Improving Network Energy Efficiency through Transmit Antenna Number and Transmission Mode Selection in Multicell Systems

Shichao Li and Ling Qiu
Department of Electronic Engineering and Information Science
University of Science and Technology of China
Hefei, P.R. China
lqn@mail.ustc.edu.cn, lqiu@ustc.edu.cn

***Abstract*—We consider the problem of maximizing network energy efficiency (NEE) in multicell systems, which is defined as the total capacity of all users divided by the total base station (BS) power consumption in the system. We first provide closed-form expressions for NEE when BSs take different combinations of transmission modes and active transmit antenna number. Based on these and assuming all users' statistical channel state information (CSI) is available in all BSs, we provide an algorithm in which the combination with the best network energy efficiency can be selected. Simulations show that, for each combination the calculation results of NEE fit well with the simulation results, and the NEE-optimal combination can be adaptively selected given the users's locations. At last we analyze why the chosen combination is optimal with respect of NEE.**

I. Introduction

In recent years, multicell-processing (MCP) in the downlink is proposed as a promising method to suppress inter-cell interference (ICI) through coordination among multiple base stations (BSs), and the spectral efficiency (SE) is improved dramatically [1]. According to different levels of data and channel state information at transmitters (CSIT) sharing in cooperative BSs, MCP can be categorized into two classes. One is coordinated multicell transmission with full data and CSIT sharing, where cooperative BSs form a "super" BS and global precoding can be applied [2]. Unfortunately, this scheme requires a significant amount of inter-BS information exchange and is of high complexity, so it is quite challenging for practical implementation. The other one is coordinated single-cell transmission, which is of lower complexity and more practical, as no inter-BS data exchange is needed and normally each user needs to provide instantaneous or statistical channel state information only to some of its neighboring BSs.

Coordinated single-cell transmission is often applied in the form of spatial intercell interference cancelation (ICIC). BSs employing ICIC can totally cancelate the interferences to users in neighboring cells whose number is determined by the BS's transmit antenna number. On the other hand, selfish beamforming (BF) is an uncoordinated transmission mode, in which the BS selfishly maximizes its serving users' received signal to noise ratio (SNR) and does nothing to suppress its interference to users in other cells. With multiple antennas at BSs using BF, the serving user's capacity benefits from the transmit diversity. So the sum capacity in multicell systems relies on the transmission mode and active transmit antenna number in each BS. When one BS generates strong ICI to users in neighboring cells, employing ICIC in the BS can generate a more improvement than BF with respect of the capacity, and vice versa. [3] provides an algorithm in which BSs adaptively select one mode from ICIC and BF based on users' locations to maximize the total capacity of the network.

On the other hand, energy efficiency (EE) is becoming more and more important for the future radio access networks due to the climate change and the operator's increasing operational cost. As BSs take the majority of the energy consumption [4], it is necessary to improve the EE of BS. There are many works focusing on maximizing the link energy efficiency (LEE) in single-cell systems. The literatures on LEE can be mainly divided into two classes and the first one focuses on the LEE of frequency selective channels [5][6] and the second class mainly considers the LEE of MIMO [7]. From these works we know that power allocation and link adaption are the key technologies to improve LEE, and since MIMO channels can be seperated into several parallel sub-channels based on singular value decomposition (SVD), the similar power allocation and link adaption in frequency selective fading channels can be applied to MIMO systems

However, there are only few literatures considering EE in multicell systems and [8] is a pioneering study about this topic and proposes a cooperative idling scheme to improve network energy efficiency (NEE), which is defined as sum capacity in the cooperative cluster divided by the total BS power consumption of the cluster. [9] gives detailed BS power consumption model and it is dependent on many factors such as transmit power, active transmit antenna number etc.. Since the sum capacity relies on the transmit power, transmission mode and active transmit antenna number in each BS, NEE

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Corresponding author: Ling Qiu, lqiu@ustc.edu.cn.

is a function of the transmit power, transmission mode and active antenna number in each BS.

In this paper, we consider the problem of improving NEE through active transmit antenna number and transmission mode selection in a multicell network with multiple transmit antennas in BSs and only one receive antenna in users. At first, we provide the closed-form expressions of NEE for all combinations of the transmission mode, active transmit antenna number in each BS. Based on these and assuming all users' statistical channel state information is available in all BSs, we provide an algorithm in which the combination with the best network energy efficiency can be selected. Simulations show that for each combination, the calculation results of NEE fit well with the simulation results, and the NEE-Optimal combination can be adaptively selected given the users's locations. At last we analyze the reason why the chosen combination is optimal with respect of NEE.

The rest of this paper is organized as follows: We first introduce the system model in Section II. In Section III, the problem of improving NEE is formulated. We propose an adaptive algorithm in Section IV. Then we provide simulation results and performance analysis in Section V. At last we conclude this paper in Section VI.

Regarding the notation, uppercase and lowercase boldface letters are used to denote matrices and vectors respectively. The superscript H and T represent the conjugate transpose and transpose, respectively. $\|\mathbf{x}\|$ denotes the 2-norm of vector $\mathbf{x}$. $E_H\{\cdot\}$ denotes the expectation with respect of random variable H.

II. System Model

We consider a M-cell wireless network where each BS has N_T antennas and each mobile user has a single antenna. Each user has a serving BS whose channel has the highest gain, and in this paper we assume BS j is user j's serving cell. There is only one user in one cell receiving data signals from its serving BS while suffering ICI from other BSs. The received signal at user j can be denoted as

$$y_j = \sum_{i=1}^{M} \mathbf{h}_{i,j}\mathbf{x}_i + z_j \tag{1}$$

Here $\mathbf{x}_i = \sqrt{P_{T,i}}\mathbf{f}_i s_i$ is the transmitted signal form BS i where $P_{T,i}$ and s_i are BS i's transmit power and scalar symbol for user i, respectively. The vector $\mathbf{f}_i$ is BS i's normalized precoding vector whose form is dependent on the transmission mode, and this will be discussed in Section III. The scalar z_j is the jth user noise and in this paper we assume all users' noise power equals to P_N. In practial systems, there is a maximal transmit power constraint, i.e. $P_{T,i} \leq P_{T,\max}$. The channel from BS i to user j is denoted as

$$\mathbf{h}_{i,j} = \zeta_{i,j}\hat{\mathbf{h}}_{i,j} = \Phi_{i,j} d_{i,j}^{-\lambda}\Psi_{i,j}\hat{\mathbf{h}}_{i,j} \tag{2}$$

Here $\zeta_{i,j}$ is the large scale fading including pathloss and shadowing, in which $d_{i,j}$ and λ denote the distance from the BS i to user j and the pathloss exponent, respectively. The random variable $\Psi_{i,j}$ accounts for the shadowing. The random variable $\Phi_{i,j}$ denotes the pathloss parameters to further adapt the model which accounts for the BS and user antenna heights, carrier frequency, propagation conditions and reference distance. The vector $\hat{\mathbf{h}}_{i,j}$ is the small scale fading channel, with each entry $CN(0,1)$.

We use BS power model specified by [9]. Besides transmit power, the BS power consumption is comprised of dynamic power P_{dyn} and static power P_{sta} accounting for the power consumed by signal processing, feeder, A/D converter, antenna, power supply, battery backup, cooling etc. Since the dynamic power P_{dyn} is dependent on bandwidth, transmit antenna number and the static power is constant, we denote the power model at BS i as

$$P_{total,i} = \frac{P_{T,i}}{\eta} + P_{dyn,i} + P_{sta} \tag{3}$$

where

$$P_{dyn,i} = N_{AT,i}P_{cir} + P_{ac,bw}B + N_{AT,i}P_{sp,bw}B \tag{4}$$

Here η is the RF efficiency and B is the bandwidth. In this paper we assume the bandwidth B, circuit power P_{cir}, A/D converter power $P_{ac,bw}$ and signal processing power $P_{sp,bw}$ are constant, so the total power consumption at BS i can be written as a function of the transmit power $P_{T,i}$ and the active transmit antenna number $N_{AT,i}$.

Now we define NEE as our optimization object, which is the total capacity in the network divided by the total power consumption at all BSs. It is denoted as

$$NEE = \frac{\sum_{j=1}^{M} R_j}{\sum_{i=1}^{M} P_{total,i}} \tag{5}$$

in which R_j is the achievable capacity of user j.

III. Problem Description

From the above we know that one BS's power consumption is dependent on its transmit power and active transmit antenna number. In multicell systems, each user's achievable capacity relies on all BSs' transmission mode besides the transmit power and active transmit antenna number at all BSs. Assuming no inter-BS user data sharing, selfish beamforming and ICIC are two widely-used transmission modes and each BS can select one of them. Here BF is that the BS serves its own user with eigen-beamforming and does not cancel interference for any users in other cells while the BS using ICIC does interference cancelation for all users in other cells.

Denote the set of BSs adopting ICIC as Ω and the set of BSs adopting BF as Θ. When BS j adopts BF mode, user j's received signal can be written as

$$\begin{aligned} y_j = &\sqrt{P_{T,j}}\mathbf{h}_{j,j}\mathbf{f}_{BF,j}s_j + \sum\nolimits_{i\in\Theta\backslash j}\sqrt{P_{T,i}}\mathbf{h}_{i,j}\mathbf{f}_{BF,i}s_i \\ &+ \sum_{k\in\Omega}\sqrt{P_{T,k}}\mathbf{h}_{k,j}\mathbf{f}_{IC,k}s_k + z_j \end{aligned} \tag{6}$$

where $\mathbf{f}_{BF,j} = \mathbf{h}_{j,j}^*/\left\|\mathbf{h}_{j,j}^*\right\|$ is the normalized precoding vector of BS j using BF mode. The interference power from BS k with IC to user j is denoted as $P_{T,k}|\mathbf{h}_{k,j}\mathbf{f}_{IC,k}|^2$ and it equals to zero since BS k employs ICIC. So the SINR of user j is

$$\text{SINR}_{BF,j} = \frac{P_{T,j}|\mathbf{h}_{j,j}\mathbf{f}_{BF,j}|^2}{P_N + \sum_{i\in\Theta\setminus j} P_{T,i}|\mathbf{h}_{i,j}\mathbf{f}_{BF,i}|^2} \tag{7}$$

Substituting (2) into (7), we get

$$\text{SINR}_{BF,j} = \frac{\gamma_{j,j}\left|\hat{\mathbf{h}}_{j,j}\mathbf{f}_{BF,j}\right|^2}{1 + \sum\limits_{i\in\Theta\setminus j} \gamma_{i,j}\left|\hat{\mathbf{h}}_{i,j}\mathbf{f}_{BF,i}\right|^2} \tag{8}$$

where $\gamma_{j,j} = \frac{P_{T,j}\zeta_{j,j}^2}{P_N}$ is the average received SNR from BS j to user j and $\gamma_{i,j} = \frac{P_{T,i}\zeta_{i,j}^2}{P_N}$ is the averge received interference to noise ratio (INR) from BS i to user j. The random variables $\left|\hat{\mathbf{h}}_{j,j}\mathbf{f}_{BF,j}\right|^2$ and $\left|\hat{\mathbf{h}}_{i,j}\mathbf{f}_{BF,i}\right|^2$ are distributed as $\left|\hat{\mathbf{h}}_{j,j}\mathbf{f}_{BF,j}\right|^2 \sim \chi^2_{2N_{AT,j}}$ and $\left|\hat{\mathbf{h}}_{i,j}\mathbf{f}_{BF,i}\right|^2 \sim \chi^2_2$, where χ^2_n is the chi-square random variable with n degrees of freedom.

When BS j adopts ICIC mode, denote $\tilde{\mathbf{H}}_j = [\mathbf{h}_{j,1}^T, ..., \mathbf{h}_{j,j-1}^T, \mathbf{h}_{j,j+1}^T, ..., \mathbf{h}_{j,M}^T]^T$. And the normalized precoding vector of BS j is

$$\mathbf{f}_{IC,j} = (\mathbf{I} - \frac{\tilde{H}_j^H\tilde{H}_j}{\left\|\tilde{H}_j\right\|^2})\mathbf{h}_{j,j}^H / \left\|(\mathbf{I} - \frac{\tilde{H}_j^H\tilde{H}_j}{\left\|\tilde{H}_j\right\|^2})\mathbf{h}_{j,j}^H\right\| \tag{9}$$

Similarly, the SINR of user j is

$$\text{SINR}_{IC,j} = \frac{\gamma_{j,j}\left|\hat{\mathbf{h}}_{j,j}\mathbf{f}_{IC,j}\right|^2}{1 + \sum\limits_{i\in\Theta} \gamma_{i,j}\left|\hat{\mathbf{h}}_{i,j}\mathbf{f}_{BF,i}\right|^2} \tag{10}$$

where the random variable $\left|\hat{\mathbf{h}}_{j,j}\mathbf{f}_{IC,j}\right|^2$ is distributed as $\left|\hat{\mathbf{h}}_{j,j}\mathbf{f}_{IC,j}\right|^2 \sim \chi^2_{2(N_{AT,j}-M+1)}$.

So the achievable capacity of user j is

$$R_j = B \cdot \log_2(1 + \text{SINR}_{\text{Mode}_j,j}) \tag{11}$$

where the SINR of user j is dependent on the active transmit antenna number, transmission mode and transmit power at all BSs. And so is user j's capacity.

From the above, we know that the sum capacity of the multicell system is the function of the transmit power, active antenna number and selected transmission mode at all BSs. So the final NEE formulation is

$$\text{NEE} = \frac{\sum\limits_{i=1}^{M} R_i(\{N_{AT,k}\}_{k=1}^M, \{P_{T,k}\}_{k=1}^M, \{\text{Mode}_k\}_{k=1}^M)}{\sum\limits_{j=1}^{M} P_{total,j}(N_{AT,j}, P_{T,j})} \tag{12}$$

And the optimization problem can be written as

$$\max_{\substack{\{N_{AT,k}\}_{k=1}^M,\\ \{P_{T,k}\}_{k=1}^M,\\ \{\text{Mode}_k\}_{k=1}^M}} \frac{\sum\limits_{i=1}^{M} R_i(\{N_{AT,k}\}_{k=1}^M, \{P_{T,k}\}_{k=1}^M, \{\text{Mode}_k\}_{k=1}^M)}{\sum\limits_{j=1}^{M} P_{total,j}(N_{AT,j}, P_{T,j})}$$
$$\text{subject to} \begin{cases} 1 \le N_{AT,k} \le N_T \\ 0 < P_{T,k} \le P_{T,\max} \quad \text{for } k = 1, ..., M \\ Mode_k = \{BF, IC\} \end{cases} \tag{13}$$

IV. Improving NEE through Transmit Antenna number and transmission Mode Selection

[3] provides closed-form expressions of each user's ergodic capacity for each combination of the transmission mode and active transmit antenna number at each BS when there are no more than three cells in the system. Here one user's statistical CSI means the large-scale channel information from all BSs to this user. In this paper, we only consider the scenario that there are no more than three cells and leave the case when there are more than three cells for further studies.

From the above discussions and the definition of NEE in (5), we can easily derive closed-form expressions of NEE for each combination. Since all users' statistical CSI is available in all BSs, NEE of each combination can be calculated individually in each BS and all BSs can get the same calculation results. Here we give an adaptive algorithm to select the NEE-optimal one based on the statistical CSI. For each possible combination, the NEE-optimal transmit power in each BS can be calculated while satisfying the maximal transmit power constraint. Then, BSs compare these maximal NEEs of all combinations and get the most network-energy-efficient one. At last, each BS implements transmissions using the selected NEE-optimal transmission mode, active antenna number and corresponding transmit power.

We take the 2-cell system for example. At first, we denote the selected transmission mode and active transmit antenna number at BS j as Mode_j-$N_{AT,j}$ and the combination in two cells as $(\text{Mode}_1\text{-}N_{AT,1}, \text{Mode}_2\text{-}N_{AT,2})$. Here IC-1 is forbidden because there are not enough degrees of freedom for ICIC while BF-1 is SISO in fact. According to $Lemma2$ of [3], if the random variable X is distributed as $X \sim \chi^2_{2M}$, and define the function $R_{E1}(\gamma, M) = E_X\{\log_2(1+\gamma X)\}$, then we have

$$R_{E1}(\gamma, M) = \log_2(e)e^{1/\gamma} \sum_{k=0}^{M-1} \frac{\Gamma(-k, 1/\gamma)}{\gamma^k} \tag{14}$$

From this lemma and discussions in Section III, user 1's ergodic capacity of $(BF\text{-}N_{AT,1}, IC\text{-}N_{AT,2})$ can be written as $R_{E1}(\gamma_{11}, N_{AT,1})$ while user 1's ergodic capacity of $(IC\text{-}N_{AT,1}, IC\text{-}N_{AT,2})$ can be written as $R_{E1}(\gamma_{11}, N_{AT,1} - 1)$.

According to [3]'s $Lemma3$, denote the random variable $V = \frac{\gamma_1 Z}{1+\gamma_2 Y}$, where $Z \sim \chi^2_{2M}$, $Y \sim \chi^2_2$, and Z is independent of Y, and define the function $R_{E2}(\gamma_1,\gamma_2,M)=E_V\{\log_2(1+V)\}$. Then we have

$$R_{E2}(\gamma_1,\gamma_2,M)=\log_2(e)\sum_{i=0}^{M-1}\sum_{l=0}^{i}\frac{\gamma_1^{l+1-i}}{\gamma_2(i-l)!}\cdot I_1(\frac{1}{\gamma_1},\frac{\gamma_1}{\gamma_2},i,l+1) \quad (15)$$

where $I_1(\cdot,\cdot,\cdot,\cdot)$ is the integral as (16) and its closed-form expression is given in (27) of [3]

$$I_1(a,b,m,n)=\int_0^{\infty}\frac{x^m e^{-ax}}{(x+b)^n(x+1)}\mathrm{d}x \quad (16)$$

From this lemma and discussions in Section III, user 1's ergodic capacity of $(BF\text{-}N_{AT,1},BF\text{-}N_{AT,2})$ can be written as $R_{E2}(\gamma_{11},\gamma_{21},N_{AT,1})$ while the user 1's ergodic capacity of $(IC\text{-}N_{AT,1},BF\text{-}N_{AT,2})$ can be written as $R_{E2}(\gamma_{11},\gamma_{21},N_{AT,1}-1)$.

Now we get the closed-form expressions of the user's ergodic capacity for all possible combinations in the 2-cell system. Replacing the numerator of (12) with the sum of all users' ergodic capacity formulations, we derive the closed-form expressions of the average NEE for all combinations. Given the combination, NEE is only dependent on the transmit power in each BS. Considering there is a maximal transmit power constraint in each BS i.e. $P_{T,i}\leq P_{T,\max}$, there always exists a NEE-optimal transmit power vector in all BSs. Based on the derived NEE formulation, we can calculate the maximal NEE and the corresponding transmit power in each BS for each combination through optimization theory. Then we compares these maximal NEEs of different combinations and get the NEE-optimal one. At last, all BSs select this combination and then implement transmissions with the corresponding NEE-optimal transmit power.

For the 3-cell case, we can also get NEE's closed-form expressions for all possible combinations according to (5) and [3]'s $Theorem2$. So the algorithm above can be applied here, too.

V. Simulation Results

Simulation results are provided in this section. According to [9], practical power consumption parameters are given as follows, $\eta=0.38$, $P_{cir}=66.4W$, $P_{sta}=36.4W$, $P_{sp,bw}=3.32\mu W/Hz$, $P_{ac,bw}=1.82\mu W/Hz$, $P_{T,\max}=20W$. The bandwidth is set as $B=5MHz$ and the noise power density is set as $-174dBm/Hz$. So the total power consumption in BS j is given as

$$P_{total,j}=\frac{P_{T,j}}{0.38}+83N_{AT,j}+45.5(W) \quad (17)$$

The pathloss model is set as $128.1+37.6\log_{10}(d_{i,j})$ and we assume there is no shadow fading. So one user's statistical CSI is determined by its location only.

A two-cell network is illustrated in Fig.1, where BS 1 and 2 are located in $(-R,0)$ and $(R,0)$, respectively. Here R is the cell's radius and set as 1 km. Two users are generated on the line connecting BS 1 and BS 2, and we denote the location of user 1 and user 2 as $(-\mu_1 R,0)$ and $(\mu_2 R,0)$, respectively, where $0\leq\mu_1<1$ and $0\leq\mu_2<1$. When $N_T=2$, all nine combinations of the transmission mode and active transmit antenna number in each BS are listed as follows, $(BF\text{-}1,BF\text{-}1)$, $(BF\text{-}1,BF\text{-}2)$, $(BF\text{-}2,BF\text{-}1)$, $(BF\text{-}2,BF\text{-}2)$, $(IC\text{-}2,BF\text{-}1)$, $(IC\text{-}2,BF\text{-}2)$, $(BF\text{-}1,IC\text{-}2)$, $(BF\text{-}2,IC\text{-}2)$ and $(IC\text{-}2,IC\text{-}2)$.

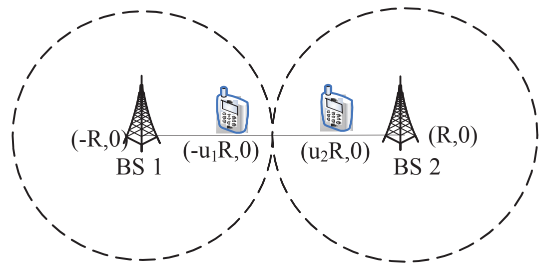

Fig. 1. A two-cell network. Each BS serves only one user, which is suffering ICI from the neighboring cell.

In Fig.2 we compare the simulation and calculation results of NEE of these combinations with NEE-optimal transmit power when user 1 and 2 are distributed symmetrically, i.e. $\mu_1=\mu_2$. We see that simulation results and calculation results of the same combination fit well with the other, so calculation results can be used to accurately describe simulation results. On the other hand, Fig.2 shows that when both users are near the cell edge, employing the $(IC\text{-}2,IC\text{-}2)$ combination is the most network-energy-efficient, and when both users are near the cell center, employing the $(BF\text{-}1,BF\text{-}1)$ combination brings the maximal NEE. Notice that we omit the combination $(BF\text{-}2,BF\text{-}1)$, $(BF\text{-}1,IC\text{-}2)$ and $(IC\text{-}2,BF\text{-}2)$ because they are identical to $(BF\text{-}1,BF\text{-}2)$, $(IC\text{-}2,BF\text{-}1)$ and $(BF\text{-}2,IC\text{-}2)$, respectively.

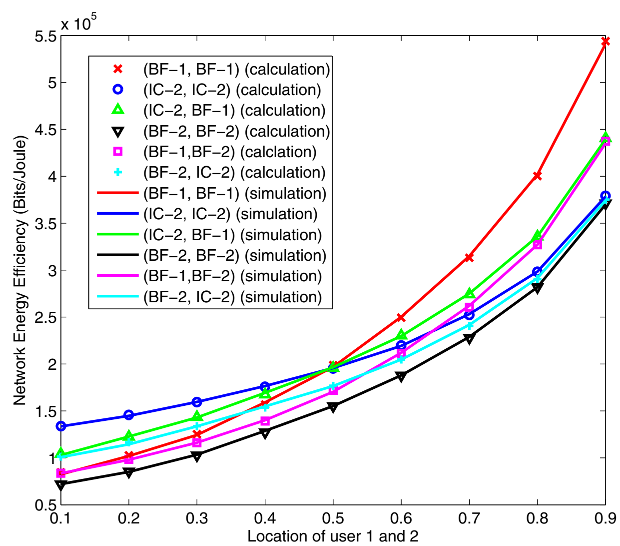

Fig. 2. Calculation and simulation results for all the possible combination with the NEE-optimal transmit power in each BS, assuming the two users are distributed symmetrically on the line connecting BS 1 and BS 2 and users' statistical CSI is available at both BSs.

Fig.3 gives the most network-energy-efficiency combination adaptively selected by the algorithm given users' locations in the two-cell system. We can see from it that, with the practial BS power model, the combinations $(BF\text{-}1, BF\text{-}1)$, $(IC\text{-}2, BF\text{-}1)$, $(BF\text{-}1, IC\text{-}2)$ and $(IC\text{-}2, IC\text{-}2)$ are the most network-energy-efficient for all possible users' locations.

Specifically, when both users are near cell edge, employing the combination $(IC\text{-}2, IC\text{-}2)$ brings the maximal NEE. The reason is that each user suffers a strong ICI from the neighboring cell and both BSs do ICIC can dramatically improve the total capacity. This can generate a positive impact on NEE, which is more significant than the negtive impact of the additional power consumption from activating a more transmit antenna.

When both users are near the cell center, employing the combination $(BF\text{-}1, BF\text{-}1)$ is the most network-energy-efficient. The reason is that, although activating a more transmit antenna can improve the sum capacity, no matter $BF\text{-}2$ or $IC\text{-}2$, its positive impact on NEE is less significant than the negative impact of the additional power consumption from activating a more transmit antenna.

When user 1 is near the cell center and user 2 is near the cell edge, the most network-energy-efficient combination is also $(BF\text{-}1, BF\text{-}1)$. The reason why the optimal one is not $(IC\text{-}2, BF\text{-}1)$ is that, when $(BF\text{-}1, BF\text{-}1)$ is adopted, user 1's SINR is much higher than user 2's SINR so user 1's ergodic capacity is much higher than user 2's ergodic capacity. Although the employment of ICIC in BS 1 for user 2 can dramatically improve user 2's ergodic capacity, it can do little to improve the total capacity of the two users. So the positive impact on NEE from improving the total capacity is less significant than the negative impact of the additional power consumption from activating a more transmit antenna in BS 1. This reason is also for the case that user 2 is near the cell center and user 1 is near the cell edge.

When $0.5 \leq \mu_1 \leq 0.6$ and $0.2 \leq \mu_2 \leq 0.4$, BS 1 does ICIC for user 2 while BS 2 activates only one transmit antenna seems the most network-energy-efficient. The reason is that, user 2 is interference-limited and ICIC in BS 1 can dramatically improve the user 2's capacity. On the other hand, when $(BF\text{-}1, BF\text{-}1)$ is employed, user 1's SINR is a little higher than user 2's SINR and user 1's capacity is also a little higher than user 2's capacity. So the total capacity of the two user can also be improved dramatically and its positive impact on NEE is more significant than the negative impact on NEE from the additional power consumption from activating a more transmit antenna in BS 1. This reason is also for the case that $0.5 \leq \mu_2 \leq 0.6$ and $0.2 \leq \mu_1 \leq 0.4$.

VI. Conclusion

The problem of Maximizing NEE in multicell systems is addressed in this paper. At first, we provide the closed-form expressions of NEE for all combinations of the transmission mode, active transmit antenna number in each BS when there are no more than three cells. Assuming all users' statistical CSI is available in all BSs, we provide an algorithm so that the combination with the best network energy efficiency can be selected using these closed-form expressions. Simulations show that, for each combination the calculation results of NEE fit well with the simulation results, and the NEE-optimal combination can be adaptively selected given the users's locations. At last we analyze the reason why the chosen one is optimal with respect of NEE.

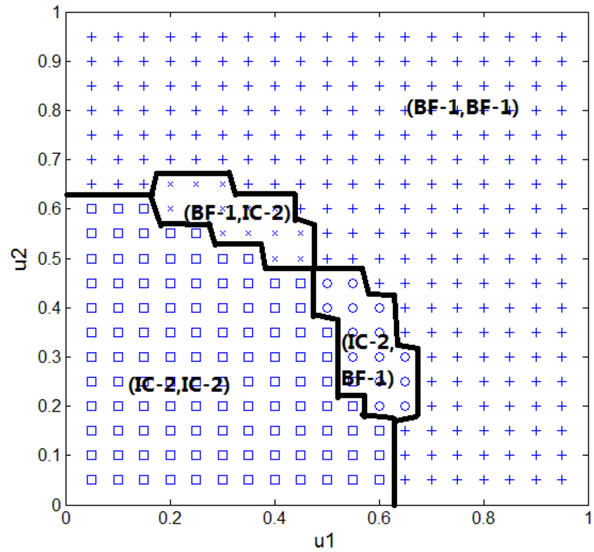

Fig. 3. Selected NEE-optimal combination of the transmission mode and active transmit antenna number for different user location where the two users are on the line connecting BS 1 and BS 2

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