Smart Antenna Performance Simulation in Multipath Propagation Environment

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ABSTRACT

This paper presents the effect of multipath propagation on the performance of smart antenna. The influence of the correlation between the source multipath components on the uplink beam pattern shape, as well as the resulting signal-noise-plus-interference ratio when the base station uses the RLS uplink beamformer was investigated. For this purpose, various communication scenarios are simulated. Both the favorable and undesirable communication scenarios in the multipath propagation environment were found out. These results will be useful for the wireless communications engineers who deal with smart antenna application in mobile communication.

I - INTRODUCTION

One of the most promising techniques for increasing capacity of wireless communication systems is through the application of smart or adaptive antennas [1], [2], [3]. Smart antenna combines an antenna array with DSP capability to maximize capacity of the wireless system. Such a system automatically changes the radiated pattern attaining maximum gain in the direction of the desired user and suppresses signals from interfering users. In many smart antenna applications, the uncorrelated sources in the communication scenario are assumed [3], [5]. But in practice replicas of the desired signal as well interfering signals are correlated, and correlation coefficients range from zero to one [4]. These situations occur in the multipath propagation environment, when many replicas of both desired and interference signals arrive at the antenna array aperture.

In this paper, the influence of the correlation between the multipaths of desired as well as interference signals on the main parameters of the smart antenna (beam pattern distortion and the signal-noise-plus interference ratio (SNIR) convergence to the optimum solution) were investigated by Matlab simulation. The signal model for multipath propagation in uplink was introduced. Then, the RLS beamformer was considered and the effect of correlation for the final number of processing snapshots was analyzed. Various communication scenarios were simulated, and both the favorable and worst situations were analyzed.

II- UPLINK SIGNAL MODEL IN MULTIPATH PROPAGATION ENVIRONMENT

A uniform linear array (ULA) of N identical uncoupled isotropic sensors with half-wavelength spacing between array elements [5] is considered. Each sensor converts the received radio frequency signal to a complex baseband signal, which is sampled afterwards. The ULA operates in a multipath signal environment with M narrowband uncorrelated sources including a desired signal $s_1(t)$ as well as M-1 interfering signals $s_i(t), i = 2,3,...,M$. The desired signal multipath components arrive from known Direction of Arrival (DoA) $\theta_{1j}, j = 1,2,...$ that is preferably located in the spatial angle that coincides with the beam pattern main lobe direction. The multipath components of the i^{th} interfering signal arrive at the outside of the main lobe with the not obviously known DoAs $\theta_{ij}, i = 2,3,...,M, j = 1,2,...$

It is assumed that the DoA's of all multipath components of the desired signal are known. In practice, for example, the Multiple Signal Classification (MUSIC) algorithm can be used [5] to estimate the DoA of each desired signal multipath component. Since the number of multipath components, theoretically, can be enormous, a powerful DSP would be required in the smart antenna signal processing part. But. most of the rake receiver schemes operate only with three strongest multipaths [4], we assume that some preprocessing is done in order to select those three stronger components. Hence, the manifold vectors that correspond to three multipath components for all active users can be presented as a matrix

$$\mathbf{V} = \left[\mathbf{v}_{11}, \mathbf{v}_{12}, \mathbf{v}_{13}, \mathbf{v}_{21}, \mathbf{v}_{22}, \mathbf{v}_{23}, ..., \mathbf{v}_{i1}, \mathbf{v}_{i2}, \mathbf{v}_{i3}, ..., \mathbf{v}_{M1}, \mathbf{v}_{M2}, \mathbf{v}_{M3}\right], \qquad (1)$$

where

$$\mathbf{v}_{ij} = \left[1, e^{-j2\pi(d/\lambda)\sin\varphi_{ij}}, e^{-j4\pi(d/\lambda)\sin\varphi_{ij}}, ..., e^{-j(N-1)\pi(d/\lambda)\sin\varphi_{ij}}\right]^T$$

is a manifold vector of the j^{th} multipath component for i^{th} source, the angle φ_{ij} is the DoA of i^{th} user's j^{th} component, and d and λ are the antenna element spacing and wave length, respectively.

Taking into account all multipath components that were introduced in (1), the complex vector at the output of the antenna elements at the sample time k are presented as

$$\mathbf{x}(k) = \sum_{i=1}^{M}\left(\sum_{j=1}^{3}\mathbf{v}_{ij}s_i(k) + \mathbf{n}(k)\right), \qquad (2)$$

where $\mathbf{n}(k)$ is the column vector of a zero-mean thermal noise at the input of the receiver, and $S_i(k)$ is the arriving signal from the i^{th} user.

III- MINIMUM MEAN-SQUARE ERROR BEAMFORMER FOR MULTIPATH PROPAGATION SIGNAL

It is assumed that the training signals are available for each active user, and those signals can be used for user classification and as a reference signal for smart antenna. For example, the training signal for a first user is $d(t)$, which is known to both the transmitter and receiver, is sent from the transmitter to the receiver during the training period. The uplink beamformer uses the training signal information to compute the optimal weight vector, $\mathbf{W}_{opt}$. After the training period, the data are sent and the beamformer uses the weight vector previously computed to process the received data signal. If the radio channel and the interference characteristics remain constant from one training period until the next, the weight vector $\mathbf{W}_{opt}$

contains the information about the propagation channel as well as the interference parameters. Afterwards, the effect of the interference on the received signal can be compensated in the array output.

For the known training signal, the smart antenna beamformer minimizes the mean-squared error between the desired signal $d(k)$ and the array output $y(k)$. That kind of scheme is called Minimum Mean-Square Error (MMSE) beamformer [2], [5]. The error signal is given by $e(k) = d(k)-y(k)$, and the least mean square error is defined by

$$\begin{aligned} &E\{|d(k)-y(k)|^2\} \\ &= E\{|d(k)|^2\} - \mathbf{p}^H\mathbf{w} - \mathbf{w}^H\mathbf{p} + \mathbf{w}^H\mathbf{R}_x\mathbf{w}\}, \end{aligned} \quad (3)$$

where $\mathbf{R}_x = E\{\mathbf{x}(k)\mathbf{x}^H(k)\}$ is the correlation matrix of the input data vector, and $\mathbf{p} = E\{\mathbf{x}(k)d^*(k)\}$ is the cross correlation vector between the input data and the desired signal $d(k)$.

In the presence of multipath the correlation matrix of the input data can be presented as

$$\mathbf{R_x} = \mathbf{V}\Sigma\mathbf{V}^H + \sigma_w\mathbf{I}\ , \quad (4)$$

where

$$\Sigma = \begin{bmatrix} \sigma_{11}^1 & \sigma_{12}^1 & \sigma_{13}^1 & & & & & & \\ \sigma_{21}^1 & \sigma_{22}^1 & \sigma_{23}^1 & & & & & \mathbf{0} & \\ \sigma_{31}^1 & \sigma_{32}^1 & \sigma_{33}^1 & & & & & & \\ & & & \sigma_{11}^2 & \sigma_{12}^2 & \sigma_{13}^2 & & & \\ & & & \sigma_{21}^2 & \sigma_{22}^2 & \sigma_{23}^2 & & & \\ & & & \sigma_{31}^2 & \sigma_{32}^2 & \sigma_{33}^2 & & & \\ & & & & & & \text{o} & & \\ & & & & & & \sigma_{11}^M & \sigma_{12}^M & \sigma_{13}^M \\ & \mathbf{0} & & & & & \sigma_{21}^M & \sigma_{22}^M & \sigma_{23}^M \\ & & & & & & \sigma_{31}^M & \sigma_{32}^M & \sigma_{33}^M \end{bmatrix} \quad (5)$$

is the cross correlation block diagonal matrix with the elements $\sigma_{ij}^n = \sqrt{r_{ij}^n}$ that shows the degree of dependence of the i^{th} and j^{th} multipath components of the n^{th} source, and σ_w is a white noise power.

The weight vector that minimizes the mean square error $E\{e^2(k)\}$ yields the Wiener solution $\mathbf{w}_{opt} = \mathbf{R}_x^{-1}\mathbf{p}$, subject to the constraint

$$\mathbf{w}_{opt}[\mathbf{v}_{11}, \mathbf{v}_{12}, \mathbf{v}_{13}] = \mathbf{C}, \quad (6)$$

where $\mathbf{C} = [g_1, g_2, g_3]$ are the coefficients that maintain a distortionless solution, $\mathbf{w}_{opt}$.

In order to achieve a distortionless solution the vector $\mathbf{w}_{opt}$ is divided into two orthogonal components [5]:

$$\mathbf{w}_{opt} = \mathbf{w}_C - \mathbf{w}_p\ , \quad (7)$$

where $\mathbf{w}_C$ is defined as the projection of $\mathbf{W}_{opt}$ onto the constraint subspace and $\mathbf{w}_p$ is the projection of $\mathbf{w}_{opt}$ onto the interference subspace, and both of them are defined as

$$\mathbf{w}_C^H = \mathbf{w}_{opt}^H\mathbf{P}_C\ , \quad (8)$$

$$\mathbf{w}_p = -\mathbf{P}_C^{\perp}\mathbf{w}_{opt}\ . \quad (9)$$

The projection matrix $\mathbf{P}_C$ into the constraint subspace is

$$\mathbf{P}_C = \mathbf{C}[\mathbf{C}^H\mathbf{C}]^{-1}\mathbf{C}^H\ . \quad (10)$$

The orthogonal to $\mathbf{P}_C$ subspace is computed as

$$\mathbf{P}_C^{\perp} = \mathbf{I} - \mathbf{C}[\mathbf{C}^H\mathbf{C}]^{-1}\mathbf{C}^H\ . \quad (11)$$

Substituting (11) into (9), we obtain the weight vector that satisfies the constraint condition

$$\begin{aligned} \mathbf{w}_p &= -\mathbf{P}_C^{\perp}\mathbf{w}_{opt} = \{\mathbf{C}\,[\mathbf{C}^H\mathbf{C}]^{-1}\mathbf{C}^H - I\}\mathbf{w}_{opt} \\ &= (1/N)\mathbf{C}\mathbf{C}^H\mathbf{w}_{opt} - \mathbf{w}_{opt} \end{aligned}\ . \quad (12)$$

If the criterion of SNIR maximization (MSNIR) is applied, then the beamformer output signal/noise + interference ratio is

$$SNIR = \frac{|\mathbf{w}_p^H\mathbf{v}_s|^2}{\mathbf{w}_p^H\mathbf{R_n}\mathbf{w}_p} \quad (13)$$

where $\mathbf{V}_s$ is a DoA of the strongest multipath component of the desired signal.

Although the optimum solution can be determined solving (6) and (12), some strong enough if some multipath components of the desired signal arrive simultaneously at the main and side lobes.

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