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On The Study of Interference Mitigation Method in *K*-user MIMO Interference Channel

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Abstract
A study of interference mitigation methods is explained. Interference mitigation has become a major issue in current communication system. Understanding the advantages and drawbacks of each method is essential so that it could be implemented effectively. In this paper, we compare five interference mitigation methods, consists of 2 ordinary equalization methods, matched filter and zero forcing; and 3 interference alignment methods, min weighted leakage interference, alternating minimization, and max SINR. Simulation is done in*K*-user MIMO interference channel. Through sum rate and bit error rate performance we show that max SINR method has the best performance although the complexity is larger than an ordinary equalization.

Keywords: BER, interference mitigation, *K*-user MIMO interference channel, sum rate.

Introduction

The user demand in transmitting faster and larger data is growth, thus the need of a faster and more reliable technique to increase capacity and data rate has become a main issue. Began from Single Input Single Output (SISO) system where each user only have one antenna to transmit data until Multiple Input Multiple Output (MIMO) communication system, with more than one antenna is developed to achieve higher capacity. Nowadays, the trend is using more antennas as the massive MIMO become a major research topic. However, we must know that the increase of the number of antennas and also the number of user will affect the transmission. In single user SISO, the interference will come mainly from the transmission media, while in single user MIMO, the interference also comes from the user antennas. In massive MIMO, since the number of antennas is larger, the interference comes from a user antennas will be larger. The interference will be higher when the number of user is increasing since the interference source is not only from its own antennas but also from other user's. In real world, the number of user will get higher due to the population growth, thus interference management has become the main issue in recent communications systems.

Interference occured during transmission could modify the characteristic of transmitted signal such that it will be hard to recover to the original signal. The need of a method that could deal with interference is now become a main concern especially in wireless communication. Since few decades earlier, researchers have already invent methods to overcome interference during transmission. Basically, there are 3 types of interference management approac as stated in [1]. Knowing the advantages and the drawbacks of interference mitigation technique is essential so that it could be implemented effectively in the system. In this paper, we evaluate several interference mitigation techniques in *K*- user MIMO interference channel. The evaluation is based on its sum rate and bit error rate (BER) performance.

The rest of this paper is organized as follows. In Section II, we describe the system model of *K*-user MIMO interference channel. We briefly explain interference mitigation method in Section III. Simulation results are discussed in Section IV. Finally, Section V gives conclusion of this paper.

System Model

Fig. 1 shows the scenario of K −user MIMO interference channel. All K users have M and N transmit and receive antennas, respectively, where $M = N$. Each user k transmit d data streams , denoted asvector$\mathbf{x}_k \in \mathbb{C}^{d\times 1}$with transmit power p_k and $E\{\mathbf{x}_k^H\mathbf{x}_k\} = p_k$. The precoding matrix is denoted by $\mathbf{F}_k \in \mathbb{C}^{M\times d}$. Several techniques also introduce decoding matrix $\mathbf{C}_k \in \mathbb{C}^{M\times d}$ to suppress the interference in receiver. The channel matrix from transmitter l to receiver k is denoted by $\mathbf{H}_{\mathrm{kj}} \in \mathbb{C}^{N\times M}$ and the noise for user k is given by $\mathbf{Z}_k \in \mathbb{C}^{M\times 1}$.The noise vector has the statistics $E\{\mathbf{Z}_k\mathbf{Z}_k{}^{\mathrm{H}}\} = \sigma^2\mathbf{I}_M$. Generally, the received signal in user k, $\mathbf{Y}_k \in \mathbb{C}^{M\times 1}$ is defined as:

$$\mathbf{Y}_k = \sum_{j=1}^{K} p_j\mathbf{H}_{kj}\,\mathbf{x}_j + \mathbf{Z}_k \quad (1)$$

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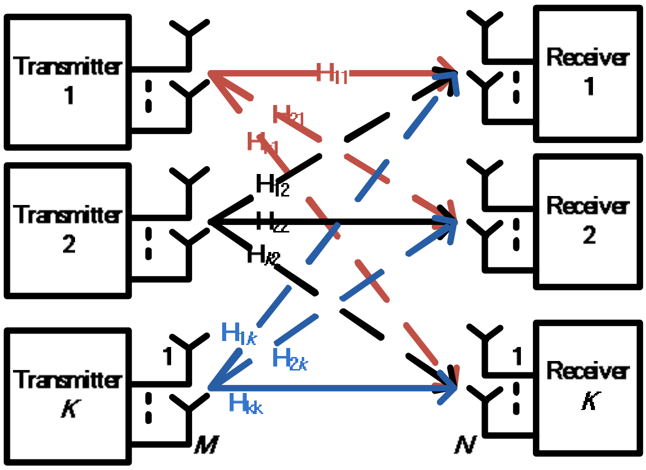

Fig.1 K **−user MIMO Interference Channel**

In this paper, we evaluate the sum rate and bit error rate (BER) performance of K −user MIMO interference channel. Sum rate is the maximum capacity that a system could provide. Sum rate performance is given by

$$R_{sum} = \sum_{j=1}^{K} \log_2 \left| \mathbf{I} + \frac{\frac{p_j}{d_j}\overline{\mathbf{H}_j}\overline{\mathbf{H}_j}^H}{\sum_{i=1;i\neq j}^{K} \frac{p_i}{d_i}\overline{\mathbf{H}_i}\overline{\mathbf{H}_i}^H} \right| \quad (2)$$

where $\overline{\mathbf{H}_j}$ is the equivalent channel matrix after precoding and decoding (if applicable) for each user j.
On the other hand BER is the ratio between the number error bit to the total transmitted bit. The error in receiver side occured due to the noise during transmission. The definition of BER could be stated as:

$$BER = \frac{\Sigma error\ bit}{\Sigma transmitted\ bit} \quad (3)$$

Interference Mitigation Method

This section explains the interference mitigation methods that are being evaluated. We choose the basic method that only design the precoder matrix, matched filter and zero forcing and compare it with interference alignment method which now become the main attraction in interference mitigation.

A. Precoder Design

i. Matched Filter

This method aimed to maximize the power of desired signal. The Matched Filter precoding was first initiated by [1]. The authors use the channel matched filter $\mathbf{H}^{H}$ from receiver as the transmitter precoding matrix. Matched Filter precoding matrix is designed as:

$$\mathbf{F}_k^{MF} = \frac{\mathbf{H}_{kk}^H}{\|\mathbf{H}_{kk}^H\|} \quad (4)$$

The equivalent channel matrix $\overline{\mathbf{H}_k}$ using matched filter is stated as $\overline{\mathbf{H}_k^{MF}} = \mathbf{H}_{kk}^{MF}\mathbf{F}_k^{MF}$.

ii. Zero Forcing

Precoder based on zero forcing method could suppress the interference in the receiver. The basic principle is finding the orthogonal vector to the matrix which is multiplied by interference [2]. This method only consider the desired channel to calculate precoding matrix and consider the remaining channel as interference. This method is a common technique used in MIMO communication due to its simplicity and acceptable performance. Several papers usually combine other techniques with Zero Forcing to enhance the performance of this method. Zero Forcing precoding matrix is defined as:

$$\mathbf{F}_k^{ZF} = \mathbf{H}_{kk}^{H}\left(\mathbf{H}_{kk}\mathbf{H}_{kk}^{H}\right)^{-1} \quad (5)$$

The equivalent channel matrix $\overline{\mathbf{H}_k}$ using matched filter is stated as $\overline{\mathbf{H}_k^{ZF}} = \mathbf{H}_{kk}^{ZF}\mathbf{F}_k^{ZF}$.

B. Interference Alignment

There are 3 basic interference alignment method use in this paper, minimum Weighted Interference Leakage (min WLI), alternating minimization, and maximum SINR method.

i. Min Weighted Interference Leakage (Min WIL)

One of the early methods inspired by IA, named Minimum Weighted Leakage Interference (Min Leakage) was proposed in [3]. In this algorithm, the quality of alignment is measured by the power in the leakage interference at each receiver, which is the remaining interference power in the received signal after decoding. The idea is to achieve IA by minimizing the interference power at all receivers. If the leakage interference converges to zero, the signal spaces will be free from interference. The initial precoding matrix is set to be arbitrary orthonormal matrix, and the decoding matrix $\mathbf{C}_k$ is calculated by:

$$\mathbf{C}_k = \mathbf{v}_{\min_d}\left(\sum_{j\neq k}^{K}\frac{p_j}{d_j}\mathbf{H}_{kj}\mathbf{F}_j\mathbf{F}_j^H\mathbf{H}_{kj}^H\right) \quad (6)$$

where $\mathbf{v}_{\min_d}(x)$= the eigenvectors correspond to the d smallest eigenvalues of x
During iterative procedure, precoding matrix $\mathbf{F}_k$ will be updated by exploiting reciprocity principle in which $\overleftarrow{\mathbf{H}} = \mathbf{H}^{H}$ as

$$\mathbf{F}_k = \mathbf{v}_{\min_d}\left(\sum_{j\neq k}^{K}\frac{p_j}{d_j}\overleftarrow{\mathbf{H}}_{kj}\mathbf{C}_j\mathbf{C}_j^H\overleftarrow{\mathbf{H}}_{kj}^H\right) \quad (7)$$

The leakage interference will be reduced in each iteration because they choose the smallest eigenvectors in the interference leakage covariance matrix. Since the value of leakage interference is monotonically reduced after each iteration, convergence of this algorithm is guaranteed [4]. However, due to its non-convex nature of interference optimization, the problem may have more than one optimal solution that depends on the initial guess. The convergence to global maximum is not guaranteed [4].

ii. Alternating Minimization

The basic principle of this method is to iteratively update the precoders for each transmitter and the receive interference subspaces at each receiver. This algorithm makes no assumptions on the reciprocity of the channel, the distribution of antennas or streams, or on how information is passed between the two iterative steps [5]. As the Min WLI method, initial precoder is set to be arbitrary orthonormal matrix. The decoding matrix is designed as:

$$\mathbf{C}_{k} = \mathbf{v}_{\max_{d}}\left(\sum_{j\neq k}^{K}\frac{p_j}{d_j}\mathbf{H}_{kj}\mathbf{F}_{j}\mathbf{F}_{j}^{H}\mathbf{H}_{kj}^{H}\right) \tag{8}$$

and the precoding matrix is updated from:

$$\mathbf{F}_{k} = \mathbf{v}_{\min_{d}}\left(\sum_{k\neq l}^{K}\frac{p_l}{d_l}\mathbf{H}_{kl}^{H}\left(\mathbf{I}_{N_k} - \mathbf{C}_{k}\mathbf{C}_{k}^{H}\right)\mathbf{H}_{kl}\right) \tag{9}$$

Although this method doesn't have to consider channel reciprocity, it cannot prove whether interference alignment is feasible for a particular antenna/stream allocation due to there is no lower bound on the objective function when a perfectly aligned solution doesn't exist.

iii. Max SINR

The author in [4] then proposed another method called Maximum Signal to Interference plus Noise Ratio (MaxSINR) to improve the performance of Min Leakage algorithm.Max SINR algorithm considers the noise occurred during the transmission. The basic idea of this method is to design the precoding and decoding matrix that could maximize the per-stream SINR. Due to this criterion, the performance of MaxSINR algorithm is better than Min Leakage method at low and mediate SNR where the noise has a large effect to the system and matches its performance at high SNR when the noise is too small to be considered.

Using arbitrary orthonormal matrix as initial precoding, the l^{th} column of decoding matrix for user k, $[\mathbf{C}_{k}]_{l}$ is calculated by:

$$[\mathbf{C}_{k}]_{l} = \frac{\mathbf{B}_{kl}^{-1}\mathbf{H}_{kk}[\mathbf{F}_{k}]_{l}}{\left\|\mathbf{B}_{kl}^{-1}\mathbf{H}_{kk}[\mathbf{F}_{k}]_{l}\right\|} \tag{10}$$

where $\mathbf{B}_{kl}$ is the per stream interference and noise covariance given by:

$$\mathbf{B}_{kl} = \sum_{j=1}^{K}\frac{p_j}{d_j}\sum_{e=1}^{d_j}\mathbf{H}_{kj}[\mathbf{F}_{j}]_{e}[\mathbf{F}_{j}^{H}]_{e}\mathbf{H}_{kj}^{H} - \frac{p_k}{d_k}\mathbf{H}_{kk}[\mathbf{F}_{k}]_{l}[\mathbf{F}_{k}^{H}]_{l}\mathbf{H}_{kk}^{H} + \sigma^2\mathbf{I}_{N_k} \tag{11}$$

The precoding matrix is updated in the same way as the reciprocal of Equation (10)

Results and Discussion

In this section, we serve the performance of interference mitigation methods discussed in previous section. To simulate the performance of various interference mitigation method, we implement the method in 3 user MIMO interference channel with 2 transmit and receive antennas sending 1 data stream. The BER evaluation is done with QPSK modulation scheme. Simulation result is the mean of 3000 channel realization. In interference alignment method, the iterative procedure is done 30 times.

A. Sum Rate Performance

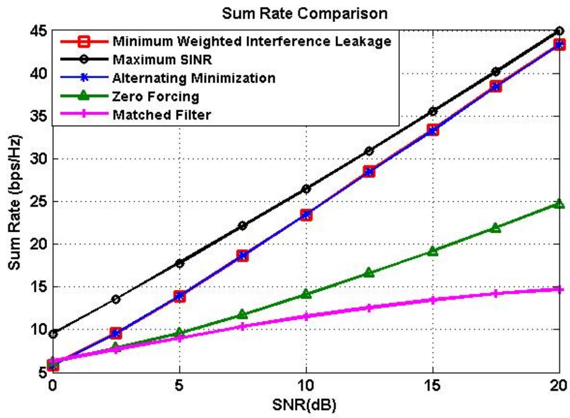

Fig.2 Sum Rate Performance

Fig. 2 shows the sum rate performance of 3 user 2×2 MIMO interference channel with 1 data streams. As we can see, matched filter has the lowest performance. However, comparing matched filter and zero forcing, in low SNR region, matched filter is slightly better than zero forcing. Authors in [6] derive the formula to show that in low SNR, the mean square error of matched filter method converge to the covariance of desired signal power, while the MSE of zero forcing converge to the maximum value of desired signal power covariance. In low SNR, the MSE of mathced filter is always less than or equal to zero forcing, thus matched filter's performance in low SNR is better. On the other hand, as the SNR gets higher, the MSE of matched filter is larger than or equal to zero. When the MSE is zero, matched filter is interference limited since no noise is present and it exhibits a residual error from remaining interference. Thus the performance of matched filter in high SNR region is saturated. Simulation result shows that Max SINR method has the best performance in all SNR region because it consider noise effect during the calculation of precoding and decoding matrix. The performance of alternating minimization and min WLI method is overlapped since their basic principle is the same. The main difference between the two is the reciprocity assumption.

B. BER Performance

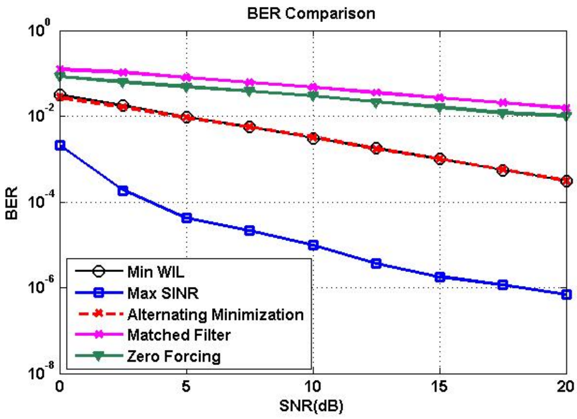

Fig.3 BER comparison for different interference mitigation methods

The BER performance of different interference mitigation methods is shown in Fig. 3. The best BER performance is Max SINR method since it deals with noise effect during the calculation of precoding and decoding matrix. On the other hand, the worst is Matched Filter method. In BER performance, zero forcing is better than matched filter in all SNR region because although the MSE in low SNR is larger, zero forcing method could not only enhance the strength of desired signal but also suppress the interference in receiver. Alternating minimization and min WLI method have the same performance but are worse than Max SINR method because the two methods neglect the noise effect during the iterative procedure to calculate precoding and decoding matrix.

As the simulation result shown in Fig 2 and Fig 3, each method has its own advantages and drawbacks. The simple method such as matched filter and zero forcing is easy to implement because it does not require iterative procedure and thus the complexity is low although the performance is not good. On the other hand, the interference alignment method has better performance but the complexity is higher due to the iterative procedure. The choice of which interference mitigation method that will be used in the system depends on the system requirement. For example, in a system that require an average performance but choose simplicity as its priority, then the equalization method, zero forcing could be implemented. Otherwise, when system require better performance and could support higher complexity, then interference alignment method could be implemented.

Conclusion

Interference mitigation method is an important method to reduce the interference and noise during transmission. In this paper we compare several interference mitigation methods, which are Max SINR method, Min WLI, alternating minimization, zero forcing, and matched filter. The performance of Max SINR in both sum rate and BER is the best compared the other algorithm because the noise is considered during the calculation. Interference alignment, which which introduce precoding and decoding matrix has better performance than the ordinary equalization method with precoding only, although the complexity is higher since it goes through an iterative procedure. The choice of which interference mitigation method used in system depends on the system requirement.

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