV beamformer's response pattern to the MVDR beamformer's response pattern can be seen in Fig. 5. In the second part, the use of a beamformer with a uniform rectangular array (URA) is simulated. The beamformer can be applied to a URA in the same way as to the ULA. Simulation results of MVDR and LCMV beamformers for the URA are illustrated.

First, a URA is defined with 10 rows and 5 columns of isotropic antenna elements. The spacing between the rows and the columns are 0.4 and 0.5 wavelength, respectively. The same source signal as was used in the ULA is applied. The source signal arrives at the URA from 40 degrees in azimuth and -5 degrees in elevation. A ULA can only differentiate the angles in azimuth direction but a URA can differentiate angles azimuth and elevation directions. Therefore, we specify three interference signals arriving along the directions [20; -5], [60; 10] and [70; 20] degrees, respectively.

suppresses the interference signals along [20 -5], [60 10] and [70 20] directions respectively.

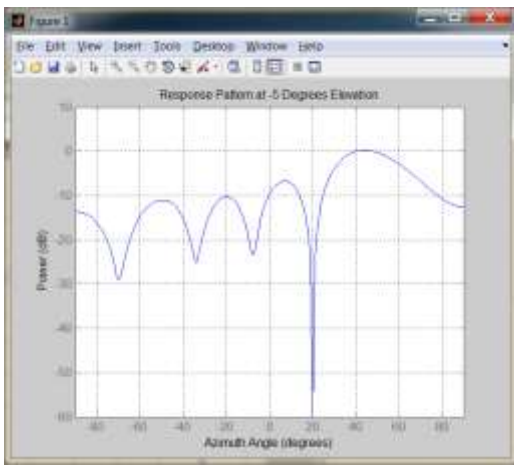


Fig. 6. Response Pattern at -5 Degrees Elevation (MVDR Beamformer)

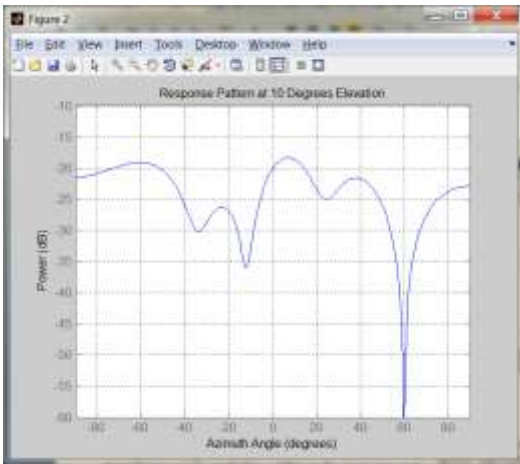


Fig. 7. Response Pattern at 10 Degrees Elevation (MVDR Beamformer)

The MVDR beamformer is applied to the received signal and plot its output. It can be seen clearly that the beamformer puts the nulls along the interference directions. The beamformer response pattern of the array along -5 degrees, 10 degrees and 20 degrees in elevation are illustrated respectively. Figure 6 to 8 show that the beamformer

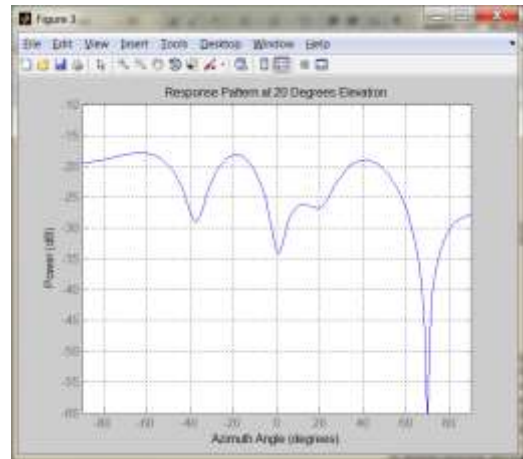


Fig. 8. Response Pattern at 20 Degrees Elevation (MVDR Beamformer)

The LCMV beamformer is also tested for the URA. The received signal and interference signals arriving direction are same in above. The results are shown that the LCMV beamformer also suppresses the interference signals.

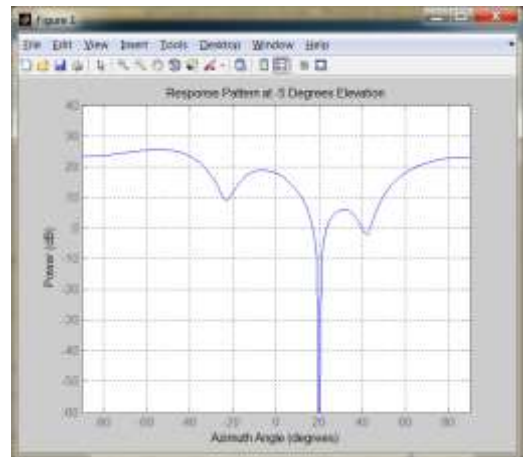


Fig. 9. Response Pattern at -5 Degrees Elevation (LCMV Beamformer)

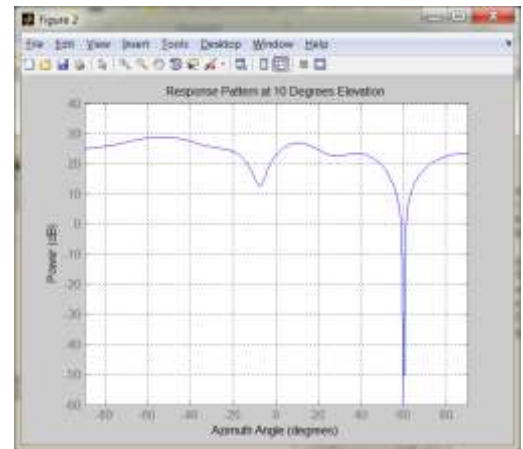


Fig. 10. Response Pattern at -5 Degrees Elevation (LCMV Beamformer)

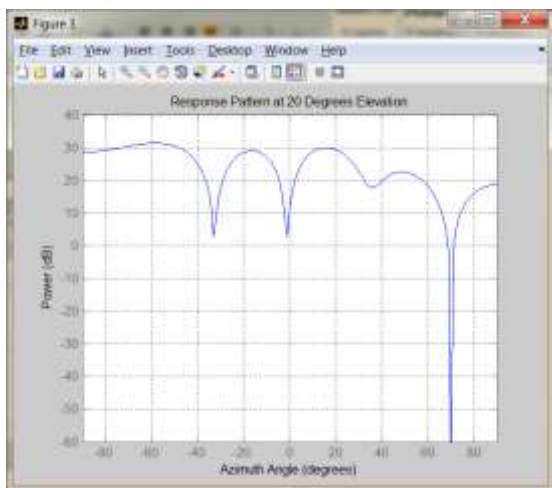


Fig. 11. Response Pattern at 20 Degrees Elevation (LCMV Beamformer)

IV. CONCLUSIONS

This paper presents beamforming technique which has gained importance in wireless mobile communication system due to its ability to reduced cochannel and adjacent channel interferences. In this paper performance of two beamforming algorithms namely MVDR and LCMV beamforming are compared. Beamformer to retrieve the signal from a particular direction using a ULA or a URA antenna are illustrated. MVDR beamforming requires only desired user direction. The choice of the beamformer depends on the operating environment. When the knowledge about the target direction is not accurate, the LCMV beamformer is preferable because it prevents signal self-nulling.

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