Digital Communication Integrated Circuits Design Final Project:

Multi-user MIMO with LTE codebook precoder

Group 5

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Abstract
Multi-user (MU) MIMO is used to improve spectral efficiency comparing with single-user (SU) MIMO. Precoding can reduce the inter-beam interference under the proper channel conditions of multiple users. We proposed three precoding schemes, including choosing eigen vectors and selecting PMI from LTE codebook, and we used MATLAB to get the simulation results.

MU-MIMO with Precoding
Our purpose is to reduce the inter-beam interference by adding precoding procedures. Precoding vectors are determined with the feedback of channel. Just like homeworks we have done before, channel response is estimated by pilot signals, then we can get channel direction information with PMI (Precoder Matrix Indicator). In the simulation, precoding is used on transmitter side, and ZF detector is implanted on receiver side.

Scenario
Fig. 1 shows our simulation scenario, which is 2x2 MIMO. The base station and 2 users each have 2 antennas. As for data transmission, there are two beams (layers) in the scenario because the number of transmit antenna is 2. Equivalently, single beam is for single UE. Therefore, Tx1 and Tx 2 should send the same data, i.e, we use one data stream.

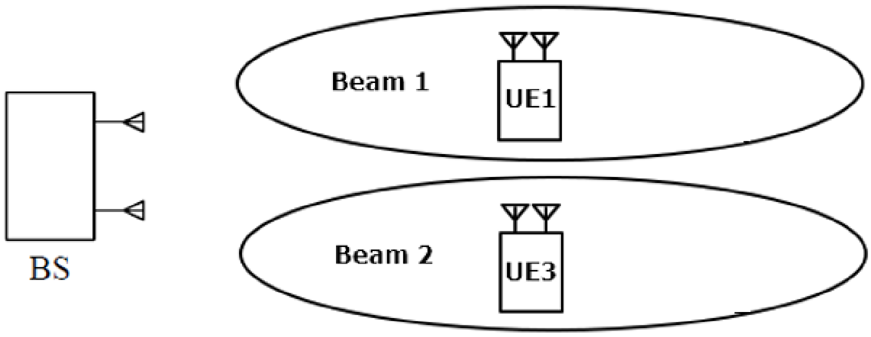


Fig. 1 Basic Scenario of MU-MIMO.

Transmitter: Precoding
The transmitted signal $y = w_1 S_1 + w_2 S_2$, where S_1, S_2 are UE1's and UE2's desired data, and w_1, w_2 are the precoding vector of UE1 and UE2. The processes of generating precoding vectors would be discussed later. On the receiver side, $Z_1 = H_1 y + \mathrm{n} = H_1(w_1 S_1 + w_2 S_2) + n,$ where Z_1 is the received signal of UE1, H_1 is the channel response between BS and UE1, and n represents AWGN noise. Therefore $H_1 w_2 S_2$, the interference term, should be as small as possible to get lower error rate. Similarly, $Z_2 = H_2 y + \mathrm{n} = H_2(w_1 S_1 + w_2 S_2) + n$, so $H_2 w_1 S_1$ should be as small as possible, too.

Receiver: ZF detector

Taking UE1 as example, because we want to reduce the influence of $H_1 w_1 S_1$, beside transmitter side, ZF detector is implemented to coordinate with precoding. ZF detector:$V_{ZF,u} = (g_{e,u}^H g_{e,u})^{-1} g_{e,u}^H$, where $g_{e,u} = H_u w_u$ is effective channel vector. Then multiplying received signal Z_1 and ZF detector, signal to UE1 can be solved by $\widehat{S_1} = V_{ZF,1} Z_1$.

Precoding Schemes

We proposed three precoding schemes, (1) and (2) are choosing eigen vectors of channels, (3) is choosing from codebook according to PMI feedback by receiver.

(1) Own Eigen Vector

Each UE's first eigen vector is their precoding vector. That means precoding vectors are generated by i^{th} UE's channel response H_i. By singular value decomposition (SVD), H_i=$U_i S_i V_i$, so the eigen vectors V_i are know
Next, let $w_i = [V_i]_1$, UE_i choose its first eigen vector as its precoding vector. Different user would choose their precoding vectors from different channel response H_i. In this way, we make UE1 and UE2 has good response of their own data. However, UE1 might also be disturbed by UE2 because their channel correlation might not small enough.

(2) Eigen vector of UE1

Find out first UE's eigen vectors, the other's precoding vectors are the first UE's eigen vectors. Like (1), UE1's precoding vectors is generated by SVD, H_1=$U_1 S_1 V_1$, then let $w_1 = [V_1]_1$, UE_1 choose its first column of V_1, i.e. first eigen vector H_1 as its precoding vector. As for UE2, let $w_2 = [V_1]_2$, so UE_2's precoding vector would be null space of w_1. The second scheme makes UE1 not be disturbed by UE2, so we predict that UE1 would have good performance (error rate) with its own eigen vectors as precoding vectors. However, it can not ensure that the performance of UE2 with UE1's eigen vector as its precoding vector.

(3) PMI Selection - Codebook in LTE

We apply feedback PMI to reduce feedback overhead. PMI is selected from codebook in LTE. In our scenario, there are 2 transmit antennas and 2 receive antennas. However, we transmit the same data for the multiple Tx antennas, so the layer is 1. That means one data stream for one layer.

Codebook index	Layer = 1	Layer =2
0	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1&0\\0&1\end{bmatrix}$
1	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	-
2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	-
3	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	-
4	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\0\end{bmatrix}$	-
5	$\frac{1}{\sqrt{2}}\begin{bmatrix}0\\1\end{bmatrix}$	-

First, receiver will feedback PMI by choosing the highest value which can be mapped to a codebook index (PMI) in table 1.

In Fig. 2, information of codebook is known for transmitter, so transmitter can get the precoding vector by mapping PMI to the channel vector with codebook.

Table 1 Codebook in LTE.[1]

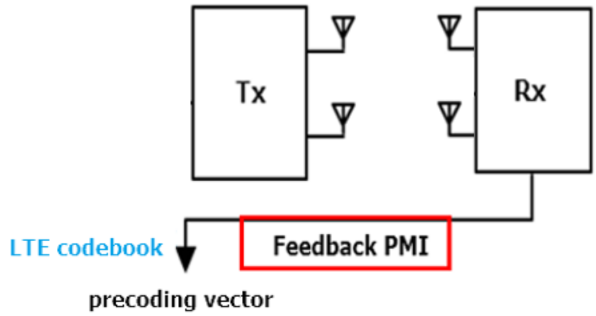


Fig. 2 Precoding vector selected by feedback PMI in LTE codebook.

Simulation Results

(1) Different Precoding Schemes

Fig. 3 shows the average bit error rate of both UE with 3 precoding schemes. Eigen vector of UE1 has significant performance against other metheds. Because it can make sure that UE1 would not be interfered by signal of UE2 by choosing two orthogonal vectors from H_1 as precoding vectors for 2 UEs separately, the error rate of UE1 might be better than others to keep low average error rate.

Own eigen vector is applied to itself, so the performance would be better for one UE, and the other might be worse. Codebook design is based on orthogonality, so it is also good for our simulation scenario.

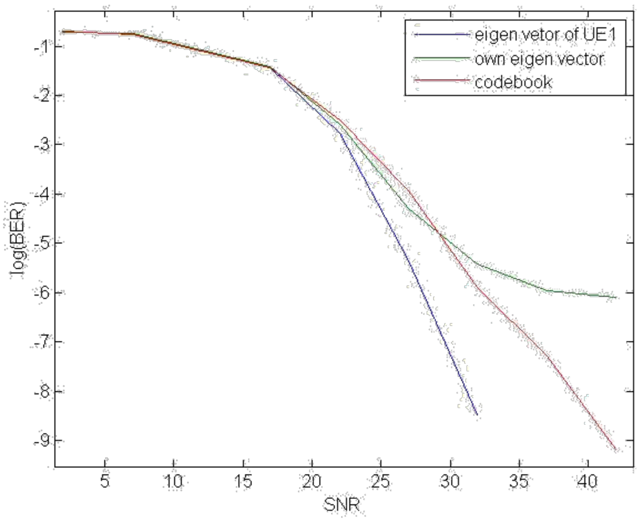


Fig. 3 BER with different Schemes

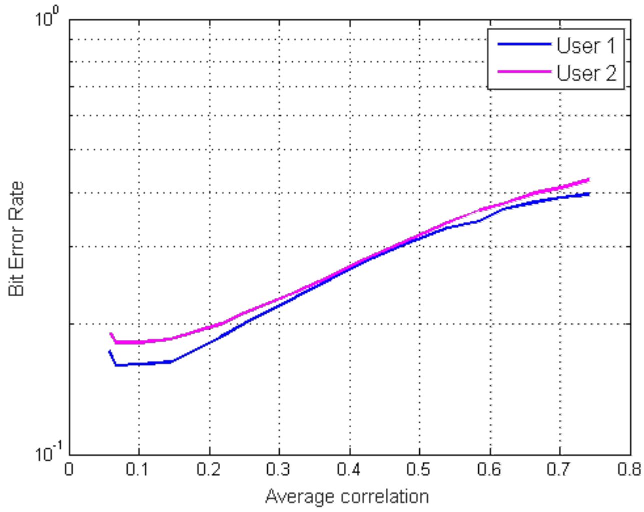
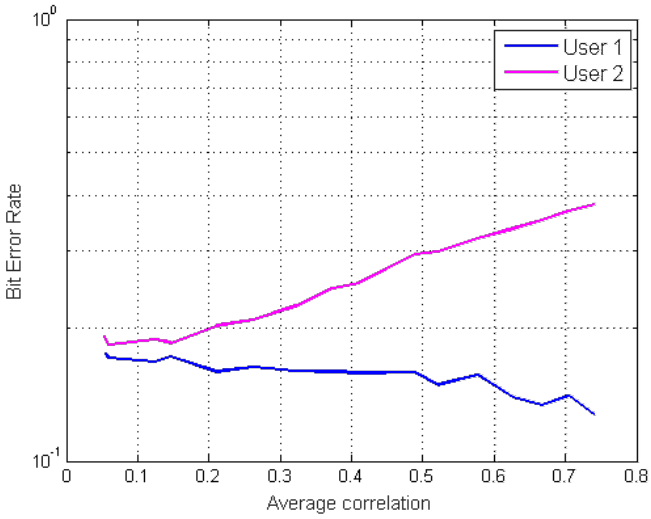


Fig. 4 BER with different channel correlation for scheme (1)

(2) Channel Correlation v.s. Bit Error Rate
Fig. 4 ~ 6 compare bit error rate of 2 users with different channel correlation. We know that MU-MIMO would have better performance with low correlation between users. So we changed the absolute value of correlation, and used different precoding schemes. In Fig. 4, precoding vectors generated by their own eigen vectors, when correlation getting lager, their channel response are more similar, so signal of each user would be interference of the other, and error rate would increase for both users.

Result of the second scheme is shown in Fig. 5. Because the precoding vectors of both users are all chosen from eigen vectors of UE1, bit error rate of UE1 would not increase, and even decrease a little with correlation getting lager. Error rate of UE2 would get higher with larger correlation, just like scheme (1).

According to Fig. 6, when channel correlation < 0.45, codebook in LTE can solve UE1 well and has similar error rate of UE2 as previous schemes. However, UE1 would still have high error rate with much higher correlation. In practical situation, we think that when value of correlation is too large, instead of MU-MIMO we can use alternative transmission such as SU-MIMO.



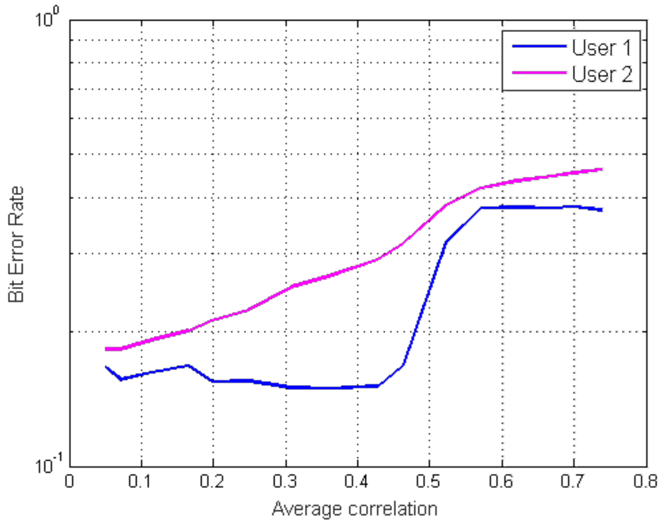


Fig. 5 BER with different channel correlation for scheme (2)

Fig. 6 BER with different channel correlation for scheme (3)

Conclusion

Correlation of channels is very important for precoding. If correlation is larger, the both users would have better performance with precoding. When the correlation is high, it's better to use precoding scheme: Eigen vector of UE1 code book method has quantized error, so the SNR tolerance is lower. Precoding can reduce the inter-beam interference, if the channel condition is proper.

Reference:

[1] Table 5.3.3A.2-1: Codebook for transmission on antenna ports {0,1} from LTE 3GPP TS 36.211 Release 10

[2] Chen, Long, et al. "Successive precoding and user selection in MU-MIMO broadcast channel with limited feedback." *2014 Wireless Telecommunications Symposium*. IEEE, 2014.

[3] Yong Soo Cho, et al. "MIMO-OFDM Wireless Communications with MATLAB." 2010.