Int. J. Electron. Commun. (AEÜ) 65 (2011) 235–238

Contents lists available at ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.de/aeue

LETTER

Distributed joint power control and beamforming algorithms

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ARTICLE INFO

Article history:
Received 24 April 2009
Accepted 15 February 2010

Keywords:
Power control
Beamforming
Feedback
Broadcast
Overhead

ABSTRACT

Two distributed joint power control and beamforming algorithms, namely, the power feedback based algorithm and the broadcast based algorithm, are proposed. The power feedback based algorithm can dispense with the redundancy of power computation that occurs in the algorithm in Rashid et al. (1998) and Olfat et al. (2005) [1,2]. Also, the power feedback based algorithm and the broadcast based algorithm can both consume less overhead of feedback than the algorithm in Rashid et al. (1998) and Olfat et al. (2005) [1,2].

1. Introduction

Cochannel interference, which is inevitable in wireless networks due to the frequency reuse, can decrease the received signal to interference and noise ratio (SINR). Two techniques are commonly used for enhancing the SINR in wireless networks with cochannel interference: beamforming and power control. Beamforming acts as a spatial filter that aims to maintain constant gain at the direction of the target signal and minimizes the cochannel interferences that come from other directions. On the other hand, power control is a technique that aims to appropriately adjust the power levels for all users so that the cochannel interference can be suppressed and the SINR requirement can be satisfied.

Beamforming and power control can be jointly operated to further improve the performance as in [1–3]. An algorithm, namely, *Algorithm A*, was proposed in [1] to find the optimal feasible power and weight for joint power control and beamforming. To make *Algorithm A* work in practice, the authors of [1] further suggest a distributed algorithm to implement *Algorithm A*. This distributed algorithm was also used in [2] for the OFDM system. In the distributed algorithm in [1,2], each user computes the updated power according to the interference received at the base station, however, the base station also needs to compute the power of the user to determine the interference, as a result, there is a redundancy of power computation. In this paper, we first propose a power feedback based algorithm in which the updated power of the user is determined by the base station so that the base station always knows the power of the user. Compared to the distributed algorithm in [1,2], the power feedback based algorithm can dispense with the redundancy of power computation and reduce the overhead (in terms of the number of parameters to be sent). In addition, we further propose a broadcast based algorithm that broadcasts a set of parameters to all users in the same cell so that each user can use these parameters to determine its updated power. Numerical results show that the broadcast based algorithm can outperform the distributed algorithm in [1,2] in the saving of the overhead for the CDMA networks.

2. System model

Assume that each user i is equipped with transmitter i and receiver i on opposite sides of the link, each transmitter has one antenna element, and each receiver has M antenna elements. Let P_i and s_i represent the transmitting power and the message signal of user i, respectively. Also, let x_i^j and w_i^j represent the total received signal and the weight at the jth antenna element of receiver i. Then the output of the combiner for receiver i is given by

$$y_i = \sum_{j=1}^{M} (\overset{j}{\underset{i}{w}})^* \overset{j}{\underset{i}{x}}$$

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doi:10.1016/j.aeue.2010.02.011

Note that

$$x_i^j = \sum_l \sqrt{P_l G_{li}} a_{li}^j s_l + n_i^j$$

where G_l^i denotes the link gain between transmitter l and receiver i, a_{li}^j denotes the array response between transmitter l and receiver i at the jth antenna element, and n_i^j denotes the noise at the jth antenna element of receiver i. Furthermore, the received signal of receiver i at the jth antenna element that comes from transmitter i is denoted by d_i^j, which can be expressed as

$$d_i^j = \sqrt{P_i G_{ii}} a_{ii}^j s_i$$

The SINR for receiver i is given by

$$\Gamma_i = \frac{E(\mathbf{w}_i^H \mathbf{d}_i \mathbf{d}_i^H \mathbf{w}_i)}{[E(\mathbf{w}_i^H \mathbf{x}_i \mathbf{x}_i^H \mathbf{w}_i) - E(\mathbf{w}_i^H \mathbf{d}_i \mathbf{d}_i^H \mathbf{w}_i)]} = \frac{\mathbf{w}_i^H \Omega_i \mathbf{w}_i}{\mathbf{w}_i^H \Phi_i \mathbf{w}_i - \mathbf{w}_i^H \Omega_i \mathbf{w}_i}$$

where $\mathbf{w}_i = \{w_i^j\}$, $\mathbf{x}_i = \{x_i^j\}$, $\mathbf{d}_i = \{d_i^j\}$, $\Phi_i = E(\mathbf{x}_i \mathbf{x}_i^H)$ and $\Omega_i = E(\mathbf{d}_i \mathbf{d}_i^H)$. Note that Φ_i and Ω_i are the correlation matrixes for the total received signal and the received signal of interest, respectively. Assume that the message signals are uncorrelated with zero mean and $E(|s_i|^2) = 1$, then we have

$$\Omega_i = P_i G_{ii} \mathbf{a}_{ii} \mathbf{a}_{ii}^H$$

and

$$\Phi_i = \sum_l P_l G_{li} \mathbf{a}_{li} \mathbf{a}_{li}^H + N_i \mathbf{I}$$

where $\mathbf{a}_{li} = \{a_{li}^j\}$ and N_i denotes the noise power at receiver i. Therefore, we have

$$\Gamma_i = \frac{P_i G_{ii} \mathbf{w}_i^H \mathbf{a}_{ii} \mathbf{a}_{ii}^H \mathbf{w}_i}{\sum_{l \neq i} P_l G_{li} \mathbf{w}_i^H \mathbf{a}_{li} \mathbf{a}_{li}^H \mathbf{w}_i + N_i \mathbf{w}_i^H \mathbf{w}_i} \tag{1}$$

Let I_i denote the total interference and noise for receiver i, then we also have

$$I_i = \sum_{l \neq i} P_l G_{li} \mathbf{w}_i^H \mathbf{a}_{li} \mathbf{a}_{li}^H \mathbf{w}_i + N_i \mathbf{w}_i^H \mathbf{w}_i$$

The minimum variance distortionless response (MVDR) beamforming is accomplished by minimizing the interference and noise subject to $\mathbf{w}_i^H \mathbf{a}_{ii} = 1$. It was reported in [1] that the weight for the MVDR beamforming is given by

$$\tilde{\mathbf{w}}_i = \frac{(\Phi_i - \Omega_i)^{-1} \mathbf{a}_{ii}}{\mathbf{a}_{ii}^H (\Phi_i - \Omega_i)^{-1} \mathbf{a}_{ii}} \tag{2}$$

As a result, the received SINR with the MVDR beamforming for receiver i can be expressed as

$$\Gamma_i = P_i G_{ii} (\mathbf{a}_{ii}^H (\Phi_i - \Omega_i)^{-1} \mathbf{a}_{ii}) \tag{3}$$

And the total interference with the MVDR beamforming for receiver i can be expressed as

$$I_i = \tilde{\mathbf{w}}_i^H (\Phi_i) \tilde{\mathbf{w}}_i - P_i G_{ii} \tag{4}$$

3. Distributed joint power control and beamforming algorithms

An algorithm, namely, *Algorithm A*, was proposed in [1] to find the optimal feasible power and weight for joint power control and beamforming. To make *Algorithm A* work in practice, the authors of [1] further suggest a distributed algorithm to implement *Algorithm A*. This distributed algorithm was also used in [2] for the OFDM system. For convenience, such a distributed algorithm is called the distributed joint power control and beamforming (DJPCB) algorithm in this paper. The DJPCB algorithm uses only local information to iteratively adjust the power and weight of each individual user. In the following, we give the description for the DJPCB algorithm that works in the uplink. For this description, we let Φ_i^m, $\mathbf{x}_i^m$, Ω_i^m, $\mathbf{w}_i^m$, P_i^m, Γ_i^m and I_i^m denote the m th-discrete-time value for Φ_i, $\mathbf{x}_i$, Ω_i, $\mathbf{w}_i$, P_i, Γ_i and I_i, respectively, and we let γ_i denote the SINR requirement of user i.

3.1. DJPCB algorithm

Step 1: Let $P_i^0 = P_0$.
Step 2: Measure $\mathbf{x}_i^m$ and calculate Φ_i^m by

$$\Phi_i^m = E[\mathbf{x}_i^m (\mathbf{x}_i^m)^H]$$

Step 3: Calculate the optimal weight vector by

$$\mathbf{w}_i^m = \frac{(\Phi_i^m - \Omega_i^m)^{-1} \mathbf{a}_{ii}}{\mathbf{a}_{ii}^H (\Phi_i^m - \Omega_i^m)^{-1} \mathbf{a}_{ii}}$$

where $\Omega_i^m = P_i^m G_{ii} \mathbf{a}_{ii} \mathbf{a}_{ii}^H$.
Step 4: Compute the total interference by

$$I_i^m = (\mathbf{w}_i^m)^H (\Phi_i^m) \mathbf{w}_i^m - P_i^m G_{ii}$$

Step 5: Send the value of I_i^m to each user i.
Step 6: Each user i updates the power according to the following iteration:

$$P_i^{m+1} = \frac{\gamma_i}{G_{ii}} I_i^m$$

then go to Step 2.

Note that in each iteration of the above algorithm, the base station first sends the value of I_i^m to each user i, then each user i determines P_i^{m+1} as per the value of I_i^m. It is observed that the DJPCB algorithm has the problem below: the base station needs to know P_i^m to calculate $\mathbf{w}_i^m$ and I_i^m. To overcome this problem, we can let the base station execute Step 6 to obtain the value of P_i^m. However, Step 6 is also executed by each user, thus, there is a redundancy of power computation in the DJPCB algorithm. To dispense with the redundancy of power computation, we propose the following power feedback based DJPCB algorithm, which is similar to the DJPCB algorithm except for Step 5 and Step 6.

3.2. Power feedback based DJPCB algorithm

Step 1 to Step 4: Same as Step 1 to Step 4 of the DJPCB algorithm.
Step 5: Determine the updated power of each user i according to the following iteration:

$$P_i^{m+1} = \frac{\gamma_i}{G_{ii}} I_i^m$$

Step 6: Send the value of P_i^{m+1} to each user i and go to Step 2.

Note that in the power feedback based DJPCB algorithm, the updated power is computed by the base station, so the base station has learned P_i^m and can directly use it to calculate $\mathbf{w}_i^m$ and I_i^m, also, the user need not compute the updated power, thus there is no redundancy of power computation. As the DJPCB algorithm requires the base station to send the value of I_i^m to each user i in each iteration, the power feedback based DJPCB algorithm requires the base station to send the value of P_i^{m+1} to each user i in each iteration, and this may consume much overhead (in terms of the number of parameters to be sent) when the number of users per