Semi-Dynamic Mode Selection in Base Station Cooperative Transmission System

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***Abstract*—Base stations (BSs) cooperative transmission provides high spectrum efficiency for cellular networks, where the performance gain of each user depends on its location. When training overhead is considered, however, a user jointly served by multiple BSs may even achieve lower net rate than with non-cooperative transmission. In this paper, we consider semi-dynamic mode selection for users. We first derive the average rate of each user when it is served under cooperative or non-cooperative transmission. We then propose a closed-form mode selection method where only large-scale fading gains of a user are used. Simulation results validate our analysis and demonstrate a performance gain of the proposed method over both full cooperative and non-cooperative transmission.**

I. Introduction

Inter-cell interference (ICI) is a bottleneck for improving spectrum efficiency of universal frequency reuse cellular networks, especially for multi-input-multi-output (MIMO) systems. Base stations (BSs) cooperative transmission, also known as coordinated multi-point (CoMP) transmission, has been recognized as a promising technique to avoid ICI [1, 2].

Coherent CoMP transmission can significantly improve system performance [2]. This however implies considerable overhead in practice including the training overhead for estimating the channel state information (CSI) and the feedback overhead for reporting the CSI [3]. On the other hand, the performance gain of CoMP transmission largely depends on the user's location [4, 5]. Specifically, cell-edge users will gain more from cooperative transmission than cell-center users, because they experience severe ICI. When training overhead is taken into account, the performance of cell-center users may even degrade under CoMP transmission [5]. This motivates mode switching between CoMP and NonCoMP for each user.

Transmission mode selection has been extensively studied for single cell MIMO systems, see [6, 7] and the reference therein. By switching the transmission mode between using single user and multiuser MIMO precoding, or between transmitting single and multiple data streams based on the channel condition, spectrum efficiency can be increased. An adaptive transmission strategy is proposed for multi-cell systems in [4]. Multiple BSs select transmission mode between single-cell beamforming and coordinated multi-cell beamforming, which is a type of CoMP transmission with only CSI shared.

Differing from the existing mode switching method in multi-cell systems [4], we strive for developing a mode selection method for cellular systems to switch between non-cooperative (NonCoMP) and coherent CoMP transmission where both CSI and data are shared among BSs[1]. To this end, we first derive the average per-user throughput of CoMP and NonCoMP system. A closed-form decision formula for mode selection is provided to select the preferred transmission mode for each user, which only needs its own large-scale fading gains.

The rest of the paper is organized as follows. In Section II, we present the system model. In Section III, we analyze the average performance of NonCoMP and CoMP mode, respectively. The transmission mode selection method is proposed in section IV and simulation results are provided in Section V, followed by conclusions in Section VI.

II. System model

Consider a cooperative cluster consisting of B BSs each with N_t antennas and K active single-antenna MSs, where $K \leq N_t$. Define $\{u_1^b, \ldots, u_K^b\}$ as the set of active users in the bth cell, then BS b is the local BS for user u_k^b, $b = 1, \ldots, B$, $k = 1, \ldots, K$. Let $\mathbf{h}_{iu_k^b} = \alpha_{iu_k^b} \mathbf{g}_{iu_k^b}$ denote the composite channel between BS i and user u_k^b, $i = 1, \ldots, B$, where $\alpha_{iu_k^b}$ and $\mathbf{g}_{iu_k^b} \in \mathbb{C}^{N_t \times 1}$ are respectively the large-scale fading gain and small-scale channel vector. Then $\mathbf{h}_{u_k^b} = [\mathbf{h}_{1u_k^b}^H, \cdots, \mathbf{h}_{Bu_k^b}^H]^H \in \mathbb{C}^{BN_t \times 1}$ is the global channel vector of the user u_k^b.

A. NonCoMP transmission

Under conventional single-cell transmission mode, i.e., NonCoMP transmission mode, each BS serves its own K local users by precoding, and each user receives the desired signal from its local BS while suffering ICI from other BSs. The received signal of user u_k^b in the bth cell is given by

$$y_{u_k^b}^{\mathrm{NC}} = \mathbf{h}_{bu_k^b}^H \mathbf{V}_b \mathbf{x}_b + \underbrace{\sum_{i=1, i \neq b}^{B} \mathbf{h}_{iu_k^b}^H \mathbf{V}_i \mathbf{x}_i}_{\mathrm{ICI}} + z, \qquad (1)$$

where $\mathbf{x}_b = [x_{u_1^b}, \ldots, x_{u_K^b}]^H$ is the data vector of the K local users in bth cell, $\mathbf{V}_b = [\mathbf{v}_{bu_1^b}, \ldots, \mathbf{v}_{bu_K^b}] \in \mathbb{C}^{N_t \times K}$

This work was supported by the International S&T Cooperation Program of China (ISCP) under grant No.2008DFA12100 and by Key project of Next Generation Wideband Wireless Communication Network, Ministry of Industry and Information (MII): Coordinated Multiple-point Transmission for IMT-Advanced Systems under grant No.2009ZX03003-003.

[1]For simplicity, we refer coherent CoMP as CoMP in the following

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is the precoding matrix at BS b whose columns represent the precoding vectors for the K active users, and z is white Gaussian random variable with zero mean and variance σ^2 which denotes the inter-cluster interference plus noise.

In this paper, Zero-Forcing (ZF) precoder is considered which is a low complexity yet effective linear precoder to eliminate inter-user interference [8]. The precoding matrix at BS b can be expressed as

$$\mathbf{V}_b = \mathbf{H}_b(\mathbf{H}_b^H\mathbf{H}_b)^{-1}\mathbf{P}_b, \tag{2}$$

where $\mathbf{H}_b = [\mathbf{h}_{bu_1^b}, \ldots, \mathbf{h}_{bu_K^b}]$ denotes the channel matrix of the K active users in the first cell, and $\mathbf{P}_b = \mathrm{diag}\{\sqrt{p_{u_1^b}^{\mathrm{NC}}}, \ldots, \sqrt{p_{u_K^b}^{\mathrm{NC}}}\}$ indicates the power allocation matrix. By substituting (2) into (1), the received signal of user u_k^b under NonCoMP transmission mode can be simplified as

$$y_{u_k^b}^{\mathrm{NC}} = \sqrt{p_{u_k^b}^{\mathrm{NC}}}x_{u_k^b} + \sum_{i=1, i\neq b}^{B} \mathrm{ICI}_{iu_k^b} + z, \tag{3}$$

where $\mathrm{ICI}_{iu_k^b} \triangleq \mathbf{h}_{iu_k^b}^H\mathbf{V}_i\mathbf{x}_i$ is the ICI from BS i to user u_k^b.

B. CoMP transmission

Coherent CoMP transmission can avoid ICI within the cooperative cluster, where the B BSs are connected with a central unit (CU). After collecting CSI from each BS, the CU computes the global precoding vectors for all active users, then sends the vectors and the data to the B BSs, who jointly serve the BK active users. With ZF precoding, the global precoding vector from all BSs to user u_k^b, $\mathbf{w}_{u_k^b} \in \mathbb{C}^{BN_t\times 1}$, can be obtained from

$$\mathbf{W} = \mathbf{H}(\mathbf{H}^H\mathbf{H})^{-1}\mathbf{P}, \tag{4}$$

where $\mathbf{W} \triangleq [\mathbf{w}_{u_1^1}, \ldots, \mathbf{w}_{u_K^B}]$, $\mathbf{H} = [\mathbf{h}_{u_1^1}, \ldots, \mathbf{h}_{u_K^B}]$ is the channel matrix of all active users in the B cells, and $\mathbf{P} = \mathrm{diag}\{\sqrt{p_{u_1^1}^{\mathrm{C}}}, \ldots, \sqrt{p_{u_K^B}^{\mathrm{C}}}\}$ is the power allocation matrix.

The received signal of user u_k^b under CoMP transmission mode is given as

$$y_{u_k^b}^{\mathrm{C}} = \mathbf{h}_{u_k^b}^H\mathbf{w}_{u_k^b}x_{u_k^b} + z = \sqrt{p_{u_k^b}^{\mathrm{C}}}x_{u_k^b} + z. \tag{5}$$

III. Average SINR under CoMP and NonCoMP Transmission

In this section, we derive the average received signal to interference plus noise ratio (SINR) of user u_k^b under NonCoMP and CoMP transmission modes, respectively, which is used for selecting transmission mode in section IV.

A. SINR under NonCoMP transmission

The total transmit power at each BS is denoted as P. Under NonCoMP transmission mode, the power at each BS is allocated to its K active users. For analytical tractability, we consider equal power allocation, i.e.,

$$p_{u_k^b}^{\mathrm{NC}} = \frac{P}{K\left[(\mathbf{H}_b^H\mathbf{H}_b)^{-1}\right]_{k,k}}, \tag{6}$$

where $[\cdot]_{k,k}$ denotes the element on the kth row and kth column of a matrix.

Note that $1/[(\mathbf{H}_b^H\mathbf{H}_b)^{-1}]_{k,k} = |\mathbf{h}_{bu_k^b}^H\mathbf{\Lambda}_{K-1}^{\perp}|^2$, where $\mathbf{\Lambda}_{K-1}^{\perp}$ represents the null space of $K-1$ partner users for user u_k^b who are co-scheduled with the user u_k^b and share the same time-frequency resource with it. Therefore, from (3) and (6) the received SINR of user u_k^b under NonCoMP transmission mode can be expressed as

$$\gamma_{u_k^b}^{\mathrm{NC}} = \frac{p_{u_k^b}^{\mathrm{NC}}}{|\sum_{i=1,i\neq b}^{B}\mathrm{ICI}_{iu_k^b}|^2 + \sigma^2} = \frac{P|\mathbf{h}_{bu_k^b}|^2\lambda_{K-1}/K}{|\sum_{i=1,i\neq b}^{B}\mathrm{ICI}_{iu_k^b}|^2 + \sigma^2}, \tag{7}$$

where $\lambda_{K-1} = |\mathbf{h}_{bu_k^b}^H\mathbf{\Lambda}_{K-1}^{\perp}|^2/|\mathbf{h}_{bu_k^b}|^2$ is the projection energy from the local channel of user u_k^b to the null space of its partner users normalized by the energy of $\mathbf{h}_{bu_k^b}$. It can represent the orthogonality between user u_k^b and its $K-1$ partner users, which has a value between 0 and 1. A larger λ_{K-1} indicates a better orthogonality between user u_k^b and its partner users, which leads to a larger $\gamma_{u_k^b}^{\mathrm{NC}}$.

Assuming that all the ICIs from $B-1$ BSs are uncorrelated Gaussian noises and independent from the desired signal. Then the average SINR can be approximated as [9]

$$\mathbf{E}\{\gamma_{u_k^b}^{\mathrm{NC}}\} \approx \frac{P\mathbf{E}\{|\mathbf{h}_{bu_k^b}|^2\lambda_{K-1}\}}{K(\sum_{i=1,i\neq b}^{B}\mathbf{E}\{|\mathrm{ICI}_{iu_k^b}|^2\} + \sigma^2)}, \tag{8}$$

which can serve as a lower bound of the average SINR, where $\mathbf{E}\{\cdot\}$ is the expectation over small-scale fading channels.

Assume that all the small-scale fading channel vectors $\mathbf{g}_{iu_k^b}$ are independent and identically distributed (*i.i.d*), and each entry of $\mathbf{g}_{iu_k^b}$ is complex Gaussian with unit variance. Due to the independence between the norm and the direction of a Gaussian vector, the random variable $|\mathbf{h}_{bu_k^b}|^2$ and λ_{K-1} are mutually independent, i.e., $\mathbf{E}\{|\mathbf{h}_{bu_k^b}|^2\lambda_{K-1}\} = \mathbf{E}\{|\mathbf{h}_{bu_k^b}|^2\}\mathbf{E}\{\lambda_{K-1}\}$.

Since $|\mathbf{g}_{bu_k^b}|^2$ subjects to Chi-squared distribution with $2N_t$ degrees of freedom and mean value N_t, we have $\mathbf{E}\{|\mathbf{h}_{bu_k^b}|^2\} = \mathbf{E}\{\alpha_{bu_k^b}^2|\mathbf{g}_{bu_k^b}|^2\} = N_t\alpha_{bu_k^b}^2$.

The random variable λ_{K-1} has been proved to subject to Beta distribution with freedom degree of $(N_t-1, 1)$ when $K=2$ [10]. Applying the derivation results in the appendix of [11] and after some regular manipulations, we can show that λ_{K-1} also subjects to Beta distribution for any $K \leq N_t$ with freedom degree of $(N_t-K+1, K-1)$. The detailed derivation is not shown due to the lack of space. The probability density function (PDF) of λ_{K-1} can be expressed as

$$f_{\lambda_{K-1}}(x) = \frac{x^{N_t-K}(1-x)^{K-2}}{\mathrm{B}(N_t-K+1, K-1)}, \quad 0 < x < 1, \tag{9}$$

where $\mathrm{B}(p,q) = \Gamma(p)\Gamma(q)/\Gamma(p+q)$ is the Beta function, and $\Gamma(x) = (x-1)!$ is the Gamma function. The mean of λ_{K-1} can be obtained from (9) as follows,

$$\mathbf{E}\{\lambda_{K-1}\} = \frac{N_t-K+1}{N_t}\ . \tag{10}$$

It shows that in average the orthogonality between user u_k^b and its $K-1$ co-scheduled users will become worse if user u_k^b has more partner users, i.e., if K is larger.

Based on the fact that the precoder $\mathbf{V}_i$ at BS i is independent from $\mathbf{h}_{iu_k^b}$, $i = 1, \ldots, B, i \neq b$, it has been shown in [5] that $\mathbf{E}\{|\mathrm{ICI}_{iu_k^b}|^2\} = \alpha_{iu_k^b}^2$. By substituting the value of $\mathbf{E}\{|\mathbf{h}_{bu_k^b}|^2\}$, $\mathbf{E}\{\lambda_{K-1}\}$ and $\mathbf{E}\{|\mathrm{ICI}_{iu_k^b}|^2\}$ into (8), we have

$$\mathbf{E}\{\gamma^{\mathrm{NC}}_{u^b_k}\} \approx \frac{P(N_t - K + 1)\alpha^2_{bu^b_k}}{K(\sum_{i=1,i\neq b}^{B}\alpha^2_{iu^b_k} + \sigma^2)}. \quad (11)$$

It shows that the average SINR of user u^b_k under NonCoMP transmission mode depends on its own large-scale fading gains, i.e., $\alpha_{1u^b_k}, \cdots, \alpha_{Bu^b_k}$.

B. SINR under CoMP transmission

For comparison with NonCoMP transmission and also for mathematical tractability, we assume that under CoMP transmission mode, the sum power of all BSs, i.e. BP, is equally allocated to the BK active users[2],

$$p^{\mathrm{C}}_{u^b_k} = \frac{BP}{BK\,[(\mathbf{H}^H\mathbf{H})^{-1}]_{(b-1)+k,(b-1)+k}}. \quad (12)$$

The received SINR of user u^b_k under CoMP transmission mode is obtained from (5) and (12) as,

$$\gamma^{\mathrm{C}}_{u^b_k} = \frac{p^{\mathrm{C}}_{u^b_k}}{\sigma^2} = \frac{P}{K\sigma^2[(\mathbf{H}^H\mathbf{H})^{-1}]_{(b-1)+k,(b-1)+k}}. \quad (13)$$

The average of $\gamma^{\mathrm{C}}_{u^b_k}$ over small-scale fading channels has been derived in [12] via asymptotic analysis for large systems, which is

$$\mathbf{E}\{\gamma^{\mathrm{C}}_{u^b_k}\} = \frac{PN_t}{K\sigma^2}\sum_{i=1}^{B}\eta_i\alpha^2_{iu^b_k}, \quad (14)$$

where the values of parameter η_i are determined by the following equations,

$$\eta_i = 1 - \frac{BK-1}{BKN_t}\sum_{j=1}^{B}\sum_{n=1}^{K}\frac{\eta_i\alpha^2_{iu^j_n}}{\sum_{l=1}^{B}\eta_l\alpha^2_{lu^j_n}},\ i = 1, \cdots, B. \quad (15)$$

Note that in (15) the values of η_i depend on both the large-scale fading gains of the user u^b_k and those of its partner users. To determine $\mathbf{E}\{\gamma^{\mathrm{C}}_{u^b_k}\}$ only by the statistical channel information of user u^b_k, we need to remove the impact of its partner users on η_i. However, the analytical relationship between η_i and the large-scale fading gains of the partner users for user u^b_k is hard to obtain, since the nonlinear equations shown in (15) is not easy to solve in general.

By observing (15), we find that the sum of all η_i is a constant, which is $\sum_{i=1}^{B}\eta_i = (BN_t - BK + 1)/N_t$. Moreover, if the K active users in each cell have the same relative location away from their local BS, i.e., $\alpha^2_{ju^j_k} = \alpha^2_{bu^b_k}$ for $j, b = 1, \ldots, B$, $k = 1, \ldots, K$, every η_i will have the same value because in this special case the B equations of (15) are identical.

Now let us find the connection between η_i and the large-scale fading gains of the partner users for user u^b_k in a special scenario of $B = 2$. By substituting $\eta_1 + \eta_2 = (2N_t - 2K + 1)/Nt \triangleq S$ into (15), we obtain

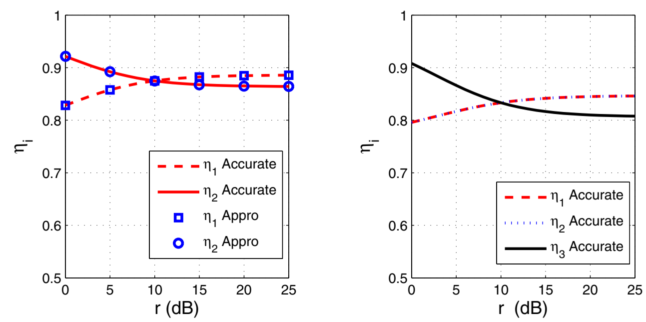
$$\eta_1 - 1 + \frac{2K-1}{2KN_t}\sum_{j=1}^{2}\sum_{n=1}^{K}\frac{\eta_1\alpha^2_{1u^j_n}}{(\alpha^2_{1u^j_n} - \alpha^2_{2u^j_n})\eta_1 + S\alpha^2_{2u^j_n}} = 0. \quad (16)$$

[2]Although per-BS power constraint is more proper in the context of CoMP [2], for the prevalent multi-carrier systems, the results obtained from the two power constrains are almost the same since on average the per-BS power constraint will be fulfilled over multiple carriers.

By taking first-order Taylor expansion, the nonlinear equation of η_1 can be transformed to a linear equation. Then, the closed-form approximated solution of (16) is obtained as,

$$\eta_1^* \approx \frac{1 - A\sum_{j=1}^{2}\sum_{n=1}^{K}\frac{1-Q^j_n}{(1+Q^j_n)^2}}{1 + D\sum_{j=1}^{2}\sum_{n=1}^{K}\frac{Q^j_n}{(1+Q^j_n)^2}},$$
$$\eta_2^* \approx \frac{1 - A\sum_{j=1}^{2}\sum_{n=1}^{K}\frac{Q^j_n(Q^j_n-1)}{(1+Q_j)^2}}{1 + D\sum_{j=1}^{2}\sum_{n=1}^{K}\frac{Q^j_n}{(1+Q^j_n)^2}}, \quad (17)$$

where $A \triangleq (2K-1)/(2KN_t)$, $D \triangleq 2(2K-1)/[K(2N_t - 2K+1)]$, and $Q^j_n \triangleq \alpha^2_{2u^j_n}/\alpha^2_{1u^j_n}$.



(a) $B = 2$, $\alpha^2_{1u^1_1} = 10\alpha^2_{2u^1_1}$, $\alpha^2_{2u^2_1} = r\alpha^2_{1u^2_1}$

(b) $B = 3$, $\alpha^2_{1u^1_1} = 10\alpha^2_{2u^1_1} = 10\alpha^2_{3u^1_1}$, $\alpha^2_{2u^2_1} = 10\alpha^2_{1u^2_1} = 10\alpha^2_{3u^2_1}$, $\alpha^2_{3u^3_1} = r\alpha^2_{1u^3_1} = r\alpha^2_{2u^3_1}$

Fig. 1. Solution of η_i in (15) when $K = 1$

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Fig. 1(a) shows the approximate solutions of η_1^* and η_2^* as well as the accurate solutions obtained by employing Newton iterative algorithm to (16). We can see that the approximated solutions are almost the same as the accurate results.

Both the expressions in (17) and the simulation results in Fig. 1(a) indicate that η_1^* is a monotonic increasing function of $\alpha^2_{2u^2_k}/\alpha^2_{1u^2_k}$, and η_2^* decreases with $\alpha^2_{2u^2_k}/\alpha^2_{1u^2_k}$. We can extend this conclusion to the scenario of $B > 2$: when the co-scheduled users of user u^b_k in another cell moves towards its local BS, the value of η_b will increase. This can be validate by simulation results shown in Fig. 1(b).

We can find from the figures that the partner users has little impact on the value of η_i, e.g., the range of its value is within 0.1. To remove this impact, we approximately regard all the η_i as identical.

Then from (14) we have,

$$\mathbf{E}\{\gamma^{\mathrm{C}}_{u^b_k}\} \approx \frac{PN_t}{K\sigma^2}\sum_{i=1}^{B}\overline{\eta}_i\alpha^2_{iu^b_k} = \frac{P(BN_t - BK + 1)}{BK\sigma^2}\sum_{i=1}^{B}\alpha^2_{iu^b_k}, \quad (18)$$

where $\overline{\eta}_i \approx \frac{BN_t - BK+1}{BN_t}$, $i = 1, \ldots, B$ is the approximated value of η_i.

The approximation (18) will be further validated in Section V, where we will see that the approximate average SINR under CoMP transmission is quite close to the practical results after averaging the impact of partner users.

IV. Transmission Mode Selection Considering Training Overhead

During downlink transmission, training signals should be transmitted together with data to facilitate channel estimation at the user side [13], which consume available downlink resources for data transmission. Compared with NonCoMP transmission where only N_t channel coefficients in each cell need to be estimated, BN_t channel coefficients need to be estimated under CoMP transmission which leads to more training overhead [13].

In this section, we first provide the approximate performance of user u_k^b under NonCoMP and CoMP transmission mode by taking into account the training overhead. Then a transmission mode selection method is proposed, where each user chooses a preferred transmission mode based on its large scale fading gains.

The upper bounds of average achievable throughput for user u_k^b under NonCoMP and CoMP transmission mode can be obtained as

$$R_{u_k^b}^{\mathrm{NC}} = \mathbf{E}\{\log_2\left(1+\theta^{\mathrm{NC}}\gamma_{u_k^b}^{\mathrm{NC}}\right)\} \le \log_2\left(1+\theta^{\mathrm{NC}}\mathbf{E}\{\gamma_{u_k^b}^{\mathrm{NC}}\}\right), \tag{19}$$

$$R_{u_k^b}^{\mathrm{C}} = \mathbf{E}\{\log_2\left(1+\theta^{\mathrm{C}}\gamma_{u_k^b}^{\mathrm{C}}\right)\} \le \log_2\left(1+\theta^{\mathrm{C}}\mathbf{E}\{\gamma_{u_k^b}^{\mathrm{C}}\}\right), \tag{20}$$

where θ^{NC} and θ^{C} respectively represent the impact of training overhead on the transmitting power of NonCoMP and CoMP transmission[3], $0 < \theta^{\mathrm{C}} < \theta^{\mathrm{NC}} < 1$.

The user u_k^b prefers CoMP transmission mode if $R_{u_k^b}^{\mathrm{C}} > R_{u_k^b}^{\mathrm{NC}}$. By substituting the upper bounds of $R_{u_k^b}^{\mathrm{C}}$ and $R_{u_k^b}^{\mathrm{NC}}$, the inequality $R_{u_k^b}^{\mathrm{C}} > R_{u_k^b}^{\mathrm{NC}}$ can be simplified as

$$\theta \cdot \mathbf{E}\{\gamma_{u_k^b}^{\mathrm{C}}\} > \mathbf{E}\{\gamma_{u_k^b}^{\mathrm{NC}}\}, \tag{21}$$

where $\theta \triangleq \theta^{\mathrm{C}}/\theta^{\mathrm{NC}}$ has a value between 0 and 1.

Substituting (11) and (18) into (21), we have

$$\frac{\theta P(BN_t - BK + 1)}{BK\sigma^2}\sum_{i=1}^{B}\alpha_{iu_k^b}^2 > \frac{P(N_t - K + 1)\alpha_{bu_k^b}^2}{K(\sum_{i=1, i\neq b}^{B}\alpha_{iu_k^b}^2 + \sigma^2)},$$

which can be further transformed into

$$\underbrace{(1+\underbrace{\frac{\sum_{i\neq b}^{B}\alpha_{iu_k^b}^2}{\alpha_{bu_k^b}^2}}_{(a)})(1+\underbrace{\frac{\sum_{i\neq b}^{B}\alpha_{iu_k^b}^2}{\sigma^2}}_{(b)})}_{\mathrm{Decision variable}} > \underbrace{\frac{1}{\theta}\frac{B(N_t-K)+B}{B(N_t-K)+1}}_{\mathrm{Decision Threshold}} \triangleq T. \tag{22}$$

The decision threshold T in (22) is a constant for all users, whose value is larger than 1. It grows when the number of active users, K, increases. The consideration of training overhead enhance the value of T.

The decision variable in (22) is also larger than 1. The term (a) in the decision variable reflects the location of the desired user. When a user moving away from its local BS, the value of the term (a) increases, i.e., a cell-edge user has a large value. However, the value of term (a) is upper bounded by $B-1$, since $\alpha_{iu_k^b}^2 \le \alpha_{bu_k^b}^2$, $i \neq b$. The term (b) is in fact the ratio of the average ICI under NonCoMP transmission to the noise plus inter-cluster interference power.

Note that the decision variable of each user only depends on its own large-scale fading gains. Therefore, the proposed transmission mode selection method can be implemented in a semi-dynamic manner. This avoids the large signalling overhead and high protocol complexity induced by using a dynamic transmission mode selection, where instantaneous channel information is used.

[3]The frequency and time resources consumed by training overhead are converted to equivalent power resource for analytical tractability. This is in fact an optimistic estimate of the overhead.

V. Simulation and Numerical Results

A cooperative cluster of three cells is considered with a 500 m BS-to-BS distance. Each BS has maximal transmission power as 46 dBm. The path loss factor is 3.76, and the minimum distance from user to BS is 35 m [14]. Assume that 4 antennas are equipped at each BS and 2 active users are dropped in each cell, i.e. $N_t = 4$, $K = 2$. The Edge SNR is defined to indicate the strength of the noise plus inter-cluster interference power as in [4], which is the received SNR of the cell-edge user. The value of θ is set as 0.5 ($\theta^{\mathrm{NC}} = 0.8$ and $\theta^{\mathrm{C}} = 0.4$), which corresponds to 2% training overhead on the bandwidth for each antenna.

Figure 2 presents the average SINR under CoMP mode, where both the approximation in (18) and simulation results are given. It shows that the approximation is very accurate.

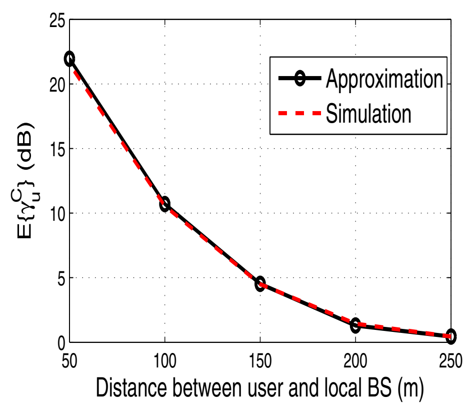

Fig. 2. Simulated and approximated average SINR when Edge SNR= -5 dB

Figure 3 illustrates the decision variable and threshold obtained from (22) for users with different locations. The decision variable increases as the user moving away from its local BS. As expected, the users located at cell edge prefer CoMP transmission mode. It is shown that with the considered setting, the "cell-edge region" is from 210 m to 250 m. When the Edge SNR increases, this region will extend. For example, when Edge SNR=5 dB, the "cell-edge region" is from 80 m to 250 m.

In Fig. 4, we compare the cumulative distributed function (CDF) of user throughput for three different systems, i.e., NonCoMP system, CoMP system and the system with the proposed transmission mode selection. The two active users in each cell are uniformly dropped, and the results are obtained from 10000 drops. Both simulation results and the upper bounds in (19) and (20) are presented. It shows that the simulated throughput is quite close to the upper bounds, which validates that the upper bound in (19) and (20) is tight. We can see that the CoMP system improves the performance of cell-edge users but degrades the performance of cell-center users. As expected, the proposed mode selection achieves good performance for both cell-edge and cell-center users.

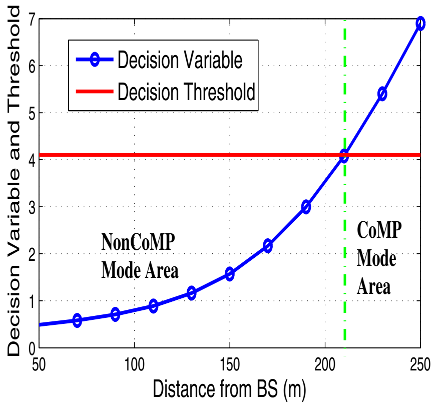

Fig. 3. Decision variable and threshold in (22) when Edge SNR=-5 dB

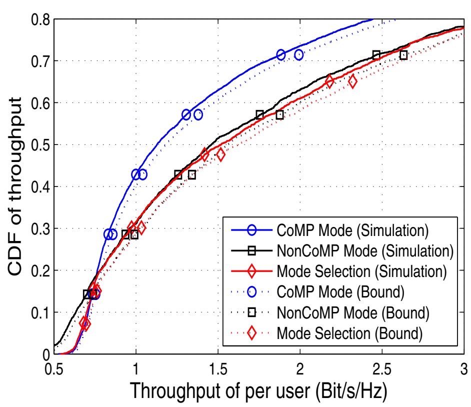

Fig. 4. CDF of Per-user Throughput when Edge SNR=-5 dB

Figure 5 plots the average throughput and the cell-edge throughput defined as the 5% point on the CDF of user throughput [14], for the three systems under different Edge SNR. It is shown that CoMP system provides performance gain on both average and cell-edge throughput over NonCoMP system in high Edge SNR region, while the gain reduces with the Edge SNR. On the other hand, under low Edge SNR, the cell-edge throughput of CoMP system has minor gain over that of NonCoMP system, while the average throughput of CoMP system is even inferior to of NonCoMP system, e.g., a 0.7 bps/Hz loss when Edge SNR = -5 dB. This indicates that transmission mode selection is more necessary for systems with low Edge SNR in order not to induce an average throughput loss.

VI. Conclusions

We proposed a semi-dynamic transmission mode selection method in multi-cell systems, where each user selects its

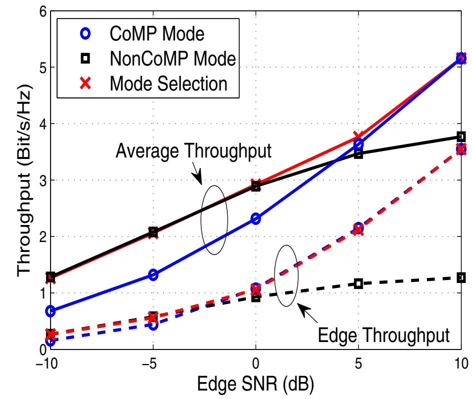

Fig. 5. Average throughput and cell-edge throughput when $\theta = 0.3$ (corresponds to 4% training overhead on the bandwidth for each antenna)

preferred serving mode between coherent BS cooperative transmission and non-cooperative transmission according to its own large-scale fading gains. Simulation results showed that the proposed method provides good performance for both cell-center and cell-edge users when training overhead is taken into account.

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