Extending Linear Constraint Adaptive Array and Null-Space Adaptive Array for Spectrum Sharing Environments

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Abstract

Linear Power Constraint Adaptive Array (LPCAA) and Null Space based Array Antenna (NSAA) were investigated to increase the transmit opportunities of low priority systems under the spectrum sharing condition in [4]. The applicable conditions of LPCAA, however, were limited and the desired signal enhancement by NSAA was not considered in the study. This paper extends LPCAA to cover the case wherein the victim receiver and/or the wanted receiver have multiple antennas. Moreover, desired signal enhancement by NSAA is investigated by using selection or combining possible candidates of weights. Numerical results are given to compare performance in terms of the signal to interference ratio (SIR).

Keywords: MIMO, Adaptive Array, Spectrum Sharing, Null-Space, Lagrange multiplier method

1 Introduction

Multiple Input Multiple Output (MIMO) techniques are promising techniques to alleviate the restriction faced by spectrum sharing, as is reported in [1]–[4]. To apply MIMO techniques, interfering transmitters are required to have several antennas and send signals so as to suppress the interference to the victim receiver in addition to supply sufficient power to the wanted receivers. The capacities achievable by the low priority systems largely depend on the algorithm used to calculate the array antenna weights, since they determine the beam patterns.

Null-Space based Adaptive Array (NSAA) [3] is a simple method for calculating adaptive array weights. NSAA suppresses the interference signals, however, desired signal enhancement has yet to be considered. NSAA yields multiple weight candidates when the degree of freedom is larger than 1. Here the degree of freedom corresponds to the number of antennas at the interfering transmitter minus the number of antennas at the victim receiver. In [4], one weight is randomly selected from a set of possible weights, thus the degradation in the signal to interference ratio (SIR) strengthens as the degree of freedom increase.

One weight calculation method that considers the desired signal enhancement and interference suppression is the Linear Power Constraint Adaptive Array (LPCAA) [4]. LPCAA yields weights that maximize the array outputs under the constraint that the interference signal level does not exceed a predetermined threshold. The LPCAA weights are obtained by using the method of Lagrange multiplier, so it can be said the method is optimal for the spectrum-sharing environment. The condition assumed in [4] was, however, limited to the case

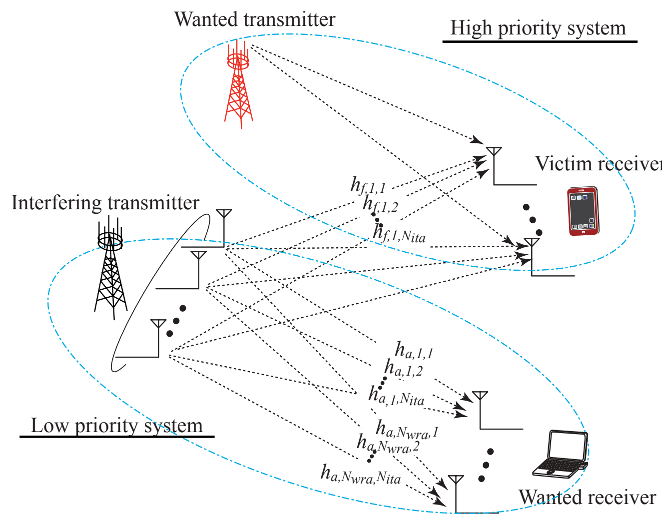

Figure 1: Assumed environment

that both the victim receiver and wanted transmitter had only one antenna.

In this paper, we extend NSAA and LPCAA to take the desired signal enhancement into consideration and to make it applicable to the cases where the victim receiver and transceiver have multiple antennas. The signal to interference power ratios yielded by the extended methods are evaluated in computer simulations.

2 System model and problem formulation

Fig. 1 shows the spectrum sharing environment examined here. Stations of a high-priority system, shown as a wanted transmitter and a victim receiver, are communicating each other. On the other hand, stations of low priority systems, shown as the interfering transmitter and wanted receiver, try to communicate without imposing harmful interference on the victim receiver. Here we assume N_{ita} antennas on the interfering transmitter, N_{vra} antennas on the victim receiver and N_{wra} on the wanted receiver.

Let us denote the channel between the interfering transmitter and the victim receiver as

$$\mathbf{H}_f = \begin{bmatrix} h_{f,1,1} & h_{f,1,2} & \cdots & h_{f,1,N_{ita}} \\ h_{f,2,1} & h_{f,2,2} & \cdots & h_{f,2,N_{ita}} \\ \vdots & & \ddots & \vdots \\ h_{f,N_{vra},1} & h_{f,N_{vra},2} & \cdots & h_{f,N_{vra},N_{ita}} \end{bmatrix}, \quad (1)$$

here each path is regarded as a flat fading channel; this assumption is valid for broadband communications based on orthogonal frequency division multiplexing.

When the following weights are used

$$\mathbf{W} = \left[\begin{array}{cccc} w_1 & w_2 & \ldots & w_{N_{ita}} \end{array} \right]^{\mathrm{T}}, \quad (2)$$

the interfering signals received at the victim receiver are expressed as

$$\mathbf{r}_f = \mathbf{H}_f \mathbf{W} s + \mathbf{N}_{rf}. \quad (3)$$

Here, $\mathbf{M}^{\mathrm{T}}$ denotes a transpose matrix of matrix $\mathbf{M}$, s is a transmit symbol, and $\mathbf{N}_{rf}$ is a vector composed of noise incurred at the victim receiver where

$$\mathbf{N}_{rf} = \left[\begin{array}{cccc} n_{rf,1} & n_{rf,2} & \ldots & n_{rf,N_{vra}} \end{array} \right]^{\mathrm{T}} \quad (4)$$

On the other hand, the received signal at the wanted receiver is expressed as

$$r_a = \mathbf{H}_a \mathbf{W} s + \mathbf{N}_{ra}, \quad (5)$$

where $\mathbf{N}_{ra}$ is the noise vector at the wanted receiver and $\mathbf{H}_a$ is the channel matrix between the interfering transmitter and the wanted receiver.

$$\mathbf{H}_a = \left[\begin{array}{cccc} h_{a,1,1} & h_{a,1,2} & \ldots & h_{a,1,N_{ita}} \\ h_{a,2,1} & h_{a,2,2} & \ldots & h_{a,2,N_{ita}} \\ \vdots & & \ddots & \vdots \\ h_{a,N_{wra},1} & h_{a,N_{wra},2} & \ldots & h_{a,N_{wra},N_{ita}} \end{array} \right], \quad (6)$$

and

$$\mathbf{N}_{ra} = \left[\begin{array}{cccc} n_{ra,1} & n_{ra,2} & \ldots & n_{ra,N_{wra}} \end{array} \right]^{\mathrm{T}}. \quad (7)$$

3 Extended NSAA

The weights of NSAA are calculated by using singular value decomposition of $\hat{\mathbf{H}}_f$, which is the estimated channel matrix between the interfering transmitter and victim receiver $\mathbf{H}_f$. In the case of $N_{ita} - N_{vra} > 1$, this method yields multiple vectors ,$\mathbf{V}_{n,i}$ $(i = N_{vra}+1 \ldots N_{ita})$, which are orthogonal to channel vector $\hat{\mathbf{H}}_f$. Study [4] selected one weight randomly from them, which we call random weight selection (RWS).

To further improve the SIR performance, we introduce two methods. The first method is Best Weight Selection (BWS). Here, best weight means the one that yields the maximum received signal power at the wanted receiver. In this case the weight is given as

$$\mathbf{W} = \arg_{W} \max_{i \neq 1,2,\ldots N_{vra}} |h_a \mathbf{V}_{n,i}|^2. \quad (8)$$

The second method is Maximum Ratio Combining (MRC), which combines all weight candidates obtained by the SVD using resultant received signal amplitudes as their weights.

$$\mathbf{W} = \sum_{x=1}^{d_f} |h_a \mathbf{V}_{n,j}| \left[\mathbf{V}_{n,j} \frac{|h_a \mathbf{V}_{n,j}|}{h_a \mathbf{V}_{n,j}} \right] \quad (9)$$

$$= \sum_{x=1}^{d_f} \frac{|h_a \mathbf{V}_{n,j}|^2 \mathbf{V}_{n,j}}{h_a \mathbf{V}_{n,j}}, \quad (10)$$

where d_f is the number of the orthogonal weight candidates. d_f equals to $N_{ita} - N_{vra}$. h_a is the first row of $\mathbf{H}_a$, which means that weight combining considers only the first antenna at the wanted receiver if the receiver has multiple antennas. Term $|h_a \mathbf{V}_{n,j}|$ is the weight for maximum ratio combining while term $\frac{|h_a \mathbf{V}_{n,j}|}{h_a \mathbf{V}_{n,j}}$ is required to realize in-phase combining of the received signals.

4 Extended LPCAA

In the case $N_{vra} > 1$ and/or $N_{wra} > 1$, the objective function and the constraints are given as

$$\mathbf{W}_{LPCAA} = \arg_{W} \max \left(\mathbf{W}^{\mathrm{H}} \hat{\mathbf{H}}_a^{\mathrm{H}} \hat{\mathbf{H}}_a \mathbf{W} \right), \quad (11)$$

subject to

$$\mathbf{W}^{\mathrm{H}} \mathbf{R}_f \mathbf{W} = P_{th}, \quad (12)$$

where $\hat{\mathbf{H}}$ is an estimate of $\mathbf{H}$, and $\mathbf{M}^{\mathrm{H}}$ denotes a Hermite matrix of matrix $\mathbf{M}$ and

$$\mathbf{R}_f = \hat{\mathbf{H}}_f^{\mathrm{H}} \hat{\mathbf{H}}_f + \sigma^2 \mathbf{I}. \quad (13)$$

Here, I is the identity matrix and σ^2 is the noise variance.

They are the same with those of $N_{vra} = 1$ and $N_{wra} = 1$ in [4]. Thus, the weight $\mathbf{W}_{LPCAA}$ under the spectrum sharing environment is obtained in the same way, using the method of Lagrange multipliers. The weight is expressed as

$$\mathbf{W}_{LPCAA} = \frac{\zeta_a}{\lambda} \mathbf{R}_f^{-1} \hat{\mathbf{H}}_a^{\mathrm{H}}, \quad (14)$$

where

$$\frac{\zeta_a}{\lambda} = \left(\frac{P_{th}}{\left(\mathbf{R}_f^{-1} \hat{\mathbf{H}}_a^{\mathrm{H}} \right)^{\mathrm{H}} R_f \left(\mathbf{R}_f^{-1} \hat{\mathbf{H}}_a^{\hat{\mathrm{H}}} \right)} \right)^{1/2}. \quad (15)$$

5 Performance comparisons

This section presents performance comparisons between LPCAA and NSAA. In the evaluation, each path is modeled as an independent one-path Rayleigh fading channel, all have identical mean path loss. The results are obtained by using 10000 realizations of the channels. Noise levels of channel estimates at the victim receiver and the wanted receiver are set to 20 dB lower than the signal level from each antenna of the interfering transmitter. Moreover, SIR is defined by

$$\mathrm{SIR} = P_a / P_f, \quad (16)$$

where P_a is the received signal power from interfering transmitter at the wanted receiver and P_f is the received signal power from interfering transmitter at the victim receiver. Norm of transmit weights are normalized to 1 in the evaluations.

Fig. 2 plots the distribution of SIR when N_{ita} is four. In these cases, LPCAA and NSAA with MRC achieve the same distribution, which is the best among the four methods. SIR by NSAA with OWS largely improves SIR performance compared to NSAA with RWS, still both are weaker than LPCAA and NSAA with MRC.

Fig. 3 and 4 show cumulative distribution functions (CDF) of SIR achieved by LPCAA and NSAAs when $N_{vra} = 2$. N_{wra} is one for both cases and $N_{ita} = 4$ is applied for Fig. 3 and $N_{ita} = 6$ for Fig. 4. The results show that larger N_{ita} enhances the capacity in all methods other than "NSAA with RWS". This is because NSAA with RWS does not try to enhance the desired signal power. It is also confirmed that, LPCAA and "NSAA with MRC" yield the same SIR. Moreover, with regard to the case of $N_{vra} = 1$ (Fig. 2) and 2 (Fig. 3), the difference between the CDF of LPCAA(NSAA with MRC) and the other method falls as N_{vra} increases.

Fig. 5 shows the SIR distribution $N_{wra} = 2$; N_{vra} is one and N_{ita} is four. If we compare the case of $N_{wra} = 1$ (Fig. 2) and 2 (Fig. 5), distributions with $N_{wra} = 2$ are closer each to other than those with $N_{wra} = 1$.

6 Conclusion

LPCAA and NSAA were investigated to increase the transmit opportunities of low priority systems under the spectrum sharing condition [4]. Original LPCAA studies were limited to the case wherein both the victim receiver and the wanted receiver had only one antenna. As for original NSAA, the desired signal enhancement was not considered for degrees of freedom larger than one. This paper extended LPCAA and NSAA to avoid the limitation and to enhance the performance. Numerical results were given to compare SIR performance of the extended algorithms. Numerical results showed that the linear power constrained array antenna and null space based array antenna with maximum ratio combining share the same SIR distribution.

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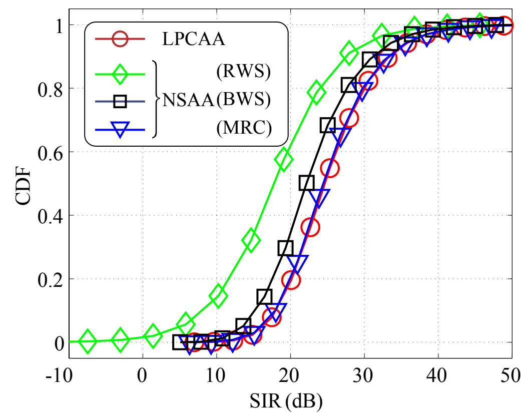

Figure 2: CDF of SIR when $N_{ita} = 4$, $N_{wra} = 1$, $N_{vra} = 1$

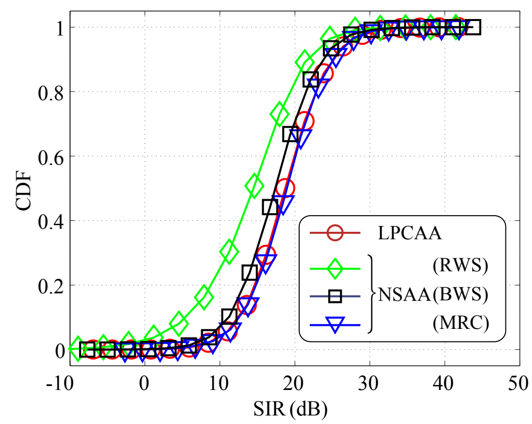

Figure 3: CDF of SIR when $N_{ita} = 4$, $N_{wra} = 1$, $N_{vra} = 2$

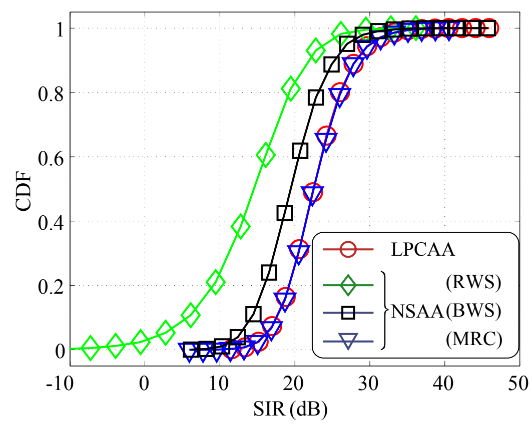

Figure 4: CDF of SIR when $N_{ita} = 6$, $N_{wra} = 1$, $N_{vra} = 2$

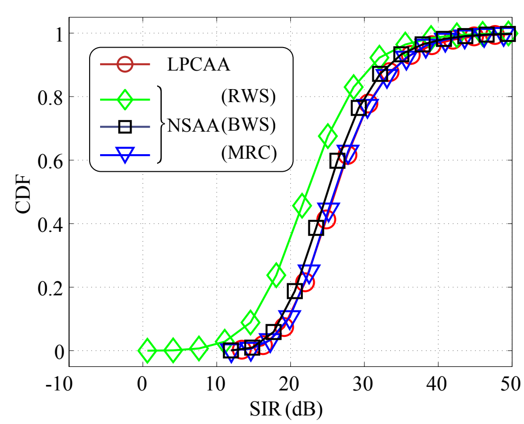

Figure 5: CDF of SIR when $N_{ita} = 4$, $N_{wra} = 2$, $N_{vra} = 1$