Codebook Design and Selection for Multi-cell Cooperative Transmission Limited Feedback Systems

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***Abstract*—Coherent multi-cell cooperative transmission, also referred to as coordinated multi-point transmission (CoMP), is a promising way to provide high spectral efficiency for universal frequency reuse cellular systems. To report the required channel information to the transmitter in frequency division duplexing systems, limited feedback techniques are often applied. Considering that the large scale fading gains of channels from multiple base stations (BSs) to one mobile station are different and the number of cooperative BSs may be dynamic, it is not flexible nor compatible to employ a large codebook for directly quantizing the CoMP channel. In this paper, per-cell codebook for separately quantizing local and cross channels are studied. We first optimize the bit allocation among per-cell codebooks, aiming at minimizing the average quantization error of the aggregated CoMP channel. A closed-form codebook size allocation method is proposed, which only depends on the large scale fading gains of per-cell channels. Considering that the optimal per-cell codeword selection for CoMP channel is of high complexity, we propose a serial codeword selection method, whose complexity is quite low but the performance approaches that of the optimal codeword selection. Simulation results validate our analysis and demonstrate an evident performance gain of our methods.**

I. INTRODUCTION

Base station (BS) cooperative transmission, also known as coordinated multi-point transmission (CoMP) in Long Term Evolution Advanced (LTE-A), is an effective way to avoid inter-cell interference in universal frequency reuse cellular systems. Coherent cooperative transmission provides the full benefit of CoMP systems, if both data and channel state information (CSI) can be obtained at a central unit (CU) [1,2].

We consider coherent CoMP system with limited feedback, which is referred to as CoMP in the following for simplicity. Although such kind of systems are often viewed as a large MIMO system with a "super BS" (i.e., the CU), there are distinct features in CoMP channels and systems. An inherent feature of CoMP channels is *asymmetry*, which means that the average channel powers from different BSs to each MS are different [2–4]. As a result, the channels are no longer identically independent distribution (i.i.d.) and the channel statistics of each MS highly depend on its position. A unique feature of CoMP system is with varying number of antennas, because the cluster of cooperative BSs may be formed dynamically [3,5].

Limited feedback technique is widely applied for reporting CSI to transmitter in frequency division duplexing multi-input multi-output (MIMO) systems and has been extensively studied [6]. If conventional codebooks designed for single-cell systems are directly applied to quantize the large channel matrix in CoMP systems, not only enormous feedback overhead is in demand, but also prohibitive complexity is necessary to dynamically generate the location-dependent and cluster-dependent codebook and to search for the optimal codeword. Moreover, frequently re-designing a large codebook is neither flexible nor compatible to existing systems.

Considering that CoMP channel is an aggregation of multiple single-cell channels, we can reuse the codebook designed for single-cell channels to separately quantize the single-cell channel vectors in global CoMP channel, which is referred to as per-cell codebook quantization. Though this does not yield the optimal codebook for CoMP channel, it can reduce the complexity to generate the codebook as well as the complexity to select the codeword. It also introduces new degree of freedom to reduce the feedback overhead.

In this paper, we study codebook size allocation and codebook selection for per-cell codebook quantization. Considering that different per-cell channels have different contributions to the global channel due to the channel asymmetry, we develop an optimal bit allocation among codebooks for quantizing local and cross channels, which aims at minimizing the average quantization error of global channels. For single-user CoMP, dynamically allocating feedback bits among per-cell channels is shown to outperform the equal bit allocation through simulations in [4]. For coordinated beamforming in multicell multiuser system, where only CSI are shared among the BSs, adaptive feedback bits assignment among desired and interfering channels is proposed in [7], and joint codebook generation and codeword selection are proposed in [8]. In per-cell codebook feedback schemes, the codeword for each per-cell channel can be selected either jointly or separately [9]. Joint codeword selection is optimal, but is of high complexity [3]. To reduce the complexity, we propose a new method which selects the codeword for per-cell channel vector in a serial way. Simulation results show that the per-cell codebook with the

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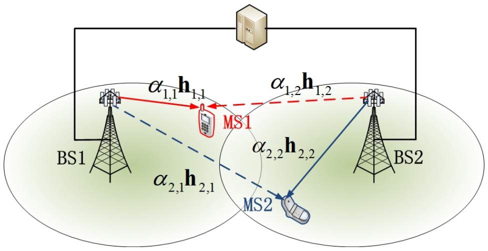

Fig. 1. An example of CoMP system, where the solid lines denote local channels while the dash lines denote cross channels.

optimal bit allocation performs closely to the optimal global codebook, and the proposed codeword selection method can significantly improve the quantization performance with low complexity, especially for the cell-edge users.

II. SYSTEM MODEL

Consider a cellular system with N BSs, each equipped with n_t antennas, cooperatively serving M single-antenna MSs. We assume that the channel information from the coordinated N BSs to the M MSs are forwarded to the CU via ideal backhaul links, and multi-user precoding is applied for coherent cooperative transmission. An example of CoMP system is shown in Fig.1.

The global channel vector from all cooperative BSs to MS$_k$ is represented by

$$\mathbf{g}_k = [\alpha_{k,1}\mathbf{h}_{k,1}^H, \cdots, \alpha_{k,N}\mathbf{h}_{k,N}^H]^H, \tag{1}$$

where $\alpha_{k,b}$ and $\mathbf{h}_{k,b} \in \mathbb{C}^{n_t \times 1}$ are respectively the large scale fading coefficient and the small scale fading channel vector between BS$_b$ and MS$_k$, the entries of $\mathbf{h}_{k,b}$ are assumed to be i.i.d. unit variance complex Gaussian variables, $(\cdot)^H$ denote the Hermitian conjugate transpose, $\alpha_{k,k}\mathbf{h}_{k,k}$ is the composite local channel of MS$_k$ and $\alpha_{k,b}\mathbf{h}_{k,b}$ for $b \neq k$ are its composite cross channels.

Denote the instantaneous per-cell channel direction information (CDI) between MS$_k$ and BS$_b$ as $\bar{\mathbf{h}}_{k,b} = \mathbf{h}_{k,b}/\|\mathbf{h}_{k,b}\|$, and the codebook for quantizing the CDI as $\mathcal{C}_{k,b}$, which consists of unit norm column vectors $\mathbf{c}_i$, $i = 1, \cdots, 2^{B_{k,b}}$, $B_{k,b}$ is the number of bits used to quantize the per-cell CDI. Then in the per-cell codebook based feedback scheme, a codeword in codebook $\mathcal{C}_{k,b}$ is chosen as the quantized CDI, i.e., $\hat{\mathbf{h}}_{k,b} = \mathbf{c}_{i_{k,b}}$, where the index $i_{k,b}$ is determined according to some criterion.

Define $\sin^2\theta_{k,b} = 1 - |\bar{\mathbf{h}}_{k,b}^H\hat{\mathbf{h}}_{k,b}|^2$ and $\delta_{k,b}^2 = \mathbb{E}\{\sin^2\theta_{k,b}\}$ as the instantaneous and average per-cell CDI quantization errors, respectively. When random vector quantization (RVQ) is applied to quantize the per-cell CDI, the average quantization error is upper bounded by $\delta_{k,b}^2 < 2^{-\frac{B_{k,b}}{n_t-1}}$ [10].

After MS$_k$ quantizes the CDI for both local and cross channels, it feeds back the index $\{i_{k,1}, \cdots, i_{k,N}\}$ to its serving BS, i.e., BS$_k$, which requires $B_{k,sum} = \sum_{b=1}^N B_{k,b}$ bits in total. We assume that the large scale fading gains can be obtained by the BSs without errors. Then all BSs send the channel information to the CU, and the CU reconstructs the global channel of MS$_k$ as follows,

$$\hat{\mathbf{g}}_k = [\alpha_{k,1}\hat{\mathbf{h}}_{k,1}^H, \cdots, \alpha_{k,N}\hat{\mathbf{h}}_{k,N}^H]^H. \tag{2}$$

We define the quantization error for the CDI of global channel in (1) as

$$\begin{aligned}\sin^2\theta_{g_k} &= 1 - \cos^2\theta_{g_k} = 1 - \frac{|\mathbf{g}_k^H\hat{\mathbf{g}}_k|^2}{\|\mathbf{g}_k\|^2\|\hat{\mathbf{g}}_k\|^2} \\ &= 1 - \frac{\left|\sum_{b=1}^N \alpha_{k,b}^2\|\mathbf{h}_{k,b}\|\bar{\mathbf{h}}_{k,b}^H\hat{\mathbf{h}}_{k,b}\right|^2}{(\sum_{b=1}^N \alpha_{k,b}^2\|\mathbf{h}_{k,b}\|^2)(\sum_{j=1}^N \alpha_{k,j}^2)}. \end{aligned} \tag{3}$$

III. OPTIMAL BIT ALLOCATION AMONG LOCAL AND CROSS CHANNELS

It is shown from (3) that the per-cell CDI quantization errors are of unequal importance to the global CDI quantization error, which motivates a bit allocation among the codebooks for local and cross channels.

If the total bits for quantizing the global channel are fixed, we can design the optimal bit allocation among codebooks for local and cross channels of each MS by minimizing the average quantization error of global channel. However, it is non-trivial to obtain an explicit expression of the average quantization error in (3). Nonetheless, since only the part $\xi_k \triangleq |\mathbf{g}_k^H\hat{\mathbf{g}}_k|^2$ in (3) is associated with the per-cell channel CDI quantization, the minimizing of average $\sin^2\theta_{g_k}$ can be replaced by maximizing $\mathbb{E}\{\xi_k\}$ to optimize the bit allocation.

The average of ξ_k over small scale fading channel and per-cell CDI quantization errors can be derived as follows,

$$\begin{aligned}\mathbb{E}\{\xi_k\} =& \mathbb{E}\{|\mathbf{g}_k^H\hat{\mathbf{g}}_k|^2\} \\ =& \mathbb{E}\left\{\left|\sum_{b=1}^N \alpha_{k,b}^2\|\mathbf{h}_{k,b}\|\bar{\mathbf{h}}_{k,b}^H\hat{\mathbf{h}}_{k,b}\right|^2\right\} \\ =& \mathbb{E}\left\{\sum_{b=1}^N \xi_{k,b}^{\text{ind}} + \sum_{b=1}^N \sum_{a=1,a\neq b}^N \xi_{k,(b,a)}^{\text{corr}}\right\} \\ =& n_t\sum_{b=1}^N \alpha_{k,b}^4(1-\delta_{k,b}^2), \end{aligned} \tag{4}$$

where $\xi_{k,b}^{\text{ind}} = \alpha_{k,b}^4\|\mathbf{h}_{k,b}\|^2|\bar{\mathbf{h}}_{k,b}^H\hat{\mathbf{h}}_{k,b}|^2$ includes the per-cell CDI quantization error of only $\bar{\mathbf{h}}_{k,b}$, $\xi_{k,(b,a)}^{\text{corr}} = \Re\{\alpha_{k,b}^2\alpha_{k,a}^2\|\mathbf{h}_{k,b}\|\|\mathbf{h}_{k,a}\|\bar{\mathbf{h}}_{k,b}^H\hat{\mathbf{h}}_{k,b}\hat{\mathbf{h}}_{k,a}^H\bar{\mathbf{h}}_{k,a}\}$ includes the per-cell CDI quantization error of both $\bar{\mathbf{h}}_{k,b}$ and $\bar{\mathbf{h}}_{k,a}$, $a \neq b$, $\Re\{\cdot\}$ is the real part of a complex scalar, the last equation comes from the fact that the mean values of small scale fading channels are zero, which results in $\mathbb{E}\{\xi_{k,(b,a)}^{\text{corr}}\} = 0$.

Considering that the number of bits should be non-negative and integer-valued, we need exhaustive searching to find the optimal solution for the bit allocation, which however does not lead to a closed-form solution. Alternatively, we first ignore the integer constraint, then adjust the obtained non-integer $B_{k,b}$ to its nearest integer. The simulations shown later will demonstrate that ignoring the integer constraint lead to negligible performance loss.

By replacing the average quantization errors in (4) with their upper bounds achieved by RVQ codebook, the optimization problem of bit allocation is formulated as follows,

$$\begin{aligned} \min_{B_{k,1},\cdots,B_{k,N}} \quad & \sum\nolimits_{b=1}^{N} \alpha_{k,b}^{4} 2^{-\frac{B_{k,b}}{n_t-1}} \\ s.t. \quad & \sum\nolimits_{b=1}^{N} B_{k,b} \leq B_{k,sum} \\ & B_{k,b} \geq 0, \; b = 1, \cdots, N. \end{aligned} \tag{5}$$

It is not hard to find the solution of the optimization problem, which is

$$B_{k,b} = \left[(n_t - 1) \left(\log_2 \lambda - \log_2 \frac{1}{\alpha_{k,b}^{4}} \right) \right]^{+}, \tag{6}$$

where λ is the Lagrangian multiplier, whose value should be chosen to satisfy $\sum_{b=1}^{N} B_{k,b} \leq B_{k,sum}$, $(x)^{+} = \max\{x, 0\}$.

It is interesting to see that the optimal bit allocation is analogous to the water-filling power allocation, and similar results are also discussed widely in rate distortion theory [11]. When the large scale fading gains from all coordinated BSs to MS$_k$ are the same, i.e., $\alpha_{k,1}^{2} = \cdots = \alpha_{k,B}^{2}$, (6) leads to equal bit allocation. When the value of $\alpha_{k,b}^{4}$ is large, more bits should be allocated to quantize the CDI between MS$_k$ and BS$_b$, $\bar{\mathbf{h}}_{k,b}$. This can be easily understood from (4) that in this scenario the quantization error of $\bar{\mathbf{h}}_{k,b}$ contributes more to the quantization error of the global channel.

Note that the bit allocation only depends on the large scale fading gains of the local and cross channels of MS$_k$. This means that the bit allocation is semi-dynamic because the large scale fading gains do not vary quickly.

IV. SERIAL CODEWORD SELECTION

The optimal codewords in a sense of minimizing global CDI quantization error with per-cell codebook should be chosen to minimize $\sin^2 \theta_{g_k}$ in (3). Considering that only the part

$$\begin{aligned} \xi_k &= |\mathbf{g}_k^H \hat{\mathbf{g}}_k|^2 \\ &= \left| \sum\nolimits_{b=1}^{N} \alpha_{k,b}^{2} \|\mathbf{h}_{k,b}\| \bar{\mathbf{h}}_{k,b}^{H} \mathbf{c}_{i_{k,b}} \right|^2 \\ &= \sum\nolimits_{b=1}^{N} \xi_{k,b}^{\text{ind}} + \sum\nolimits_{b=1}^{N} \sum\nolimits_{a=1, a \neq b}^{N} \xi_{k,(b,a)}^{\text{corr}}, \end{aligned} \tag{7}$$

is associated with the selection of per-cell codewords, minimizing $\sin^2 \theta_{g_k}$ is equivalent to maximizing ξ_k.

To find the best per-cell codewords from the codebooks, joint codeword selection are required, which includes exhaustive searching over the N per-cell codebooks and the complexity is too high for MS to afford in practice. In the following, based on the observation that different per-cell channel quantization errors have different impacts on the global CDI quantization error, we propose a heuristic codeword selection criterion, whose complexity is quite low.

A. Serial Codeword Selection

The basic idea of the proposed codeword selection method is to select the codeword for each per-cell CDI in a serial manner, whose order depends on the contribution of per-cell CDI to the global channel. In the selection procedure, the per-cell channel with largest norm should be selected firstly, in order to provides the maximal degrees of freedom of codeword selection for this channel vector and yields the minimal quantization error for it. The choosing of codeword for the subsequent per-cell CDIs should based on the previous selection results.

Specifically, we sort the per-cell channel vector indices according to the descending of instantaneous norm of per-cell channels, i.e., $\alpha_{k,b}\|\mathbf{h}_{k,b}\|$, as $\Omega = [\pi_1, \cdots, \pi_N]$. Considering that the quantization error of the π_1th per-cell channel contributes most to the quantization error of global channels, we first choose a codeword to minimize the quantization error of this per-cell CDI. Next we quantize the π_2th per-cell channel. If the per-cell channel with the second largest channel norm is quantized independently, we can obtain a codeword with the smallest per-cell CDI quantization error, which will maximize the value of $\xi_{k,\pi_2}^{\text{ind}}$. However, in this way we can not ensure the maximization of $\xi_{k,(\pi_1,\pi_2)}^{\text{corr}}$, whose value depends on the per-cell CDI and codeword of both π_1th and π_2th per-cell channels. Therefore when selecting the codeword for the π_2th per-cell channel, we should choose a codeword from codebook $\mathcal{C}_{k,\pi_2}$ which maximizes $\xi_{k,\pi_2}^{\text{ind}} + \xi_{k,(\pi_1,\pi_2)}^{\text{corr}}$. With such a serial codeword selection method, the most important per-cell CDI will achieve minimal quantization error, the second most important per-cell CDI will have larger quantization error, and finally the most unimportant CDI will have the lowest quantization quality.

The procedure of the serial codeword selection method is summarized as follows.

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Serial Per-cell Codeword Selection
Step 1: Sort the per-cell channel vector indices in descending order of their instantaneous norm, i.e., $\alpha_{k,b}\|\mathbf{h}_{k,b}\|$, as $\Omega = [\pi_1, \cdots, \pi_N]$.
Step 2: Choose the quantized CDI with the largest instantaneous per-cell channel norm as $\hat{\mathbf{h}}_{k,\pi_1} = \mathbf{c}_{i_{k,\pi_1}}$, whose index is chosen as follows,
    $i_{k,\pi_1} = \arg \max_{1 \leq m_{k,\pi_1} \leq 2^{B_{k,\pi_1}}} |\bar{\mathbf{h}}_{k,\pi_1}^{H} \mathbf{c}_{m_{k,\pi_1}}|^2.$
    where $\mathbf{c}_{m_{k,\pi_1}}$ is the $m$th codeword in codebook $\mathcal{C}_{k,\pi_1}$.
Step 3: Choose the quantized CDI for $\mathbf{h}_{k,\pi_j}$, $j \geq 2$, as $\hat{\mathbf{h}}_{k,\pi_j} = \mathbf{c}_{i_{k,\pi_j}}$, whose index is chosen as follows,
    $i_{k,\pi_j} = \arg \max_{1 \leq m_{k,\pi_j} \leq 2^{B_{k,\pi_j}}} |\hat{\mathbf{g}}_{\pi_j}^{H} \mathbf{g}_{\pi_j}|^2,$
    where $\mathbf{g}_{\pi_j} = [\alpha_{\pi_1}\mathbf{h}_{k,\pi_1}^{H}, \cdots, \alpha_{\pi_j}\mathbf{h}_{k,\pi_j}^{H}]^{H}$ is the channel vector from BS$_{\pi_1}$, $\cdots$, BS$_{\pi_j}$ to MS$_k$, $\hat{\mathbf{g}}_{\pi_j} = [\alpha_{\pi_1}\hat{\mathbf{h}}_{k,\pi_1}^{H}, \cdots, \alpha_{\pi_{j-1}}\hat{\mathbf{h}}_{k,\pi_{j-1}}^{H}, \alpha_{\pi_j}(\mathbf{c}_{m_{k,\pi_j}})^{H}]^{H}$ is the quantization of $\mathbf{g}_{\pi_j}$, $\hat{\mathbf{h}}_{k,\pi_{j-1}}^{H}$ is the selected codeword for $\mathbf{h}_{k,\pi_{j-1}}^{H}$ in the previous steps, $\mathbf{c}_{m_{k,\pi_j}}$ is the $m$th codeword in the codebook $\mathcal{C}_{k,\pi_j}$.
Step 4: $j = j + 1$. If $j \leq N$ go to step 3, otherwise stop the selection algorithm.
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B. Complexity Analysis

For joint codeword selection, it is not hard to obtain that the selection complexity is of the order of $\mathcal{O}(\prod_{b=1}^{N} 2^{B_{k,b}})$.

A per-cell codeword selection of low complexity is proposed in [3]. The basic idea is to first construct a sub-codebook with codewords that lie in the neighborhood of the per-cell CDI to be quantized, then find the feedback indices through exhaustive searching among the reconstructed codebooks. The complexity of the first step is of the order of $\mathcal{O}(\sum_{b=1}^{N} 2^{B_{k,b}})$, and the complexity of the second step is of the order of $\mathcal{O}(\prod_{b=1}^{N} \varphi_{k,b})$, where $\varphi_{k,b}$ is the cardinality of the sub-codebook for quantizing the bth per-cell CDI. The range of the neighborhood, i.e. the size of $\varphi_{k,b}$, determines the tradeoff between complexity and performance.

From the procedure of the proposed serial per-cell codeword selection method we can observe that, to quantize the π_jth per-cell CDI of MS_k, we only need to search for a codeword in the codebook $\mathcal{C}_{k,\pi_j}$. Thereby the codeword selection complexity for per-cell CDI quantization is of the order of $\mathcal{O}(2^{B_{k,\pi_j}})$. The total complexity of codeword selection for global channel is of the order of $\mathcal{O}(\sum_{b=1}^{N} 2^{B_{k,b}})$. For better comparison, the computational complexity of the three codeword selection methods are summarized in Table I.

Now we give an example, where the number of cooperative BSs $N = 3$. We consider a MS located at the exact cell edge of the three cells. According to the optimal bits allocation in (6), the total bits should be equally allocated to quantize the three per-cell links. We consider the size of three per-cell codebooks as $B_{k,1} = B_{k,2} = B_{k,3} = 4$ bits. Then the complexity of joint codeword selection is of the order of $\mathcal{O}(4096)$. The complexity of the codeword selection method proposed in [3] is of the order of $\mathcal{O}(48 + \prod_{b=1}^{3} \varphi_{k,b})$. When $\varphi_{k,b} = 8$, which means that the size of sub-codebook is half of the original codebook, the complexity is of $\mathcal{O}(560)$. By contrast, the complexity of the proposed serial codeword selection method is only of the order of $\mathcal{O}(48)$.

TABLE I

COMPUTATIONAL COMPLEXITY OF THREE CODEWORD SELECTION METHODS

Methods	Computational Complexity
Joint Selection	$\mathcal{O}(\prod_{b=1}^{N} 2^{B_{k,b}})$
Method in [3]	$\mathcal{O}(\sum_{b=1}^{N} 2^{B_{k,b}}) + \mathcal{O}(\prod_{b=1}^{N} \varphi_{k,b})$
Serial Selection	$\mathcal{O}(\sum_{b=1}^{N} 2^{B_{k,b}})$

V. SIMULATION RESULTS

In this section, we will illustrate the bit allocation results and compare the performance of different quantization methods.

Although our previous theoretical analysis as well as the proposed methods are applicable for general cases with any number of cooperative BSs, we simulate a simple scenario with two BSs to clearly observe the results of bit allocation and quantization performance.

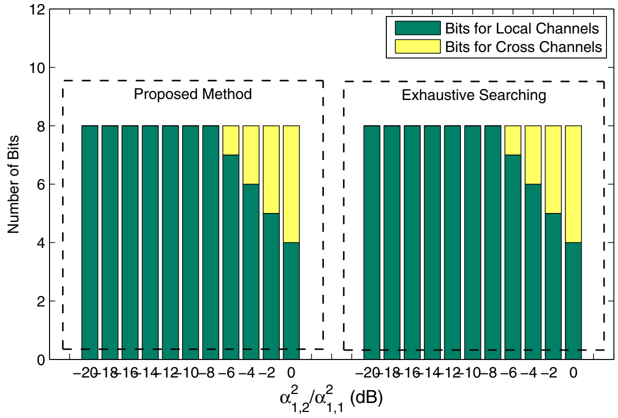

Fig. 2. Average quantization error of CDI of global CoMP channel. The decrease of $\alpha_{1,2}^2/\alpha_{1,1}^2$ at x-axis represents the case of MS_1 moving from cell edge towards cell center. When $\alpha_{1,2}^2/\alpha_{1,1}^2 \leq -8$ dB, all bits are allocated to quantize the local channels.

In the simulations, each BS is equipped with 4 antennas. Two BSs cooperatively serve two single-antenna MSs. The small scale fading channels between BSs and MSs are i.i.d. Rayleigh channels. The codebooks used for quantizing the per-cell channels are obtained by RVQ. The total bits used to quantize the global channel is 8 bits.

Figure 2 shows the bit allocation results for MS_1 to quantize its global channel. Both the bit allocation achieved by rounding the results obtained by (6) and that obtained by exhaustive searching without ignoring the integer-value constraint are shown. We can see that the bit allocation obtained by the two methods are the same, which means that neglecting the integer-value constraint has minor impact on the optimal bit allocation. It is shown that the bits allocated to cross CDIs reduces with the decrease of $\alpha_{1,2}^2/\alpha_{1,1}^2$, i.e., the case when the MS moves from cell edge to cell center.

Figure 3 illustrates the average quantization error of global CDI when using different quantization methods. The optimal quantization is obtained by exhaustive searching the optimal global codeword from a global codebook generated by Lloyd algorithm. From the figure we can observe that if bits are equally allocated to the codebooks for local and cross channels, the quantization error of CDI of global CoMP channel will approach to a floor when the MS moves towards the cell center. When the optimal bit allocation is used, the performance gap between optimal quantization and per-cell quantization reduces significantly. Comparing the performance obtained by per-cell codebook with different codeword selection methods, we can see that the quantization error under exhaustive codeword searching is the smallest. However, the good performance is payed by high codeword searching complexity, which is of the order of $\mathcal{O}(256)$. The independent codeword selection is to select the per-cell codeword that has the maximal inner product with the per-cell CDI, which is equivalent to the method proposed in [3] by setting the $\varphi_{k,b} = 1$, i.e., the sub-codebook comprises only one codeword.

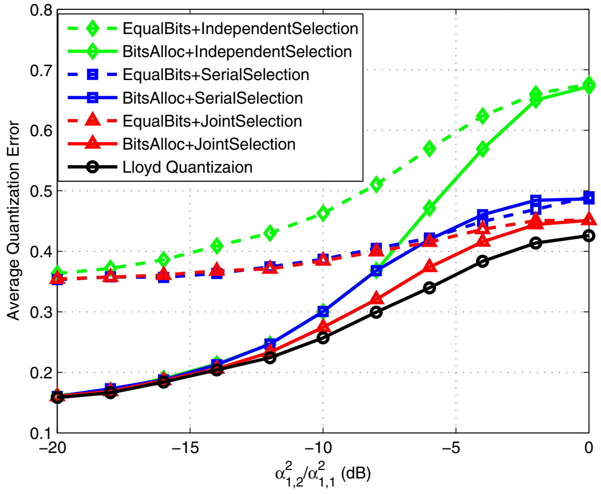

Fig. 3. Average quantization error of CDI of global CoMP channel.

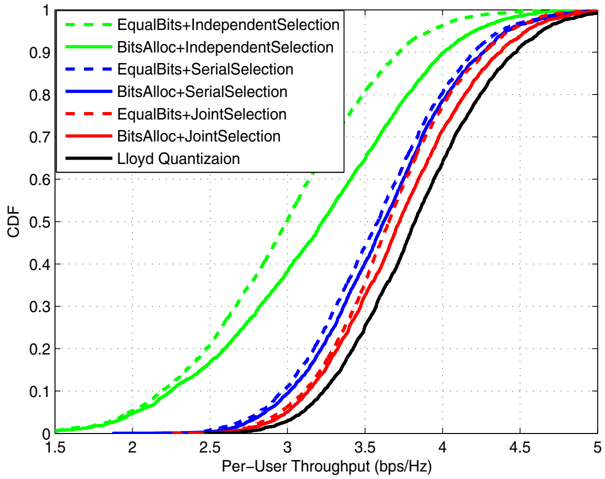

Fig. 4. CDF of per-user throughput.

The complexity of this method is the same as that of our serial codeword selection, which is of the order of $\mathcal{O}(32)$. The performance gain of the proposed codeword selection method is more evident when the value of $\alpha^2_{1,2}/\alpha^2_{1,1}$ is low, i.e., for cell-edge MSs.

Figure 4 shows the cumulative distribution function (CDF) of per-user throughput when different quantization methods are used. In the simulation, the cell radius r is set to be 250m. We assume that the receive SNR of the cell edge MS, γ_{edge}, is 10dB. The path loss factor ϵ is 3.76. Then the receive SNR of the signal from a BS to a MS with MS-BS distance of d can be calculated according to $\gamma(d) = \gamma_{edge} + \epsilon 10 \log_{10}(\frac{r}{d})$. We consider the case that the two MSs are randomly distributed in a 'cell edge region', in which the energy imbalance of local and cross channels are within 10dB. No multi-user scheduling is employed, which is equivalent to a random user selection [1]. The two MSs are served by multi-cell zero-forcing beamforming [12]. From Fig. 4 we can observe that when the optimal bit allocation is applied, the per-user throughput is higher than that obtained under equal bit allocation. The performance of downlink CoMP transmission using codeword selected by serial codeword selection is close to that using exhaustive codeword searching.

VI. CONCLUSIONS

In this paper, we have studied bit allocation among codebooks for local and cross channels and codeword selection for centralized CoMP system with per-cell codebook feedback. Based on the observation that different per-cell channel direction information have different contributions to the global channel, we derived a closed-form optimal bit allocation which resembles the well-known water-filling power allocation. Based on the same observation, we proposed a low-complexity codeword selection method which selects a codeword for each per-cell channel in a serial manner. Simulation results validate our analysis and show significant performance gain of the proposed codebook with semi-dynamic size and the codeword selection method.

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[1] Note that the feedback of channel quality indicator (CQI), which is important for user scheduling, is also an interesting topic need to be studied. However, it is out of the scope of this paper.