Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Multi-cell MIMO Schemes for IEEE 802.16m**
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Re:	IEEE 802.16m-08/024, Call for Contributions on IEEE 802.16m-08/003 System Description Document (SDD) Topic: Interference mitigation
Abstract	Proposal for IEEE 802.16m multi-cell MIMO schemes
Purpose	Discussion and approval
Notice	
Release	
Patent Policy	

Multi-cell MIMO schemes for IEEE 802.16m

1. Introduction

As a part of the physical layer procedure, inter-cell interference mitigation is widely relevant to physical (PHY) layer designs, medium access control (MAC) layer designs, inter-cell coordination, and inter-BS coordination. The purposes and scopes of those designs may be much different from each other and hard to be harmonized as a single layer operation. Generally, three approaches to the inter-cell interference mitigation are currently being considered.

- Inter-cell-interference randomization
- Inter-cell-interference cancellation
- Inter-cell-interference co-ordination/avoidance

On the other hand, based on the same basic principles (even under different terminologies), many contributions are proposing to use "Multi-Cell MIMO" to change the interference signal into useful signal through joint processing at the coordinated BSs [1-3]. Essentially, this is a more aggressive (or efficient) way of performing inter-cell interference mitigation.

It is interesting to note that both inter-cell interference cancellation and multi-cell MIMO focus on the scenario where the BSs are transmitting to their intended MSs in the same frequency band simultaneously. The corresponding system setting is illustrated in Fig.1 for the case where two BSs are talking to two MSs in the time frequency band simultaneously.

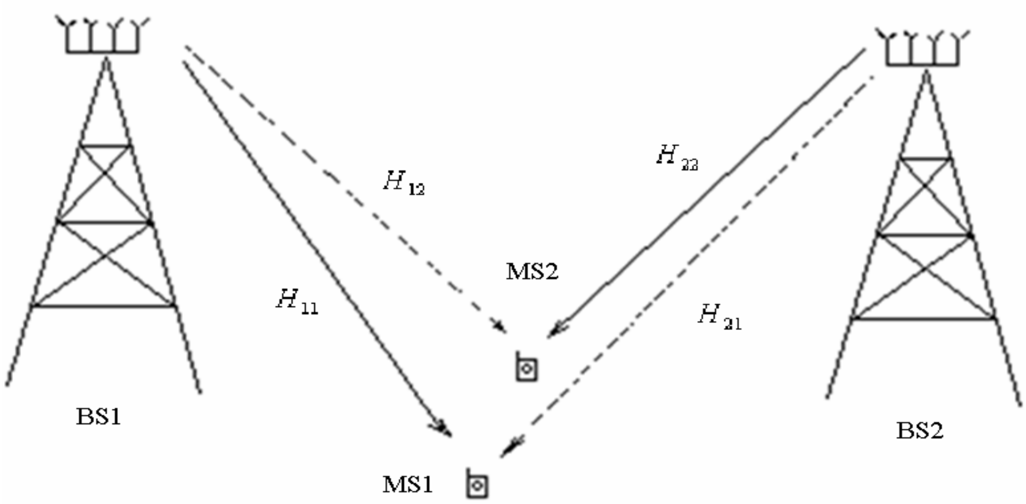

Figure 1: Two BSs are communicating with two MSs simultaneously

In Fig. 1 the serving base station for MS1 is BS1 and the serving base station for MS2 is BS2. Let N_T be the number of transmit antennas at the BSs, N_R be the number of receive antennas at the mobile users. Also let H_{11}, H_{12} , H_{21}, and H_{22} be the respective channel gains. Then the received signal at MS1 and MS2 can be represented by

$$\begin{aligned} Y_1 &= H_{11}X_1 + H_{21}X_2 + N_1 \\ Y_2 &= H_{12}X_1 + H_{22}X_2 + N_2 \end{aligned} \quad (1)$$

where Y_i is the $N_R \times 1$ vector of received signal at mobile user *i*, X_i is the $N_T \times 1$ vector of transmitted signal at base station *i*, and N_i is the $N_R \times 1$ AWGN noise vector. We know that the particular technologies to optimize the system performance heavily depend on the system assumptions. That is, depends on the coordination level we are able to allow in the system, we may need to use different technologies to perform the inter-cell interference mitigation. Therefore, this contribution tries to set up a unified framework of jointly considering inter-cell interference cancellation and multi-cell MIMO based on the shared information between the coordinated BSs. By doing this, we can identify various operation modes of the coordinated system and try to characterize various technologies to improve the system performance under different operational modes.

2. Various Operation Modes

In this section, we try to identify various operation modes of the coordinated system. In order to do this, let us take a second look at the interfering system described in Fig. 1. In this system, we have four channel gain matrices which are H_{11}, H_{12}, H_{21}, and H_{22}. Furthermore, we have two sets of data: one set is intended for MS1 while the other set is intended for MS2. Accordingly, the information shared between the two BSs in Fig. 1 is classified into two categories: channel knowledge related information and data information.

In the category of channel knowledge related information, we have three situations: no channel knowledge sharing, partial channel knowledge sharing, and total channel knowledge sharing among base stations.

1. In the case of no channel knowledge sharing, each BS only knows the information related to the channel between himself and his serving MS. That is, BS1 only knows information related to H_{11} while BS2 only knows information related to H_{22}.
2. In the case of total channel knowledge sharing, the information related to H_{11}, H_{12}, H_{21} and H_{22} are shared between the two BSs.
3. In the case of partial channel knowledge sharing, a subset of the information related to H_{11}, H_{12}, H_{21} and H_{22} are shared between the two BSs. For example, BS1 may only know information related to H_{11} and H_{12} while BS2 only knows the information related to H_{21} and H_{22}.

Similarly in the category of data, we can also consider three situations: no data sharing, partial data sharing and total data sharing among base stations

1. In the case of no data sharing, each BS only has the data for his intended MS.
2. In the case of total data sharing, both BSs have access to both of the data.
3. In the case of partial data sharing, both BSs have access to part of the other MS's data.

By dividing channel sharing and data sharing into different situations, we obtain the following 3 by 3 grid. The various operation modes together with the potential technologies that may help to improve the system performance are listed in Table 1.

Table 1: Potential Technologies in Various Operation Modes

CSI/Data Sharing Among BSs	No Data Sharing	Partial Data Sharing	Full Data Sharing
No CSIT Sharing	(1-1) Inter-cell Interference Coordination	(1-2)	(1-3) Inter-cell open loop MIMO/TxD
Partial CSIT Sharing	(2-1) Beam Collision Avoidance PMI Coordination Based on CQI improvement or Interference Level	(2-2)	(2-3)
Full CSIT Sharing	(3-1)	(3-2) MIMO X Channel (Interference Alignment)	(3-3) Multi-Cell MIMO

3. Potential Technologies

In the case of (1-1), since no information is shared between the BSs, we can apply fractional frequency reuse (FFR) or inter-cell interference coordination to mitigate interference. The basic idea of this technology is to schedule cell-edge users in different frequency bands so that the information is mitigated. Fast inter-cell interference coordination and semi-static inter-cell interference coordination may be good candidates within this category.

In the case of (2-1), we may consider beam collision avoidance where MSs send feedback information about least interfering precoding vectors of the interfering BSs and suggest them to use it. In this sense, the interference can be mitigated by limited coordination. Alternatively, MSs may feedback information about worst interfering precoding vectors of the interfering BSs and suggest not to use them.

In the case of (3-2), we may utilize the results from MIMO X channel (interference alignment) [4] where we jointly design the precoding matrices such that the intended signals are orthogonal to the interference signals.

In the case of (3-3), we can apply the standard multi-cell MIMO method where joint beamforming and MIMO broadcast channels with individual power constraints on each BS (Zero-forcing, Dirty Paper Coding) can be applied.

4. Proposed PMI Coordination Scheme

In order to employ MIMO related technologies to mitigate ICI through BS cooperation, it is better that ICI can be initially mitigated by some optional methods. One possible solution is soft frequency reuse (SFR) with reuse factor 1, which is an SINR dependent subchannel allocation scheme. For example, for 3 adjacent cells, divide spectrum as F=(F-f1)+f1=(F-f2)+f2=(F-f3)+f3, with f1, f2 and f3 non-overlapping. f1, f2, f3 are allocated to cell edge region (with generally low SINR) of each BS, and F-f1, F-f2, F-f3 allocated to corresponding cell center region (with generally high SINR). BS transmit power to cell center region shall be lower than that for cell edge region, i.e., different power allocation for (F-f1) and f1, (F-f2) and f2, (F-f3) and f3. In this way, only cell center users of one cell will interfere with adjacent BS cell edge users, with much lower transmit power.

We propose in this contribution one PMI coordination scheme for closed loop MIMO-OFDMA systems (with SFR like pre-cancelation scheme or not) to counteract intercell interference. To facilitate PMI coordination, different feedback schemes are utilized for MS with different SINR.

- High SINR users will only feed back information for normal operation, which includes RSSI and physical SINR for non-MIMO transmission mode, Effective SINR per codeword, MIMO scheme and transmission rank (for spatial multiplexing) for open loop MIMO mode, and effective SINR per codeword, transmission rank and PMI for close loop single user (SU) and multiuser (MU) MIMO.
- Low SINR users will feed back not only necessary information for normal cell operation like high SINR user, but also information related to a number of adjacent BS for BS cooperation, like PMI, differential CQI/normalized interference power and IDs of dominant BSs.

The proposed PMI coordination scheme includes PMI restriction and recommendation, whose main procedure is outlined in figure 2. The steps of the procedure for interference coordination are described below.

1. Each MS feeds back information for normal closed-loop SU or MU MIMO operation.

2. MS measures n ($0 \le n \le N$) most dominant interfering channels from adjacent BSs on the same subchannel. Generally $n \le 2$ case is considered due to implementation complexity. The measurement is based on reference signals from other BSs.

3. Two approaches are proposed for PMI calculation regarding dominant interfering links. The calculation of PMI is either for restriction or recommendation, whose decision will be made either by MS or by BS (or BS controller which considers all the feedback information). The indicator of recommendation or restriction needs only 1 bit.

    - MS calculates the worst PMI or the best PMI information for each dominant interfering channel based on rank 1 or 2 transmission. The worst PMI indicates the PMI which yields the biggest interference to the MS and the best PMI indicates the PMI which yields the smallest interference to the MS. Since precoding codebook is different for different rank transmission, the best and worst PMI may also be different for rank 1 and rank 2 transmission. Generally, rank 1 transmission is considered.

    - Alternatively, based on the estimated channel matrices, the MS searches the codebook vector or matrix which maximizes its own receive signal power together with the codebook vector or matrix which maximizes the received signal power from the BSs. From the interference level parameter obtained from the BSs, the MS also computes a message ξ i indicating the recommended PMI set or the restricted PMI set for the interfering base stations..

4. In addition to PMI feedback, information about the impact of dominant interference link on MS performance shall also be measured, thus assisting interfering BS's decision making in PMI selection.

    - Differential ESINR (CQI) is obtained for each dominant link, indicating potential ESINR improvement due to PMI restriction or recommendation.
    - Alternatively, normalized interference power (NIP) is obtained as the ratio of interference power with worst PMI to total interference power received by this MS.

5. The n dominant BS ID together with PMI or PMI subset (messages of ξ), NIP or differential CQI, and PMI indication of recommendation or restriction are fed back to the serving BS.

6. The *n* dominant BS ID together with PMI or PMI subset, NIP or differential CQI and PMI indicator, or some aggregate measures representing the potential benefits to the serving BS throughput, are forwarded by the serving BS to related BS or sector within an active BS set.

7. One BS within an active BS set (which is the BS set for coordination) will collect the requests for those MS in its adjacent cell edge regions, and choose PMI and rank for transmission to its own MS on the subchannel.

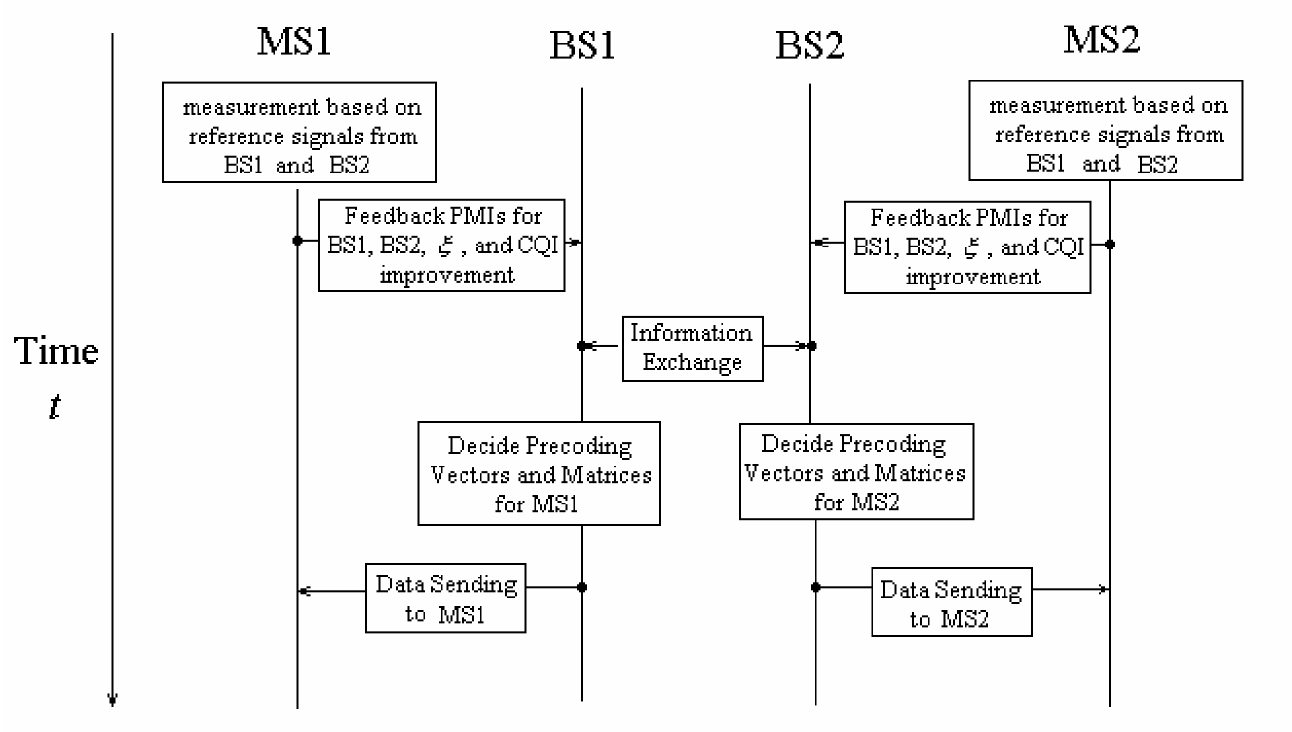

Fig. 2. Interference Coordination Procedure

5. Performance comparison:

In this section, we compare the performance of the uncoordinated system, PMI restriction system, together with the PMI coordination based on interference level. We consider the system shown in Fig. 1. The performance measure used in this comparison is the average SINR value shown in Fig. 3.

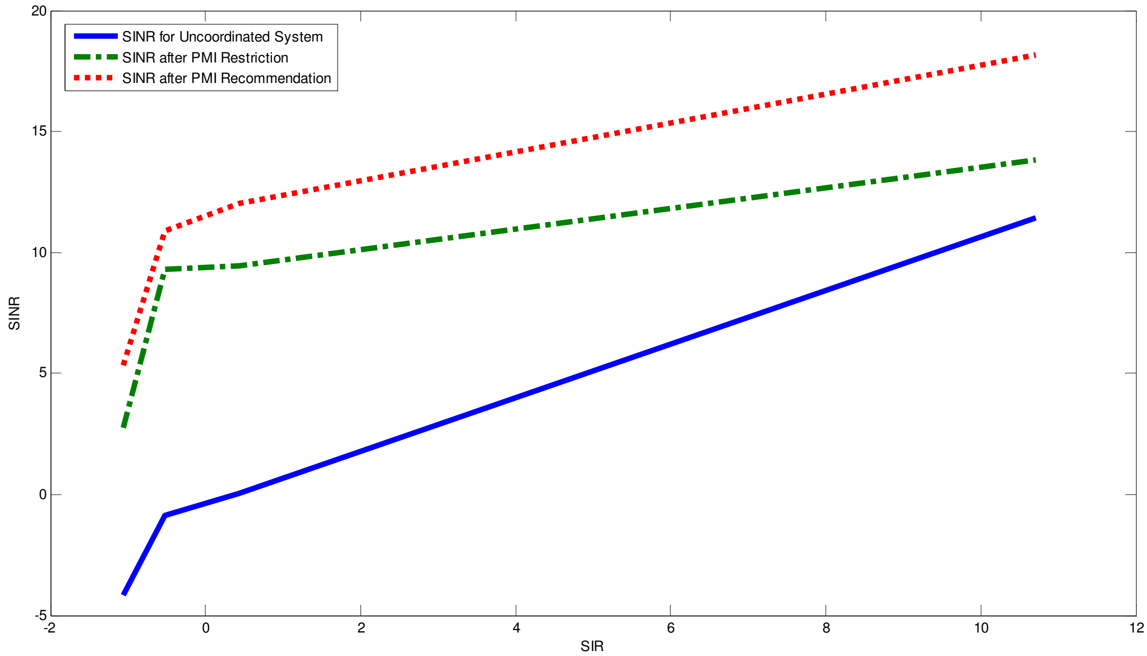

Figure 3: Comparison Between Uncoordinated System, PMI Restriction and PMI Recommendation

X-axis stands for the average SIR values while the Y-axis stands for the average SINR values after interference coordination processes. Basically the uncoordinated system is the system where the BSs choose the PMI which maximizes its own serving MS' SNR. The system parameters to obtain the above results is listed in Table 2.

Table 2: Simulation Parameters

Parameters	Values
System bandwidth	10 MHz
Transmit antenna at BSs	4
Receive antennas at MSs	1 (uncorrelated)
Antenna Spacing at BSs (wavelength)	0.5
Number of Interferer cells	1
Channel Model	SCM
IoT model	AWGN
Channel Estimation	Perfect Channel Estimation

6. Conclusion:

Inter-cell interference management is a promising technology to achieve targets of IMT-Advanced on the cell-edge throughput. In this contribution, we provide a unified framework to analyze inter-cell interference cancellation together with multi-cell MIMO. We show that various operation modes exist for inter-cell interference mitigation and the particular technologies to improve cell-edge throughput really depends on the underlying operation mode.

We also show that there exist techniques to improve the cell-edge performance through limited coordination between BSs. To be specific, PMI coordination based on CQI improvement or interference level offers a very good gain over uncoordinated system.

7. Reference:

[1] IEEE C802.16m-08/438r2, "Analog beamforming", Mitsubishi Electric
[2] IEEEC80216m-08_374r1, "Network Coordinated Beamforming", ETRI
[3] IEEE C802.16m-08/430:The PMI Restriction for the downlink Closed-loop MIMO, LG
[4] Syed A. Jafar, S. Shamai, "Degrees of Freedom Region for the MIMO X Channel", *IEEE Transactions on Information Theory*, Vol. 54, No. 1, Jan. 2008, Pages: 151-170.

Text Proposal for 802.16m

Insert the following text into SDD Sections indicated below

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11.x.4.2 Multi-cell MIMO

Multi-cell MIMO techniques shall be supported for improving sector throughput and cell-edge throughput through multi-BS collaborative precoding, network coordinated beamforming, or inter-cell interference mitigation. Both open-loop and closed-loop multi-cell MIMO techniques can be considered. For closed-loop multi-cell MIMO, CSI feedback via codebook based feedback or sounding channel is supported. The feedback information may be shared by neighboring base stations via network interface. Mode adaptation between single-cell MIMO and multi-cell MIMO should be considered.

11.x.4.2.1 Inter-cell interference mitigation

Neighboring BSs may coordinate their MIMO precoding schemes to reduce the inter-cell interference to MSs. MSs severely interfered by neighboring BSs can measure the channel from the dominant interfering BS and calculate the recommended set of PMIs and/or the restricted set of PMIs for the link. The MS may also estimate the interference reduction or the CQI improvement due to the inter-cell interference mitigation. The MS may feed back information including the identification of the dominant interfering BS, the recommended set of PMIs, the restricted set of PMIs, and the interference reduction or the CQI improvement. The MS should transmit the feedback information to the serving BS. The serving BS then forwards the information to the interfering BS as a requests for inter-cell interference mitigation. The interfering BS chooses a proper PMI for its served MSs considering the inter-cell interference mitigation requests from neighboring cells, and acknowledges the request from the serving BS.

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