Coordinated Precoding and Proactive Interference Cancellation in Mixed Interference Scenarios

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***Abstract*—In heterogeneous cellular networks, cross-tier inter-cell interference is often in mixed interference scenario where the macro-cell causes strong interference to pico-cells while pico-cells only cause weak interference to the macro-cell. In this scenario, the popular interference coordination schemes using power control or time/frequency division multiplexing are far from achieving the spectrum efficiency potential. Exploiting the difference of transmit powers and channel gains in heterogeneous networks, the transmission schemes based on interference cancelation have great opportunity to gain more throughput benefit. In this paper, we propose a coordinated precoding and proactive interference cancelation scheme, where the precoding design is based on the known decoding order and is to maximize the sum-rate of two interfering users. Since the optimization problem is non-convex, we find a local maximum by constructing a concave lower bound of the objective function and iteratively tightening it. Simulation results show that the network throughput is remarkably improved in mixed interference scenarios relative to orthogonal division scheme and coordinated multi-point transmission scheme with zero forcing precoding.**

I. Introduction

Due to the large difference of transmit powers and channel gains, the interference environments in heterogeneous networks are more complicated than in homogeneous networks [1]. Conventional inter-cell interference mitigation schemes, including power control, interference orthogonalization and interference cancelation, can not achieve the potential of particular mixed interference channels, where the macro-cell causes strong interference to pico-cells while pico-cells only cause weak interference to the macro-cell.

With orthogonal transmission, each user in a two-user network only uses half of the time, frequency, or spatial resource. In interference cancelation schemes, the interference may not be decodable if the interference-to-signal power ratio is less than a required value determined by the conveyed data rate. Without transmitter-side joint design, the performance of conventional interference cancelation scheme depends on the opportunity provided by the channel. Therefore, we call it passive interference cancelation.

In heterogeneous networks, macro-cells are more likely to cause strong interference to pico-cells. This particular cross-tier interference characteristic give us chance to exploit the transmit power and channel gain differences of different links. With elaborated coordinations at transmitter sides, the strong interference is assured decodable at the suffering receiver when the macro-BS and pico-BS transmit simultaneously at highest possible data rates. We call this kind of transmission scheme as proactive interference cancellation.

In single-antenna interference channels, the amplitude-space sharing based proactive interference cancelation scheme was studied in [2]. Depending on the signal-to-noise ratio (SNR) and interference-to-noise ratio (INR) relations of the direct link and cross link channels, six scenarios are divided as very strong, strong, mixed 1, mixed 2, weak, and very weak interference. In each scenario, there is a corresponding transmission scheme to achieve the capacity or the best known achievable rate. In multiple-antenna interference channels, however, only the capacity-regions of strong or generally strong interference channels have been derived [3]. For the more general mixed interference channels, the capacity-region is unknown and the achievable sum-rate expression is non-convex over the precoding matrices, there is no efficient algorithm available to find the optimal precoding matrices [4].

In this paper, we first introduce a transmission scheme with coordinated precoding and proactive interference cancelation, and provide its achievable sum-rate and achievable rate-region. Then, the precoding matrices design is formulated as a non-convex optimization problem. To find a solution, a concave lower bound is constructed for the objective function and an iterative block coordinate descent method is used to continually tighten the lower bound. Simulation results demonstrate remarkable improvement in sum-rate and user fairness of the proposed scheme. Through comparisons, we can see that the proposed scheme and the coordinated multi-point transmission with joint processing (CoMP-JP) scheme are complementary in different interference scenarios.

II. Transmission Scheme and Problem Formulation

A. Mixed Interference Condition and Transmission Scheme

Consider a two-user MIMO interference channel, where BS_1 serves user 1 and BS_2 serves user 2. The i-th BS is equipped with M_i antennas and the i-th user is equipped with N_i antennas, and $\mathbf{H}_{ji} \in \mathbb{C}^{N_j \times M_i}$ denotes the channel matrix from BS_i to user j. Considering downlink transmission, the

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received symbols at user 1 and user 2 are respectively

$$\mathbf{y}_1 = \mathbf{H}_{11}\mathbf{x_1} + \mathbf{H}_{12}\mathbf{x_2} + \mathbf{z}_1 \quad (1)$$

$$\mathbf{y}_2 = \mathbf{H}_{21}\mathbf{x_1} + \mathbf{H}_{22}\mathbf{x_2} + \mathbf{z}_2 \quad (2)$$

where $\mathbf{x}_i$ is the symbol transmitted by BS_i with power P_i, and $\mathbf{z}_i$ is circular symmetric complex Gaussian noise with zero mean and normalized covariance matrix $\mathbf{I}$.

In heterogeneous networks, macro-BS usually has much larger transmit power than pico-BS, and the channel gains of direct links and cross links are dependent on the pico-BS deployment and user locations. When a pico-cell is close to a macro-BS, the pico-user transmission link will encounter serious interference.

In single-antenna Gaussian interference channel, the interference scenarios can be divided into strong, mixed, and weak cases according to the relationship between direct channel and cross channel gains [2]. For example, the channel conditions for the mixed interference scenario are

$$\begin{cases} |h_{11}| < |h_{21}| \\ |h_{22}| > |h_{12}| \end{cases} \text{or} \begin{cases} |h_{11}| > |h_{21}| \\ |h_{22}| < |h_{12}| \end{cases}, \quad (3)$$

which imply that one transmit signal is stronger as an interferer than as a desired signal, and another transmit signal is stronger as the desired signal than as an interferer. These interference conditions are not determined from the point of view of the receiver, which is somewhat counter-intuitive.

In MIMO interference channel, however, there is no clear division between various interference scenarios. As an approximation, the trace of the channel covariance matrix can be used as a metric, such as

$$\begin{cases} \text{Tr}(\mathbf{H}_{11}\mathbf{H}_{11}^H) < \text{Tr}(\mathbf{H}_{21}\mathbf{H}_{21}^H) \\ \text{Tr}(\mathbf{H}_{22}\mathbf{H}_{22}^H) > \text{Tr}(\mathbf{H}_{12}\mathbf{H}_{12}^H) \end{cases}. \quad (4)$$

The transmission scheme to improve the achievable rates under the mixed interference scenario is as follows. Firstly, the decoding order at each receiver is fixed according to the channel gains. For example, if BS_1 causes strong interference, at user 2 the interference from BS_1 should be decoded and canceled first and then the desired signal from BS_2 is decoded in an interference-free environment; while at user 1 the desired signal from BS_1 is decoded simply by treating the interference from BS_2 as noise. Then we coordinate two transmitters (i.e., their precoding matrices and data rates) so that the strong interference is guaranteed to be decodable meanwhile the achievable sum rate can be maximized.

B. Achievable Sum-Rate

Assume that the precoding matrix of BS_i is $\mathbf{V}_i$, and the transmit power of BS_i is constrained as $\text{Tr}(\mathbf{V}_i\mathbf{V}_i^H) \le P_i$, for $i = 1, 2$. With the decoding order described above, the achievable rate of user 2 is

$$R_2 \le \ln\left|\mathbf{I} + \mathbf{H}_{22}\mathbf{V}_2\mathbf{V}_2^H\mathbf{H}_{22}^H\right| = R_{2,\max} \quad (5)$$

since the decoding of user 2 is under an interference-free environment.

The achievable rate of user 1 is more complicated since the transmitted signal of BS_1 should be decodable both at user 1 and user 2 under different interference environment, i.e.,

$$R_1 = \min\{R_{1a}, R_{1b}\} \quad (6)$$

where

$$R_{1a} \le \ln\left|\mathbf{I} + \frac{\mathbf{H}_{11}\mathbf{V}_1\mathbf{V}_1^H\mathbf{H}_{11}^H}{\mathbf{I} + \mathbf{H}_{12}\mathbf{V}_2\mathbf{V}_2^H\mathbf{H}_{12}^H}\right| = R_{1a,\max} \quad (7)$$

denotes the achievable rate at user 1 where the cross link signal from BS_2 behaves as interference, and

$$R_{1b} \le \ln\left|\mathbf{I} + \frac{\mathbf{H}_{21}\mathbf{V}_1\mathbf{V}_1^H\mathbf{H}_{21}^H}{\mathbf{I} + \mathbf{H}_{22}\mathbf{V}_2\mathbf{V}_2^H\mathbf{H}_{22}^H}\right| = R_{1b,\max} \quad (8)$$

denotes the achievable rate at user 2 where the direct link signal from BS_2 behaves as interference. The transmit date rate of BS_1 should be less than R_{1a} and R_{1b} to assure the signal is decodable at both receivers.

We can see that with a fixed decoding order the achievable rates are determined by the precoding matrices. However, the conventional linear precoding design method, such as zero-forcing, is no longer applicable. Note that we do not avoid interference through spatial orthogonalization. On the contrary, we strive to improve the spectrum utilization efficiency by allowing the two users sharing spatial resources.

In this paper, we optimized the precoding matrices to maximizing the sum rate of the system using proactive interference cancelation. For this purpose, a central processor is required to collect all the channel information for the optimization. The obtained precoding matrices are then sent to every transmitters, which do not need high capacity backhaul links.

The optimization problem can be formulated as

$$\begin{aligned} \max_{\mathbf{V}_1,\mathbf{V}_2} \quad & \{\min(R_{1a}, R_{1b}) + R_2\} \\ s.t. \quad & \text{Tr}(\mathbf{V}_1\mathbf{V}_1^H) \le P_1 \\ & \text{Tr}(\mathbf{V}_2\mathbf{V}_2^H) \le P_2 \end{aligned} \quad (9)$$

where R_2, R_{1a} and R_{1b} are given in (5), (7) and (8), respectively.

C. Achievable Rate Region

In this subsection, we study the achievable rate of each user through rate region analysis and give the possible rate pairs of both users with the maximized sum-rate.

The achievable sum-rate expression can be expressed as

$$\begin{aligned} & R_{\text{sum}} \\ & = \min\{R_{1a} + R_2, R_{1b} + R_2\} \\ & \le \min\begin{cases} \ln\left|\mathbf{I} + \frac{\mathbf{H}_{11}\mathbf{V}_1\mathbf{V}_1^H\mathbf{H}_{11}^H}{\mathbf{I}+\mathbf{H}_{12}\mathbf{V}_2\mathbf{V}_2^H\mathbf{H}_{12}^H}\right| + \ln\left|\mathbf{I} + \mathbf{H}_{22}\mathbf{V}_2\mathbf{V}_2^H\mathbf{H}_{22}^H\right| \\ \ln\left|\mathbf{I} + \mathbf{H}_{21}\mathbf{V}_1\mathbf{V}_1^H\mathbf{H}_{21}^H + \mathbf{H}_{22}\mathbf{V}_2\mathbf{V}_2^H\mathbf{H}_{22}^H\right| \end{cases}. \end{aligned} \quad (10)$$

We can find that given $\mathbf{V}_1$ and $\mathbf{V}_2$ the first sum-rate constraint is a summation of two point-to-point channel capacities, where decreasing R_2 does not provide any help to increase R_{1a}. The

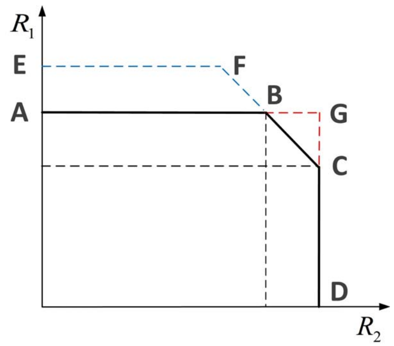

Fig. 1. Illustration of the achievable rate region.

second sum-rate constraint is a multiple-access channel sum-capacity, where R_{1b} and R_2 can be compromised.

Figure 1 shows the achievable rate region of user 1 and user 2, where the region inside A-G-D is determined by the first sum-rate constraint, the region inside E-F-C-D is determined by the second sum-rate constraint, and their intersection, i.e., the region inside A-B-C-D is the achievable rate region of the system. Specifically, the achievable rate region of user 1 and user 2 is

$$\begin{cases} R_1 \le \ln \left| \mathbf{I} + \frac{\mathbf{H}_{11}\mathbf{V}_1\mathbf{V}_1^H\mathbf{H}_{11}^H}{\mathbf{I}+\mathbf{H}_{12}\mathbf{V}_2\mathbf{V}_2^H\mathbf{H}_{12}^H} \right| \\ R_1 \le \ln \left| \mathbf{I} + \mathbf{H}_{21}\mathbf{V}_1\mathbf{V}_1^H\mathbf{H}_{21}^H \right| \\ R_2 \le \ln \left| \mathbf{I} + \mathbf{H}_{22}\mathbf{V}_2\mathbf{V}_2^H\mathbf{H}_{22}^H \right| \\ R_1 + R_2 \le \ln \left| \mathbf{I} + \mathbf{H}_{21}\mathbf{V}_1\mathbf{V}_1^H\mathbf{H}_{21}^H + \mathbf{H}_{22}\mathbf{V}_2\mathbf{V}_2^H\mathbf{H}_{22}^H \right| \end{cases} . \quad (11)$$

In Fig. 1, the boundaries A-G and F-C may or may not have intersection, depending on the relationship of the two constraints on R_1.

To achieve the data rate pair (R_1,R_2) on the boundary B-C, the decoding order at user 2 should be changed and rate-splitting technique should be resorted. The possible compromise between R_1 and R_2 allows us to assign different priority to the two users when the achievable sum-rate is fixed.

III. Optimization Algorithm for Coordinated Precoding

By observing (7) and (8), we know that R_{1a} and R_{1b} are non-concave functions over $\mathbf{V}_2$, and the max-min optimization problem (9) is non-convex.

To find a feasible solution, we first introduce a concave lower bound for each of the functions R_{1a}, R_{1b} and R_2. Since the summation and the minimization of two concave functions are also concave, problem (9) can be transformed to a convex optimization problem. The lower bound is tight and will converge to a stationary point after iterations. Therefore, we can at least find a local maximum.

A. Concave Lower Bounds

Inspiring by [5], we define a new function as

$$f_{1a}(\mathbf{V}_1, \mathbf{V}_2, \mathbf{U}_{1a}, \mathbf{W}_{1a}) = \ln|\mathbf{W}_{1a}| - \mathrm{Tr}(\mathbf{W}_{1a}\mathbf{E}_{1a}) + d_1, \quad (12)$$

where $\mathbf{U}_{1a}$ is the linear detection matrix for the desired signal at user 1, $\mathbf{E}_{1a}$ is the covariance matrix of mean-square-error (MSE), d_1 is the number of data streams, and $\mathbf{W}_{1a}$ is an auxiliary positive definite matrix. With linear detection, the estimation MSE of the desired signal is

$$\begin{aligned} \mathbf{E}_{1a} =& (\mathbf{I} - \mathbf{U}_{1a}^H\mathbf{H}_{11}\mathbf{V}_1)(\mathbf{I} - \mathbf{U}_{1a}^H\mathbf{H}_{11}\mathbf{V}_1)^H \\ &+ \mathbf{U}_{1a}^H\mathbf{H}_{12}\mathbf{V}_2\mathbf{V}_2^H\mathbf{H}_{12}^H\mathbf{U}_{1a} + \mathbf{U}_{1a}^H\mathbf{U}_{1a}. \end{aligned} \quad (13)$$

Proposition 1: $f_{1a}(\mathbf{V}_1, \mathbf{V}_2, \mathbf{U}_{1a}, \mathbf{W}_{1a})$ is a concave function over $\mathbf{V}_1$, $\mathbf{V}_2$, $\mathbf{U}_{1a}$, and $\mathbf{W}_{1a}$, respectively, and

$$f_{1a}(\mathbf{V}_1, \mathbf{V}_2, \mathbf{U}_{1a}, \mathbf{W}_{1a}) \le R_{1a,\max} \quad (14)$$

where the equality holds when the minimum MSE (MMSE) detection is employed, i.e.,

$$\mathbf{U}_{1a}^* = (\mathbf{I} + \mathbf{H}_{11}\mathbf{V}_1\mathbf{V}_1^H\mathbf{H}_{11}^H + \mathbf{H}_{12}\mathbf{V}_2\mathbf{V}_2^H\mathbf{H}_{12}^H)^{-1}\mathbf{H}_{11}\mathbf{V}_1, \quad (15)$$

$$\mathbf{E}_{1a}^* = \mathbf{I} - \mathbf{V}_1^H\mathbf{H}_{11}^H\mathbf{U}_{1a}^*, \quad (16)$$

and

$$\mathbf{W}_{1a}^* = (\mathbf{E}_{1a}^*)^{-1}. \quad (17)$$

The proof of Proposition 1 is similar with the proof of Theorem 1 in [6], which is omitted due to the lack of space. Proposition 1 implies that $f(.)$ is a lower bound of $R_{1a,\max}$ and the lower bound becomes tight when the minimum MSE (MMSE) detection is employed.

The concave lower bound of $R_{1b,\max}$ can be similarly defined as

$$f_{1b}(\mathbf{V}_1, \mathbf{V}_2, \mathbf{U}_{1b}, \mathbf{W}_{1b}) = \ln|\mathbf{W}_{1b}| - \mathrm{Tr}(\mathbf{W}_{1b}\mathbf{E}_{1b}) + d_1 \quad (18)$$

where

$$\begin{aligned} \mathbf{E}_{1b} =& (\mathbf{I} - \mathbf{U}_{1b}^H\mathbf{H}_{21}\mathbf{V}_1)(\mathbf{I} - \mathbf{U}_{1b}^H\mathbf{H}_{21}\mathbf{V}_1)^H \\ &+ \mathbf{U}_{1b}^H\mathbf{H}_{22}\mathbf{V}_2\mathbf{V}_2^H\mathbf{H}_{22}^H\mathbf{U}_{1b} + \mathbf{U}_{1b}^H\mathbf{U}_{1b}. \end{aligned} \quad (19)$$

Although $R_{2,\max}$ is a concave function over $\mathbf{V}_2\mathbf{V}_2^H$, it is not concave over $\mathbf{V}_2$. Rewrite the expression of $R_{2,\max}$ as

$$R_{2,\max} = \ln \left| \mathbf{I} + \frac{\mathbf{H}_{22}\mathbf{V}_2\mathbf{V}_2^H\mathbf{H}_{22}^H}{\mathbf{I} + \mathbf{H}_0\mathbf{V}_1\mathbf{V}_1^H\mathbf{H}_0^H} \right| \quad (20)$$

where $\mathbf{H}_0$ is a zero matrix. A concave lower bound of $R_{2,\max}$ can be similarly defined as

$$f_2(\mathbf{V}_1, \mathbf{V}_2, \mathbf{U}_2, \mathbf{W}_2) = \ln|\mathbf{W}_2| - \mathrm{Tr}(\mathbf{W}_2\mathbf{E}_2) + d_2 \quad (21)$$

where

$$\begin{aligned} \mathbf{E}_2 =& (\mathbf{I} - \mathbf{U}_2^H\mathbf{H}_{22}\mathbf{V}_2)(\mathbf{I} - \mathbf{U}_2^H\mathbf{H}_{22}\mathbf{V}_2)^H \\ &+ \mathbf{U}_2^H\mathbf{H}_0\mathbf{V}_1\mathbf{V}_1^H\mathbf{H}_0^H\mathbf{U}_2 + \mathbf{U}_2^H\mathbf{U}_2 \\ =& (\mathbf{I} - \mathbf{U}_2^H\mathbf{H}_{22}\mathbf{V}_2)(\mathbf{I} - \mathbf{U}_2^H\mathbf{H}_{22}\mathbf{V}_2)^H + \mathbf{U}_2^H\mathbf{U}_2. \end{aligned} \quad (22)$$

The matrix $\mathbf{U}_{1b}$ is for detecting the interference signal from BS_1 at user 2, while the matrix $\mathbf{U}_2$ is for detecting the desired signal after interference cancelation at user 2. Thus the MMSE detection matrices are respectively

$$\mathbf{U}_{1b}^* = (\mathbf{H}_{21}\mathbf{V}_1\mathbf{V}_1^H\mathbf{H}_{21}^H + \mathbf{H}_{22}\mathbf{V}_2\mathbf{V}_2^H\mathbf{H}_{22}^H + \mathbf{I})^{-1}\mathbf{H}_{21}\mathbf{V}_1 \quad (23)$$

and

$$\mathbf{U}_2^* = (\mathbf{H}_{22}\mathbf{V}_2\mathbf{V}_2^H\mathbf{H}_{22}^H + \mathbf{I})^{-1}\mathbf{H}_{22}\mathbf{V}_2. \tag{24}$$

The corresponding optimal auxiliary matrices $\mathbf{W}_{1b}^*$ and $\mathbf{W}_2^*$ that make the lower bounds tight are respectively

$$\mathbf{W}_{1b}^* = (\mathbf{E}_{1b}^*)^{-1} = (\mathbf{I} - \mathbf{V}_1^H\mathbf{H}_{21}^H\mathbf{U}_{1b}^*)^{-1} \tag{25}$$

and

$$\mathbf{W}_2^* = (\mathbf{E}_2^*)^{-1} = (\mathbf{I} - \mathbf{V}_2^H\mathbf{H}_{22}^H\mathbf{U}_2^*)^{-1}. \tag{26}$$

B. Optimization Algorithm

Using the constructed lower bounds, optimization problem (9) is transformed to

$$\begin{aligned} \max\ & g(\mathbf{V}_1, \mathbf{V}_2, \mathbf{U}_{1a}, \mathbf{W}_{1a}, \mathbf{U}_{1b}, \mathbf{W}_{1b}, \mathbf{U}_2, \mathbf{W}_2) \\ s.t.\ & \mathrm{Tr}(\mathbf{V}_1\mathbf{V}_1^H) \le P_1 \\ & \mathrm{Tr}(\mathbf{V}_2\mathbf{V}_2^H) \le P_2 \end{aligned} \tag{27}$$

where the maximization is over all matrices $\mathbf{V}_1$, $\mathbf{V}_2$, $\mathbf{U}_{1a}$, $\mathbf{W}_{1a}$, $\mathbf{U}_{1b}$, $\mathbf{W}_{1b}$, $\mathbf{U}_2$, $\mathbf{W}_2$, and the objective function is

$$\begin{aligned} & g(\mathbf{V}_1, \mathbf{V}_2, \mathbf{U}_{1a}, \mathbf{W}_{1a}, \mathbf{U}_{1b}, \mathbf{W}_{1b}, \mathbf{U}_2, \mathbf{W}_2) \\ &= \min\left\{\begin{matrix} f_{1a}(\mathbf{V}_1, \mathbf{V}_2, \mathbf{U}_{1a}, \mathbf{W}_{1a}) \\ f_{1b}(\mathbf{V}_1, \mathbf{V}_2, \mathbf{U}_{1b}, \mathbf{W}_{1b}) \end{matrix}\right\} + f_2(\mathbf{V}_1, \mathbf{V}_2, \mathbf{U}_2, \mathbf{W}_2). \end{aligned} \tag{28}$$

The new objective function in (28) is a tight lower bound of the original objective function in (9) when $\mathbf{U}_k = \mathbf{U}_k^*$ and $\mathbf{W}_k = \mathbf{W}_k^*$, for $k = 1a$, $1b$, and 2.

The objective function (28) is concave over each of the variables, so the transformed optimization problem is convex. We can use the block coordinate descent method to solve this problem [7], where the three variable groups $\mathbf{V}$, $\mathbf{U}$ and $\mathbf{W}$ are updated one by one. When one group variables are optimizing, the other two groups are fixed as known matrices. The iteration steps of the optimization algorithm are listed in Table I.

TABLE I
ITERATION STEPS OF THE OPTIMIZATION ALGORITHM

1) Initialize $\mathbf{V}_i$ under the condition of $\mathrm{Tr}(\mathbf{V}_i\mathbf{V}_i^{\mathbf{H}}) \le P_i, \quad i = 1, 2.$
2) Update $\mathbf{U}_k$ $(k = 1a, 1b, 2)$ by using (15), (23) and (24).
3) Update $\mathbf{W}_k$ $(k = 1a, 1b, 2)$ by using (17), (25) and (26).
4) Update $\mathbf{V}_i$ $(i = 1, 2)$ by solving the convex problem in (27).
5) Go back to step **2)** until convergence.

Each time when we update a variable group, the objective function $g(\cdot)$ is maximized with two other variable groups fixed. That is to say, when the number of iteration grows, the objective function will monotonically increase. Since the sum-rate has a finite upper bound, the algorithm will converge after a number of iterations. In practice, we can stop when the increment between two iterations is less than a threshold.

Since the original optimization problem is non-convex, it may have more than one local optima. The proposed algorithm can only achieve one of these local optima. However, we will see in next section that the local optimal result has already significantly improved the system performance.

IV. SIMULATION RESULTS

In this section, we evaluate the achievable rates of the proposed coordinated precoding and proactive interference cancelation scheme (CP-PIC) in heterogeneous networks. Assume that a macro-BS serves a macro-user and a pico-BS serves a pico-user, all the BSs and users are equipped with two antennas. The radiuses of the macro-cell and pico-cell are respectively 500 m and 60 m. The path loss is computed using the 3GPP channel models [8], and small-scale Rayleigh fading is considered. The maximal transmit powers of the macro-BS and pico-BS are 46 dBm and 30 dBm, respectively. The noise power is determined by the cell-edge SNR of the macro-cell, which is set as 5 dB.

To simulate the system performance under different interference scenarios, we fix the position of macro-user at 250 m away from the macro-BS, and move the pico-cell from macro-cell center to macro-cell edge while keep the relative position between pico-BS and pico-user fixed.

For comparison, we also simulate the achievable sum-rates of the systems with time/frequency orthogonal transmission (Orthogonal), treating interference as background noise (BG-NOISE), and CoMP-JP [9]. In the BG-NOISE scheme, the precoding matrices of two BSs are jointly optimized with the iteratively weighted MMSE approach to maximize the sum-rate [5], but in this scheme interference cancelation is not applied while the interference is always regarded as background noise no matter how large it is. In CoMP-JP scheme, ZFBD precoding is employed and the power allocation among transmit data streams are optimized to maximize the sum-rate under the per BS power constraint [10].

The achievable sum-rates of the four transmission schemes are shown in Fig. 2. We can see that four regions are successively experienced along with the moving of pico-cells, which represent mixed 1, strong, mixed 2, and weak interference scenarios respectively. In all the four regions, the proposed CP-PIC scheme is superior to the BG-NOISE scheme, and the BG-NOISE scheme is superior to the orthogonal scheme. In mixed 1 scenario, the achievable sum-rate of CP-PIC scheme also exceeds that of the CoMP-JP scheme; and in strong and mixed 2 scenario, CoMP-JP scheme overwhelmingly performs the best.

For CoMP-JP scheme, due to the per BS power constraint, when the pico-cell moves close to the macro-BS, the macro-BS can only transmit with a small portion of its power to avoid the pico-BS exceeding its power constraint. When the pico-cell moves away, the performance of CoMP-JP scheme becomes better. These comparison results show that the performance of CoMP-JP will degrade in some kinds of interference scenarios, where CP-PIC becomes a good complementary scheme. The CP-PIC scheme is able to exploit the channel gain differences and can benefit from the mixed interference scenario.

We also show the achievable data rate of the macro-user and pico-user separately, where the results of CP-PIC scheme are shown in Fig. 3 and the results of BG-NOISE and CoMP-JP schemes are shown in Fig. 4. To focus on the behavior of

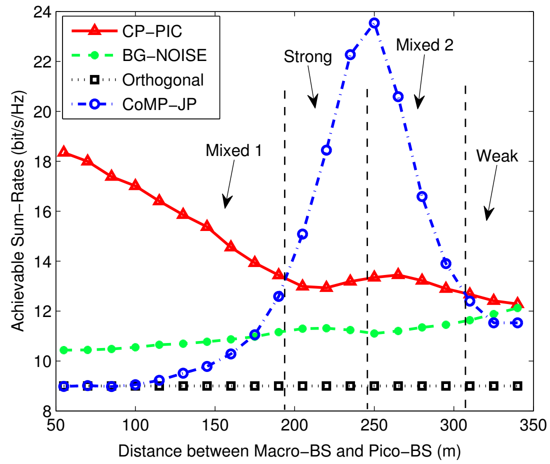

Fig. 2. Achievable sum-rates of different transmission schemes.

various schemes in mixed interference scenario, only mixed 1 region is shown. For the CP-PIC scheme, we have known that there is an achievable rate region where the data rates of macro-user and pico-user can be compromised. In Fig. 3, when the macro-user is of high priority, the data rate of macro-user is slightly higher than that of the pico-user, and the maximal gap is about 1.5 bps/Hz; when the pico-user is of high priority, the data rate curves of the two users will cross. On the contrary, we can see that for the BG-NOISE scheme, basically only the macro-user is served, the data rate of pico-user is almost zero. This is because the interference is too strong at the pico-user. For the CoMP-JP scheme, the data rate of pico-user is much higher than that of the macro-user. Under the per BS power constraint, the service of macro-user is dramatically deteriorated in order to support the service of the pico-user. These results demonstrate that the proposed CP-PIC scheme can provide fairness among users for the particular kind of cross-tier interference.

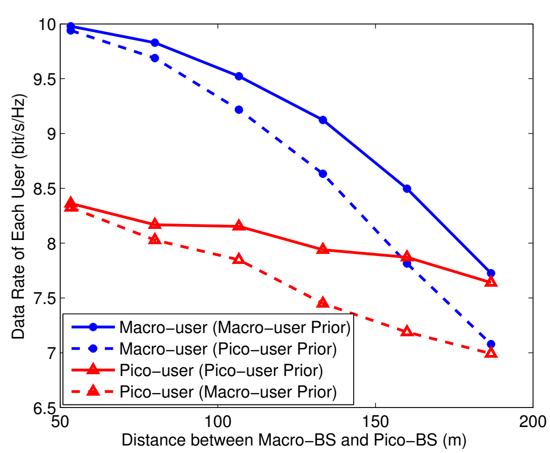

Fig. 3. Data rates of each user with CP-PIC scheme when different user priority is set.

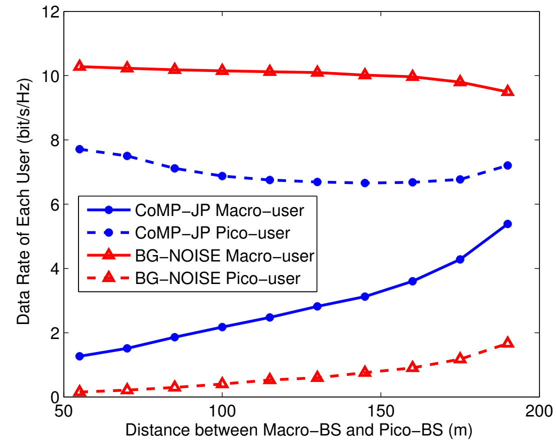

Fig. 4. Data rates of each user with CoMP-JP and BG-NOISE schemes.

V. Conclusion

We introduced a transmission scheme with coordinated precoding and proactive interference cancelation to cope with the strong cross-tier interference in heterogeneous networks, where the large channel gain differences are exploited. The precoding matrices are obtained by solving an optimization problem to maximize the sum-rate achieved by the proactive interference cancelation. Although only local optimum is approached, simulation results demonstrated significant improvement on the sum-rate and user fairness in mixed interference scenarios.

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