Computer Communications 32 (2009) 231–234

Contents lists available at ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

Short Communication

Combined switching and power control for diversity and multiplexing in MIMO systems with cochannel interference

Jui Teng Wang *

Graduate Institute of Communication Engineering, National Chi Nan University, Puli, Nantou, Taiwan

ARTICLE INFO

Article history:
Received 22 February 2008
Received in revised form 9 November 2008
Accepted 11 November 2008
Available online 21 November 2008

Keywords:
Diversity
Mulitiplexing
Throughput
Switching
Power control

ABSTRACT

Diversity and multiplexing can relax the throughput limitations caused by the interference and the frequency-selective fading channel, respectively. An algorithm that uses the throughput as the selection criterion for switching between diversity and multiplexing is thus proposed in this paper. Owing to the throughput-based switching, the proposed algorithm can always get the largest throughput between diversity and multiplexing. In addition, the power control procedures for diversity and multiplexing are also proposed to further enhance the throughput.

1. Introduction

There are two popular approaches for improving quality, capacity and reliability in multiple-input multiple-output (MIMO) systems: diversity and (spatial) multiplexing. For diversity, the same information is transmitted over multiple antenna elements, and then the received signals on all antenna elements are combined to increase the signal-to-interference-and-noise ratio (SINR), while for multiplexing, the data stream is divided into multiple substreams, and each substream is transmitted and received over a different antenna element to increase the capacity. It is clear that there is a tradeoff between diversity and multiplexing in MIMO systems [1–3]. To improve the performance, a switching mechanism, where either diversity or multiplexing is chosen based on the instantaneous channel state, was proposed in [4].

The work in [4] considers only the noise and the frequency-flat channel. However, the interference and the frequency-selective fading channel are inevitable in real wireless networks, and they will both limit the transmission rate. Diversity and multiplexing can relax the limitations caused by the interference and the frequency-selective fading channel, respectively. We can use diversity to minimize the interference so that the transmission rate can be increased. Also, we can use multiplexing to make each substream transmitted within the coherence bandwidth (a result of the frequency-selective fading channel) so that the overall transmission rate can be several times the transmission rate of each substream.

In real applications, the interference and the channel condition are random and unknown to the users, so it is hard for the users to known whether diversity or multiplexing can give the largest throughput. To solve this problem, we propose in this paper an algorithm that evaluates the throughput on the basis of the SINR measurements and uses the evaluated throughput as the selection criterion for switching between diversity and multiplexing. Owing to this throughput-based switching, the proposed algorithm can always get the largest throughput between diversity and multiplexing. To further enhance the performance, we also propose the power control procedures that are executed for diversity and multiplexing after the switching is completed. Simulation results show that the power control can effectively increase the throughput.

2. System model and throughput evaluation

We consider the reverse link of a wireless network and assume there are N active base stations in the network with K_i users connected to base station i, $1 \leqslant i \leqslant N$. Notice that K_i is constant during the operation of the proposed algorithm and all users use the same frequency band with bandwidth f_w. The transmitter and the receiver are assumed to have M_t and M_r antenna elements, respectively, and the pair (i, k) is used to denote the kth user connected to the ith base station. Consider user (i, k). Let P_{ik} represent its transmitting power and assume that each transmitting antenna element of it has the same transmitting power share P_{ik}/M_t, also, let $\hat{w}^j_{ik}$ and w^j_{ik} denote its transmitter weight and receiver weight on the jth antenna element, respectively. In addition, we let x^j_i represent the total received signal at the jth antenna element of the ith base

* Tel.: +886 49 2910960.
E-mail address: jtwang@ncnu.edu.tw

0140-3664/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.comcom.2008.11.011

station. On the basis of the above system model, we will evaluate the throughput for the diversity mode and the multiplexing mode in the following derivations.

We first evaluate the throughput for the diversity mode, in which the same information of each user is transmitted over all M_t antenna elements and the received signals on all M_r antenna elements are combined. The output of the combiner for user (i, k) is given by

$$y_{ik} = \sum_{j=1}^{M_r} (w_{ik}^j)^* x_i^j. \tag{1}$$

Note that

$$x_i^j = \sum_{n=1}^{N} \sum_{l=1}^{K_n} \sum_{u=1}^{M_t} \sqrt{P_{nl}/M_t} (\hat{w}_{nl}^u)^* a_{(n,l)i}^{uj} s_{nl} + n_i^j, \tag{2}$$

where s_{nl} represents the message signal for user (n, l), $a_{(n,l)i}^{uj}$ denotes the array gain between the uth antenna element of user (n, l) and the jth antenna element of base station i, and n_i^j denotes the noise at the jth antenna element of the ith base station. Furthermore, the received signal of user (i, k) at the jth antenna element is denoted by d_{ik}^j, which can be expressed as

$$d_{ik}^j = \sum_{u=1}^{M_t} \sqrt{P_{ik}/M_t} (\hat{w}_{ik}^u)^* a_{(i,k)i}^{uj} s_{ik}. \tag{3}$$

Let r_{ik} represent the transmitting rate for user (i, k), the received SINR (per bit) for user (i, k) is given by

$$\begin{aligned} E_{ik} \equiv \left(\frac{E_b}{I_0}\right)_{ik} &= \frac{E(\mathbf{w}_{ik}^H \mathbf{d}_{ik} \mathbf{d}_{ik}^H \mathbf{w}_{ik})/r_{ik}}{[E(\mathbf{w}_{ik}^H \mathbf{x}_i \mathbf{x}_i^H \mathbf{w}_{ik}) - E(\mathbf{w}_{ik}^H \mathbf{d}_{ik} \mathbf{d}_{ik}^H \mathbf{w}_{ik})]/f_w} \\ &= \frac{\mathbf{w}_{ik}^H \Omega_{ik} \mathbf{w}_{ik}}{\mathbf{w}_{ik}^H \Phi_i \mathbf{w}_{ik} - \mathbf{w}_{ik}^H \Omega_{ik} \mathbf{w}_{ik}} \frac{f_w}{r_{ik}}, \end{aligned} \tag{4}$$

where $\mathbf{w}_{ik} := (w_{ik}^j)_{M_r \times 1}$, $\hat{\mathbf{w}}_{ik} := (\hat{w}_{ik}^u)_{M_t \times 1}$, $\mathbf{x}_i := (x_i^j)_{M_r \times 1}$, $\mathbf{d}_{ik} := (d_{ik}^j)_{M_r \times 1}$, $\Phi_i = E(\mathbf{x}_i \mathbf{x}_i^H)$ and $\Omega_{ik} = E(\mathbf{d}_{ik} \mathbf{d}_{ik}^H)$. Note that Φ_i and Ω_{ik} are the correlation matrixes for the total received signal and the received signal of interest, respectively. Assume the message signals are uncorrelated with zero mean and $E(|s_{ik}|^2) = 1$, then we have

$$\Omega_{ik} = P_{ik} \mathbf{a}_{(i,k)i} \mathbf{a}_{(i,k)i}^H \tag{5}$$

and

$$\Phi_i = \sum_{n,l} P_{nl} \mathbf{a}_{(n,l)i} \mathbf{a}_{(n,l)i}^H + N_i \mathbf{I}, \tag{6}$$

where $\mathbf{a}_{(n,l)i} := (\sum_{u=1}^{M_t} (1/\sqrt{M_t}) (\hat{w}_{nl}^u)^* a_{(n,l)i}^{uj})_{M_r \times 1}$ and N_i denotes the noise power at the ith base station. As reported in [6], the minimum variance distortionless response (MVDR) combining can maximize the SINR for a fixed power allocation. Also, it is clear that maximizing the SINR implies maximizing the throughput. Therefore, we use the MVDR combining for the diversity mode. The MVDR combining is accomplished by minimizing the interference-and-noise subject to $\mathbf{w}_{ik}^H \mathbf{a}_{(i,k)i} = 1$. It was shown in [11] that by using the method of Lagrange multipliers, the weight for the MVDR combining is given by

$$\tilde{\mathbf{w}}_{ik} = \frac{(\Phi_i - \Omega_{ik})^{-1} \mathbf{a}_{(i,k)i}}{\mathbf{a}_{(i,k)i}^H (\Phi_i - \Omega_{ik})^{-1} \mathbf{a}_{(i,k)i}}. \tag{7}$$

As a result, the received SINR with the MVDR combining for user (i, k) can be expressed as

$$\begin{aligned} E_{ik} &= \frac{P_{ik} \tilde{\mathbf{w}}_{ik}^H \mathbf{a}_{(i,k)i} \mathbf{a}_{(i,k)i}^H \tilde{\mathbf{w}}_{ik}}{\tilde{\mathbf{w}}_{ik}^H (\Phi_i^{-} \Omega_{ik}) \tilde{\mathbf{w}}_{ik}} \frac{f_w}{r_{ik}} = \frac{P_{ik} \tilde{\mathbf{w}}_{ik}^H \mathbf{a}_{(i,k)i} \mathbf{a}_{(i,k)i}^H \tilde{\mathbf{w}}_{ik}}{\frac{\tilde{\mathbf{w}}_{ik}^H (\Phi_i - \Omega_{ik})(\Phi_i - \Omega_{ik})^{-1} \mathbf{a}_{(i,k)i}}{\mathbf{a}_{(i,k)i}^H (\Phi_i - \Omega_{ik})^{-1} \mathbf{a}_{(i,k)i}}} \frac{f_w}{r_{ik}} \\ &= \frac{P_{ik} \tilde{\mathbf{w}}_{ik}^H \mathbf{a}_{(i,k)i} \mathbf{a}_{(i,k)i}^H \tilde{\mathbf{w}}_{ik}}{\frac{\tilde{\mathbf{w}}_{ik}^H \mathbf{a}_{(i,k)i}}{\mathbf{a}_{(i,k)i}^H (\Phi_i - \Omega_{ik})^{-1} \mathbf{a}_{(i,k)i}}} \frac{f_w}{r_{ik}}. \end{aligned} \tag{8}$$

With the MVDR combining, it holds that $\tilde{\mathbf{w}}_{ik}^H \mathbf{a}_{(i,k)i} = 1$, so the received SINR with the MVDR combining for user (i, k) is given by

$$E_{ik} = P_{ik} (\mathbf{a}_{(i,k)i}^H (\Phi_i - \Omega_{ik})^{-1} \mathbf{a}_{(i,k)i}) (f_w / r_{ik}). \tag{9}$$

To quantify the throughput, we define the available rate as the transmitting rate that makes the received SINR equal the SINR requirement. Therefore, if user (i, k) transmits with rate r_{ik}, then its available rate, which is denoted by a_{ik}, can be expressed as

$$a_{ik} = E_{ik} \frac{r_{ik}}{Q_{ik}}, \tag{10}$$

where Q_{ik} denotes the SINR requirement of user (i, k). In the frequency-selective fading channel, the coherence bandwidth sets the limit on the transmitting rate, hence, we can define the throughput as the constrained available rate, which is expressed as

$$H_{ik}^D = \min\{R_{\max}, a_{ik}\} = \min\left\{R_{\max}, E_{ik} \frac{r_{ik}}{Q_{ik}}\right\}, \tag{11}$$

where H_{ik}^D denotes the throughput of user (i, k) for the diversity mode and $R_{\max}$ denotes the maximal transmitting rate for the frequency-selective fading channel.

Then we evaluate the throughput for the multiplexing mode, in which we let $M_t = M_r = M$, also, the data stream is divided into M substreams and each substream j is transmitted (and received) over the jth antenna element. The received SINR per bit for the jth antenna element of user (i, k), which is denoted by $\widehat{E}_{ik}^j$, can be expressed as

$$\widehat{E}_{ik}^j = \frac{P_{ik} |\hat{w}_{ik}^j a_{(i,k)i}^{jj}|^2 / M}{R_i^j - P_{ik} |\hat{w}_{ik}^j a_{(i,k)i}^{jj}|^2 / M + \eta_{ik}^j} \frac{f_w}{r_{ik}^j}, \tag{12}$$

where R_i^j represents the total power received at the jth antenna element of base station i, η_{ik}^j denotes the noise power for the jth antenna element of user (i, k) and r_{ik}^j represents the transmission rate for the jth antenna element of user (i, k). Accordingly, the throughput of each user is equal to the summation of the constrained available rate for all antenna elements, and we have

$$H_{ik}^M = \sum_{j=1}^{j=M} \min(R_{\max}, a_{ik}^j) = \sum_{j=1}^{j=M} \min\left(R_{\max}, \widehat{E}_{ik}^j \frac{r_{ik}^j}{Q_{ik}}\right), \tag{13}$$

where H_{ik}^M denotes the throughput of user (i, k) for the multiplexing mode and a_{ik}^j denotes the available rate for the jth antenna element of user (i, k).

3. Combined switching and power control for diversity and multiplexing

In this section, we propose the algorithm that combines switching and power control for diversity and multiplexing. The proposed algorithm first evaluates the throughput for the diversity mode and the multiplexing mode, respectively, then it switches to the mode that has the largest throughput and executes power control for this mode. For executing power control for the diversity mode and the multiplexing mode, the proposed algorithm contains two power control procedures: the power control for diversity (PC-D) procedure and the power control for multiplexing (PC-M) procedure. In these two procedures, we use the following iteration for updating the power:

$$P_{ik}^{m+1} = \frac{\min(E_{ik}^m, Q_{ik})}{E_{ik}^m} P_{ik}^m. \tag{14}$$

where P_{ik}^m and E_{ik}^m denote the power and the SINR, respectively, for user (i, k) in the mth iteration. In addition, we let $P_{\max}$ represent the maximal transmitting power level and assume that L iterations of power control are executed.