Interference Mitigation Based on Enhanced Interference PMI Notification*

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Abstract. This paper considers interference mitigation in multicell scenarios where transmitters and receivers are both equipped with multiple antennas. In multicell system, both the local Pre-coding Matrix Index (PMI) and the interference PMI can be utilized by Interference Reject Combing (IRC) algorithm, and more interference information can be obtained from the enhanced interference PMI notification. The IRC interference mitigation algorithm can deal with both noise and interference. The specific formulas of calculating receiver weight vector (matrix) based on different criterions are given. And the IRC-adaptive algorithm is proposed, which can have a compromise effect between the complexity and interference mitigation. It is shown in the simulation results that the receiver algorithms can improve the system performance effectively.

Keywords: multi-cell scenarios, interference mitigation, weight vector, interference reject combine (IRC).

1 Introduction

Multicell multiple user Multi-input and Multi-output (MIMO) technology can achieve a very high sum capacity and spectral efficiency. The multicell coordinated beamforming is very helpful to exploit the multiuser diversity gain in the Multiuser MIMO (MU-MIMO) system [1]. However, the same subcarrier of the different users will cause co-channel interference (CCI). [2] indicates that user throughput will reach a performance limit with SNR increasing in multicell coordination scheme. This is because that the limited number of the feedback bit will cause channel information imprecise, and the multiuser interference can not be completely eliminated. In the high SNR, multiuser interference will become the main factor that affects the user performance. So how to eliminate the CCI is critical for the system performance.

In terms of how to eliminate interference, much previous work has been done [3]. There are several ways to eliminate interference: such as interference averaging techniques and interference avoidance techniques. The former averaged the interference

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over all users, to reduce the interference experienced by individual users. The latter is to avoid interference, e.g. by setting restrictions on how the radio resources are used. [4] discussed about how to utilize zero forcing (ZF) algorithm and minimum mean square error (MMSE) algorithm to eliminate the interference between users in TD-CDMA system. [5] proposed a method which is called Hybrid Inter-cell Interference Mitigation scheme that utilized multiple sub-bands coordination scheme and soft frequency reuse scheme to achieve robust performance. [6] proposed a two-stage interference mitigation technique for coded Multiband Orthogonal Frequency Division Multiplexing (MB-OFDM), and showed that it was very effective for the WIMAX interference.

Interference Reject Combine (IRC) algorithm can distinguish the serving cell signal and interference cell signal by distinguishing space channel discrepancy from different base stations (BS) to mobile terminal. IRC algorithm deal with both interference and noise at the receiver by utilizing receive diversity, realizing the inhibition to the colored noise (interference and noise). And IRC algorithm is a receiver technology without requiring additional standardization work. Compared to IRC, both the traditional Maximum Ratio Combination (MRC) algorithm and MMSE algorithm ignore the impact of interference between users. It is why that the IRC algorithm could suppress the interference more effectively. [7] indicates that the IRC algorithm has greatly improved the system performance, in an ideal situation with one flat-fading timeslot synchronized. It could bring more than 15dB performance improvement than the MRC receiver in GSM system.

In this paper, an IRC interference eliminating method by utilizing the enhanced interference Pre-coding Matrix Index (PMI) notification from the BS is proposed. In this scheme, the signaling from BS to users not only includes the local PMI but also the interference PMI. Therefore, the users can get accurate interference information, and directly calculate the correlation matrix of interference and noise, which is used to eliminate multi-user interference. On this basis, an adaptive IRC receiver based on interference condition is future proposed. When the interference is larger relative to the noise, the IRC algorithm is adapted; If not, the traditional MRC algorithm can be directly used, which can greatly reduce the complexity without significant performance decrease.

The remainder of this paper is organized as follows. Section 2 presents system model. And Section 3 describes several IRC algorithms based on different criterions. Section 4 presents simulation results and conclusions are drawn in section 5 finally.

2 System Model

In this paper we consider a multicell MIMO system shown in fig.1 for an array of linearly arranged cells, which is based on the Wyner model [8]. Assumed that there are K base stations totally in the system, where K goes to infinity for the Wyner model. Each user could receive the data signal from its corresponding base station and the inter-cell interference signal from adjacent base stations. It is supposed that all the base stations are equipped with N antennas, and each user is equipped with M antennas.

With the assumption of linear precoding, the transmitted signal intended for the *k*th $k \in \{1, 2 ... K\}$ UE could be given by:

$$\mathbf{x}_k = \mathbf{w}_k \mathbf{s}_k \tag{1}$$

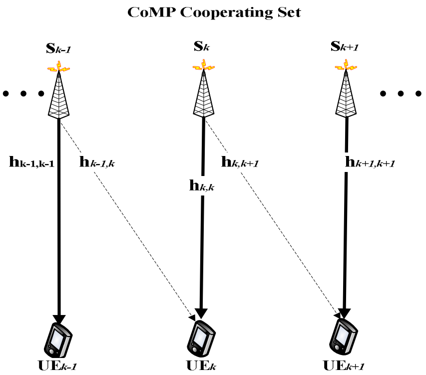

Fig. 1. System Model

where $\mathbf{s}_k \in CN(0,1)$ denotes the data symbol intended for the *k*th user and $\mathbf{w}_k$ is denoted as the quantized precoding vector. Under above assumption, the signal received at the *k*th UE can be described as:

$$\mathbf{y}_k = \underbrace{\mathbf{H}_{k,k}\mathbf{w}_k\mathbf{s}_k}_{\text{data}} + \underbrace{\mathbf{H}_{k-1,k}\mathbf{w}_{k-1}\mathbf{s}_{k-1}}_{\text{interference}} + \mathbf{n}_k \tag{2}$$

where $\mathbf{H}_{k,k}$ denotes the local channel state information from the *k*th base station to the *k*th user, $\mathbf{H}_{k-1,k}$ denotes the interference channel, and $\mathbf{n}_k \in CN(0,\sigma^2)$ is the noise with zero mean and variance σ^2. Assumed that the users know the local and interference channel state information, and ZF-BF scheme is applied in this scheme. The pre-coding vector (matrix) is computed based on the quantized channel information. Since there are quantization errors existing, the interference item can not be eliminated completely.

Herein, the effective channel is defined as $\mathbf{h}_{ek} = \mathbf{H}_{k,k}\mathbf{w}_k \quad (k = 1,2...K)$, and the effective interference channel is defined as $\mathbf{f}_{e(k-1)} = \mathbf{H}_{k-1,k}\mathbf{w}_{k-1}$. Then the formula (2) can be simplified as:

$$\mathbf{y}_k = \underbrace{\mathbf{h}_{ek}\mathbf{s}_k}_{\text{data}} + \underbrace{\mathbf{f}_{e(k-1)}\mathbf{s}_{k-1}}_{\text{interference}} + \mathbf{n}_k \tag{3}$$

Supposed that the receiver takes the linear detection with weight vector **g**, then the detected signal $\mathbf{r}_k$ can be depicted as:

$$\mathbf{r}_k = \mathbf{g}_k^H \left(\underbrace{\mathbf{h}_{ek}\mathbf{s}_k}_{\text{data}} + \underbrace{\mathbf{f}_{e(k-1)}\mathbf{s}_{k-1}}_{\text{interference}} + \mathbf{n}_k \right) \tag{4}$$

The SINR of the received signal of the *k*th UE is given by:

$$SINR_k = \frac{\left|\mathbf{g}_k^H \mathbf{h}_{ek}\right|^2}{\left|\mathbf{g}_k^H \mathbf{f}_{e(k-1)}\right|^2 + \sigma^2} \tag{5}$$

The key problem is how to construct the linear weight vector (matrix) **g** to maximize (5). We study the long-term average throughput, and could get the rate at the *k*th UE as follows:

$$C_k = E\{\log_2(1+SINR_k)\} \tag{6}$$

And the system sum rate can be given by:

$$C = \sum_{k=1}^{K} E\{\log_2(1+SINR_k)\} \tag{7}$$

3 IRC Interference Mitigation Algorithm

In this section, several IRC algorithms based on different criterions are discussed. IRC algorithm is an effective receiver algorithm which can suppress the interference. Its basic idea is to construct a weight vector (matrix) **g** which can eliminate or reduce the interference, in the case of known interference PMI. The specific expressions of the weight vector (matrix) **g** of different IRC algorithms are given in the following parts.

A. IRC-ZF Algorithm

The basic idea of IRC-ZF algorithm is to make the interference item zero. It can be described as follows:

$$\mathbf{r}_k = \left(null(\mathbf{f}_{e(k-1)})\mathbf{h}_{ek}\right)^H \left(null(\mathbf{f}_{e(k-1)})\mathbf{h}_{ek}\mathbf{s}_k + null(\mathbf{f}_{e(k-1)})\mathbf{n}_k\right) \tag{8}$$

Equivalent weight vector (matrix) can be expressed as:

$$\mathbf{g}^H_{IRC-ZF} = \mathbf{h}^H_{ek}\mathbf{R}^{-1}_{\mathbf{ff}} \tag{9}$$

where $\mathrm{R}_{\mathbf{ff}}$ is the autocorrelation matrix of the effective interference channel.

When using the above formula as a weighted vector, multi-user interference can be completely suppressed. Hence, in high SNR scenarios (interference limited), system performance will be greatly improved. But it doesn't consider the impact of noise, especially for the low SNR scenarios (noise limited).

B. IRC-SINR Algorithm

Compared to IRC-ZF algorithm, IRC-SINR algorithm takes the noise into account, which makes up the shortage of the IRC-ZF algorithm in the low SNR scenarios. The goal of IRC-SINR algorithm is to maximize the SINR of the detected signals. For convenience, (3) is rewritten as:

$$\mathbf{y}_k = \underbrace{\mathbf{h}_{ek}\mathbf{s}_k}_{\text{data}} + \underbrace{\mathbf{u}_k}_{\text{interference}} \tag{10}$$

where $\mathbf{u}_k$ is the sum of the interference and the noise. Then, the following objective function can be given by:

$$\max_{\mathbf{g}} SINR = \frac{E\left\{\left|\mathbf{g}^H \mathbf{h}_{ek} \mathbf{s}_k\right|^2\right\}}{E\left\{\left|\mathbf{g}^H \mathbf{u}_k\right|^2\right\}} = \frac{\mathbf{g}^H \mathbf{h}_{ek} \mathbf{h}_{ek}^H \mathbf{g}}{\mathbf{g}^H \mathbf{R}_{\mathbf{uu}} \mathbf{g}} \tag{11}$$

where $\mathrm{R}_{\mathbf{uu}}$ is the autocorrelation matrix of matrix $\mathbf{u}_{\mathrm{k}}$.

According to the theory of generalized Rayleigh quotient, the optimal receive combining vector was given by [9]:

$$\mathbf{g}^H_{IRC-SINR} = \mathbf{h}^H_{ek} \mathbf{R}^{-1}_{\mathbf{uu}} \tag{12}$$

C. *IRC-MMSE Algorithm*

IRC-MMSE algorithm also considers the noise. The goal of this method is to minimize the mean square error of the detected signal:

$$\min_{\mathbf{g}} J = E\left\{\left|\mathbf{g}^H \mathbf{y} - \mathbf{s}\right|^2\right\} = \mathbf{g}^H \mathbf{R}_{\mathbf{yy}} \mathbf{g} + \mathbf{I} - \mathbf{g}^H \mathbf{R}_{\mathbf{ys}} - \mathbf{R}^H_{\mathbf{ys}} \mathbf{g} \tag{13}$$

where $\mathbf{R}_{\mathbf{yy}}$ is the autocorrelation matrix of the received vector; $\mathbf{R}_{\mathbf{ys}}$ is the correlation matrix of the received vector $\mathbf{y}$ and detected vector $\mathbf{s}$. The optimal receive combining vector was given by:

$$\mathbf{g}^H_{\text{IRC-MMSE}} = (\mathbf{I} + \mathbf{h}^H_{ek} \mathbf{R}^{-1}_{\mathbf{uu}} \mathbf{h}_{ek})^{-1} \mathbf{h}^H_{ek} \mathbf{R}^{-1}_{\mathbf{uu}} \tag{14}$$

D. *IRC-Adaptive Algorithm*

To reduce the complexity of calculating receiver weight vector, the IRC-adaptive algorithm is proposed in this subsection. When the interference is relatively large, IRC-SINR algorithm is adapted to suppress the interference. And if the interference is relatively small, MRC algorithm is directly chosen to reduce the complexity. The key is to set a threshold for selecting the receiver algorithm. Here, the interference term is defined as $Z = \left\|\mathbf{f}_{e(k-1)}\right\|^2$. Then, if $Z/\sigma^2 \le \alpha$, MRC algorithm is directly used. And if $Z/\sigma^2 \le \alpha$, the IRC-SINR algorithm is adapted. Hence, the weight vector (matrix) can be formulated as :

$$\mathbf{g}^H_{\text{IRC-adaptive}} = \begin{cases} \mathbf{h}^H_{ek} & Z/\sigma^2 \le \alpha \\ \mathbf{h}^H_{ek} \mathbf{R}^{-1}_{\mathbf{uu}} & Z/\sigma^2 \le \alpha \end{cases} \tag{15}$$

How to set the threshold α is critical. It hopes to reduce the complexity of the receiver as much as possible without significant decline in performance. If the threshold α is too small, the IRC algorithm may be chosen at the low interference. IRC-adaptive algorithm will not reduce the complexity relative to the IRC-SINR algorithm. If α is set too large, the MRC algorithm may be used in the high interference situation. The system performance will decrease correspondingly. In the next section, the comparison curves of the system performance with different α will be presented.

It should be noted that the key of IRC algorithm is to calculate the covariance matrix $\mathbf{R}_{\mathbf{uu}}$ of the interference and noise. In this scheme, UE can easily obtain the precise interference information $\mathbf{f}$ by the interference PMI. Hence, it is easy to get the interference correlation matrix $\mathbf{R}_{\mathbf{ff}}=E\{\mathbf{ff}^H\}$, and the covariance matrix of the interference and noise $\mathbf{R}_{\mathbf{uu}}=E\{\mathbf{uu}^H\}$. Suppose noise is the Gaussian white noise. It is irrelevant with the interference. It is easy to get the following formula:

Thus it can easily get $\mathbf{R}_{\mathbf{uu}}$ and weight vector corresponding to IRC receiver algorithm. All kinds of the receiver algorithm are listed in Table 1.

Table 1. Different Receiver Algorithm In The Multi-antenna Scenarios

Receiver algorithm	**Weight Vector(matrix)**	**Features**	**Performance**
MRC	$\mathbf{g}_{opt}^H=\mathbf{h}_{ek}^H$	no considering interference	Performance limited at high SNR
MMSE	$\mathbf{g}_{opt}^H=\mathbf{h}_{ek}^H\left(\mathbf{h}_{ek}\mathbf{h}_{ek}^H+\sigma^2\mathbf{I}\right)^{-1}$	no considering interference	Performance limited at high SNR
IRC-ZF	$\mathbf{g}_{opt}^H=\mathbf{h}_{ek}^H\mathbf{R}_{\mathbf{ff}}^{-1}$	no considering noise	Performance increase at high SNR
IRC-SINR	$\mathbf{g}_{opt}^H=\mathbf{h}_{ek}^H\mathbf{R}_{\mathbf{uu}}^{-1}$	considering interference and noise	Performance increase at high SNR
IRC-MMSE	$\mathbf{g}_{opt}^H=(\mathbf{I}+\mathbf{h}_{ek}^H\mathbf{R}_{\mathbf{uu}}^{-1}\mathbf{h}_{ek})^{-1}\mathbf{h}_{ek}^H\mathbf{R}_{\mathbf{uu}}^{-1}$	considering interference and noise	Equivalent with IRC-SINR
IRC-adaptive	$\mathbf{g}_{opt}^H=\begin{cases}\mathbf{h}_{ek}^H & Z/\sigma^2\le\alpha\\ \mathbf{h}_{ek}^H\mathbf{R}_{\mathbf{uu}}^{-1} & Z/\sigma^2\le\alpha\end{cases}$	Choose MRC or IRC adaptively	IRC-adaptive

$$\mathbf{g}_{\text{IRC-adaptive}}^H=\begin{cases}\mathbf{h}_{ek}^H & Z/\sigma^2\le\alpha\\ \mathbf{h}_{ek}^H\mathbf{R}_{\mathbf{uu}}^{-1} & Z/\sigma^2\le\alpha\end{cases} \tag{16}$$

4 Simulations

In this section, numerical results of the proposed scheme are presented. It is assumed that the BS is equipped with four antennas and each user is equipped with two antennas. All the simulations are based on flat fading Rayleigh channel and Random Vector Quantization (RVQ).

Fig. 2 and 3 show the sum-rate and BER performance for different receiver algorithms. It can be seen that IRC algorithm have a great improvement in system performance at high SNR. With SNR increasing, the performance of IRC-ZF comes close to IRC-SINR. But at low SNR, the performance incensement of IRC algorithms is not obvious compared to traditional MRC. Besides, the performance of IRC-ZF decreases obviously. This is because that IRC-ZF reduces the received signal energy when the interference is not the key factor of affecting system performance.

Fig. 4 and 5 show the throughput and BER performance of IRC-adaptive algorithm for different α values. It can be seen that the IRC-adaptive algorithm can reduce the complexity while ensuring the system performance. When interference and noise are in the same order of magnitude, IRC-adaptive performance has a small little decline relative to IRC-SINR. And the greater α is, the larger performance loss is. When $\alpha = 1$, there is no obvious performance loss; When $\alpha = 5$, the performance loss is about 1dB. In practical application, α can be set to meet the system requirement.

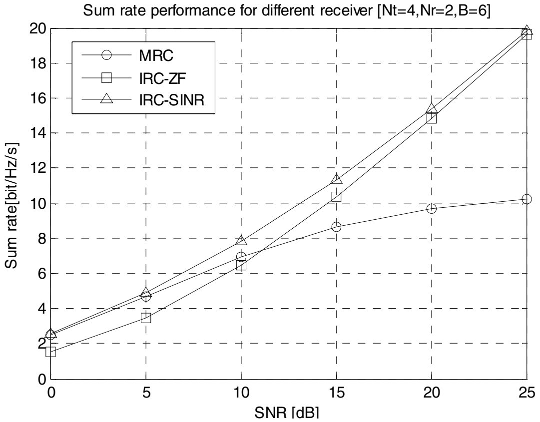

Fig. 2. Sum rate performances for different receiver

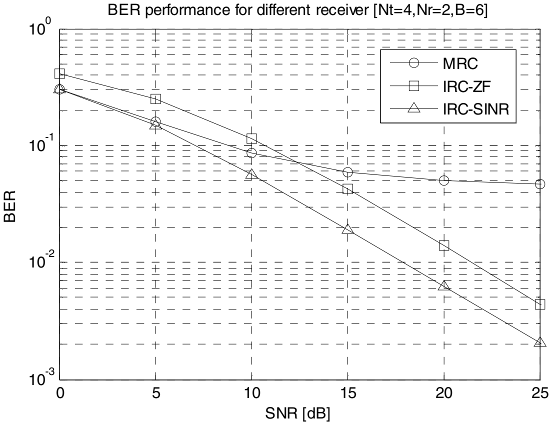

Fig. 3. BER performances for different receiver

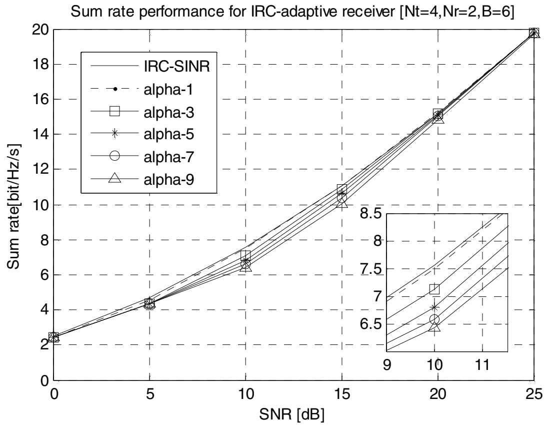

Fig. 4. Sum rate performance for IRC-adaptive receiver [Nt=4, Nr=2, B=6]

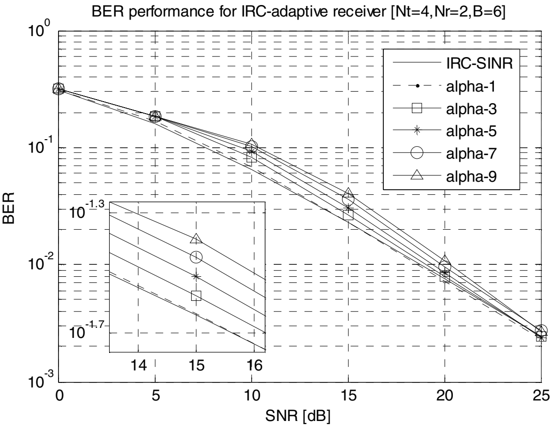

Fig. 5. BER performance for IRC-adaptive receiver [Nt=4, Nr=2, B=6]

5 Conclusions

This paper propose some kinds of IRC receiver algorithm based on enhanced interference PMI notification in multiuser system, to eliminate interference among users. Simulation results show that IRC algorithm performance comes close to MRC at low SNR (noise limited). And at high SNR, it has a great improvement for system performance. A new algorithm —IRC-ZF is also proposed, by utilizing which the interference can be completely eliminated in theory. However, IRC-ZF algorithm only considers the interference without noise, and there is some performance loss at low SNR. Because the complexity of IRC algorithm is relatively high comparing to traditional receiver algorithm, the IRC-adaptive algorithm based on interference situation is proposed. Adaptive receiver can balance the system performance and receiver algorithm complexity.

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