A channel adaptive power allocation scheme based on SLNR precoding for multiuser MIMO systems

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***Abstract*—In the downlink of multiuser MIMO (MU-MIMO) systems, the co-channel interference (CCI) and noise are two major impairments. Maximizing signal to leakage plus noise ratio (SLNR) is a good criterion for the design of precoders since it making a balance between eliminating the CCI and noise. In this text, we propose a channel adaptive power allocation scheme based on SLNR precoding. Simulation results show that the proposed scheme can improve the BER performance considerably with a minor loss in the sum capacity performance. And we also illustrate that the additional computational complexity is very small.**

Keywords- MU-MIMO; SLNR; power allocation

I. INTRODUCTION

There has been considerable interest in MIMO wireless communications in the past years. More recently, the point-to-point system has been generalized to a multiuser scenario, in which a base station is communicating with several mobile stations in the same frequency and time slots. The MU-MIMO technology has attractive advantage in spectrum-efficiency and can further improve the reliability and capacity performance [1]. In the downlink, CCI arises at the user side, and the additive channel noise also degrades the system performance. Therefore, they are two major impairments to a MU-MIMO downlink.

In order to suppress CCI and channel noise, precoding schemes based on different criterions have been proposed. The ZF (Zero Forcing) design [2]-[3] cancels the CCI completely. But it ignores the noise component and may suffer from noise enhancement. Besides, it imposes a restriction on the system configuration in terms of the number of antennas. The SINR (Signal to Interference plus Noise Ratio) precoding introduced in [4]-[5] takes both the CCI and noise elimination into consideration and seems to achieve the best system performance. However, the solution can only be obtained iteratively due to the coupled nature of the corresponding optimization problem which is usually too complex to implement in practice.

In [6]-[7], the SLNR precoding is proposed. It also makes a balance between eliminating the CCI and noise. The closed form of solution can be obtained by generalized Rayleigh quotient and it doesn't impose any condition on the relation between the number of transmit and receive antennas. Therefore, it seems to realize a better trade-off between the performance and the complexity.

However, in the conventional SLNR precoding scheme, it is always assumed that the transmitter distributes equal power to each user. Since the channel state of every user is different, allocating the transmit power in a reasonable way may further improve the system performance. In this text, based on SLNR precoding we propose a channel adaptive scheme where the value of each user's SLNR is used as the reference for power allocation. Simulation results show that this scheme can improve the system BER performance considerably with a minor loss in the sum capacity performance.

This text is organized as follows: In Section II, we describe the model of the MU-MIMO system. In Section III, we firstly review the SLNR precoding scheme, and then present the novel channel adaptive power allocation scheme. Simulation results are shown in Section IV. The final Section is the conclusion.

Notation: For matrix $\mathbf{A}$, $\mathbf{A}^T, \mathbf{A}^H$ and $\|\mathbf{A}\|_F$ denote its transpose, conjugate transpose and Frobenious norm, respectively. $\mathbf{I}_M$ is the $M \times M$ identity matrix. $\mathrm{E}\{\bullet\}$ stands for the expectation operator.

II. SYSTEM MODEL

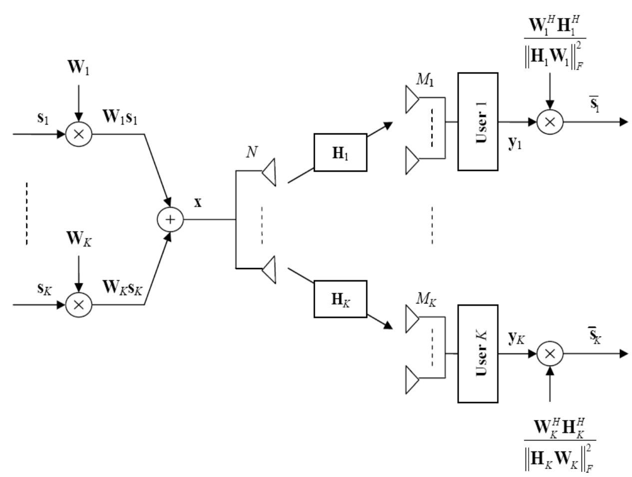

Fig.1 A block diagram of the MU-MIMO system

Consider a multiuser downlink environment with a base station communicating with K users simultaneously. The base

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station employs N transmit antennas and user i is equipped with M_i receive antennas. A block diagram of the system is shown in Figure 1.

The received signal of user i can be denoted as

$$\mathbf{y}_i = \mathbf{H}_i \mathbf{W}_i \mathbf{s}_i + \mathbf{H}_i \sum_{k=1,k\neq i}^{K} \mathbf{W}_k \mathbf{s}_k + \mathbf{v}_i \tag{1}$$

where $\mathbf{s}_i$ is the data vector and $\mathbf{W}_i$ the precoding matrix for user i. Assuming a narrow-band channel which means frequency flat fading for each user, the $M_i \times N$ channel matrix $\mathbf{H}_i$ of user i can be written as

$$\begin{aligned}\mathbf{H}_i &= \left[\mathbf{h}_i^1, \cdots, \mathbf{h}_i^{M_i}\right]^T \\ &= \begin{bmatrix} h_i^{(1,1)} & \cdots & h_i^{(1,N)} \\ \vdots & \ddots & \vdots \\ h_i^{(M_i,1)} & \cdots & h_i^{(M_i,N)} \end{bmatrix}, \quad 1 \le i \le K \end{aligned} \tag{2}$$

where $h_i^{(m,n)}, 1 \le m \le M_i, 1 \le n \le N$ is the fading coefficient between the nth transmitting antennas and the mth receiving antenna of user i. In this text, the elements of $\mathbf{h}_i^j, 1 \le i \le K$, $1 \le j \le M_i$ are assumed to be independent and identically distributed (i.i.d) circularly symmetric complex Gaussian variables with zero-mean and unit-variance. Furthermore, the additive noise vector is also assumed to have independent and identically distributed (i.i.d) circularly symmetric complex Gaussian elements with zero-mean and variance σ^2. The above-mentioned model can also be applied to the frequency selective fading case by using OFDM.

The channel is assumed to be slow-fading which means that the channel coefficients are constant during a block of symbol periods, and then change independently from block to block. And in this text, we assume that the channel matrices $\mathbf{H}_i, 1 \le i \le K$ are perfectly known at the base station and the corresponding user i, but are not known by the other users.

III. THE PROPOSED POWER ALLOCATION SCHEME

A. Review the SLNR precoding scheme

Back to (1), the second term is CCI and the third is channel noise. It is therefore necessary to rely on the transmission scheme to suppress these two impairments in the MU-MIMO system. Several related research works have proposed different schemes for CCI and channel noise cancellation. In order to realize a better trade-off between the system performance and the complexity, a novel concept named SLNR is introduced in [4]. Start from (1) and note that the power of the interference that is caused by user i on the signal received by some other user k is given by $\left\|\mathbf{H}_k \mathbf{W}_i\right\|_F^2$. Thus, the leakage of user i, as the total power leaked from this user to all other users, can be denoted by $\sum_{k=1,k\neq i}^{K} \left\|\mathbf{H}_k \mathbf{W}_i\right\|_F^2$. Based on this novel concept, the SLNR precoding scheme can be defined as

$$\begin{aligned} &\max_{\mathbf{W}_i} \ \mathrm{SLNR}_i = \frac{\left\|\mathbf{H}_i \mathbf{W}_i\right\|_F^2}{M_i \sigma^2 + \sum_{k=1,k\neq i}^{K} \left\|\mathbf{H}_k \mathbf{W}_i\right\|_F^2} \\ &\text{subject to } \left\|\mathbf{W}_i\right\|_F^2 = m, 1 \le i \le K \end{aligned} \tag{3}$$

where m denote the dimension of the data streams for each user. With the data vectors $\mathbf{s}_i, 1 \le i \le K$ being normalized as $\mathrm{E}\left\{\mathbf{s}_i \mathbf{s}_i^H\right\} = \frac{1}{m}\mathbf{I}_m$, the constraint in (3) ensures that the power transmitted per user is normalized to 1.

As presented in (3), the SLNR precoding scheme circumvents the coupled difficulty encountered in the SINR precoding because all the $\mathrm{SLNR}_i, 1 \le i \le K$ are independent with respect to the precoding matrices $\mathbf{W}_i, 1 \le i \le K$. The closed form of solution for the SLNR precoding can be obtained by generalized Rayleigh quotient [4]. When $m = 1$, it is given by

$$\mathbf{W}_i^o \propto \max. \text{ eigenvector}\left[\left(M_i \sigma^2 \mathbf{I}_N + \sum_{k=1,k\neq i}^{K} \mathbf{H}_k^H \mathbf{H}_k\right)^{-1} \mathbf{H}_i^H \mathbf{H}_i\right] \tag{4}$$

in terms of the eigenvector corresponding to the largest eigenvalue of the matrix $\left(M_i \sigma^2 \mathbf{I}_N + \sum_{k=1,k\neq i}^{K} \mathbf{H}_k^H \mathbf{H}_k\right)^{-1} \mathbf{H}_i^H \mathbf{H}_i$. When $m > 1$, the optimized solution $\mathbf{W}_i^o$ is composed of eigenvectors corresponding to the m largest eigenvalues of the matrix $\left(M_i \sigma^2 \mathbf{I}_N + \sum_{k=1,k\neq i}^{K} \mathbf{H}_k^H \mathbf{H}_k\right)^{-1} \mathbf{H}_i^H \mathbf{H}_i$. The norm of $\mathbf{W}_i^o$ is then adjusted to $\left\|\mathbf{W}_i^o\right\|_F^2 = m$ to satisfy the power constraint in (3).

Research works [6]-[7] have shown that the SLNR precoding scheme always outperforms the ZF solution even when the dimension requirement of the latter is satisfied. And on the other hand, it reduces the complexity considerably by avoiding iteration when compared with the SINR solution with a minor performance loss.

B. The proposed power allocation scheme

In the majority of existing precoding schemes, it is always assumed that the transmitter distributes equal power to each user. But in the real wireless communication system, the channel state of every user is usually different. Thus, if the transmit power is allocated according to the real channel state information (CSI), some gains may be achieved due to the improved power-efficiency.

According to the related research works [4]-[7], there is an obvious gap in the BER performance between the SLNR and SINR precoding scheme, while the latter is usually considered to be optimal. And for a MU-MIMO system, it is believed that the average BER of all users is dominated by the worst one. Therefore, we consider a channel adaptive scheme based on the

SLNR precoding to improve the communication quality of the worst user by increasing its transmitted power.

In the conventional SLNR precoding, the value of SLNR seems to be useless. However, we can utilize it as the indicator of each user's channel quality and then allocate the transmit power in reference to it. Since the value of each user's SLNR is related to the real CSI, this power allocation scheme is thought to be channel adaptive.

The detailed power allocation process is described as follows:

As the initialization, the optimized precoding matrices $\mathbf{W}_i^o, 1 \le i \le K$ and the corresponding SLNR values SLNR_i^o, $1 \le i \le K$ are calculated in accordance to the solution introduced in [6]. Then, the transmit power is allocated according to each user's SLNR values. When $m = 1$, the power distributed to user i is inversely proportional to its SLNR value. It can be denoted as

$$\frac{p_i}{P_T} = \frac{1/\mathrm{SLNR}_i}{\sum_{i=1}^{K} \left(1/\mathrm{SLNR}_i\right)}, \; 1 \le i \le K \tag{5}$$

where P_T is the total transmit power. When $m > 1$, considering the value of each user's SLNR is composed of several generalized eigenvalues, the minimum is used as the indicator to perform similar power allocation as denoted in (5). At last, the power coefficients $p_i^{1/2}, 1 \le i \le K$ are right multiplied by the corresponding precoding matrice $\mathbf{W}_i^o, 1 \le i \le K$.

According to the solution of the conventional SLNR precoding, no matter what value m is, the optimized precoding matrices are composed of the generalized eigenvectors. And the value of each user's SLNR consists of the corresponding generalized eigenvalues. Thus, no additional computation is needed for the transmitter to obtain the value of each user's SLNR.

IV. SIMULATION RESULTS

In this section, we compare the performance of the following transmission schemes.

- The SINR precoding scheme introduced in [4], which includes a power allocation process (SINR)
- The conventional SLNR precoding scheme with equal power allocation to each user. (SLNR)
- The SLNR precoding scheme with power allocation introduced in [8] (SLNR+CN). It uses each user's channel norm as the indicator of channel quality and then allocates the transmit power similar to (5).
- The SLNR precoding scheme with power allocation proposed in this text (SLNR+SLNR).

All simulations are conducted using a QPSK modulation and the results are averaged over 50000 channel realizations for the curves. Every channel realization during which the channel coefficients keep constant includes 200 symbol periods. The noise variance per receiving antenna is σ^2, and the curves are plotted versus $1/\sigma^2$ as the SNR: $1/\sigma^2$ functions as the SNR per receiving antenna since the channel and precoding coefficients are all normalized. Similar to the description in Fig.1, the matched filter is adopted in this text at each receiver.

Firstly, we consider the case when $m = 1$. We set $N = K = 4, M_i = 1$.

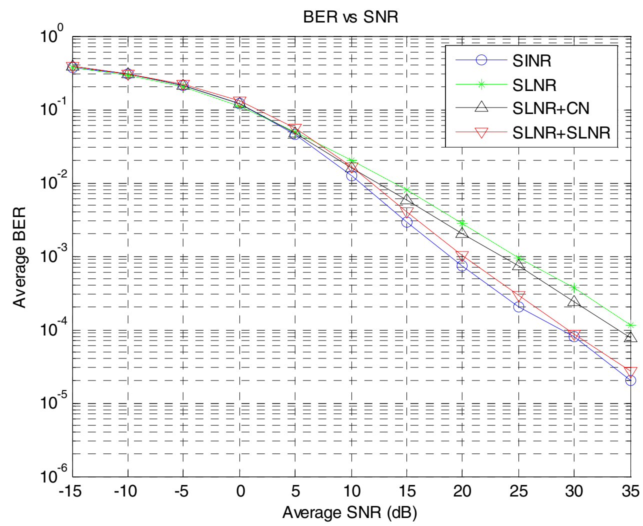

Fig.2 The average BER curves for $N = 4, K = 4, M_i = 1$

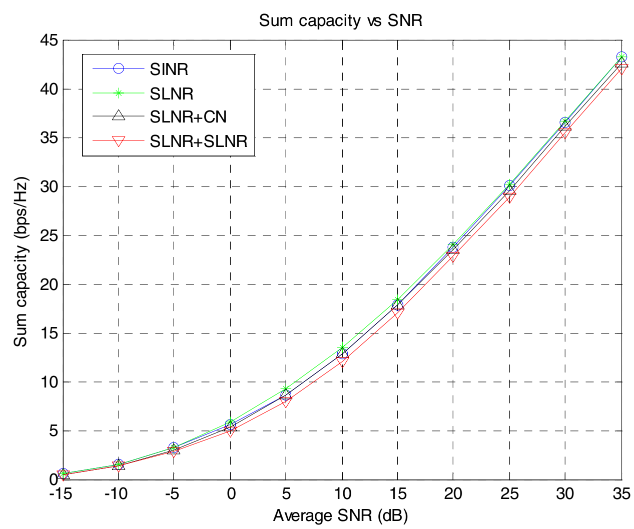

Fig.3 The sum capacity curves for $N = 4, K = 4, M_i = 1$

Fig.2 and Fig.3 present the average BER and sum capacity of the above-mentioned schemes versus the average SNR. We can see that there is an obvious gap in the average BER performance between the conventional SINR and SLNR precoding. And the gap can be reduced by the two power allocation schemes. Especially with the proposed power allocation process, the improvement is significant. However, on the other hand, we also observe that both the two power allocation schemes may result in some minor loss in the sum capacity performance compared with the conventional precoding scheme. And the one proposed in this text suffers less than that introduced in [8].

Then, we consider the case when $m = 2$. We set $N = 8, K = 4, M_i = 2$.

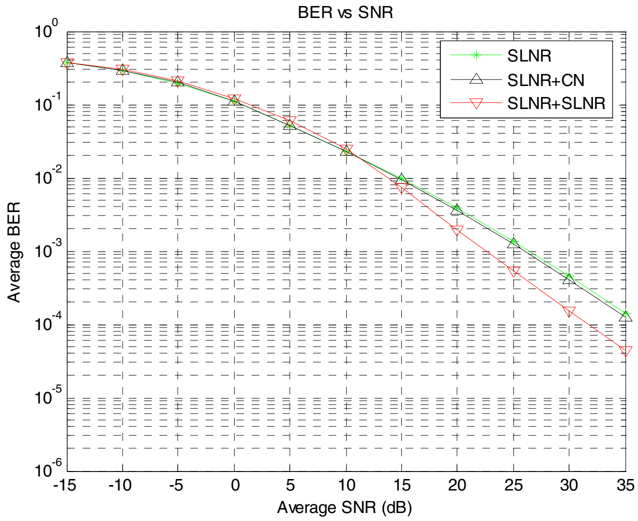

Fig.4 The average BER curves for $N = 8, K = 4, M_i = 2$

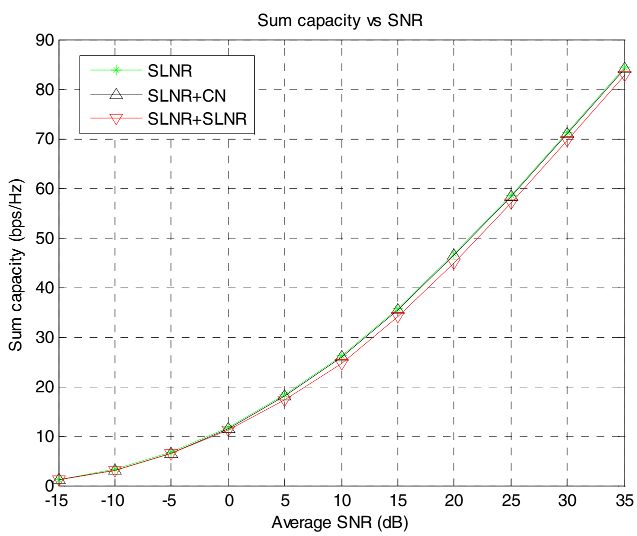

Fig.5 The sum capacity curves for $N = 8, K = 4, M_i = 2$

Fig.4 and Fig.5 also present the average BER and sum capacity of the above-mentioned schemes versus the average SNR. The SINR precoding introduced in [4] is just fit for the case when $m = 1$, so it is included in these two figures. Similar to the results when $m = 1$, the two power allocation schemes both improve the average BER performance compared with the conventional precoding with a minor loss in the sum capacity performance. And the one proposed in this text seems to realize a better trade-off between the gain and loss.

V. CONCLUSION

In this text, based on SLNR precoding, a novel power allocation scheme is presented. Due to the difference of every user's channel state, transmit power is no longer distributed to users equally. The value of every user's SLNR is utilized as the indicator of its channel quality. When combined with the SLNR precoding, the acquirement of these values needs no additional computation. The transmit power is then allocated according to these indicators. Simulation results show that the proposed scheme can significantly improve the average BER performance of the conventional SLNR precoding with a minor loss in the sum capacity performance.

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