A Novel Network Coding Multi-User Coordinated Multipoint Downlink Transmission Scheme

Wei Zhou[1], Ying Li[1], Yue Sun[1], and Dengkui Zhu[2]
[1]State Key Lab. of Integrated Service Networks, Xidian Univ., Xi'an 710071, China
[2]ZTE Corporation, Shenzhen 518004, China
Email: yli@mail.xidian.edu.cn

***Abstract*—A novel network coding based coordinated multi-point (NC-CoMP) process, which allows one of the cooperative base stations (BSs) to serve one more non-cell-edge UE simultaneously in its own cell, is proposed in this paper. To implement the NC-CoMP transmission, an alignment combined precoding(ACP) algorithm is designed to eliminate the inter-user interference and simultaneously to extract useful signal from the network coded signals. Two algorithms are presented to optimize the precoding vectors with the aim at maximizing the receive signal-to-noise rate(SNR) of the cell-edge users. Compared with the conventional two UE multi-user coherent joint processing CoMP (CJP-CoMP) scheme, the proposed NC-CoMP scheme can increase the date throughput significantly without requiring any extra resources. Simulations also illustrate that the bit error rate (BER) performance of the cell-edge users can be improved significantly when the NC-CoMP scheme is employed.**

I. Introduction

Coordinated multiple point (CoMP) transmission, which is also called as collaborative MIMO (multiple-input multiple-output) or network MIMO[1], is being considered as a candidate technique to improve the performance of the cell-edge users in the interference-limited environments, such as LTE-Advanced or IEEE 802.16m[2-4]. Joint processing (JP) and coordinated scheduling/beam-forming (CS/CB) are two main kinds of typical downlink (DL) CoMP techniques. In order to mitigate the interference in DL JP-CoMP, both nonlinear and linear precoding algorithms are considered. Though the nonlinear precoding algorithms such as dirty paper coding (DPC) and THP can provide significant performance improvement, it is too complex to practical implementation[5-7]. Therefore, some simpler linear precoding techniques are regarded as alternative solutions for DL JP-CoMP to decrease the complexity of the base stations (BSs) as well as that of the user equipments (UEs). In the case that each UE equipped with multiple antennas, conventional block diagonalization (BD) precoding algorithm is applied to eliminate the inter-user interference within the cooperative BSs[8, 9]. In [10], a polar decomposition (PD) based precoding algorithm, which takes the cost of backhaul and signaling of the system into consideration, is designed for the non-coherent DL JP-CoMP to improve the cell-edge performance. Chris and Huang proposed a soft interference nulling precoding technique for the case that the coordination clusters are limited[11]. In order to avoid the interference, none of the cooperative base stations is allowed to use the same resource to provide extra service to a non-CoMP UE when they jointly transmit data to the cell-edge CoMP UEs.

Besides CoMP, several other interference managements are also available, such as the interference alignment[12] and the network coding[13]. The interference alignment is designed to cast the interference signal into an overlapping shadows at the receivers while the desired signals remain distinct. Network coding initially proposed in [13] provides a new perspective which utilizes the interference, instead of mitigates, to improve the throughput in wireless networks.

Motivated by the idea of interference alignment and network coding, we propose a new DL network coding based CoMP (NC-CoMP) scheme which combines the conventional JP-CoMP scheme with the interference alignment and network coding. Without requiring any extra resources, the NC-CoMP scheme can provide service for the cell-edge UEs and one more non-CoMP UE simultaneously. To eliminate the inter-user interference, an alignment combined precoding(ACP) algorithm and the optimization of the precoding vectors are also discussed carefully. The remainder of the paper is organized as follow. The downlink model of the MIMO cellular network is presented in Section II. A detailed description of the NC-CoMP transmission scheme is also introduced. In Section III, the ACP algorithm is presented for the proposed new scheme. And two algorithms to optimize the alignment combined precoders are described in section IV, followed by the numerical results in Section V. Finally, Section VI concludes the paper.

$Notation$: In this paper, we use $\boldsymbol{I}_M$ represents an M by M unit matrix. $(\cdot)^*$, $(\cdot)^T$ and $(\cdot)^H$ denote conjugate, transpose, and Hermitian transpose operation, respectively. $\|.\|$ represents the L2-norm of a vector or a matrix.

II. System Model

A homogeneous cellular network, containing three sites, each with 3 sectors, is illustrated in Fig.1, where two users, i.e. u_1 and u_2, locate at the cell-edge of their serving cell and one, i.e. u_3, at the cell-center of its serving cell. Traditionally, if the two cell-edge users need the BSs to perform CoMP transmission, the three BSs will jointly broadcast the same signal to both users via precoding. And extra resource will be required when BS3 serves the cell-central UE. We call u_1 and u_2 as CoMP UEs and u_3 as non-CoMP UE.

978-1-4673-1881-5/12/$31.00 ©2012 IEEE

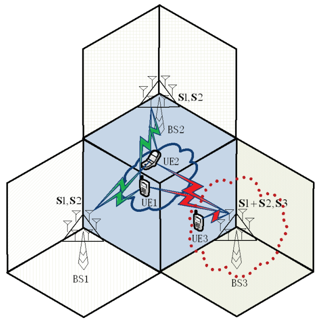

Fig. 1. Network coding based CoMP transmission scheme

Assume that each cooperative BS is equipped with N antennas and each user is equipped with M antennas, where $N > M$ and $M \geq 2$. Each data sequence $\boldsymbol{S}_i$ intended for user u_i is a κ dimension vector($\kappa < M$) and the transmitter precoding matrix at the BS i is denoted as $\boldsymbol{V}^{[i]}$, the received signal at user u_i can be written as

$$\boldsymbol{y}_i = \sum_{j=1}^{3} \boldsymbol{H}_{ji} \boldsymbol{V}^{[j]} \boldsymbol{X}_j + \boldsymbol{N}_i \tag{1}$$

where $\boldsymbol{X}_j$ is the signal transmitted from BS j and $\boldsymbol{V}^{[j]}$ is a $N \times 2\kappa$ matrix, $\boldsymbol{H}_{ji} \in \mathbb{C}^{M \times N}$ $(\,j = 1,\ 2,\ 3\ \ i = 1,\ 2,\ 3\,)$ is a $M \times N$ downlink channel matrix between the cooperative BS j and the user u_i and $\boldsymbol{N}_i = [n_1, n_2, \cdots, n_M]^T$ represents an additive complex-valued white Gaussian noise vector with zero means and variance matrix $\sigma_{ni}^2 \boldsymbol{I}_M \in \mathbb{C}^{M \times M}$, i.e. $\boldsymbol{N}_i \sim \mathcal{CN}(0,\ \sigma_{ni}^2 \boldsymbol{I}_M)$, $i = 1, 2, 3$.

To allow the serving BS3 to transmit extra information to the non-CoMP UE without requiring any extra resources, we let BS1 and BS2 broadcast the same information $\boldsymbol{X}_1 = \boldsymbol{X}_2 = [\boldsymbol{S}_1, \boldsymbol{S}_2]^T$, while BS3 broadcast a different signal $\boldsymbol{X}_3 = [\boldsymbol{S}_1 + \boldsymbol{S}_2, \boldsymbol{S}_3]^T$.

Remark 1: The non-CoMP user u_3 can be chosen flexibly via considering the interference with the measurements of RSRP (Reference Signal Receiving Power) of the other two cooperative BSs. Therefore, it is feasible for the BS3 to get the non-CoMP user which is close to the cell-center and suffers the least interference from the other two cooperative BSs in the candidate UEs set. In such a case, the interference from the other two cooperative BSs can be ignored and the received signal at user u_3 can be rewritten as

$$\boldsymbol{y}_3 = \boldsymbol{H}_{33} \boldsymbol{V}^{[3]} \boldsymbol{X}_3 + \boldsymbol{N}_3 \tag{2}$$

Different from the traditional CoMP scheme, the three cooperative BSs transmit different signals in the proposed scheme. More specifically, the cooperative BS3 combines the signals $\boldsymbol{S}_1$ and $\boldsymbol{S}_2$ into a network coded form $\boldsymbol{S}_1 + \boldsymbol{S}_2$, and then some freedom are available to transmit signals to the non-CoMP UE. We call BS3 which broadcasts network coding signals to the three users as the cooperative BS with network coding and the other two BSs as cooperative BSs without network coding.

III. Precoding design for the network coding based CoMP scheme

Assume that each user receives only one data stream from the BSs in each downlink CoMP transmission. Consequently, the precoding matrix $\boldsymbol{V}^{[i]}$ can be rewritten as $\boldsymbol{V}^{[i]} = [\boldsymbol{v}_1^{[i]}, \boldsymbol{v}_2^{[i]}]$. Let s_i be the data symbols to be received by the user u_i and the power of each data symbol is limited by $\mathbb{E}[\,s_i \cdot {s_i}^*\,] = \sigma_s^2\ (\,i = 1,\ 2,\ \ 3\,)$. The signal jointly sent by the cooperative BS1 and BS2 is expressed as $\boldsymbol{X}_1 = \boldsymbol{X}_2 = [\,s_1, s_2\,]^T$ and $\boldsymbol{X}_3$ sent by cooperative BS3 is expressed as $\boldsymbol{X}_3 = [\,s^{\Lambda}, s_3\,]^T$, where $s^{\Lambda} = s_1 + s_2$ is the netwok coding signal. In the following two subsections, we will discuss the design of the precoders $\boldsymbol{V}^{[i]} = [\,\boldsymbol{v}_1^{[i]}\ \ \boldsymbol{v}_2^{[i]}]$ employed by the three cooperative BSs to eliminate all the inter-user interference.

A. Alignment combined precoding (ACP) algorithm for the cooperative BSs without network coding

The the received signal in (1) at the cell-edge user u_i $(i = 1,\ 2)$ can be rewritten as

$$\begin{aligned}\boldsymbol{y}_i =& (\,\boldsymbol{H}_{1i}\boldsymbol{v}_i^{[1]} + \boldsymbol{H}_{2i}\boldsymbol{v}_i^{[2]})s_i + (\,\boldsymbol{H}_{1i}\boldsymbol{v}_{3-i}^{[1]} + \boldsymbol{H}_{2i}\boldsymbol{v}_{3-i}^{[2]})s_{3-i} \\ &+ \boldsymbol{H}_{3i}\boldsymbol{v}_1^{[3]}s^{\Lambda} + \boldsymbol{H}_{3i}\boldsymbol{v}_2^{[3]}s_3 + \boldsymbol{N}_i\end{aligned} \tag{3}$$

where the vectors $\boldsymbol{H}_{1i}\boldsymbol{v}_i^{[1]} + \boldsymbol{H}_{2i}\boldsymbol{v}_i^{[2]}$, $\boldsymbol{H}_{1i}\boldsymbol{v}_{3-i}^{[1]} + \boldsymbol{H}_{2i}\boldsymbol{v}_{3-i}^{[2]}$, $\boldsymbol{H}_{3i}\boldsymbol{v}_1^{[3]}$ and $\boldsymbol{H}_{3i}\boldsymbol{v}_2^{[3]}$ are $M \times 1$ complex vectors.

It can be seen from (3) that the received signal $\boldsymbol{y}_i$ are deteriorated by three kinds of interference. The first interference is the signal that the cooperative BS1 and BS2 transmit to the other cell edge user, i.e. the second part on the right hand side(RHS) of (3). The second interference is the network coded signal comes from the cooperative BS3 and the last one is the signal that BS3 transmits to the cell-center user u_3, corresponding to the third and fourth part on the RHS of (3) respectively.

Considering that the network coded signal s^{Λ} contains the information s_1 and s_2, it is possible to eliminate the second part interference via aligning the third interference on a special direction, i.e. the opposite direction of the second part. By doing so, a useful signal related to s_i can be extracted and the interference from both the second and third part can be eliminated. This can be achieved by designing proper precoding vectors $\boldsymbol{v}_{3-i}^{[1]}$ and $\boldsymbol{v}_{3-i}^{[2]}$, which are denoted as alignment combined precoding (ACP) vectors. The last interference can also be mitigated via the design of the precoding vector $\boldsymbol{v}_2^{[3]}$, which will be discussed carefully in the next subsection.

Assume the vector $\boldsymbol{H}_{3i}\boldsymbol{v}_1^{[3]}$ is in the direction $\boldsymbol{z}_1$, $\boldsymbol{H}_{1i}\boldsymbol{v}_i^{[1]} + \boldsymbol{H}_{2i}\boldsymbol{v}_i^{[2]}$ in the direction $\boldsymbol{z}_2$ and $\boldsymbol{H}_{3i}\boldsymbol{v}_2^{[3]}$ in the direction $\boldsymbol{z}_3$. As illustrated in Fig.2, to achieve the alignment discussed above, we should guarantee that the vector $\boldsymbol{H}_{1i}\boldsymbol{v}_{3-i}^{[1]} + \boldsymbol{H}_{2i}\boldsymbol{v}_{3-i}^{[2]}$ is in the opposite direction of $\boldsymbol{z}_1$. Therefore, we have

$$span(\boldsymbol{H}_{1i}\boldsymbol{v}_{3-i}^{[1]} + \boldsymbol{H}_{2i}\boldsymbol{v}_{3-i}^{[2]}) = span(\,-\boldsymbol{H}_{3i}\boldsymbol{v}_1^{[3]}) \tag{4}$$

Let $\boldsymbol{H}_i = [\,\boldsymbol{H}_{1i}\ \boldsymbol{H}_{2i}\,]$, $\boldsymbol{H}_i \in \mathbb{C}^{M \times 2N}$. Denote the pseudo inverse of $\boldsymbol{H}_i$ by $\boldsymbol{H}_i^{+} = \boldsymbol{H}_i^H(\,\boldsymbol{H}_i\boldsymbol{H}_i^H\,)^{-1}$. From (4), we can

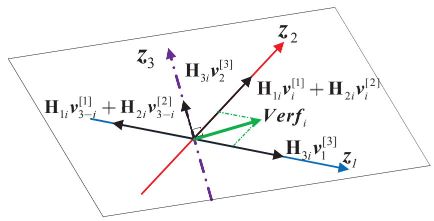

Fig. 2. The signal receive model of the cell-edge CoMP UE i, $i \in \{1,\ 2\}$

obtain the ACP vectors $\boldsymbol{v}_{3-i}^{[1]}$ and $\boldsymbol{v}_{3-i}^{[2]}$ as

$$\begin{bmatrix} \boldsymbol{v}_{3-i}^{[1]} \\ \boldsymbol{v}_{3-i}^{[2]} \end{bmatrix} = -\boldsymbol{H}_i^{+}\boldsymbol{H}_{3i}\boldsymbol{v}_1^{[3]}, \forall i \in \{1,\ 2\} \tag{5}$$

Substituting (5) into (3), the inter-user interference is aligned to the opposite direction of the network coded signal, and therefore the former can be eliminated. In such a case, (3) can be rewritten as

$$\boldsymbol{y}_i = (\sum_{j=1}^{2}\boldsymbol{H}_{ji}\boldsymbol{v}_i^{[j]} + \boldsymbol{H}_{3i}\boldsymbol{v}_1^{[3]})s_i + \boldsymbol{H}_{3i}\boldsymbol{v}_2^{[3]}s_3 + \boldsymbol{N}_i \tag{6}$$

It can be observed from (6) that, after the alignment, some useful signal is recovered from the interference signal and only the interference from the cooperative BS3 is remained, which will be eliminated via the design of the precoder $\boldsymbol{v}_2^{[3]}$.

B. Precoding design for the cooperative BS with network coding

As described above, the precoding matrix $\boldsymbol{V}^{[3]}$ designed for the cooperative BS with network coding, i.e. BS3 in Fig.1, should achieve two objectives. The first one is that the network coded signal s^{Λ} should be simultaneously eliminated at user u_3. The other is that, as shown in (6), the interference signal s_3 should be eliminated at user u_1 and u_2.

To eliminate the interference signal s^{Λ} at user u_3, the precoding vector $\boldsymbol{v}_1^{[3]}$ can be designed to lie in the null space of the channel matrix $\boldsymbol{H}_{33}$, i.e., $\boldsymbol{v}_1^{[3]} \in null(\boldsymbol{H}_{33})$. By doing so, (2) can be rewritten as

$$\boldsymbol{y}_3 = \boldsymbol{H}_{33}\boldsymbol{v}_2^{[3]}s_3 + \boldsymbol{N}_3 \tag{7}$$

From now on, we will discuss the design of $\boldsymbol{v}_2^{[3]}$ to eliminate the interference of s_3 at user u_1 and u_2, i.e. the second part of the RHS of (6). Assume that the receive beamforming vector at the cell-edge user u_i is denoted as $\mathbf{Verf}_i$, which is a $M \times 1$ complex vector. Let $y_i^{eq} = \mathbf{Verf}_i^H\boldsymbol{y}_i$.The received signals at UE u_i can be equivalent as

$$\begin{aligned} y_i^{eq} =& \mathbf{Verf}_i^H(\sum_{j=1}^{2}\boldsymbol{H}_{ji}\boldsymbol{v}_i^{[j]} + \boldsymbol{H}_{3i}\boldsymbol{v}_1^{[3]})s_i + \mathbf{Verf}_i^H\boldsymbol{H}_{3i}\boldsymbol{v}_2^{[3]}s_3 \\ &+ N_i^{eq} \end{aligned} \tag{8}$$

where $N_i^{eq} = {\mathbf{Verf}_i}^H\boldsymbol{N}_i,\ i = 1,\ 2$.

From the equation above, it can be seen that, if the precoding vector $\boldsymbol{v}_2^{[3]}$ are designed to make the vectors $\boldsymbol{H}_{31}\boldsymbol{v}_2^{[3]}$ and $\boldsymbol{H}_{32}\boldsymbol{v}_2^{[3]}$ orthogonal to the vectors $\mathbf{Verf}_1$ and $\mathbf{Verf}_2$, respectively, the interference signal s_3 at both users u_1 and u_2 can be eliminated. Therefore, let $\boldsymbol{H}_3 = \begin{bmatrix} \mathbf{Verf}_1^H\boldsymbol{H}_{31} \\ \mathbf{Verf}_2^H\boldsymbol{H}_{32} \end{bmatrix}$ and $\boldsymbol{H}_3 \in \mathbb{C}^{2\times N}$. The precoding vector $\boldsymbol{v}_2^{[3]}$ shall be chosen from the null space of the matrix $\boldsymbol{H}_3$, i.e. $\boldsymbol{v}_2^{[3]} \in null(\boldsymbol{H}_3)$.

So far, we obtain all the precoding matrices $\boldsymbol{V}^{[i]} = [\boldsymbol{v}_1^{[i]}\ \ \boldsymbol{v}_2^{[i]}]$ for the proposed NC-CoMP scheme. And the received signals at the cell-edge user u_i can be equivalent as

$$y_i^{eq} = \mathbf{Verf}_i^H(\sum_{j=1}^{2}\boldsymbol{H}_{ji}\boldsymbol{v}_i^{[j]} + \boldsymbol{H}_{3i}\boldsymbol{v}_1^{[3]})s_i + N_i^{eq} \tag{9}$$

From (7) and (9), we observe that all the CoMP UEs in the proposed scheme can receive their desired signal without suffering from the inter-user interference.

It should be noted that the receive beamforming vector $\mathbf{Verf}_i$, which can be a feedback from the serving BS, should lie in the same direction with the expected useful signals to maximize the SNR of the UE. Therefore, $\mathbf{Verf}_i$ can be expressed as

$$\mathbf{Verf}_i = \frac{\boldsymbol{H}_{1i}\boldsymbol{v}_i^{[1]} + \boldsymbol{H}_{2i}\boldsymbol{v}_i^{[2]} + \boldsymbol{H}_{3i}\boldsymbol{v}_1^{[3]}}{\parallel \boldsymbol{H}_{1i}\boldsymbol{v}_i^{[1]} + \boldsymbol{H}_{2i}\boldsymbol{v}_i^{[2]} + \boldsymbol{H}_{3i}\boldsymbol{v}_1^{[3]} \parallel} \tag{10}$$

IV. Optimization of the Precoding Vectors

According to the discussion above, only when the vector $\boldsymbol{v}_1^{[3]}$ is determined, can we determine the other precoding vectors to conduct the NC-CoMP transmission. Furthermore, substituting (5) into (9), we have as

$$y_i^{eq} = \mathbf{Verf}_i^H\boldsymbol{H}_i^{eq}\boldsymbol{v}_1^{[3]}s_i + N_i^{eq} \tag{11}$$

where $\boldsymbol{H}_i^{eq} = \boldsymbol{H}_{3,i} - \boldsymbol{H}_i\boldsymbol{H}_{3-i}^{+}\boldsymbol{H}_{3,3-i}$, $i = 1, 2$. Since $N_i^{eq} \sim \mathcal{CN}(0,\ \sigma_{ni}^2)$, the individual received SNR at the cell edge user u_i can be expressed as

$$SNR_{re,i} = \left|\mathbf{Verf}_i^H\boldsymbol{H}_i^{eq}\boldsymbol{v}_1^{[3]}\right|^2\sigma_s^2/\sigma_{ni}^2 \tag{12}$$

which means that it is the precoding vector $\boldsymbol{v}_1^{[3]}$ that has effect on the value of the received SNR. Therefore, it is feasible to maximize the received SNR via the optimization of the precoding vector $\boldsymbol{v}_1^{[3]}$.

According to the above precoding design principle, $\boldsymbol{v}_1^{[3]} \in null(\boldsymbol{H}_{33})$. Since $\boldsymbol{H}_{33} \in \mathbb{C}^{M\times N}$ and $N > M$, the dimension of the null space of $\boldsymbol{H}_{33}$ is $L \geq N - M$. Assume that $\{\boldsymbol{v}_{1,1}^{[3]}, \boldsymbol{v}_{1,2}^{[3]}, \cdots, \boldsymbol{v}_{1,L}^{[3]}\}$ represent the set of the orthogonal basis of $null(\boldsymbol{H}_{33})$, where $\boldsymbol{v}_{1,i}^{[3]}$ can be obtained by the Singular Value Decomposition (SVD) of $\boldsymbol{H}_{33}$. It is obvious that $\boldsymbol{v}_1^{[3]}$ can be the linear combination of the orthogonal basis, i.e. $\boldsymbol{v}_1^{[3]} = \sum_{k=1}^{L}\alpha_k\boldsymbol{v}_{1,k}^{[3]}$, where α_k is the coefficient of $\boldsymbol{v}_{1,k}^{[3]}$. And we denote $\boldsymbol{\alpha} = (\alpha_1, \alpha_2, \cdots, \alpha_L)^T$. Because the receive beanforming vector $\mathbf{Verf}_i$ lies in the same direction with the expected received signal $\boldsymbol{H}_i^{eq}\boldsymbol{v}_1^{[3]}s_i$, the maximization of the SNR at the receivers can be equivalent to maximize the strength of the expected signals, i.e.

$$\underset{\alpha_1,\alpha_2,\cdots,\alpha_L}{Max}\{\parallel \boldsymbol{H}_1^{eq}\sum_{k=1}^{L}\alpha_k \boldsymbol{v}_{1,k}^{[3]}\parallel \, and \, \parallel \boldsymbol{H}_2^{eq}\sum_{k=1}^{L}\alpha_k \boldsymbol{v}_{1,k}^{[3]}\parallel\} \tag{13}$$

subject to $\parallel \boldsymbol{v}_1^{[3]}\parallel^2 = 1$, namely $\sum_{k=1}^{L}\alpha_k^2 = 1$.

Due to the fact that $\parallel \boldsymbol{H}_1^{eq}\sum_{k=1}^{L}\alpha_k \boldsymbol{v}_{1,k}^{[3]}\parallel$ and $\parallel \boldsymbol{H}_2^{eq}\sum_{k=1}^{L}\alpha_k \boldsymbol{v}_{1,k}^{[3]}\parallel$ are independent, we cannot maximize them simultaneously. Thus, we propose two tradeoff optimization methods based on different objective functions.

A. Algorithm one: maximize the average SNR

When considering the average SNR as the objective function, the coefficient vector $\boldsymbol{\alpha} = (\alpha_1,\alpha_2,\cdots,\alpha_L)^T$ shall be optimized as

$$\begin{aligned}&\phi(\alpha_1,\alpha_2,\cdots,\alpha_L) = \\ &\underset{\alpha_1,\alpha_2,\cdots,\alpha_L}{Max}\left(\parallel \boldsymbol{H}_1^{eq}\sum_{k=1}^{L}\alpha_k \boldsymbol{v}_{1,k}^{[3]}\parallel + \parallel \boldsymbol{H}_2^{eq}\sum_{k=1}^{L}\alpha_k \boldsymbol{v}_{1,k}^{[3]}\parallel\right)\end{aligned} \tag{14}$$

subject to $\sum_{k=1}^{L}\alpha_k^2 = 1$.

B. Algorithm two: maximize either one SNR and minimize the SNR loss

This algorithm includes two steps. In the first step, we obtain the corresponding optimization coefficient vectors $\boldsymbol{\alpha}^{[i]} = (\alpha_1^{[i]},\alpha_2^{[i]},\cdots,\alpha_L^{[i]})^T$ for user u_i, which can be expressed as

$$f_i(\alpha_1^{[i]},\alpha_2^{[i]},\cdots,\alpha_L^{[i]}) = \underset{\alpha_1^{[i]},\alpha_2^{[i]},\cdots,\alpha_L^{[i]}}{Max}\parallel \boldsymbol{H}_i^{eq}\sum_{k=1}^{L}\alpha_k^{[i]}\boldsymbol{v}_{1,k}^{[3]}\parallel \tag{15}$$

subject to $\sum_{k=1}^{L}(\alpha_k^{[i]})^2 = 1,\, i = 1,2$.

Then, we will choose one from the two candidates $\boldsymbol{\alpha}^{[1]} = (\alpha_1^{[1]},\alpha_2^{[1]},\cdots,\alpha_L^{[1]})^T$ and $\boldsymbol{\alpha}^{[2]} = (\alpha_1^{[2]},\alpha_2^{[2]},\cdots,\alpha_L^{[2]})^T$ as the finial vector $\boldsymbol{\alpha} = (\alpha_1,\alpha_2,\cdots,\alpha_L)^T$. Noting that, if we choose $\boldsymbol{\alpha} = \boldsymbol{\alpha}^{[1]}$, some SNR loss might be inevitable at user u_2. Similarly, user u_1 will suffer some SNR loss if we let $\boldsymbol{\alpha} = \boldsymbol{\alpha}^{[2]}$. Therefore, the loss of the SNR should be minimized. To quantize such SNR loss, we define the following coefficient.

If the vector $\boldsymbol{\alpha}^{[i]}$ is employed, the SNR loss at cell-edge user u_{3-i} can be expressed as

$$\begin{aligned}&\Phi_i(\boldsymbol{\alpha}^{[i]}) = \\ &f_{3-i}(\alpha_1^{[3-i]},\alpha_2^{[3-i]},\cdots,\alpha_L^{[3-i]}) - \parallel \boldsymbol{H}_{3-i}^{eq}\sum_{k=1}^{L}\alpha_k^{[i]}\boldsymbol{v}_{1,k}^{[3]}\parallel\end{aligned} \tag{16}$$

According to (16), we can obtain the coefficient vector $\boldsymbol{\alpha} = (\alpha_1,\alpha_2,\cdots,\alpha_L)^T$ as follow

$$\boldsymbol{\alpha} = \begin{cases}\boldsymbol{\alpha}^{[1]} & if\; \Phi_1(\boldsymbol{\alpha}^{[1]}) < \Phi_2(\boldsymbol{\alpha}^{[2]}), \\ \boldsymbol{\alpha}^{[2]} & else\end{cases} \tag{17}$$

As described above, the first optimization method has a low complexity and promises the maximization of the average SNR of the two cell-edge users, while the second method guarantees either one of the two UEs receiving its own signal at the maximum SNR. Especially, when one of the cell-edge UEs' available maximum SNRs is relatively very low compared to the other one's, the second optimization method makes this user receive its own signal at its maximum SNR, whicht may not be usually achieved in the first optimization case.

V. Simulation resluts

Assume that the cell radius is 500m and the distance between the cooperative BS j and the cell-edge UE u_i is d_{ji}. Let $d_{min}^i = min\{d_{1\,i},\; d_{2\,i},\; d_{3\,i}\}$, $i = 1,\,2$. The downlink channel matrix $\boldsymbol{H}_{ji}$ is a quasi-static complex Gaussian channel, which is assumed to be only related to the distance d_{ji} for analytical simplicity. All the entries of $\boldsymbol{H}_{ji}$ are independently and identically distributed (i.i.d) zero mean complex Gaussian random variables with σ_{ij}^2 variance, i.e., $\mathcal{CN}(0\,,\sigma_{ij}^2)$, where $\sigma_{ij}^2 = d_{min}^i/d_{ji}$. Under such an assumption, we get $0 < \sigma_{ij}^2 \leq 1$. Considering that the non-cell-edge user u_3 is close to the center of the cooperation BS3, it is reasonable if we assume all the entries of $\boldsymbol{H}_{33}$ are i.i.d zero mean complex Gaussian random variables with unit variance, i.e., $\mathcal{CN}(0\,,1)$.

Assume that perfect channel state information (CSI) is available at all UEs and BSs and a strict equal power is allocated across all the antennas. Based on (6) and (7), the transmit SNR in our proposed scheme for the cell-edge user UE $i(i = 1,\,2)$ is defined as $SNR_{\,i} = (\sum_{j=1}^{2}\parallel \boldsymbol{v}_i^{[j]}\parallel^2 + \parallel \boldsymbol{v}_1^{[3]}\parallel^2)\sigma_s^2/N_0^{[i]}$, where $\sigma_{ni}^2 = N_0^{[i]}/2$. And the transmit SNR for the non-cell-edge user UE3 is defined as $SNR_3 = \parallel \boldsymbol{v}_2^{[3]}\parallel^2\sigma_s^2/N_0^{[3]}$, where $\sigma_{n3}^2 = N_0^{[3]}/2$.

Due to the fact that the communication quality for the cell-edge users should be guaranteed first in the CoMP transmission, we focus much more attention on the performance of the two cell-edge UEs. Fig.3 compares the bit error rate (BER) performance of the proposed network coding based CoMP scheme with that of the conventional 2-UE MU-CJP with BD precoding algorithm, where MMSE receiver is adopted. Fig.4 illustrates the sum rate performance of the two schemes. In both figures, the same cell-edge UEs, antenna configuration, quasi-static channel matrix, transmit SNR and uncoded data blocks with the BPSK modulation are assumed. From Fig.3, we observe that the performance of cell-edge UEs under NC-CoMP scheme is almost the same as that under the conventional CoMP. Therefore, it can be concluded that the proposed scheme can promise the communication quality for the cell-edge users. As illustrated in Fig.4, the sum rate of the proposed scheme exhibits superior to the conventional 2-UE MU-CJP transmission scheme. The throughput improvement mainly comes from the extra user u_3, which can get an extra service from the cooperative BS3 without exploiting any extra resources. Fig.5 and Fig.6 show the performance of the proposed scheme when we use the previous optimized

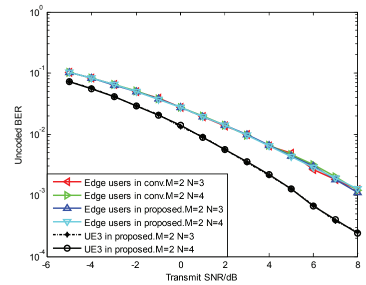

Fig. 3. Performance comparison of the cell-edge UEs with different schemes

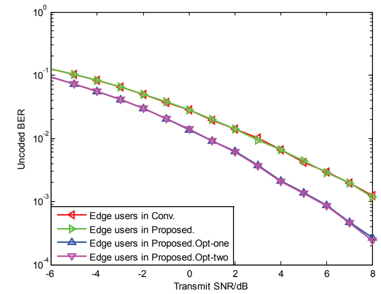

Fig. 5. BER of the proposed scheme with the optimization precoding

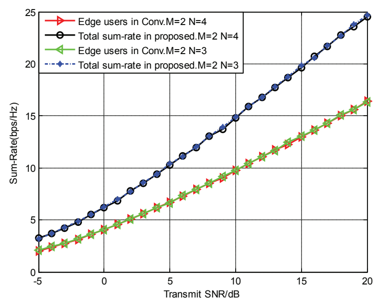

Fig. 4. Performance comparison of the system sum rates under different schemes

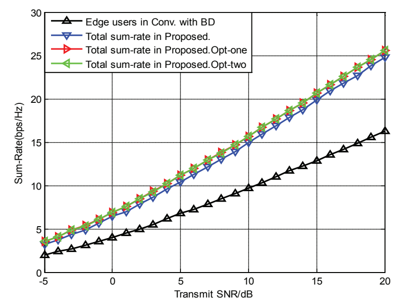

Fig. 6. Sum-Rate of the proposed scheme with the optimization precoding

precoding vectors for M=2, N=4. It can be observed that, compared with the conventional MU-CJP scheme, at least 2dB gains can be obtained if the optimized precoding vectors algorithm is employed at BER= 10^{-3}. And the sum rate is also improved by applying our proposed optimization methods. In both figures, we note that the two different optimization algorithms perform almost the same for the proposed scenario. From these figures, we can verify that the proposed scheme can efficiently improve the cooperative cells' average throughput.

VI. Conclusions

In this paper, we proposed a network coding based CoMP transmission scheme, which permit the cooperative BSs to transmit extra signal to the non-CoMP UE without requiring any extra resources. A novel precoding algorithm, called alignment combined precoding algorithm, is presented to eliminate the inter-user interference. Two optimization algorithms are also discussed to improve the performance of the proposed scheme. Simulations show that the proposed scheme can achieve improvement both in bit error rate of the CoMP UEs and in the sum rate of the system.

Acknowledgment

This work was supported by the National Science Foundation of China (61072064), the National Basic Research Program of China (973 Program, No.2012CB316100), the National Science and Technology Major Project(2010ZX03003-003-03), the Fundamental Research Funds for the Central Universities (K50510010026) and the ZTE Corporation project(2010ZTE01-01-3).

References

[1] M. Sawahashi, Y. Kishiyama, A. Morimoto, D. Nishikawa and M. Tanno,"Coordinated Multipoint Transmission/Reception Techniques for LTE-Advanced," *IEEE Wireless Communications*, vol.17, no.3, pp:26-34, April 2010.

[2] LG Electronics,"Network MIMO in LTE-Advanced",R1-082942, 3GPP TSG RAN WGI Meeting #54, 2008.

[3] LG Electronics,"CoMP Configurations and UE/eNB Behaviors in LTE-Advanced Downlink", R1-090213, 3GPP TSG RAN WGI Meeting #55b, 2009.

[4] Alcatel Shanghai Bell and Alcatel Lucent,"Collaborative MIMO for LTE-Advanced Downlink", R1-082501, 3GPP TSG RAN WGI Meeting #53b, 2008.

[5] Hitachi,"Further Considerations for Downlink CoMP Transmission using DPC MIMO", R1-091180, 3GPP TSG RAN WGI Meeting #56b, 2009.

[6] Zhenyu Tu. et. al.,"Multiuser Diversity for a Dirty Paper Approach", *IEEE Commun. Lett.*, vol.7, no.8, pp:370-372, Aug. 2003.

[7] J. Liu and A. Duel-Hallen,"Tomlinson-Harashima transmitter precoding for synchronous multi-user communications", in *Proc. CISS*'03, Baltimore, Md, USA, March, 2003.

[8] CMCC,"Downlink CoMP-MU-MIMO transmission Schemes", R1-090922, 3GPP TSG RAN WGI Meeting #56, 2009.

[9] Quentin H. Spencer, A. Lee Swindlehurst, Martin Haardt,"Zero-Forcing Methods for Downlink Spatial Multiplexing in Multiuser MIMO Channels", *IEEE Trans. on Signal Processing*, vol.52, no.2, pp:461-471, February, 2004.

[10] Huan Sun, Wei Fang, LinYang, "A Novel Precoder Design for Coordinated Multi-point Downlink Transmission", *IEEE Vehicular Technology Conference*(VTC Spring), May, 2011.

[11] T.K. Chris, H. Huang,"Linear Precoding in Cooperative MIMO Cellular Networks with Limited Coordination Clusters", *IEEE Journal on Selected Areas in Commun.*, Vol.28, No.9, pp:1446-1454, December, 2010.

[12] Viveck R. Cadambe, Syed Ali Jafar,"Interference Alignment and Degrees of Freedom of the K-User Interference Channel", *IEEE Trans. Inform. Theory*, vol.54, no.8, pp:3425-3441, Aug. 2008.

[13] R. Ahlswede, N. Cai, S.-Y. R. Li and R. W. Yeung, "Network information flow", *IEEE Trans. Inform. Theory*, vol.46, no.4, pp:1204-1216, Jul. 2000.