Two-cell MISO Interfering Broadcast Channel with Limited Feedback: Adaptive Feedback Strategy and Multiplexing Gains

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Abstract—In this paper, we study a two cell multiple-input single-output interfering broadcast channel with finite rate feedback. In this system, we first derive the rate loss due to the quantization error by considering a coordinated zero-forcing beamforming. In addition, feedback bits allocation methods are proposed to minimize the performance degradation caused by the quantization error. Lastly, we investigate how many feedback bits per user are necessary to maintain the optimal multiplexing gain in MISO-IFBC. Through numerical evaluations, we show that our proposed feedback bits allocation strategy provides significant gain compared to a trivial bits allocation scheme.

I. INTRODUCTION

An interfering broadcast channel (IFBC) [1] is an interesting channel model in the theoretical aspect, since it generalizes interference channel by allowing each transmitter to send multiple independent messages to the corresponding multiple users. In practice, IFBC is also the simplest model of multi-cell multiuser downlink transmission, which is the most promising scenario for future wireless cellular networks such as LTE-A. Unlike conventional multiple-input-single-output broadcast channels (MISO-BC), in MISO-IFBC, not only inter-user interference (IUI) but also inter-cell interference (ICI) significantly degrade the throughput performance. Therefore, our fundamental question of this channel is how can we efficiently eliminate those of two interference signals simultaneously. As one of related works for this channel, a simple zero-forcing (ZF) scheme was recently proposed in [2]. Particularity, in [2], they showed that ZF scheme achieved the optimal multiplexing gain on such a channel, assuming that each transmitter has the perfect knowledge of channel state information (CSI) of all users.

For the design of practical systems, however, we should consider a finite rate feedback to ensure a reasonable uplink feedback overhead. Therefore, limited feedback systems have extensively been investigated from point to point MISO/MIMO channels to MISO/MIMO broadcast channels in [3]-[7]. In addition, it has been considered in MISO interference channel in [8]-[9] to extend the results.

In this paper, we consider a two-cell MISO-IFBC where two base stations (BSs) equipped with multiple antennas wish to communicate with \( K_i \) \( i = 1, 2 \) users with a single antenna based on the quantized CSI. In this channel, our main goal is to provide answers to the following two questions: 1) For a given amount of feedback bits per user, what is the optimal feedback bits allocation method which minimizes the expected quantization error in the multi-cell multiuser system. 2) To maintain the optimal multiplexing gain, how many feedback bits per user are necessary?

The main contributions of this paper are summarized as follows: first, we propose a simple coordinated zero-forcing beamforming (CZFBF) with limited CSI in MISO-IFBC. On the basis of the proposed beamforming scheme, we characterize the rate loss per user due to limited feedback and propose a feedback bits allocation scheme which minimizes the expected quantization error. This feedback scheme adaptively distributes total feedback bits per user into two parts for serving channel and interfering channel according to the power ratio IUI to ICI. In addition, by using the proposed bits allocation scheme, it is shown that the total feedback bits per user scale as \( B_i \geq (M-1)\log_2(P_{Ii}P_r) + 2(M-1)\{1-\log_2(\beta-1)\} \) to keep constant rate loss as \( \log_2(\beta) \) (bits/Hz).

Notation: We use bold upper and lower case letters for matrices and column vectors, respectively. \((\cdot)^T\) and \((\cdot)^H\) stand for, transpose and Hermitian transpose, respectively. \( E(\cdot) \) denotes the expectation operator.

II. SYSTEM MODEL

In this section, we describe the system model for two-cell MISO-IFBC with finite rate feedback as shown in Fig. 1. There are two BSs, \( BS_1 \) and \( BS_2 \), each being equipped with \( M \) antennas supports \( K_i \) \( i = \{1, 2\} \) users with a single antenna. In order to attain the maximum multiplexing gain, it is assumed that the number of BSs’ transmit antennas are greater than or equal to the total number of servicing users, i.e., \( M \geq K_1 + K_2 \). For notation convenience, we refer to the \( k \)-th user in the \( i \)-th cell as user \( (k, i) \). It is assumed that equal power allocation over \( K_i \) active user per BS. The received signal at user \( (k, i) \) is given by

\[
y_{k,i} = \sqrt{P_{k,i}}h_{k,i}^H x_i + \sqrt{P_{r,k}}z_{k,i}^H x_i + n_{k,i}, \quad i = \{1, 2\},
\]

where \( P_{k,i} \) and \( P_{r,k} \) are the received power at the user \( (k, i) \) from the serving \( BS_i \) and interfering \( BS_j \), respectively, \( h_{k,i} \) and \( z_{k,i} \) denote the channel and interference vectors respectively.
represents the channel vector of size $M \times 1$ from the serving BS to user $(k, i)$, $z_{k,i}$ denotes the channel vector from the interfering BS to user $(k, i)$. In addition, $x_i$ stands for the transmit signal vector of length $M \times 1$ with $\mathbb{E}\{\text{tr}(x_i x_i^H)\} = P^t$ from the BS $i$, and $n_{k,i}$ is the additive Gaussian noise for user $(k, i)$ with zero mean and unit variance. Here, we define $I = 2$ and $2 = 1$. It is assumed that the channel elements are drawn from independent and identically distributed (i.i.d.) complex Gaussian random variables with zero mean and unit variance.

A. Finite channel feedback and channel exchange model

In this work, it is assumed that each user has perfect knowledge of CSI for both serving and interfering link, i.e., $h_{k,i}$ and $z_{k,i}$ by exploiting inter-cell orthogonal reference signals. Using these CSI, each user sends back to the serving BS $i$, a channel direction information (CDI) and a channel quality information (CQI) for two channel links. Before sending back, each user quantizes the direction of its served channel and interfering channel vectors, i.e., $\hat{h}_{k,i} = h_{k,i}/\|h_{k,i}\|$ and $\tilde{z}_{k,i} = z_{k,i}/\|z_{k,i}\|$, by exploiting distinct quantization codebooks, $C_S = \{c_{S,1}, c_{S,2}, \ldots, c_{S,2^M}\}$ and $C_I = \{c_{I,1}, c_{I,2}, \ldots, c_{I,2^M}\}$, each of which consists of $M$-dimensional unit norm vectors of size $N_i = 2^M$ and $N_i = 2^M$, respectively. By using minimum chordal distance metric, indices for CDI of serving and interfering channel vectors are obtained as

$$\hat{h}_{k,i} = c_{S,n_i}, \quad n_i = \arg \max_{1 \leq l \leq 2^M} |c_{S,l}|^H \tilde{h}_{k,i},$$

$$\tilde{z}_{k,i} = c_{I,n_i}, \quad n_i = \arg \max_{1 \leq l \leq 2^M} |c_{I,l}|^H \tilde{z}_{k,i}.$$ \hspace{1cm} (2)

For simple analysis, we apply the Quantization cell Upper Bound (QUB) model in [5], which provides performance upper bound in terms of achievable rate. After quantization, each user informs two indices $n_i$ and $n_i$ to its serving BS through error and delay free feedback channel. It is assumed that each user satisfies total feedback bits per user constraint, i.e., $B_i = B_t + B_f$. In addition, it is assumed that each user perfectly feeds back the CQI for two links to the serving BS. We assume that the channel norms, $\|h_{k,i}\|$ and $\|z_{k,i}\|$ are used as CQI and that CQI feedback is not included in total feedback amount per user for simple analysis. After obtaining the feedback information from their serving users, two BSs exchange only the CDI and CQI for only interfering links not serving links, i.e., $\hat{z}_{k,i}$ and $\|z_{k,i}\|$, by exploiting error and delay free backhaul channel.

III. A CZFBF SCHEME WITH FINITE RATE FEEDBACK

In this section, we propose a simple coordinated zero-forcing beamforming (CZFBF) scheme which mitigates both IUI and ICI, simultaneously in MISO-IFBC. As already well known, even though ZFBF scheme is not the optimal in a single-cell MISO-BC, we consider ZFBF method in this work since it is beneficial to analyze the performance and it provides asymptotically optimal performance in high SNR regime if number of users are infinitely many [5]. Using linear beamforming vector, the received signal at user $(k, i)$ in (1) can be rewritten as

$$y_{k,i} = \sqrt{P_{k,i}} h_{k,i}^H w_{k,i} s_{k,i} + \sqrt{P_{k,i}} \sum_{j=1, j \neq k}^{K} h_{k,i}^H w_{j,i} s_{j,i} + \sqrt{P_{k,i}} \sum_{j=1}^{K} z_{k,i}^H w_{j,i} s_{j,i} + n_{k,i},$$ \hspace{1cm} (3)

where $w_{k,i}$ stands for linear beamforming vector for user $(k, i)$ with size of $M \times 1$, $s_{k,i}$ denotes an data symbol for user $(k, i)$ satisfying $\mathbb{E}\|s_{k,i}\|^2 = 1$.

Each BS constructs the beamforming vectors based on both the quantized CDI of its serving users and interfering users. Let $\hat{h}_{k,i} (k = \{1, 2, \ldots, K\})$ and $\tilde{z}_{k,i} (l = \{1, 2, \ldots, K\})$ denote quantized CDI of channel $h_{k,i}$ and $z_{l,i}$, respectively. Since we assume that $M \geq K_1 + K_2$, the beamforming vectors $w_{k,i}$ for user $(k, i)$ is designed so that IUI and ICI become zero

$$[\begin{bmatrix} \hat{h}_{k,i} \\ \tilde{z}_{l,i} \end{bmatrix}]_{(K_1+K_2-1) \times M} w_{k,i} = 0, \hspace{1cm} (4)$$

where $\hat{h}_{k,i}$ denotes complementary intra-cell network channel to user $(k, i)$, which is defined as $\hat{h}_{k,i} = \left[ h_{1,i}, \ldots, h_{k-1,i}, h_{k+1,i}, \ldots, h_{K_i,i} \right]^H$ and $\tilde{z}_{l,i}$ stands for the inter-cell network channel affected by transmission for user $(k, i)$, which is also defined as $\tilde{z}_{l,i} = \left[ z_{1,i}, \ldots, z_{K_i,i} \right]^H$.

In contrast to the perfect channel knowledge, IUI and ICI are not fully eliminated under finite rate feedback system. Thus, the rate which is achievable at user $(k, i)$ is given by

$$R_{i,k}^{\text{LF}} = \log_2 \left( 1 + \frac{P_{k,i} \|h_{k,i}\|^2 \|h_{k,i}^H w_{k,i}\|^2}{I_{\text{IUI}} + I_{\text{ICI}} + 1} \right),$$ \hspace{1cm} (5)

where $I_{\text{IUI}} = P_{k,i} \|h_{k,i}\|^2 \sum_{j=1, j \neq k}^{K_1} \|\hat{h}_{k,i}^H w_{j,i}\|^2$ and $I_{\text{ICI}} = P_{k,i} \|z_{k,i}\|^2 \sum_{j=1}^{K_1} \|\tilde{z}_{l,i}^H w_{j,i}\|^2$, respectively.

To represent residual interference terms due to finite rate feedback more specifically, we decompose the channel directional vector, i.e., $\hat{h}_{k,i}$ and $\tilde{z}_{k,i}$, into two orthogonal basis by using quantized CDI as

$$\hat{h}_{k,i} = \hat{h}_{k,i} (\cos \theta_{k,i}) + q_{k,i} (\sin \theta_{k,i}),$$

$$\tilde{z}_{k,i} = \tilde{z}_{k,i} (\cos \theta_{k,i}) + r_{k,i} (\sin \theta_{k,i}),$$ \hspace{1cm} (6)

where $\theta_{k,i}$ and $\theta_{k,i}$ denotes the angle between the real channel direction and quantized channel direction for serving channel and interfering channel, respectively. Since the beamforming vector transmitting data $s_{j,i}$, i.e., $w_{j,i}$, for $j = \{1, 2, \ldots, k-1, k+1, \ldots, K_i\}$ and beamforming vector transmitting data $s_{l,i}$, i.e., $w_{l,i}$ for $l = \{1, 2, \ldots, K_i\}$ are designed to be orthogonal to $\hat{h}_{k,i}$ and $\tilde{z}_{k,i}$, the rate of user $(k, i)$ in (5) is rewritten as

$$R_{i,k}^{\text{LF}} = \log_2 \left( 1 + \frac{P_{k,i} \|h_{k,i}\|^2 \|h_{k,i}^H w_{k,i}\|^2}{I_{\text{IUI}} + I_{\text{ICI}} + 1} \right),$$ \hspace{1cm} (7)
where \( \tilde{I}_{IU} = P_{k,i}^{r} |h_{k,i}|^2 \sin^2 \theta_{k,i} \sum_{j=1, j \neq k}^{K_i} |q_{k,i}^{H} w_{j,i}|^2 \) and 
\( \tilde{I}_{IC} = P_{r}^{r} |z_{k,i}|^2 \sin^2 \theta_{k,i} \sum_{i=1}^{K_i} |r_{k,i}^{H} w_{i,i}|^2 \).

A. Characterization of rate loss

The characterization of rate loss proposed by Jindal in [4], which is the difference between the rate achieved by perfect CSI and by limited CSI, provides meaningful information to understand the finite rate feedback system. Therefore, we characterize the rate loss of two-cell MISO-IFBC with the proposed CZFBF scheme.

First, we define the rate loss \( \triangle R_{k,i}(P_{k,i}^{r}, P_{k,i}^{r}; K_i, K_i, M) \) to be the difference between the achievable rate at the user \((k, i)\) by CZFBF under the condition of perfect CSI and limited feedback CSI:

\[
\triangle R_{k,i}(P_{k,i}^{r}, P_{k,i}^{r}; K_i, K_i, M) \triangleq E\left[ R_{k,i}^{PF} - R_{k,i}^{LFB} \right],
\]

where \( R_{k,i}^{PF} \) denotes the sum rate achieved at user \((k, i)\) by CZFBF with perfect CSI, which is

\[
R_{k,i}^{PF} = \log_2 \left( 1 + P_{k,i}^{r} |h_{k,i}^{H} w_{k,i}^{PF}|^2 \right),
\]

where \( w_{k,i}^{PF} \) is the beamforming vector which nulls out both IUI and ICI, perfectly. The following theorem is the main result of this section.

**Theorem 1:** In the two-cell MISO-IFBC, when CZFBF scheme is employed, the rate loss per user due to finite rate feedback is function of the expected quantization error, \( \delta \), and which is

\[
\triangle R_{k,i}(P_{k,i}^{r}, P_{k,i}^{r}; K_i, K_i, M) \leq \log_2 \left( 1 + \delta \right),
\]

where \( \delta = P_{k,i}^{r}(K_i - 1)2^{-B_i} + P_{k,i}^{r} K_i 2^{-B_i} \).

Proof: By using (7) and (9), the rate loss in (8) can be rewritten as since Log function in (11) is monotonically increasing function and \( \tilde{I}_{IU} \) and \( \tilde{I}_{IC} \) are greater than or equal to zero, the rate loss is bounded as

\[
\triangle R_{k,i} \leq E \left[ \log_2 \left( 1 + P_{k,i}^{r} |h_{k,i}^{H} w_{k,i}^{PF}|^2 \right) \right] - E \left[ \log_2 \left( 1 + P_{k,i}^{r} K_i |w_{k,i}^{PF}|^2 \right) \right] + E \left[ \log_2 \left( \tilde{I}_{IU} + \tilde{I}_{IC} + 1 \right) \right]
\]

\[
= E \left[ \log_2 \left( \tilde{I}_{IU} + \tilde{I}_{IC} + 1 \right) \right].
\]

In (12), the last equality comes from the fact that \( w_{k,i}^{PF} \) and \( w_{k,i} \) are isotropically distributed in \( \mathbb{C}^M \) and constructed independently with respect to \( h_{k,i}^{H} \). Now, by applying Jensen’s inequality to the last term in (12), the upper bound of the rate loss is given by

\[
\triangle R_{k,i} \leq \log_2 \left( E \left[ \tilde{I}_{IU} \right] + E \left[ \tilde{I}_{IC} + 1 \right] \right). \tag{13}
\]

Note that \( |h_{k,i}^{H} w_{k,i}|^2 \) and \( |r_{k,i}^{H} w_{i,i}|^2 \) are Beta-distributed random variables with parameters \((1, M-2)\). Moreover, by using the fact that random variables \( |h_{k,i}^{H} w_{k,i}|^2 \), \( |q_{k,i}^{H} w_{j,i}|^2 \), \( |z_{k,i}|^2 \), \( \sin^2 \theta_{k,i} \), and \( |r_{k,i}^{H} w_{i,i}|^2 \) are linearly independent each other, we finally obtain the upper bound of the rate loss as

\[
\triangle R_{k,i} \leq \log_2 \left( 1 + P_{k,i}^{r} (K_i - 1)2^{-B_i} + P_{k,i}^{r} K_i 2^{-B_i} \right), \tag{14}
\]

where we use the fact that \( E(\sin^2 \theta_{k,i}) \leq \left( \frac{M-1}{M} \right) 2^{-B_i} \), \( i = \{1, 2\} \) in [5].

IV. FEEDBACK BITS ALLOCATION SCHEME

From previous section, we show that the quantization error causes performance degradation characterized by the rate loss. In contrast to single cell MISO-BC in [3]-[7] or MISO interference channel discussed in [8] and [9], the rate loss is due to major two factors, the residual IUI and ICI, in two-cell MISO-IFBC. Therefore, our fundamental question is that if the total number of feedback bits \( B_i \) per user is fixed, in order to minimize the expected quantization error due to both IUI and ICI, how many feedback bits should be differently allocated to the channel quantization for serving BS1 and interfering BS2, respectively. To answer the question above, in this section, we propose two feedback bits allocation schemes that minimizes the expected quantization error for given number of feedback bits per user.

The formulation of our problem is

\[
\begin{align*}
\min_{B_i, B_i \in \{0,2\}} & \quad P_{S} 2^{-B_i} + P_{I} 2^{-B_i} \\
\text{s.t.} & \quad B_i + B_i = B_i,
\end{align*}
\]

where \( P_S = P_{k,i}^{r} (K_i - 1) \) and \( P_I = P_{k,i}^{r} K_i \) are total received interference power from serving BS due to IUI and interfering BS due to ICI at the user \((k, i)\), respectively.

A. An optimal scheme

The optimization problem in (15) is a non-linear integer programing (NIP) problem. Therefore, the optimal solution of the NIP problems is obtained by an exhaustive search method using combinatorial optimization techniques in [10].

B. Proposed scheme

It requires very high computational complexity to get the optimal solution of the problem in (15) as the total number of feedback bits per user, \( B_i \), becomes larger. Hence, we propose a sub-optimal feedback bits allocation scheme with closed form by exploiting continuous relaxation and convex optimization techniques. The motivation using a continuous relaxation approach is that it provides a near optimal solution for the problem in (15). Furthermore, we can obtain a simple closed form solution, which enables analysis to tractable.

First, we assume that the \( B_i \) is a non-negative real value in order to relax integer constraint on \( B_i \). After constraint relaxing, we apply convex optimization technique to (15). The Lagrangian function of the optimization problem in (15) with the assumption of constraint relaxation is written as

\[
L(B_i, B_i, \lambda) = P_{S} 2^{-B_i} + P_{I} 2^{-B_i} + \lambda(B_i + B_i - B_i). \tag{16}
\]

From (16), we find the first order optimality Karush-Kuhn-Tucker (KKT) conditions as

\[
\begin{align*}
\frac{\partial L(B_i, B_i, \lambda)}{\partial B_i} &= -\frac{\ln(2) P_{S}}{M - 1} 2^{-B_i} + \lambda = 0, \tag{17} \\
\frac{\partial L(B_i, B_i, \lambda)}{\partial B_i} &= -\frac{\ln(2) P_{I}}{M - 1} 2^{-B_i} + \lambda = 0, \tag{18} \\
\frac{\partial L(B_i, B_i, \lambda)}{\partial \lambda} &= B_i + B_i - B_i = 0. \tag{19}
\end{align*}
\]
By solving the equations (17), (18) and (19), we get a suboptimal solution which is written as

$$B_t^* = \min \left\{ B_t, \left[ \frac{B_t}{2} + \frac{M - 1}{2} \log_2 \left( \frac{P_S}{P_I} \right) \right]^+ \right\}.$$  

(20)

Even if this feedback bits allocation method in (20) is a suboptimal, from this result, we can establish the following remarks:

**Remark 1**: The most significant feature in the feedback bits allocation method is that more accurate CSI for stronger channel link is necessary to minimize the overall performance loss caused by quantization error. For example, if IUI affects channel link is necessary to minimize the overall performance

**Remark 2**: The variation of feedback bits for two BSs is

**Remark 3**: If $\beta = 3$, the result in (24) turns out that $B_t \geq (M - 1) \log_2 (P_S P_I) + 2(M - 1) \{1 - \log_2 (\beta - 1)\}$. (24)


\[ \triangle R_{k,i} = E \left[ \log_2 \left( 1 + P_{r, k,i} |h_{k,i}^H w_{k,i}^{PZF}|^2 \right) \right] - E \left[ \log_2 \left( 1 + P_{r, k,i} |h_{k,i}^H w_{k,i}^{PZF}|^2 + \frac{|\tilde{h}_{k,i}^H w_{k,i}|^2}{I_{UI} + I_{ICI} + 1} \right) \right]. \]

(11)

V. SCALING LAW OF FEEDBACK BITS PER USER

In this section, we derive the scaling law of feedback bits per user for maintaining the constant rate loss. By using the proposed feedback bits allocation strategy which minimizes the quantization error, we provide the following theorem.

**Theorem 2**: In the two-cell MISO-IFBC, to maintain a constant rate loss of $\log_2 (\beta)$ bps/Hz compared to perfect CSI, the number of feedback bits for each user scales as

$$B_t \geq (M - 1) \log_2 (P_S P_I) + 2(M - 1) \{1 - \log_2 (\beta - 1)\}. \quad (21)$$

Proof): To be within $\log_2 (\beta)$ (bps/Hz), the rate loss can be represented by

$$\log_2 \beta \geq \log_2 \left( 1 + P_S 2^{\frac{B_t}{M-1}} + P_I 2^{\frac{-B_t}{M-1}} \right). \quad (22)$$

By applying the feedback bits allocation method in (20) into (22), the rate loss is written as

$$\beta - 1 \geq 2^{\frac{B_t}{M-1}} \left( P_S \sqrt{\frac{P_I}{P_S}} + P_I \sqrt{\frac{P_S}{P_I}} \right). \quad (23)$$

If we reformulate equation (23) in terms of $B_t$, then we get

$$B_t \geq (M - 1) \log_2 (P_S P_I) + 2(M - 1) \{1 - \log_2 (\beta - 1)\}. \quad (24)$$

**Remark 3**: If $\beta = 3$, the result in (24) turns out that $B_t \geq (M - 1) \log_2 (P_S P_I)$. In other words, to keep rate loss per user within $\log_2 (3)$ (bps/Hz), the number of total feedback bits per user are scaled as product of two received power from serving BS and interfering BS, i.e., $P_S P_I$, and number of antennas $M$. This result is different with the result of MISO interference channel in [8] and [9], in which the total feedback bits per user scale as function of only the received power of the interfering BS to maintain a constant rate loss.

VI. NUMERICAL RESULTS

In this section, numerical results are provided to demonstrate and get more insights of results derived in the previous sections. A simple one-dimensional two-cell network model depicted in Fig. 2 is considered, where $d_S$ and $d_I$ denotes the distance from serving BS and interfering BS to the user, respectively. In addition, we define the received signal power from the serving BS and interfering BS as

$$P_{r, k,i} = \frac{P_t}{K_i} \left( \frac{d_0}{d_S} \right)^\gamma,$$

$$P_{r, k, i} = \frac{P_t}{K_i} \left( \frac{d_0}{d_I} \right)^\gamma,$$

(25)

where $P_t$ stands for transmit power at the both BS, $d_0$ is a reference distance for the antenna far field, and $\gamma$ is the pass-loss exponent. Throughout simulation, we consider the case with the parameters $M = 4$, $K_i = K_s = K = 2$, $d_0 = 1$ m and $R = 500$ m. Random vector quantization (RVQ) in [4] is applied for quantizing the channel direction vector.

**Feedback strategies vs $d_S$**: Feedback strategies of the user are scaled as product of feedback bits allocation method. Fig. 3 shows the variation of feedback bits allocation strategy. For example, if $\beta = 3$, the result in (24) turns out that $B_t \geq (M - 1) \log_2 (P_S P_I)$. In other words, to keep rate loss per user within $\log_2 (3)$ (bps/Hz), the number of total feedback bits per user are scaled as product of two received power from serving BS and interfering BS, i.e., $P_S P_I$, and number of antennas $M$. This result is different with the result of MISO interference channel in [8] and [9], in which the total feedback bits per user scale as function of only the received power of the interfering BS to maintain a constant rate loss. 

**Remark 1**: The most significant feature in the feedback bits allocation method is that more accurate CSI for stronger interference is necessary to minimize the overall performance loss caused by quantization error. For example, if IUI affects channel link is necessary to minimize the overall performance
In this paper, we propose a simple CZFBF using finite feedback of CSI in MISO-IFBC. On the basis of the proposed scheme, we characterize the loss of sum rate performance and propose a closed form feedback bits allocation scheme which minimizes the expected quantization error by adaptively distributing given feedback bits per user according to the received power. Lastly, it is shown that the number of total feedback bits per user are scaled as product of two received power from serving BS and interfering BS, i.e, $P_S P_t$, and number of antennas $M$ to keep a constant rate loss.

VII. CONCLUSIONS

We first look at a cooperative region, $325m < d_s < 500m$, in Fig. 3. As $d_S$ becomes larger in this region, a more precise CSI for the interfering channel is required. The reason is that the user in that region tries to reduce the power level of ICI by asking the help to adjacent cooperative BS. Otherwise, in a non-cooperative region, $0 < d_S < 325m$, the CSI of interfering channel is no longer necessary since the residual IUI due to quantization error of serving channel more severely deteriorates the system performance than ICI. Interestingly, this region provides meaningful information on the system design rule for BS cooperation. If a user in the non-cooperative region is scheduled, then the serving BS can support this user without any cooperation with interfering BS. Hence, using this fact, we can design the BS cooperation level: which users should be served with the help of interfering BS or not.

**Cell-average sum-rate:** In this simulation, to verify the result of Theorem 2 and gain of the proposed feedback bits allocation strategies we observe the cell-average sum-rate performance as increasing $P_t$ so that the received power at the cell edge, $P_{r,S}(d_S = 500)$, varies from $-10\text{dB}$ to $20\text{dB}$. It is assumed that the location of the user $d_S$ is uniformly dropped in the range of $d_0 < d_S < 500m$ and the cell-average sum-rate is evaluated by taking average of 2000 user drop events per cell when $\gamma = 2.5$. As shown in Fig. 4, we can see that the proposed feedback bits allocation scheme maintain the rate loss within $K \log_2(\beta) = 2 \times 1.58 = 3.17 \text{ (bps/Hz)}$ with respect to the system with perfect CSI by scaling $B_t$ as in (25). However, the equal bits allocation scheme i.e., $B_S = B_t = B_t/2$, provides much more rate loss even if it achieves the same multiplexing gain with the case of perfect CSI. Furthermore, our proposed feedback bits allocation scheme provides cell-average sum-rate performance within $0.22 [\text{ bps/Hz}]$ of that of the optimal feedback bits allocation method, which is obtained by combinational optimization technique.

In addition, we evaluate the cell-average sum-rate to see the impact of the proposed feedback allocation method for fixed $B_t$. As shown in Fig. 5, the proposed scheme provides about $33\%$ performance gain compared with that of equal feedback bits allocation method when $B_t = 6$ at $P_t(d_S = 500m) = 5dB$. In this figure, the interesting point is that the proposed feedback allocation scheme attains more performance improvement compared with the equal allocation method as $B_t$ increases.

REFERENCES