Energy-Efficient Cooperative Downlink Transmission with Antenna and BS Closing

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***Abstract*—Energy-efficiency (EE) has been considered as an important goal for designing future high throughput cellular networks. In this paper, we strive to improve the EE of downlink coherent cooperative transmission systems by adaptively selecting the transmitting mode, i.e., by switching off some antennas and base stations (BSs) according to the required data rate of each user and then by allocating powers to the users. To show the potential gain in EE, we first propose an optimal dynamic mode selection scheme to select the most energy-efficient active antenna and BS pattern based on the instantaneous channels, where per-user date constraint and the per-BS-power constraint are taken into account. To provide a feasible scheme for practical systems, we proceed to propose an optimal semi-dynamic mode selection scheme where the antenna and BS switching is based on the average channel gains. Simulation results with typical circuit power consumptions show that the semi-dynamic scheme performs closely to the dynamic scheme when the cell-edge signal to noise ratio is high, and both mode selection schemes provide substantial EE gain over the traditional scheme with all antennas at all BSs active.**

I. INTRODUCTION

Energy-efficiency (EE) has become an important design goal for next generation wireless networks [1], [2], due to the considerable energy consumed for supporting high throughput transmission. To meet the ever-increasing demands for high date rate meanwhile to reduce the energy consumption significantly, the optimization toward high EE should not sacrifice the quality of service (QoS) requirements of the users.

Recent results on the energy consumption of cellular networks indicate that around 80% of the energy required in operation is consumed at the base stations (BSs), among which the circuit power may even be comparable to the transmit power [3]. Consequently, reducing the EE for downlink transmission is critical to decreasing the network EE, and the circuit power consumption should not be neglected.

Existing systems are configured for supporting peak throughput of the system under the assumption of uniform traffics. However, in reality the traffics may be very different at different time and different places. This suggests that we can switch off a part of the baseband circuits and radio frequency (RF) chains at the BS to reduce the energy consumption when the traffic load is low. In [4], [5], the number of active antennas at the BS was designed, where some RF circuits are closed adaptively. It was shown in [5] that when the data rate requirement of the system is low, using less antennas provides higher EE. In [6], [7], the whole BS was switched off or turned into sleep mode under low-traffic conditions, with which significant EE gain was observed.

BS cooperative transmission is regarded as a promising technology to improve the throughput especially for cell-edge users [8]. In [9], the trade-off between the EE and spectral efficiency (SE) of downlink cooperative systems was investigated. In [10], some of BSs in a cooperative cluster were switched into sleep mode and their associated users were then jointly served by the remaining active BSs in order to reduce the circuits power consumption. In [11], by studying energy efficient network planning, the authors showed that cooperating transmission can effectively reduce the number of deployed BSs while also keeping the transmission power low. The EE of the cooperative transmission will increase by 20% compared with that of the non-cooperative transmission.

In this paper, we propose to improve the EE of downlink coherent cooperative transmission systems by adaptively switching off the antennas or BSs, i.e., by selecting transmission mode, in conjunction with power allocation. Specifically, we find the optimal mode selection scheme to choose the best antenna and BS pattern that achieves the maximum EE with the QoS constraint from users. To show the potential in saving energy we first design a dynamic mode selection scheme that uses the instantaneous channels. Considering that the antennas and BSs are not able to be closed very frequently, we proceed to propose a semi-dynamic mode selection scheme, where the antenna and BS switching only depends on the average channel gains. Simulation results show that the semi-dynamic mode selection scheme achieves similar EE as that of the dynamic scheme when the cell-edge signal to noise ratio (SNR) is high, and adaptively switching off the antennas and BSs can improve the EE significantly.

The rest of the paper is organized as follows. In Section II, we present the system model and power model. The optimal mode selection schemes for switching off antennas and BSs are proposed in Section III and simulation results are given in Section IV. The conclusions are drawn in Section V.

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II. System Model and Power Model

A. System Model

Consider a cooperative cluster consisting of N_b BSs, each equipped with N_t antennas jointly serve M single-antenna active users. Assume that the BSs are connected with a central unit via backhaul links without capacity limitation, through which the data and the channels to the users can be perfectly shared.

We consider that the antennas of the BSs can be adaptively switched off. A BS can be closed, i.e., turned into idle mode, when all its N_t antennas are closed. The active antennas at multiple BSs jointly serve the active users by using multi-cell zero-forcing (ZF) precoding, which is a low-complexity yet effective precoder in practical systems to eliminate inter-user interference [12]. After the central unit gathers all the data and channel information to all the active users, it can select the operation mode for each antenna, i.e., the active antenna and BS pattern, then compute the joint precoder.

Denote $\mathbf{S} \in \mathbb{C}^{N_bN_t \times N_bN_t}$ as the antenna- and BS- closing matrix, which is a diagonal matrix. Its diagonal elements $s_{k,k}, k = 1, \cdots, N_bN_t$ represent the state of all N_bN_t antennas. $s_{k,k} = 1$ indicates that the kth antenna is active, while $s_{k,k} = 0$ means it is switched off. Then the number of active antennas at BS i can be calculated as

$$a_i(\mathbf{S}) = \sum_{k=(i-1)N_t+1}^{iN_t} s_{k,k}, \tag{1}$$

and the operating mode of BS i can be obtained as

$$b_i(\mathbf{S}) = \lceil \frac{a_i(\mathbf{S})}{N_t} \rceil, \tag{2}$$

where $\lceil x \rceil$ represents the smallest integer that is larger than x. $b_i(\mathbf{S}) = 0$ indicates that all the antennas at BS i are switched off thus the BS can be switched into idle mode.

In order to serve all M active users by the ZF precoder, at least M antennas should be active in the whole cluster, i.e., $\sum_{i=1}^{N_b} a_i(\mathbf{S}) \geq M$. The downlink *equivalent channel* matrix for all the active users after switching off the antennas and BSs can be expressed as

$$\mathbf{H}_e = \mathbf{H} \cdot \mathbf{S}, \tag{3}$$

where $\mathbf{H} = [\mathbf{h}_1, \cdots, \mathbf{h}_M]^T \in \mathbb{C}^{M \times N_bN_t}$ is the channel matrix, $\mathbf{h}_j = [\mathbf{h}_{1j}^T, \cdots, \mathbf{h}_{N_bj}^T]^T \in \mathbb{C}^{N_bN_t \times 1}$ represents the global channel vector of user j, $\mathbf{h}_{ij} = \alpha_{ij}\mathbf{g}_{ij}$ is the composite channel vector between BS i and user j, α_{ij} is the large scale fading gain including path loss and shadowing, $\mathbf{g}_{ij} \in \mathbb{C}^{N_t \times 1}$ is the small-scale fading channel vector between BS i and user j, each entry of which is a complex Gaussian random variable with zero mean and unit variance and all entries are assumed to be independent and identically distributed (i.i.d), and $(\cdot)^T$ denotes the transpose.

Denote $\mathbf{V} \in \mathbb{C}^{N_bN_t \times M}$ as the precoding matrix, each column of which is the precoding vector from all N_b BSs to each user. Then, the received signals for M active users can be expressed as

$$\mathbf{y} = \mathbf{H}_e \cdot \mathbf{V} \cdot \mathbf{x} + \mathbf{n}, \tag{4}$$

where $\mathbf{x} \in \mathbb{C}^{M \times 1}$ is the transmit signals for the users, and $\mathbf{n}$ is the Gaussian noise with zero mean and variance σ^2.

The ZF precoding matrix can be expressed as $\mathbf{V} = \mathbf{W} \cdot \mathbf{P}$, where $\mathbf{W} = \mathbf{H}_e^H \left(\mathbf{H}_e\mathbf{H}_e^H\right)^{-1}$ is the pseudo-inverse of the *equivalent channel* matrix $\mathbf{H}_e$, $(\cdot)^H$ denotes the conjugate transpose, and $\mathbf{P} = \operatorname{diag}\{\sqrt{p_1}, \cdots, \sqrt{p_M}\}$ is the power allocation matrix for all the users. Then, the achievable rate of user j is

$$R_j = \log_2\left(1 + \frac{p_j}{\sigma^2}\right) \quad \text{bit/s/Hz}. \tag{5}$$

Consider that the power allocation for all users should satisfy the per-BS-power-constraint (PBPC). Define $\mathbf{\Phi}_i \in \mathbb{C}^{N_bN_t \times N_bN_t}$ as a row selection matrix, which has all zeros except for N_t ones on the main diagonal corresponding to the N_t antennas of BS i. Then the total transmit power at BS i can be obtained as

$$\begin{aligned} P_i^{\text{tx}} &= \operatorname{Tr}\{\mathbf{\Phi}_i\mathbf{V}\mathbf{V}^H\mathbf{\Phi}_i^H\} \\ &= \operatorname{Tr}\{\mathbf{W}^H\mathbf{\Phi}_i\mathbf{W}\mathbf{P}^2\} \triangleq \boldsymbol{\theta}_i^T \cdot \mathbf{p}, \end{aligned} \tag{6}$$

where $\boldsymbol{\theta}_i \in \mathbb{C}^{M \times 1}$ is a vector consisting of the diagonal elements of the matrix $\mathbf{W}^H\mathbf{\Phi}_i\mathbf{W}$, $\mathbf{p} = [p_1, \cdots, p_M]^T$, and $\operatorname{Tr}\{\cdot\}$ stands for the trace of a matrix.

Denote the maximum transmit power at each BS as P, then the PBPC can be expressed as

$$P_i^{\text{tx}} = \boldsymbol{\theta}_i^T \cdot \mathbf{p} \leq P, \quad i = 1, \cdots, N_b. \tag{7}$$

B. Power Consumption Model

According to the model presented in [3], the total power consumption at BS i can be modeled as follows:

$$\mathcal{P}_i = \frac{P_i^{\text{tx}}}{\mu} + a_i(\mathbf{S})P_c + \left[b_i(\mathbf{S})(P_o - \tilde{P}_o) + \tilde{P}_o\right], \tag{8}$$

where P_c stands for the circuits power consumption for each antenna consisting of the bandpass filters, duplexers and other RF circuits; P_o and $\tilde{P}_o$ respectively stand for the constant power consumption at each BS under active and idle modes consisting of power supply and cooling; and μ is the efficiency of the power amplifiers.

III. Dynamic and Semi-dynamic Optimal Mode Selection With Power Allocation

In this section, we formulate the optimization problem for switching off antennas and BSs with power allocation in order to maximize the EE of the cooperative cluster while the QoS of each user is ensured.

We first develop an optimal dynamic mode selection scheme based on the small-scale channel information. Though such a dynamic mode selection may not be feasible for practical applications with time-varying channels, it can serve as a performance upper bound for the systems which can adaptively switch off the antennas and BSs. We then propose a semi-dynamic mode selection scheme, which only depends on the large-scale channel gains.

A. Optimal Dynamic Mode Selection

The EE in the cluster is defined as

$$EE = \frac{\sum_{j=1}^{M} R_j}{\sum_{i=1}^{N_b} \mathcal{P}_i} \quad \text{bit/J/Hz}. \tag{9}$$

The optimization problem to maximize the EE in the cluster by antenna-BS closing and power allocation under the QoS constraint and PBPC is formulated as follows,

$$\max_{p_j, \mathbf{S}} \quad EE \tag{10}$$

$$s.t. \quad \log_2\left(1 + \frac{p_j}{\sigma^2}\right) = R_0^j, \quad j = 1, \cdots, M \tag{10a}$$

$$\boldsymbol{\theta}_i^T \cdot \mathbf{p} \le P, \qquad i = 1, \cdots, N_b \tag{10b}$$

$$\sum_{i=1}^{N_b} a_i(\mathbf{S}) = \sum_{k=1}^{N_b N_t} s_{k,k} \ge M, \;\; s_{k,k} = 0 \text{ or } 1 \tag{10c}$$

where (10a) is the QoS constraint, R_0^j is the required data rate of user j, and (10c) is the constraint on the total number of active antennas required by the ZF precoder.

When the required data rate of each user is given, optimization problem (10) is equivalent to the following optimization problem to minimize the total power consumption,

$$\min_{p_j, \mathbf{S}} \quad \sum_{i=1}^{N_b} \mathcal{P}_i \tag{11}$$

$$s.t. \quad \log_2\left(1 + \frac{p_j}{\sigma^2}\right) \ge R_0^j, \quad j = 1, \cdots, M$$

$$\text{(10b)} \sim \text{(10c)}$$

This is a non-convex integer programming problem. Thus, its globally optimum solution is very hard to find.

When the antenna and BS pattern, i.e., $\mathbf{S}$, is fixed, problem (11) becomes an optimal power allocation problem as follows,

$$\min_{p_j} \sum_{i=1}^{N_b} \frac{P_i^{\text{tx}}}{\mu} + \sum_{i=1}^{N_b} a_i(\mathbf{S}) P_c + \sum_{i=1}^{N_b} [b_i(\mathbf{S})(P_o - \tilde{P}_o) + \tilde{P}_o] \tag{12}$$

$$s.t. \quad p_j \ge (2^{R_0^j} - 1)\sigma^2 \triangleq P_0^j, \;\; j = 1, \cdots, M \tag{12a}$$

$$\boldsymbol{\theta}_i^T \cdot \mathbf{p} \le P, \qquad i = 1, \cdots, N_b \tag{12b}$$

To find the optimal solution of problem (11), we can first solve the power allocation problem (12) for a given $\mathbf{S}$, and then compare the results for all possible choices of $\mathbf{S}$ and select the best one which leads to the minimum total power consumption.

In the objective function (12), the last two terms are constant when $\mathbf{S}$ is given. Therefore, we only need to minimize the transmit power of all BSs, i.e., $\sum_{i=1}^{N_b} \frac{P_i^{\text{tx}}}{\mu} = \sum_{i=1}^{N_b} \frac{\boldsymbol{\theta}_i^T \cdot \mathbf{p}}{\mu}$, which is an increasing function of $\mathbf{p}$ since the entries of $\boldsymbol{\theta}_i$ are constants when $\mathbf{S}$ is fixed. From (12a), we find that the minimum value of $\mathbf{p}$ is $\mathbf{p}^* = [P_0^1, \cdots, P_0^M]^T$. We assume that $\mathbf{p}^*$ satisfies the PBPC in (12b),[1] i.e, $\boldsymbol{\theta}_i^T \cdot \mathbf{p}^* \le P$. Then $\mathbf{p}^*$ is just the solution of the optimizing problem (12).

The minimum total power consumption in the cluster for a given $\mathbf{S}$ is obtained as

$$\mathcal{P}_s(\mathbf{S}) = \frac{1}{\mu} \sum_{i=1}^{N_b} \boldsymbol{\theta}_i^T \cdot \mathbf{p}^* + \sum_{i=1}^{N_b} a_i(\mathbf{S}) P_c + \sum_{i=1}^{N_b} [b_i(\mathbf{S})(P_o - \tilde{P}_o) + \tilde{P}_o]. \tag{13}$$

Different antenna and BS patterns $\mathbf{S}$ lead to different minimum power consumption $\mathcal{P}_s(\mathbf{S})$ in (13). The number of all possible antenna and BS patterns can be obtained as

$$\mathcal{N} = 2^{N_b N_t} - \sum_{k=1}^{M} \left(\begin{array}{c} k-1 \\ N_b N_t \end{array} \right). \tag{14}$$

By exhaustively searching over these $\mathcal{N}$ antenna and BS patterns, we can find the best pattern that gives rise to the minimum total power consumption in (13).

Since $\boldsymbol{\theta}_i$ defined after (6) depends on the small-scale fading channels that may vary with time, the obtained mode selection scheme above will operate in a dynamic manner. It is unacceptable in real-world cellular systems to frequently change the antenna and BS pattern due to the resulting large signaling overhead and the frequent switching on and off of the circuits.

In the sequel, we derive a semi-dynamic mode selection scheme, where the active antenna and BS pattern depends on the average channel gains.

B. Semi-dynamic Mode Selection

We propose to select the semi-dynamic optimal antenna and BS pattern based on the average minimum power consumption instead of $\mathcal{P}_s(\mathbf{S})$, which can be obtained from (13) by taking the average over the small-scale channels, i.e.,

$$\overline{\mathcal{P}}_s(\mathbf{S}) = \mathbf{E}\left\{\mathcal{P}_s(\mathbf{S})\right\}. \tag{15}$$

Note that only the first term (i.e., the transmit power) in (13) depends on the small scale channel. Therefore, in the following, we analyze the average transmit power.

From the definition in section II, we know that $\boldsymbol{\theta}_i$ is a vector consisting of the diagonal elements of the matrix $\mathbf{W}^H \boldsymbol{\Phi}_i \mathbf{W}$. Thus, the jth element of $\boldsymbol{\theta}_i$, i.e., $\theta_{i,j}$, can be expressed as $\mathbf{w}_j^H \boldsymbol{\Phi}_i \mathbf{w}_j$, where $\mathbf{w}_j \in \mathbb{C}^{N_b N_t \times 1}$ is the jth column of $\mathbf{W}$. Then, the transmit power in (13) can be expressed as

$$\begin{aligned} \sum_{i=1}^{N_b} \boldsymbol{\theta}_i^T \cdot \mathbf{p}^* &= \sum_{j=1}^{M} P_0^j \sum_{i=1}^{N_b} \theta_{i,j} \\ &= \sum_{j=1}^{M} P_0^j \mathbf{w}_j^H \left(\sum_{i=1}^{N_b} \boldsymbol{\Phi}_i \right) \mathbf{w}_j = \sum_{j=1}^{M} P_0^j ||\mathbf{w}_j||^2, \end{aligned} \tag{16}$$

where $||\cdot||$ is the two-norm. If we assume that all users have the same QoS requirement (i.e., $P_0^j = P_0, \forall j$), the overall average transmit power can be obtained as

$$\begin{aligned} \mathrm{E}\left\{ \sum_{i=1}^{N_b} \boldsymbol{\theta}_i^T \cdot \mathbf{p}^* \right\} &= P_0 \sum_{j=1}^{M} \mathbf{E}\left\{||\mathbf{w}_j||^2\right\} \\ &= P_0 \mathbf{E}\left\{\mathrm{Tr}\left\{\mathbf{W}^H \mathbf{W}\right\}\right\} = P_0 \mathbf{E}\left\{\mathrm{Tr}\left\{(\mathbf{H}_e \mathbf{H}_e^H)^{-1}\right\}\right\}. \end{aligned} \tag{17}$$

In the following, we assume that the M active users have

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[1] If $\mathbf{p}^*$ can not satisfy (12a), the feasible region of the optimization problem in (12) is empty and thus has no solution. We will not consider this case in our analysis of this paper.

the same large-scale channel gains from all BSs,[2] i.e., $\alpha_{ij} = \alpha$ for all $i = 1, \cdots, N_b, j = 1, \cdots, M$. In this case, $\mathbf{H}_e\mathbf{H}_e^H$ is a wishart matrix [13] with $A(\mathbf{S})$ degrees of freedom, where $A(\mathbf{S}) \triangleq \sum_{i=1}^{N_b} a_i(\mathbf{S})$ is the number of active antennas in the whole cluster for a given pattern $\mathbf{S}$. With *Lemma 2.10* in [13], we obtain that

$$\mathbf{E}\{\mathrm{Tr}\left\{(\mathbf{H}_e\mathbf{H}_e^H)^{-1}\right\}\} = \frac{M}{\alpha^2(A(\mathbf{S})-M)}. \qquad (18)$$

Therefore, the average minimum power consumption in (15) can be derived as

$$\begin{aligned}\overline{\mathcal{P}}_s(\mathbf{S}) = & \frac{MP_0}{\mu\alpha^2(A(\mathbf{S})-M)} + A(\mathbf{S})P_c \\ & + B(\mathbf{S})(P_o - \tilde{P}_o) + N_b\tilde{P}_o, \qquad (19)\end{aligned}$$

where $B(\mathbf{S}) \triangleq \sum_{i=1}^{N_b} b_i(\mathbf{S})$ is the total number of active BSs.

Note that the first two terms in (19) depend on the number of active antennas, i.e., $A(\mathbf{S})$, and they respectively correspond to the transmit power and the antenna circuit power. When the number of active antennas decreases, the transmit power grows while the circuit power reduces.

The number of active BSs, i.e., $B(\mathbf{S})$, depends on the value of $A(\mathbf{S})$. In order to reduce the overall power consumption, we set $B(\mathbf{S}) = \lceil \frac{A(\mathbf{S})}{N_t} \rceil$, which means that we activate as few BSs as possible. Then, the average minimum total power consumption in (19) becomes a function of $A(\mathbf{S})$, and the optimal selection of active BSs and antennas is equivalent to selecting the optimal number of active antennas $A(\mathbf{S})$.

If we ignore the ceiling operation and set $\tilde{B}(\mathbf{S}) = A(\mathbf{S})/N_t$, it is not hard to derive that the value of $\overline{\mathcal{P}}_s(\mathbf{S})$ in (19) achieves its minimum value when

$$A^*(\mathbf{S}) = M + \sqrt{\frac{MP_0}{\mu\alpha^2 P_a}}, \qquad (20)$$

where $P_a = P_c + (P_o - \tilde{P}_o)/N_t$.

The active number of antennas should be in the range of $[M+1, N_bN_t]$.[3] If $A^*(\mathbf{S}) < M+1$, the optimal number of active antennas is $M+1$. If $A^*(\mathbf{S}) > N_bN_t$, the optimal number of active antennas is N_bN_t, i.e., all the antennas are active. Otherwise, the optimal number of active antennas is selected between $\lfloor \frac{A^*(\mathbf{S})}{N_t} \rfloor N_t$ and $\lceil \frac{A^*(\mathbf{S})}{N_t} \rceil N_t$ to minimize the total power consumption in (19).

From (20), we can see that the obtained mode selection depends on the large-scale fading gain α, the number of active users M, the QoS requirement of each user P_0^j, and the power consumption model.

Different antenna and BS patterns may have the same number of active antennas or BSs. From these values of $\mathbf{S}$ that lead to the optimal number of active antennas and BSs, we can randomly select one for downlink transmission since they have the same performance on average.

After the pattern $\mathbf{S}$ is selected in such a semi-dynamic manner, the optimal power allocation can be obtained from the optimization problem (12) based on the instantaneous channel information.

IV. SIMULATION RESULTS

In this section, we evaluate the performance of the proposed dynamic and semi-dynamic mode selection schemes and show the potential of increasing the EE by adaptively switching off antennas and BSs.

The cooperative cluster of N_b hexagonal cells is considered with a cell radius $R = 250$ m. The path loss is modeled as $\alpha_{ij}^2 = \alpha_0^2(R/d_{ij})^\tau$, where α_0^2 is the path loss at the distance R, d_{ij} is the distance between user j and BS i, and $\tau = 3.76$ is the path-loss exponent. Shadowing is not considered in the simulation. The cell-edge SNR is defined as the received SNR of the user located at the distance R from the BS, where the inter-cluster interference is included and regarded as white noise. In the power model, we set the maximum transmit power as $P = 40$ W, the circuit power of the antenna and the BS as $P_c = 12.5$ W, $P_o = 56$ W, $\tilde{P}_o = 39$ W, and the efficiency of power amplifiers $\mu = 0.228$, which corresponds to the micro-cell scenario in [3]. The QoS requirements of all users are considered to be the same in the following simulations.

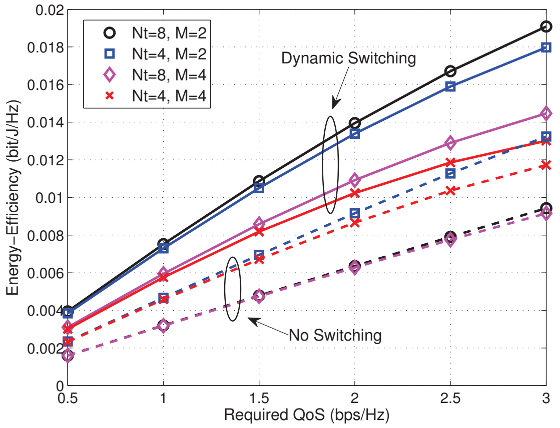

Fig. 1. Comparison of the EE between the dynamic mode switching and without model switching, $N_b = 2$ and the cell-edge SNR = 10 dB.

In Fig. 1, we compare the EE of a system using the proposed dynamic mode selection with that of a system without mode switching (where all the antennas and all BSs are active) under the setting of $N_b = 2$. Note that both these two systems are with power allocation. The results are obtained by averaging over 1000 uniformly placed locations of users, and in each location 10000 i.i.d. Gaussian small-scale fading channels are averaged. We can see that switching off antennas and BSs can significantly improve the EE, especially for the systems with more antennas at each BS and the required QoS of each user is high. When the required data rate is 3 bps/Hz for a system with $N_t = 8, M = 2$, we can observe an about 100% EE gain of the optimal dynamic mode switching over that without

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[2] This assumption implies that all the active users are located at the "exact cell-edge". In practical system, since cell-edge users are preferred to be served with cooperative transmission, this assumption is approximately valid. We leave the study of downlink cooperation transmission for users with unequal average channel gains for future work.

[3] The number of active antennas should not equal to M since this may lead the required transmit power growing without bound.

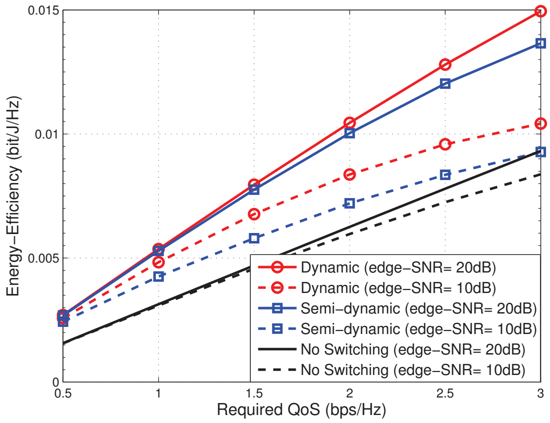

Fig. 2. Comparison of the EE among the semi-dynamic mode switching, dynamic mode switching and without switching, $N_b = 3$, $N_t = 4$ and $M = 3$.

mode switching. Moreover, without the mode switching, a system with more antennas at each BS achieves lower EE. By contrast, when the optimal dynamic mode switching is applied, the system equipped with more antennas provides higher EE. This implies that the spatial resources are efficiently used with the optimal dynamic mode switching.

In Fig. 2, we compare the performance of the proposed semi-dynamic mode selection scheme with the optimal dynamic model selection scheme and system without switching scheme under the scenario of $N_b = 3, N_t = 4, M = 3$. The three users are located in a fixed place that has the same distance from all three BSs. We can see that the system using the semi-dynamic mode selection achieves higher EE than the system without switching scheme, but has an EE loss from the dynamic mode selection system. The gap between the semi-dynamic and dynamic mode selection schemes becomes small when the cell-edge SNR is high.

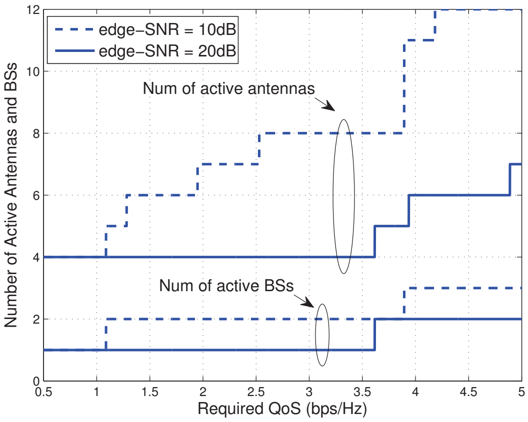

Fig. 3. Optimal number of active antennas and BSs under the semi-dynamic switching, $N_b = 3$, $N_t = 4$ and $M = 3$.

In Fig. 3, we show the optimal number of active antennas and BSs when the semi-dynamic switching scheme is employed, which is obtained numerically from the expression of (20). We can see that the numbers of active antennas and BSs are adaptive to the QoS requirements and the cell-edge SNR.

V. CONCLUSIONS

In this paper, the EE of downlink cooperative transmission systems was enhanced by adaptively selecting transmission mode, i.e., by selecting active antennas and BSs together with power allocation. An optimal dynamic mode selection scheme for selecting the most energy-efficient antenna and BS pattern was found by exhaustive searching, while the QoS requirements of multiple users are ensured. We proposed a semi-dynamic mode selection scheme that the active antenna and BS pattern selection only depending on the average channel gains. Simulation results demonstrated the potential of improving EE by switching off antennas and BSs according to the required QoS. When the required data rate of each of the two users is 3 bps/Hz for a two-cell system with eight antennas at each BS and 10 dB cell-edge SNR, roughly 100% EE gain can be obtained over an all-antenna-on system. Moreover, the semi-dynamic mode selection performs closely to the dynamic mode selection in terms of EE when the cell-edge SNR is high.

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