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Re:	IEEE 802.16m-08/024, "Call for Contributions on Project 802.16m System Description Document (SDD)" for the following topic: 1. Uplink MIMO schemes.
Abstract	This contribution discusses some uplink MIMO techniques which may be used in IEEE 802.16m systems
Purpose	Propose to be discussed and adopted by TGm for the use in Project 802.16m SDD.
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Uplink MIMO Schemes for IEEE 802.16m

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1. Introduction

The illustration of uplink MIMO is shown in Figure 1, in which I MSs are separated either by frequency division or by space division. For the ith MS, we can see that its data is first muxed to L_i streams, each of which is channel encoded and modulated. Then the resultant data streams are fed into the MIMO encoder to map them to M_i layers. After that, the power of each layer is adapted according to BS notification. Precoder then follows to map the M_i layers to the N_i transmit antennas prior to transmission.

Uplink MIMO can be divided into two categories: one is single-user MIMO and the other is collaborative MIMO. Uplink single-user MIMO is simply the symmetric part of downlink single-user MIMO. On the other hand, collaborative MIMO is a unique feature of uplink, which also can be further categorized to MS-collaborative MIMO and BS-collaborative MIMO based on the collaboration types. Under some specific environments, collaborative MIMO significantly improves the overall system performance. In the following sections, we will detail the above mentioned uplink MIMO schemes.

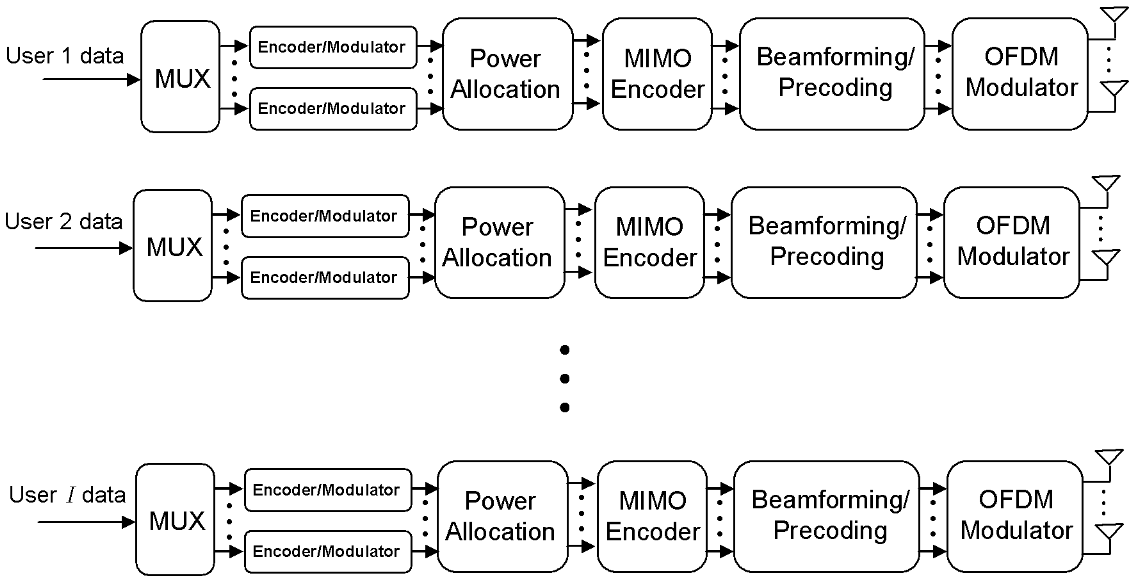

Figure 1. Illustration of uplink MIMO.

2. Uplink Single-User MIMO

In each RB, only one user is scheduled to transmit signals. In this case, BS simply considers optimizing the performance of each MS's transmission link (e.g., output SINR and throughput). Based on the channel conditions obtained from some uplink signaling, BS can determine which MIMO mode MS should use in order to achieve system requirements. The SU-MIMO schemes for uplink transmission are symmetric to that for downlink, and thus we only give a summary below.

(a) Diversity techniques

- 2Tx antennas, rate 1: STBC/SFBC
- 4Tx antennas, rate 1: STBC/SFBC with precoder

(b) Spatial multiplexing techniques

- 2Tx antennas, rate 2: rate 2 SM
- 4Tx antennas, rate 2: rate 2 SM with precoder
- 4Tx antennas, rate 3: rate 3 SM with precoder
- 4Tx antennas, rate 4: rate 4 SM

(c) Precoding techniques

Since BS can obtain CSI by sounding from MS, BS can choose a precoding matrix, which can achieve maximum beamforming gain, from pre-defined codebooks. In downlink, BS should inform MS of which precoding matrix should be used for uplink.

3. Uplink Collaborative MIMO

In uplink SU-MIMO, each MS is exclusively assigned some RBs and is served by one BS. In general, BS is equipped with multiple antennas, which provides the degrees-of-freedom for BS to serve more than one MS in each RB, such that the system throughput can be substantially boosted. This kind of MIMO scheme is referred to as MS-collaborative MIMO.

For cell-edge users, their signal strengths at the serving BS are usually much weaker than that of inner-cell users. As a result, the overall system performance bottleneck lies in how to improve the performance of those cell-edge users. Since the adjacent BSs are synchronized and connected via backbone network, their antennas can be jointly viewed as a virtual antenna array with respect to cell-edge users. That is, the cell-edge users can be jointly served by multiple BSs in a collaborative manner. Such BS collaboration is effective to improve the performance of cell-edge users. This kind of MIMO scheme is referred to as BS-collaborative MIMO. The above mentioned collaborative MIMO methods are summarized in the followings.

3.1 MS-collaborative MIMO

MS-collaborative MIMO is shown in Figure 2. Assume that there are I MSs, all of which utilize the same time-frequency resources, in a cell. The BS is equipped with N_B antennas, and the ith MS has N_i antennas. Then, the $N_B \times 1$ received signal at BS end is given by

$$\mathbf{r} = \sum_{i=1}^{I} \mathbf{H}_i \mathbf{W}_i \mathbf{P}_i \mathbf{s}_i + \mathbf{n} = \underbrace{\begin{bmatrix} \mathbf{H}_1 \mathbf{W}_1 \mathbf{P}_1 & \cdots & \mathbf{H}_I \mathbf{W}_I \mathbf{P}_I \end{bmatrix}}_{\mathbf{H}_{eff}} \begin{bmatrix} \mathbf{s}_1 \\ \vdots \\ \mathbf{s}_I \end{bmatrix} + \mathbf{n},$$

where $\mathbf{H}_i \in \mathbb{C}^{N_B \times N_i}$ denotes the channel matrix between the BS and the ith MS, $\mathbf{W}_i \in \mathbb{C}^{N_i \times M_i}$ the precoding matrix of the ith MS (either unitary or non-unitary), $\mathbf{P}_i \in \mathbb{C}^{M_i \times M_i}$ the diagonal power loading matrix of the ith

MS, and $\mathbf{s}_i \in \mathbb{C}^{M_i \times 1}$ the M_i spatial streams transmitted from the ith MS. Note that for simplicity we drop the subcarrier index in the above equation. If $N_B \geq \sum_{i=1}^{I} M_i$, the BS can detect the data streams of all MSs. Some issues regarding to MS-collaborative MIMO are summarized in the followings:

- Selection of precoding matrix: codebook based precoding is more suitable for MS-collaborative MIMO. Since BS knows the channel frequency responses between it and all MSs in uplink transmission, it can determine the precoding matrix of each MS, which optimizes overall system performance (e.g., output SINR), and inform MSs of their corresponding precoding matrix indices.
- Power allocation between MSs: since the channel diversity between the transmission layers of the MSs, proper power allocation between them is expected to obtain significant diversity gain. BS should calculate the power factors for each layer of each MS based on the channel conditions, and then inform MSs of their respective power loading factors.

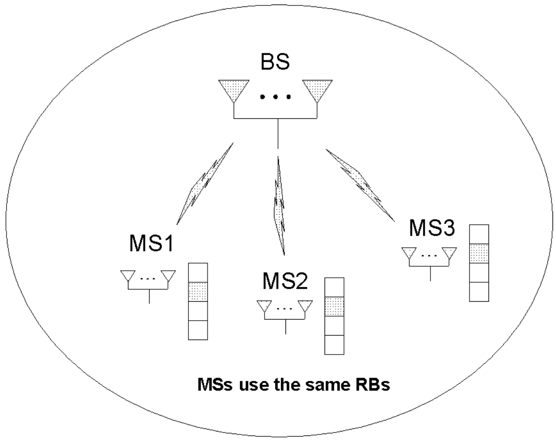

Figure 2. Illustration of MS-collaborative MIMO.

3.2 BS-collaborative MIMO

BS-collaborative MIMO is shown in Figure 3. For presentation simplicity, we only consider two (J=2) collaborating adjacent BSs (one is serving BS and the other is collaborating partners) and one cell-edge user. The BSs are equipped with N_B antennas, and the MS has N antennas. Then, the $N_B \times 1$ received signal at the jth BS is given by

$$\mathbf{r}_j = \mathbf{H}_j \mathbf{W} \mathbf{P} \mathbf{s} + \mathbf{n}_j,$$

where $\mathbf{H}_j \in \mathbb{C}^{N_B \times N}$ denotes the channel matrix between the jth BS and the MS, $\mathbf{W} \in \mathbb{C}^{N \times M}$ the precoding matrix of the MS (either unitary or non-unitary), $\mathbf{P} \in \mathbb{C}^{M \times M}$ the diagonal power loading matrix of the MS, and $\mathbf{s} \in \mathbb{C}^{M \times 1}$ the M spatial streams transmitted from the MS. Through backbone network, the signals of the two BSs ($\mathbf{r}_1$ and $\mathbf{r}_2$) are jointly decoded. In this way, the cell-edge user can enjoy some macro diversity gain. Note that the collaborating BS is not required to decode the data of the MS (and thus is not required to know the MCS type of the MS). The only job of the collaborating BS is to send the received signal and the information of the corresponding effective channel to the serving BS. Actually, BS-collaborative MIMO can be viewed as the uplink counterpart of multi-BS MIMO, which has already been proposed for downlink.

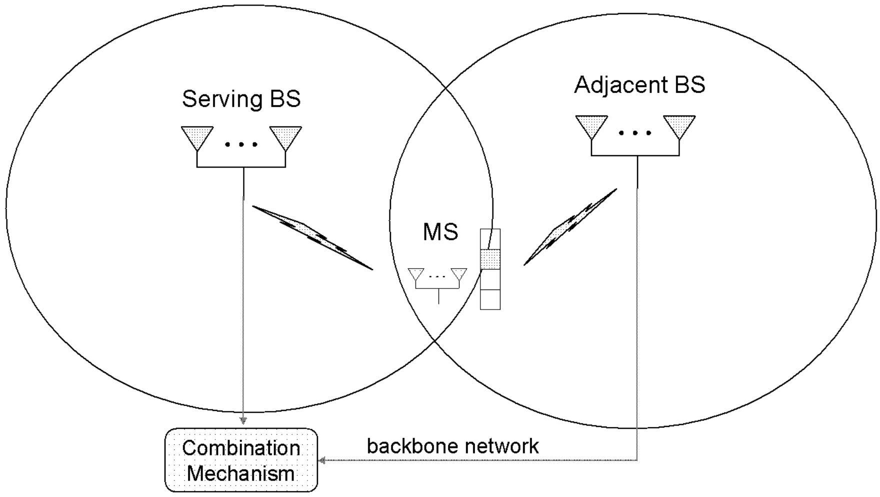

Figure 3. Illustration of BS-collaborative MIMO.

4. Conclusion

Uplink MIMO is categorized into single-user MIMO and collaborative MIMO. Single-user MIMO is simply utilized to optimize single link performance. To further improve overall system performance, collaborative MIMO should be considered in IEEE 802.16m systems. Collaborative MIMO incorporates the antennas of communication devices (either BS or MS) to form a virtual MIMO configuration. In this way, system effective degrees-of-freedom is increased, leading to the possibility for spectral efficiency boosting or link quality improvement. As a result, it is suggested that we should include collaborative MIMO in IEEE 802.16m.

Proposed Text for SDD

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11.x.x Collaborative MIMO

Collaborative MIMO scheme allows 16m system to coordinate multiple MSs and BSs to form a virtual MIMO, such that spectral resources can be efficiently exploited to boost system throughput or to improve link quality. Two types of collaborative MIMO schemes should be supported in 16m system: one is MS-collaborative MIMO and the other is BS-collaborative MIMO. MS-collaborative MIMO is used to boost inner-cell data throughput, while BS-collaborative MIMO is utilized to improve detection quality of cell-edge users.

11.x.x.1 MS-Collaborative MIMO

Assume that there are I MSs, all of which utilize the same time-frequency resources, in a cell. The BS is equipped with N_B antennas, and the ith MS has N_i antennas. Then, the $N_B \times 1$ received signal at BS end is given by

$$\mathbf{r} = \sum_{i=1}^{I} \mathbf{H}_i \mathbf{W}_i \mathbf{P}_i \mathbf{s}_i + \mathbf{n} = \underbrace{\begin{bmatrix} \mathbf{H}_1 \mathbf{W}_1 \mathbf{P}_1 & \cdots & \mathbf{H}_I \mathbf{W}_I \mathbf{P}_I \end{bmatrix}}_{\mathbf{H}_{eff}} \begin{bmatrix} \mathbf{s}_1 \\ \vdots \\ \mathbf{s}_I \end{bmatrix} + \mathbf{n},$$

where $\mathbf{H}_i \in \mathbb{C}^{N_B \times N_i}$ denotes the channel matrix between the BS and the ith MS, $\mathbf{W}_i \in \mathbb{C}^{N_i \times M_i}$ the precoding matrix of the ith MS (either unitary or non-unitary), $\mathbf{P}_i \in \mathbb{C}^{M_i \times M_i}$ the diagonal power loading matrix of the ith

MS, and $\mathbf{s}_i \in \mathbb{C}^{M_i \times 1}$ the M_i spatial streams transmitted from the ith MS. Note that for simplicity we drop the subcarrier index in the above equation. If $N_B \geq \sum_{i=1}^{I} M_i$, the BS can detect the data streams of all MSs. In TDD and FDD modes, codebook based precoding and power loading mechanism should be supported.

11.x.x.2 BS-Collaborative MIMO

Consider J collaborating adjacent BSs (one is serving BS and the others are collaborating partners) and I cell-edge user. The BSs are equipped with N_B antennas, and the ith MS has N_i antennas. Then, the $N_B \times 1$ received signal at the jth BS is given by

$$\mathbf{r}_j = \mathbf{H}_{j,i}\mathbf{W}_i\mathbf{P}_i\mathbf{s}_i + \mathbf{n}_j,$$

where $\mathbf{H}_{j,i} \in \mathbb{C}^{N_B \times N_i}$ denotes the channel matrix between the jth BS and the ith MS, $\mathbf{W}_i \in \mathbb{C}^{N_i \times M_i}$ the precoding matrix of the MS (either unitary or non-unitary), $\mathbf{P}_i \in \mathbb{C}^{M_i \times M_i}$ the diagonal power loading matrix of the ith MS, and $\mathbf{s}_i \in \mathbb{C}^{M_i \times 1}$ the M_i spatial streams transmitted from the MS. Through backbone network, the signals of the J BSs ($\mathbf{r}_j$ for $1 \leq j \leq J$) are jointly decoded. If $JN_B \geq \sum_{i=1}^{I} M_i$, the BSs can jointly detect the data streams of all MSs. In TDD and FDD modes, codebook based precoding and power loading mechanism should be supported.

11.x.x.3 Downlink Broadcast Messages for Collaborative MIMO

The following downlink broadcast messages should be supported to realize collaborative MIMO:

- Precoder matrix index
- Power loading factors

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