System Evaluation of PMI Feedback Schemes for MU-MIMO Pairing

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Abstract. A Best Companion Cluster (BCC) user terminal (UE) feedback scheme for Multi-User Multi-Input-Multi-Output (MU-MIMO) pairing is proposed in this paper. With this scheme, one UE should feedback both a preferred Precoding Matrix Index (PMI) and a cluster index with least interference to it. The system level simulation results show that this scheme can make a reasonable tradeoff between feedback overhead and throughput, especially when the system load is not so heavy.

Keywords: MU MIMO, pair, best companion cluster, PMI.

1 Introduction

In wireless communication systems, owing to the large overhead of feedback channel state information, the codebook based precoding is adopted for MIMO scenarios in FDD systems. With this scheme, the NodeB and the UE have some predefined common codebooks. In transmission process, one UE will normally feedback its preferred matrix index(PMI) to NodeB, named as Normal Feedback scheme here. With the reported PMI and the help of other system information, the NodeB will allocate one PMI to the UE if this UE is scheduled. It should be noted that the allocated PMI may or may not be same as the reported PMI.

On the way to improve the cell throughput interference among users and different cells has become a large obstacle. On the other hand, more deployed antennas have made MU MIMO possible. Then naturally the question comes: what is the information the UE can provide Node B to pair the users to efficiently control the interference level? Besides the traditional preferred PMI, can one UE feedback more information? Recently, the pairing issue in MU MIMO feedback and scheduling has attracted much attention in both academic and industrial field [1-7].

In [1][2], different scheduling and precoding matrix designs are suggested. To improve the pairing efficiency, more PMI feedbacks are suggested [3][4] for both single cell and multi-cell scenario. In IEEE 802.16m [5][6], the PMI for the interfering cell or interfering user is also similarly suggested.

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In this paper, different PMI feedback schemes are evaluated for downlink FDD scenario. The first one is the Normal Feedback Scheme (NFS) as mentioned above. The second one[3][4] is that UE feeds back a best PMI with highest SNR(Signal to Noise Ratio) and one or a set of best interfering PMI(s) with least interference to it, named Best Companion PMI (BCP). Based on the second scheme, the third one is suggested that the UE feeds back the best PMI with highest SINR and the cluster index that includes the best interfering PMI, named Best Companion Cluster (BCC). In Section 2, these three schemes and corresponding scheduling and pairing schemes will be described in more details. Section 3 provides the system simulation results and summary will be given in Section 4.

2 Feedback and Pairing Schemes

For a target user i, the received signal can be modeled as:

$$\mathbf{y}_i = \mathbf{H}_i \mathbf{F}_i x_i + \sum_{j=1, j \neq i}^{K} \mathbf{H}_i \mathbf{F}_j x_j + \mathbf{N}_i \tag{1}$$

Where **H**i is the Nr×Nt channel gain matrix from Nt transmit antennas to Nr receive antennas, **F***i* is the precoding vector for i_{th} user, x_i is the to-be-transmitted symbol of i_{th} user, and **N***i* is additive white Gaussian noise (AWGN) with variance σ^2 .

2.1 NFS

For NFS, the best PMI $\mathbf{F}_k$ for a user can be selected from a codebook based on the following rule of maximizing the received signal power:

$$\mathbf{F}_k = \arg\max_{i \in [1,\dots P]} \left(\left| \mathbf{H}_k \mathbf{F}_i \right|^2 \right) \tag{2}$$

where P is the largest PMI index of the codebook.

With this feedback, NodeB can identify the best PMI for the user but it does not know how to pair another user to make the mutual interference as less as possible. Therefore, NodeB can only make random pairing. Correspondingly the UE will have to assume the paired user to have highest interference to obtain a workable CQI (Channel Quality Information) as:

$$CQI_k = \min_{j \in [1,\dots,P], j \neq k} \frac{\left| \mathbf{H}_k \mathbf{F}_k \right|^2}{\sigma^2 + \left| \mathbf{H}_k \mathbf{F}_j \right|^2} \tag{3}$$

2.2 BCP

In [3][4][5], the Best Companion Pairing (BCP) is suggested to coordinate the multiple users in both single cell scenario and multi-cell scenarios. Additional feedback information of so- called “Best Companion” indexes are provided, which is actually the Precoding Matrix Index (PMI) of to-be-paired user with least interference to the target user, written as ($\mathbf{F}_k$, $\mathbf{F}_l$).

$$\mathbf{F}_k = \arg\max_{i\in[1,...P]}\left(\left|\mathbf{H}_k\mathbf{F}_i\right|^2\right)$$
$$\mathbf{F}_l = \arg\min_{i\in[1,...P]}\left(\left|\mathbf{H}_k\mathbf{F}_i\right|^2\right) \tag{4}$$

Equation (4) gives the example that one user feeds back one best PMI $\mathbf{F}_k$ and one best interfering PMI $\mathbf{F}_l$ to NodeB. In that case, the CQI can be calculated as:

$$CQI_k = \frac{\left|\mathbf{H}_k\mathbf{F}_k\right|^2}{\sigma^2 + \left|\mathbf{H}_k\mathbf{F}_l\right|^2} \tag{5}$$

With this scheme, for single cell scenario, to minimize the intra-cell mutual MU-MIMO interference, extra codebook-based information of the to-be-paired user(s) with least interference is reported back to NodeB. For multi-cell scenarios, to minimize the inter-cell interference, UE may report extra codebook-based information to its serving Node B to make the best companion pair and this information can be shared via backhaul to the strongest interfering neighbor cells for coordinated scheduling.

In scheduling, NodeB will try to find two users with feedbacks of ($\mathbf{F}_k$, $\mathbf{F}_l$) for one user and ($\mathbf{F}_l$, $\mathbf{F}_k$) for the other one. In that case, CQI needs not to be revised. If there is no such pair, there are two options: one is to fall back to single user mode; the other one is to randomly or with some rule choose another user. For both options, accurate CQI need to be recalculated. However, more accurate CQI generally means more overhead, which is another tradeoff to be taken and out of the discussion in this paper.

To make the scheduling more efficient and flexible, it is suggested that a set of Best Companion PMI be reported back to Node B, where the set gives the PMIs for which the intra-cell or inter-cell interference remains below a certain threshold.

However, more Best Companion PMIs means higher feedback overhead. Hence we investigate the possibility of reducing the PMI feedback without losing the interfering information, which leads to our scheme of BCC.

2.3 BCC

Considering the correlation between different PMIs, the set of PMIs can be clustered together. That is, besides the preferred PMI, UE may also need to feedback the index of clusters that has weakest interference:

$$\mathbf{F}_k = \arg\max_{i\in[1,...P]}\left(\left|\mathbf{H}_k\mathbf{F}_i\right|^2\right)$$
$$\mathbf{C}_l = \arg\min_{i\in[1,...T],l\in[1,...Q]}\left(\left|\mathbf{H}_k\mathbf{F}_i\right|^2\right) \tag{6}$$

where $\mathbf{C}_l$ is the best interfering cluster and satisfies $\mathbf{F}_l \in \mathbf{C}_l$, Q is the number of clusters of the codebook and T is the number of PMI within a cluster. Note that T may be different for different cluster.

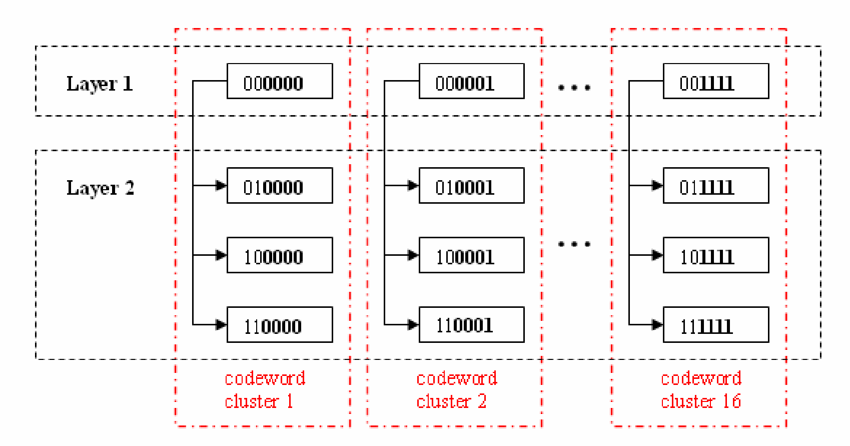


Fig. 1. Cluster Construction

Following the definition style in [3][4], this scheme can be named best companion cluster (BCC). To elaborate the issue more clearly, we can take a nesty structure codebook as an example, where the clusters can be constructed as shown in Fig.1 assuming 6bit PMI. In this scheme, all these 64 PMIs are separated into 16 clusters and each cluster has 4 PMI (Q=16, T=4). If one UE selects its preferred PMI from one cluster with 6 bits, it need only feedback the additional interfering cluster index of its best companion pairing PMI with weakest interference with only 4 bits. That is, the total feedback overhead of $\mathbf{F}_k$ and $\mathbf{C}_l$ is 10 bits. In multi-cell scenario, this cluster index will be also shared via backhaul. If this UE is scheduled, NodeB can pair another user with any PMI within the interfering cluster feedback by this UE.

Owing to the pairing PMI uncertainty within the cluster, the CQI calculation will have some ambiguity:

$$CQI_k = \min_{j \in [1,\dots,T]} \frac{\left|\mathbf{H}_k \mathbf{F}_k\right|^2}{\sigma^2 + \left|\mathbf{H}_k \mathbf{F}_j\right|^2} \tag{7}$$

Clearly, $\mathbf{F}_k$ and any $\mathbf{F}_j$ belong to different clusters and this ambiguity is in generally less than the calculation shown in (3), i.e., the CQI in (3) provides an upper bound for the one in (7). To improve the CQI, we can also take the average CQI from all PMIs in the interfering cluster:

$$CQI_k = \frac{1}{T} \sum_{j=1}^{T} \frac{\left|\mathbf{H}_k \mathbf{F}_k\right|^2}{\sigma^2 + \left|\mathbf{H}_k \mathbf{F}_j\right|^2} \tag{8}$$

2.4 Scheduling

The scheduling procedure to pair two UE in NodeB can be described as below:

1. Classification: Users which indicate the same preferred cluster $\mathbf{C}_k$ and the same interference cluster $\mathbf{C}_l$ ($\mathbf{F}_k \in \mathbf{C}_k$, $\mathbf{F}_l \in \mathbf{C}_l$)are classified into one class, denoted by ($\mathbf{C}_k$, $\mathbf{C}_l$), where $\mathbf{C}_k$ and $\mathbf{C}_l$ represent the cluster index. Class ($\mathbf{C}_k$, $\mathbf{C}_l$) and Class ($\mathbf{C}_l$, $\mathbf{C}_k$) are taken as one class pair, which exhibits good property of mutual interference;

2. Selection: Search out one UE in Class ($\mathbf{C}_k$, $\mathbf{C}_l$) and another one UE in Class ($\mathbf{C}_l$, $\mathbf{C}_k$) to combine the companion pair to meet the proportional fairness rule (or with other selection rule) with reported CQI, QoS requirement, etc;

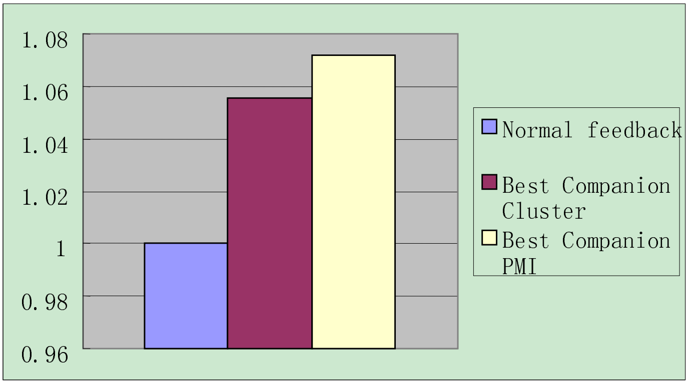
3. Scheduling and Allocation: Schedule the UE pair found in Step 2 for transmission and allocate corresponding resource, modulation and coding scheme, etc.

3 Simulation

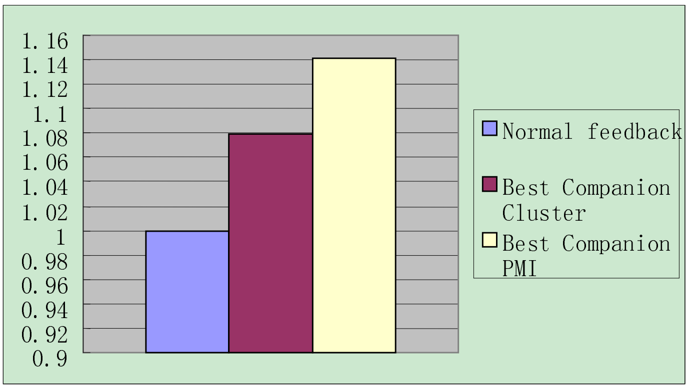
The system level simulation parameter configuration can be referred in Table A.1 in the appendix and the throughput is evaluated and compared. Each UE is assumed to be allocated only one stream and two UE will be paired to make the MU MIMO transmission. Consequently, for the given LTE 4Tx codebook[8] shown in Table A.2 in the appendix, we separated 16 PMI into 4 clusters, each with T=4 and Q=4: Cluster 0 with PMI index: {0,4,8,12}, Cluster 1: {1,5,9,13}, Cluster 2: {2,6,10,14} and Cluster 3: {3,7,11,15}. It can be found that one PMI is orthogonal to any PMI in any other cluster but the PMIs within same cluster are not orthogonal to each other, which to some degree explains the clustering principle shown in Fig.1.

The throughput is compared in Fig.2 in Mbps for 10 uers and 30 users separately while the relative gain is given in Table 1. With the results, the BCP (Best Companion PMI) scheme with 8 bits feedback can provide 7.17% and 14.16% system throughput gain over the Normal Feedback Scheme with 4 bits feedback corresponding 10 users and 30 users ineach cell respectively. While Best Companion Cluster scheme with 6 bits feedback provides 5.53% and 7.97% gain over Normal Feedback Scheme, corresponding 10 users and 30 users in each cell respectively. With less users, the gap between BCP and BCC is smaller. BCC is more robust to the number of users, i.e., system load. The reason is that BCP feeds back the accurate pairing PMI whileany PMI within the interfering cluster can be paired in BCC, which makes the pairing probability for BCP more sensitive to the number of users than BCC. That is why more PMIs are suggested to feedback in [3][4]. It seems that Best Companion Cluster can make relative reasonable trade-off among feedback overhead and throughput, especially in light system load.

Actually, we have also made the simulation to compare the throughput performance of 4bit and 6bit DFT codebook for NFS scheme, but unfortunately we have not seen much difference for such DFT codebooks. With two more bits overhead, the throughput for 6bit DFT codebook only provides throughput gain of less than 1%. The reason lies in the fact that the increase of the codebook size from 16 (4bits) to 64 (6bits) leads to better granularity on one hand while more sensitivity to the channel mismatch on the other hand, which makes it not much helpful to improve the system throughput. Consequently, we have not shown the 6bit NFS results here.



(a) 10 users



(b) 30 users

Fig. 2. Relative gain in total average cell throughput

Table 1. Relative throughput gain over Normal Feedback Scheme in total average cell throughput

Scenario	Feedback scheme	No. of Feed-back bits	Relative gain
10 users	Normal Feedback Scheme	4	-
	Best Companion PMI	8	7.17%
	Best Companion Cluster	6	5.53%
30 users	Normal Feedback Scheme	4	-
	Best Companion PMI	8	14.16%
	Best Companion Cluster	6	7.97%

4 Conclusions

Different PMI feedback schemes for MU MIMO companion are evaluated in this contribution. The Normal Feedback scheme has least feedback bits but with least throughput. The Best Companion PMI scheme provides the highest throughput but with highest feedback. The Best Companion Cluster scheme gives a reasonable compromise between the feedback overhead and throughput. It should be further investigated on how to make better compromise. The CQI estimation can also be further improved.

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Appendix: Simulation Assumptions and Codebooks

Table A.1. Simulation assumptions

Parameter	**Assumption**
Cellular Layout	Hexagonal grid, 19 sites, 3 sectors per site
Inter-site distance	500m
Load	Average 10/30 UE per sector
Bandwidth	10MHz
Total BS TX power (Ptotal)	46dBm
Noise figure at UE	9dB
Lognormal Shadowing with shadowing standard deviation	8 dB
Channel model	Spatial Channel Model (SCM)
UE speeds of interest	3Km/h
Number of antenna elements (BS, UE)	(4, 2)
Antenna separation (BS, UE) [times of wavelength]	(10, 0.5)
Antenna type	Polarized
Traffic model	Full buffer
Link to system interface	Mutual information
CQI / ACK/NAK feedback delay	4 ms
Scheduler	Proportional Fair
HARQ	HARQ-CC (Chase Combing); 8 processes Maximum 3 transmission times
Receiver algorithm	MMSE

Table A.2. LTE 4Tx Rank 1 Codebook

PMI	u_n	***Rank:1***
0	$u_0 = \begin{bmatrix}1 & -1 & -1 & -1\end{bmatrix}^T$	$W_0^{\{1\}}$
1	$u_1 = \begin{bmatrix}1 & -j & 1 & j\end{bmatrix}^T$	$W_1^{\{1\}}$
2	$u_2 = \begin{bmatrix}1 & 1 & -1 & 1\end{bmatrix}^T$	$W_2^{\{1\}}$
3	$u_3 = \begin{bmatrix}1 & j & 1 & -j\end{bmatrix}^T$	$W_3^{\{1\}}$
4	$u_4 = \begin{bmatrix}1 & (-1-j)/\sqrt{2} & -j & (1-j)/\sqrt{2}\end{bmatrix}^T$	$W_4^{\{1\}}$
5	$u_5 = \begin{bmatrix}1 & (1-j)/\sqrt{2} & j & (-1-j)/\sqrt{2}\end{bmatrix}^T$	$W_5^{\{1\}}$
6	$u_6 = \begin{bmatrix}1 & (1+j)/\sqrt{2} & -j & (-1+j)/\sqrt{2}\end{bmatrix}^T$	$W_6^{\{1\}}$
7	$u_7 = \begin{bmatrix}1 & (-1+j)/\sqrt{2} & j & (1+j)/\sqrt{2}\end{bmatrix}^T$	$W_7^{\{1\}}$
8	$u_8 = \begin{bmatrix}1 & -1 & 1 & 1\end{bmatrix}^T$	$W_8^{\{1\}}$
9	$u_9 = \begin{bmatrix}1 & -j & -1 & -j\end{bmatrix}^T$	$W_9^{\{1\}}$
10	$u_{10} = \begin{bmatrix}1 & 1 & 1 & -1\end{bmatrix}^T$	$W_{10}^{\{1\}}$
11	$u_{11} = \begin{bmatrix}1 & j & -1 & j\end{bmatrix}^T$	$W_{11}^{\{1\}}$
12	$u_{12} = \begin{bmatrix}1 & -1 & -1 & 1\end{bmatrix}^T$	$W_{12}^{\{1\}}$
13	$u_{13} = \begin{bmatrix}1 & -1 & 1 & -1\end{bmatrix}^T$	$W_{13}^{\{1\}}$
14	$u_{14} = \begin{bmatrix}1 & 1 & -1 & -1\end{bmatrix}^T$	$W_{14}^{\{1\}}$
15	$u_{15} = \begin{bmatrix}1 & 1 & 1 & 1\end{bmatrix}^T$	$W_{15}^{\{1\}}$