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Re:	802.16m AWD IEEE 802.16m-09/0020, “Call for Contributions on Project 802.16m Amendment Working Document (AWD) Content”. Target topic: “Interference Mitigation”.
Abstract	The contribution proposes the text of a interference mitigation section to be included in the IEEE 802.16m amendment.
Purpose	To be discussed and adopted by TGm for the IEEE 802.16m amendment.
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PMI Combination Proceeding in Uplink for Improvement of Throughput in A Multi-Cell Environment

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1. Introduction

Beamforming (BF) is the one of popular techniques for reducing inter-cell interference (ICI) for multi-cell MIMO systems. Since a users always wants to select the proper precoding matrix index (PMI) for maximizing signal to interference plus noise ratio (SINR), which perhaps cause very serious interference to some cell-edge users of other cells, a combination of the PMI which maximizes SINR to its own cell and one which minimizes ICI to other users of neighboring cells should be concerned in order to improve the overall system throughput and the edge area throughput.

2. Proposed Scheme

To increase the overall system throughput and edge area throughput in UL closed-loop MIMO, we propose a PMI combination scheme in the multi-cell environments. This scheme actually takes a tradeoff between maximizing a target user's SINR of its own cell and minimizing ICI to users of neighboring cells.

In order to support PMI combination to mitigate inter-cell interference, the ABSs are capable of exchanging the interference measurement results such as the recommended PMI subset to be restricted or to be applied in neighboring cells with each other or some control element in the backhaul network. Furthermore, for UL PMI combination, the ABS is capable of measuring the channel from the interfering AMS using sounding signals.

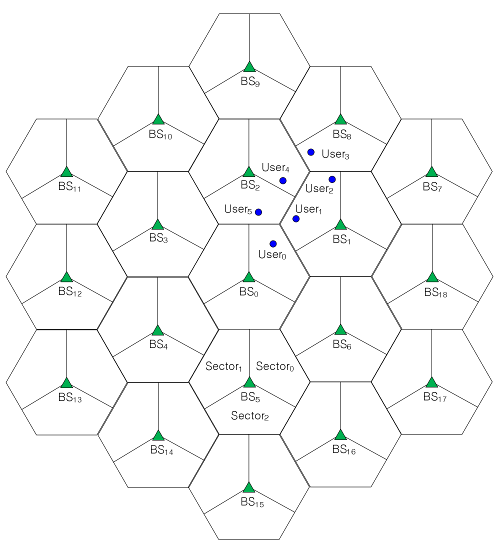

Fig.1. Two-tier cell structure

Fig.1 shows two-tier cell structure. Each cell is partitioned into three sectors. Channels between AMSs and ABSs in multi-cell environments are divided into three categories. The first category of channels from the $user_0$ to the BS of its own cell (BS_0) is named as an own channel (OC), the second one from the BS_c of the c^{th} cell to the $user_0$ or from the $user_c$ of the c^{th} cell to the BS_0 is called as an imported interference channel (IIC) and the final one from BS_0 to $user_c$ or from $user_0$ to BS_c is called as an exported interference channel (EIC). In this contribution, one-stream signal, one antenna of a BS and two antennas of a user are considered. The extension to multiple streams of signals and multiple antennas of BSs is straightforward.

The received signal at the BS can be written as follows:

$$\begin{aligned} Y_k^0 &= \mathbf{A}_k^0 \cdot X_k^0 + \mathbf{I}_k^0 + N_k^0 \\ &= \mathbf{W}_k^0 \cdot \mathbf{H}_k^0 \cdot X_k^0 + \sum_{c=1}^{18} \mathbf{A}_k^c \cdot X_k^c + N_k^0 \\ &= \begin{bmatrix} W_{0,k}^0 & W_{1,k}^0 \end{bmatrix} \begin{bmatrix} H_{0,k}^0 \\ H_{1,k}^0 \end{bmatrix} X_k^0 + \sum_{c=1}^{18} \mathbf{A}_k^c \cdot X_k^c + N_k^0 \end{aligned} , \tag{1}$$

where Y_k^c, and X_k^c with $E\left\{\left|X_k^c\right|^2\right\}=1$ denote the received and transmitted signals of the k^{th} subcarrier in the c^{th} cell, respectively. N_k^c is an additive Gaussian noise variable with a zero mean and variance σ_N^2. Since a two-tier system is considered, the total number of cells which may suffers ICI is 18, i.e., $0 \le c \le 18$. $W_{i,k}^c$ is a uniform BF value corresponding to the i^{th} transmitted antenna. $H_{i,k}^c$ with $E\left\{\left|H_{i,k}^c\right|\right\}=1$ denotes the coefficient of the channel from the i^{th} transmitted antenna to the BS. The SINR of (1) can be described as follows:

$$\mathrm{SINR}_k^0 = \frac{E\left\{|\,\mathbf{A}_k^0\,|^2\right\}}{E\{|\,\mathbf{I}_k^0\,|^2\} + \sigma_N^2} . \tag{2}$$

Recalling of the combination of BF vectors [1][2],

$$\mathbf{W}_k^c = \alpha \cdot \mathbf{W}_{\mathrm{OC},k}^c + (1-\alpha) \cdot \mathbf{W}_{\mathrm{EIC},k}^c, \quad 0 \le \alpha \le 1 , \tag{3}$$

where $\mathbf{W}_{\mathrm{oc}}$ and $\mathbf{W}_{\mathrm{EIC}}$ denote a BF vector for maximum-ration transmission (MRT) corresponding to OC and one for zero-forcing (ZF) corresponding to EIC, respectively. The MRT gain is increased as α is increased, while ICI to other users of neighboring cells is also increased. Thus, α should be properly selected. Based on (3), a combination of PMIs in UL is motivated.

Time division duplex (TDD) mode, in which channels of UL and DL are reciprocal, is firstly considered. First, a user, e.g. $user_0$, estimates OC, IIC and the propagation loss at adjacent sectors by using common pilot signals such as preamble, midamble etc.

If the propagation loss of the channel from $user_0$ to the $sector_0$ of BS_0 is denoted as $PG_{0,0}$. Similarly, $PG_{s,c}$ denotes the propagation loss of the channel from $user_0$ to $sector_s$ of BS_c with $s \ne c$, a sector and the corresponding BS of neighboring cells with the largest potential interference caused by the $user_0$ will be selected through the following criteria:

$$(\tilde{s},\tilde{c}) = \min_{s,c}\left(\left|\mathrm{PG}_{0,0} - \mathrm{PG}_{s,c}\right| < \mathrm{PG}_{\mathrm{T}}\right) , \tag{4}$$

where PG_{T} denotes a threshold which is decided based on the range for valid IIC estimation. Note that only one $(\tilde{s},\tilde{c})$ is determined because the spatial degree of freedom is two. PMIs of $\mathbf{W}_{\mathrm{oc}}$ and $\mathbf{W}_{\mathrm{EIC}}$ in a predefined codebook can be selected by the target user through the following equations:

$$\begin{aligned} \mathrm{PMI}_{\mathrm{OC}} &= \max_p\left(\sum_{k,n} \mathbf{A}_p^{0,0}\right) = \max_p\left(\sum_{k,n} \mathbf{W}_p \cdot \mathbf{H}_{\mathrm{OC}}\right) \\ \mathrm{PMI}_{\mathrm{EIC}} &= \min_p\left(\sum_{k,n} \mathbf{A}_p^{\tilde{s},\tilde{c}}\right) = \min_p\left(\sum_{k,n} \mathbf{W}_p \cdot \mathbf{H}_{\mathrm{EIC}}\right) \end{aligned} , \tag{5}$$

where *p* is the PMI in the codebook, k is the subcarrier index and n is the symbol index. The $N_f \times N_t$ resource block can be a minimum resource unit or a subband allocated to the target user. Then, $\mathrm{PMI}_{\mathrm{oc}}$ and $\mathrm{PMI}_{\mathrm{EIC}}$ will be transmitted to the user's own BS through the feedback channel. Each BS broadcasts the information of its interference level, e.g., interference over thermal (IoT) level, to users of adjacent sectors. So the user can determine α according to the received interference level of the $sector_s$ of the BS_c. Since the value of α is listed in a predefined table which is also known by the BS, the BS need to find which α is to be used by the user through the information of interference level known from the backhaul connection. Another way is BSs determine α in advance and transmit it to users instead of broadcasting the information of their interference level. If interference level is low, α is closed to 1. Note that interference level at the n^{th} frame is calculated by taking the average interference value from the $(n\text{-}S)^{\mathrm{th}}$ frame to the $(n\text{-}1)^{\mathrm{th}}$ frame, where S is the window size.

The procedure of PMI combination in frequency division duplex (FDD) mode is different with that in TDD mode due to the lack of reciprocity of channels, which is listed as follows:

1) The user ($user_0$) determines $(\tilde{s}, \tilde{c})$ by using (4).

2) The BS (BS_c) estimates OC and IIC by using common pilot signal such as sounding channel and calculates $\mathrm{PMI}_{\mathrm{oc}}$ and $\mathrm{PMI}_{\mathrm{EIC}}$ through (5). The IIC at the $sector_s$ of BS_c is equivalent to the EIC of the user in another sector.

3) BSs exchange the IoT level and $\mathrm{PMI}_{\mathrm{EIC}}$.

4) α is determined by the BS and transmitted to the user with $\mathrm{PMI}_{\mathrm{oc}}$ and $\mathrm{PMI}_{\mathrm{EIC}}$.

3. Analysis and Comparison

Upon the described procedure, the range of users who can use PMI combination for a specified BS is limited in one-tier. Moreover, only users who have $(\tilde{s}, \tilde{c})$ can use PMI combination. Thus, SINR of (2) can be rewritten as follows:

$$\mathrm{SINR}_k^{0,0} = \frac{E\left\{\left|\mathbf{A}_k^{0,0}\right|^2\right\}}{E\left\{\left|\mathbf{I}_k^{0,0,\mathrm{cr}}\right|^2\right\} + E\left\{\left|\mathbf{I}_k^{0,0,\mathrm{ucr}}\right|^2\right\} + \sigma_N^2}, \tag{6}$$

where $E\left\{\left|I_k^{0,0,cr}\right|^2\right\}$ is the controlled ICI with PMI combination of users who have $(\tilde{s}, \tilde{c}) = (0,0)$ and $E\left\{\left|I_k^{0,0,ucr}\right|^2\right\}$ is the uncontrolled ICI of users who have $(\tilde{s}, \tilde{c}) \neq (0,0)$ or have no $(\tilde{s}, \tilde{c})$. If α is zero, $E\left\{\left|I_k^{0,0,cr}\right|^2\right\}$ and $E\left\{\left|A_k^{0,0}\right|^2\right\}$ are closed to zero but not zero because of the difference between the codebook and the optimal BF vector. If α is one, $E\left\{\left|A_k^{0,0}\right|^2\right\}$ is closed to two. In other words, when a user in $sector_s$ of BS_c uses α with a low value, the transmitted power $E\left\{\left|A_k^{0,0}\right|^2\right\}$ becomes low as well as the ICI power for $BS_{0,0}$.

4. Performance Evaluation

The same codebook as that of IEEE802.16Rev2 [3] is used for link level simulation (LLS) and system level simulation (SLS) and given in Table I. Based on simulation parameters in [4][5], channels are extended ITU-R Ped-B (velocity:3km/h) and Veh-A (30km/h). $N_f \times N_t$ is given as 18×6.

Table I. Codebook for two transmitted antennas and one stream

Vector index	0	1	2	3	4	5	6	7
v1	1	0.7940	0.7940	0.7941	0.7941	0.3289	0.5112	0.3289
v2	0	-0.5801+j0.1818	-0.0576+j0.6051	-0.2978+j0.5298	0.6038+j0.0689	0.6614+j0.6740	0.4754-j0.7160	-0.8779-j0.3481

Fig.2. shows the transmitted signal power $E\left\{\left|A_k^{0,0}\right|^2\right\}$ of OC and ICI power $E\left\{\left|B_k^{0,0}\right|^2\right\}$ of EIC with respect to PMIs. If BF vectors which match the channel are used, the signal power should vary from 0 to 2. Note that the power of signal varies from 0.18 to 1.82 in Fig.2. This is because of the difference between BF vectors and the codebook. Meanwhile, the ICI power of EIC keeps constant as one because EIC is independent to OC. Thus, if any factor concerned by EIC is not considered, using the PMI maximizing the signal power of OC is the best for increasing SINR.

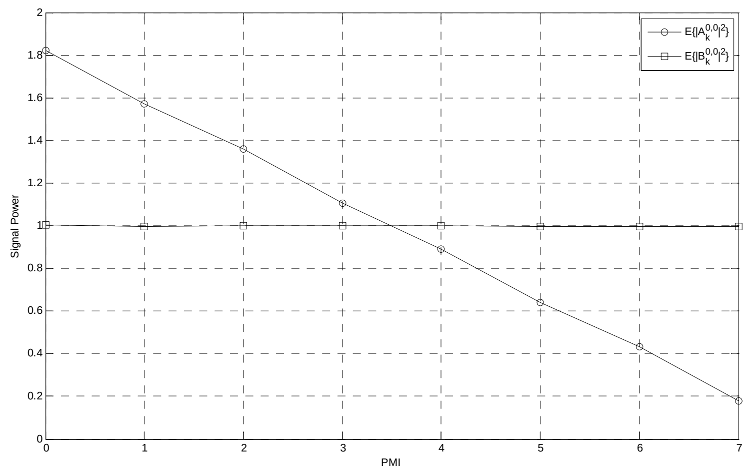

Fig.2. Signal power according to PMI

Fig.3. shows the signal power of OC and EIC with respect to α of PMI combination. In this figure, $\{\ \}_d$ denotes the case that using $\mathrm{PMI}_{\mathrm{oc}}$ and $\mathrm{PMI}_{\mathrm{EIC}}$ is delayed for 3 subframes (18 symbols) due to feedback. The power is increased as α is increased for all cases. For the Veh-A, the power is marginally larger than that for the Ped-B. The power for the Veh-A$_{\mathrm{d}}$ is reduced compared to that for the Veh-A due to the delay. The performances of three cases are deduced by Fig.3.

The first case is that two users affect each other. For example, $user_0$ and $user_1$, which use the same band, cause ICI to $sector_1$ of BS_1 and ICI to $sector_0$ of BS_0, respectively. In this case PMI combination has the performance gain according to different $\alpha\,(\neq 1)$, which depends on the propagation loss such as the user location.

The second one is the extension of the first case, in which two users don't affect each other directly. However, they affect each other through other users. For example, $user_0$ and $user_{2\ldots5}$ use the same band. $user_0$ causes ICI to $sector_1$ of BS_1; $user_2$ causes ICI to $sector_2$ of BS_8; $user_3$ causes ICI to $sector_0$ of BS_2; $user_4$ causes ICI to $sector_2$ to BS_2 and $user_5$ causes ICI to $sector_0$ of BS_0. Thus $user_0$ and $user_5$ don't affect each other directly but the effect does exist through other users. As users are connected like a ring, PMI combination ($\alpha \neq 1$) provides the same performance gain as that of the first case.

The final one is that there is no effect between two users. For example, $user_0$ and $user_1$ have the same band. $user_0$ causes ICI to $sector_1$ of BS_1 but there is no $(\tilde{s},\tilde{c})$ selected for $user_1$. In this case the best performance can be achieved when α is equal to 1.

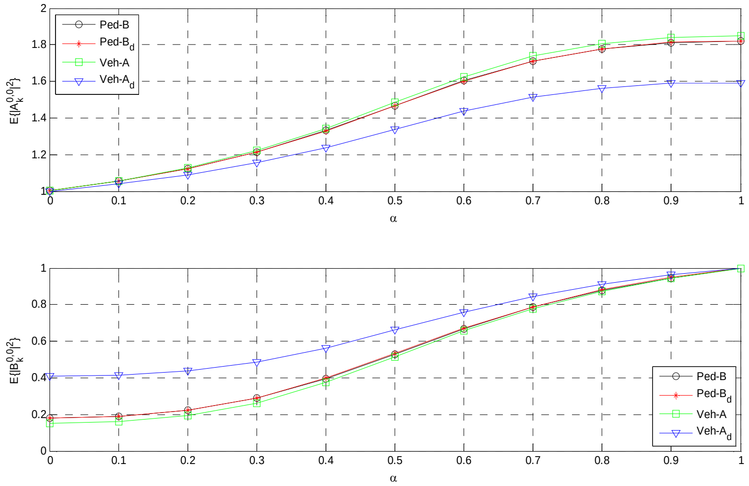

Fig.3. Signal power according to PMI combination

Table II shows the overall system throughput and the edge area throughput. The results show that the introduction of PMI combination in uplink multi-cell systems provides gains on the overall system throughput and edge area throughput as amount of 3-6% and 9-15%, respectively. In the Table II, 'Case2' denotes that the used bands for the cell-edge of all cells are the same.

Table II. Performance gain with PMI combination

	α according to user location			Edge throughput	Total throughput
	Cell-edge	Cell-mid	Cell-center	(compared with 0.28Mbps)	(compared with 3.86Mbps)
Case1	0.9	0.1	1	9%	4%
Case2	0.5	0.1	1	15%	3%
Case3	0.1	1	1	-10%	6%

5. Necessary Signaling

AMS transmits information of monitoring sectors to ABS: $(\tilde{s},\tilde{c})$

ABS transmits information of PMI combination to AMS: α , $\mathrm{PMI}_{\mathrm{OC}}$, $\mathrm{PMI}_{\mathrm{EIC}}$

ABS transmits information of PMI to another ABS: $\mathrm{PMI}_{\mathrm{EIC}}$

6. Conclusion

A PMI combination proceeding for uplink multi-cell systems is proposed to improve throughput, which leads to a tradeoff between maximizing SINR of the user to its own cell and minimizing ICI caused by it to other users in neighboring cells. The simulation results show improvement of the overall system throughput and edge area throughput. Based in the above observation, we propose PMI combination for uplink multi-cell environment as one of technologies to achieve target requirements for IEEE 802.16m.

7. Reference

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