Multi-carrier Cooperated Interference Cancelation in Heterogeneous Cellular Networks

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***Abstract*—With the increasing number of mobile terminals, the capacity of cellular network can hardly satisfy the user requirement in the future. In next generation cellular systems, heterogeneous network is proposed to improve the spatial spectrum efficiency. In this paper, we study a joint coding scheme to increase the achievable sum-rate of multi-carrier heterogeneous systems, where we introduce transmission cooperation among subcarriers in the amplitude space to assist interference elimination at the receiver. Specifically, we propose to transmit information through cross links on some of the subcarriers where the users suffer from the strong interference, and use this information at the receiver to cancel the interference experienced on other subcarriers. We develop the direct-link transmission strategy using layered lattice code, and design subcarrier allocation algorithm between direct-link and cross-link transmissions. Simulation results show that the proposed joint coding scheme achieves higher sum rate than separated coding schemes in strong interference channels.**

***Index Terms*—Cross-link transmission, interference cancelation, joint coding, layered lattice code, multi-carrier**

I. INTRODUCTION

Heterogeneous networks can improve the spectrum efficiency of cellular systems by offloading the heavy traffics. Macro-cells are able to provide basic coverage and support fast mobility, whereas pico-cells are deployed to provide high-capacity transmission for hotspot zones. In such kind of networks, the interference environments are very different from homogeneous networks. The location of the users and the transmission power difference between the macro-BS and pico-BS have great impact on the strength of the received signals, and may lead to strong interference between the macro-user and pico-user links.

For interference networks, power control is a usual way to coordinate the inter-cell interference, and power allocation across subcarriers is often used to improve the sum-rate of multi-carrier systems. It has been known that this kind of schemes are only efficient when the users suffer from weak interference [1]. For strong or mixed interference, the best known achievable transmission scheme is Han-Kobayashi (H-K) coding [2], which divides the transmit information into private and common portions, and was recently proved to be able to approach the capacity region to within 1 bit [3]. However, H-K coding is a single-carrier transmission scheme, which did not consider the potential of subcarriers cooperation that may further improve the capacity of multi-carrier systems. As indicated by a counter-example, the capacities of multi-carrier interference channels cannot be achieved by separated encoding on each subcarrier subject to a power allocation across subcarriers [4]. This information theoretic result suggests that joint coding among subcarriers is essential to attain the capacity of multi-carrier networks.

To the best of our knowledge, it is the first time of this paper to propose a practical joint coding scheme across subcarriers to provide higher rate than the separated coding schemes. To illustrate the basic idea, we consider a two-user multi-carrier system. Specifically, we employ cross-links of some subcarriers, which create interference when the traditional transmission schemes with separated coding are applied, to transmit information to facilitate the receiver for canceling the interference experienced at direct-links of other subcarriers. In this way we can support interference-free transmission for the direct-links. When the cross-links are strong, the increased capacity for the direct link transmission will be much higher than the loss of capacity due to using some subcarriers for cross-link transmission. That is to say, with judicious design the proposed joint coding scheme can achieve higher sum rate than the separated coding schemes.

In the rest of the paper, we first present the joint coding scheme in Section 2. Then in Section 3, we provide the conditions that the proposed scheme can achieve higher rate than that with separated coding. We also propose an algorithm to find the subcarrier allocation for direct-link and cross-link transmissions. Simulation results are provided in Section 4 to show the performance gain of the proposed scheme over several separated coding schemes. Finally, Section 5 concludes the paper.

II. JOINT CODING SCHEME IN MULTI-CARRIER SYSTEM

We consider two-user Gaussian interference channel with M subcarriers. The input-output equations on the m-th subcarrier can be expressed as

$$\begin{aligned} y_1^{(m)} &= h_{11}^{(m)} x_1^{(m)} + h_{12}^{(m)} x_2^{(m)} + z_1^{(m)} \\ y_2^{(m)} &= h_{21}^{(m)} x_1^{(m)} + h_{22}^{(m)} x_2^{(m)} + z_2^{(m)} \end{aligned} \tag{1}$$

where $y_i^{(m)}$ is the received symbol at the receiver Rx_i, $h_{ij}^{(m)}$ denotes the channel gain from Tx_j to Rx_i, $x_i^{(m)}$ is the symbol sent by the transmitter Tx_i with transmit power $P_i^{(m)}$, $i, j \in \{1, 2\}$, $m \in \{1, 2, ...M\}$, and the noise $z_i^{(m)} \sim \mathcal{CN}(0, N_0)$ is circular symmetric complex Gaussian with zero mean and variance N_0.

Define signal-to-noise ratio (SNR) and interference-to-noise ratio (INR) at each receiver as follows

$$\begin{aligned} \mathrm{SNR}_1^{(m)} &= |h_{11}^{(m)}|^2 P_1^{(m)}/N_0 \quad & \mathrm{SNR}_2^{(m)} &= |h_{22}^{(m)}|^2 P_2^{(m)}/N_0 \\ \mathrm{INR}_1^{(m)} &= |h_{12}^{(m)}|^2 P_2^{(m)}/N_0 \quad & \mathrm{INR}_2^{(m)} &= |h_{21}^{(m)}|^2 P_1^{(m)}/N_0 \end{aligned} \tag{2}$$

Consider that there is a central unit to coordinate the transmission of the two users, who has all the channel information. In the sequel, we first introduce the principle of a joint coding scheme with subcarrier cooperation and then the detailed transmission scheme.

A. Principle of the Joint Coding Scheme

To improve the sum rate of the two-user multi-carrier interference channel, we propose a transmission scheme with joint coding among the subcarriers, which is referred to subcarrier cooperation.

In conventional transmission schemes with separate coding, the desired information is transmitted over all the subcarriers through the direct-links, as shown in the upper part of Fig. 1, whereas the cross links will generate interference only. It is worthy to note that the strong interference in the cross link is able to provide opportunity to increase the sum rate of the system if properly exploited.

In frequency-selective channels, the desired signals transmitted on multiple subcarriers suffer from different levels of interference. In fact, we can employ some subcarriers that causes strong interference in conventional transmission schemes to transmit a part of information to the unintended receiver through cross links to help canceling interference, as shown in the lower part of Fig. 1. This is a kind of joint coding among the subcarriers, whose principle is to take advantages of the strong interference to assist eliminating the interference, which is an active interference cancelation scheme.

The proposed subcarrier cooperation scheme works in the following way: some subcarriers are used for cross-link transmission to provide information to help interference cancelation, and other subcarriers are used for direct-link transmission. Specifically, we divide all the subcarriers into three groups: $\mathcal{A}$, $\mathcal{B}$, and $\mathcal{C}$, whose transmission strategies are respectively as follows. On the subcarriers belonging to group $\mathcal{A}$, the desired information is only transmitted via direct-links, where the received signals are decoded without the aid of information in the cross links. This kind of strategy is called separated coding strategy in the rest of the paper. On the subcarriers in group $\mathcal{B}$, each user transmits as if there is no interference, where the interference will be provided to the users via the cross links and the desired signal is decodable after subtracting the interference from the received signals. On the subcarriers in group $\mathcal{C}$, cross-links are used for the transmitters to send information that are actually the interference in the subcarriers of group $\mathcal{B}$.

The achievable rate of each user with the proposed scheme can be expressed as follows

$$R_i = \sum_{m\in\mathcal{A}} R_{a,i}^{(m)} + \sum_{m\in\mathcal{B}} R_{b,i}^{(m)} \tag{3}$$

where $R_{a,i}^{(m)}$ and $R_{b,i}^{(m)}$ are the rate of user i of the subcarriers in groups $\mathcal{A}$ and $\mathcal{B}$, respectively.

The information transmitted on the subcarriers of group $\mathcal{C}$ is the interference to the subcarriers of group $\mathcal{B}$. We use $R_{F,i}^{(m)}(m \in \mathcal{B})$ to represent the rate of interference information and use $R_{c,i}^{(m)}(m \in \mathcal{C})$ to denote the achievable rate of the cross-link transmission. The received signals on the subcarriers of group $\mathcal{B}$ will be decodable only if all the interference information is provided by the subcarriers in group $\mathcal{C}$. The condition that the cross links can support the transmission of all the interference information is

$$\sum_{m\in\mathcal{C}} R_{c,i}^{(m)} \geq \sum_{m\in\mathcal{B}} R_{F,i}^{(m)}, \quad i = 1, 2 \tag{4}$$

The subscript "a","b" and "c" refer to the three transmission strategies used at the groups of $\mathcal{A}$, $\mathcal{B}$, and $\mathcal{C}$, whose details will be addressed in the following subsections, where the expressions of $R_{a,i}$, $R_{b,i}$, $R_{c,i}$ and $R_{F,i}$ will be given.

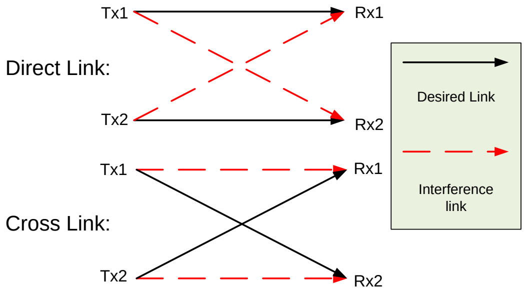

Fig. 1. Direct-link transmission (upper part) and cross-link transmission (lower part).

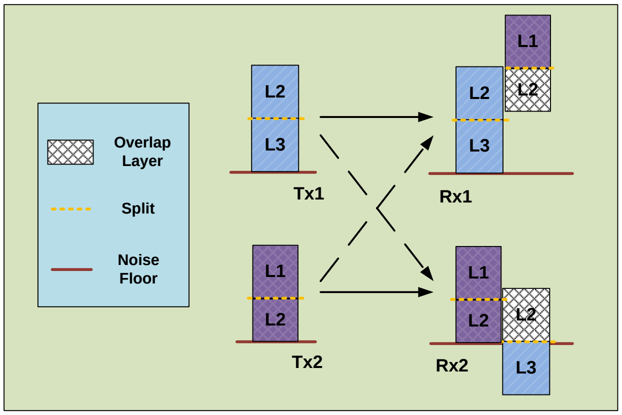

Fig. 2. Layered transmission on a subcarrier in $\mathcal{B}$.

B. Transmission Strategy for Group $\mathcal{A}$

On the subcarriers in group $\mathcal{A}$, separated coding strategy is used, i.e., no subcarrier cooperation exists among the subcarriers. There are many choices for the coding strategy to handle the interference. We take two methods as the examples.

One is orthogonal transmission strategy in time domain. The data rate on the mth subcarrier can be expressed as

$$\begin{aligned} R_{a,1}^{(m)} &= t\log_2(1+\mathrm{SNR}_i^{(m)}) \\ R_{a,2}^{(m)} &= (1-t)\log_2(1+\mathrm{SNR}_i^{(m)}) \end{aligned} \tag{5}$$

where t is the utilization ratio of the time resource for the first user ($0 \le t \le 1$).

The other method is the traditional interference cancelation strategy. In this strategy, if the interference is strong enough for reliable decoding, we will decode it firstly and then obtain the desired signal. Otherwise, we treat the interference as noise. The data rate of this strategy can be expressed as

$$R_{a,i}^{(m)} = \begin{cases} log_2(1+\mathrm{SNR}_i^{(m)}), & \mathrm{INR}_i^{(m)} \ge (\mathrm{SNR}_i^{(m)}+1)\mathrm{SNR}_j^{(m)} \\ log_2(1+\frac{\mathrm{SNR}_i^{(m)}}{1+\mathrm{INR}_i^{(m)}}), & otherwise \end{cases} \tag{6}$$

where $i, j = 1, 2,\ i \neq j$.

C. Transmission Strategy for Group $\mathcal{B}$

In amplitude space, the interference and desired signal usually partially overlap. Here we employ layered coding to separate the interference into independent layers, as shown in Fig. 2. The rate of the interference information transmitted through cross links can be reduced to the overlap part only. Specifically, the multi-layer nested lattice coding is used for the signals transmitted on the subcarriers of group $\mathcal{B}$, since it is highly structural and can be easily constructed from a multi-stage lattice partition chain [5]. It is shown in [6] that in multi-user and multi-layer system the achievable rate of nested lattice codes in additive white Gaussian noise channel is $\log_2(\mathrm{SNR})$.

Given the direct-link $\mathrm{SNR}^{(m)}$s and cross-link $\mathrm{INR}^{(m)}$s on the subcarrier m, $m \in \mathcal{B}$, there is a layer partitioning pattern at each receiver. As shown in Fig. 2, for user i, the $\mathrm{SNR}^{(m)}$ of the direct-link corresponds to a bar with a height of $\log_2(\mathrm{SNR}_i^{(m)})$, which represents the data rate for the transmission. At receiver i, there are two bars representing the received signal and interference. Their relative positions in the amplitude space depend on the corresponding $\mathrm{SNR}^{(m)}$s and $\mathrm{INR}^{(m)}$s. For the bar of user j at the receiver i, $j \neq i$, the upper and lower boundaries are $\log_2(\mathrm{INR}_i^{(m)})$ and $\log_2(\mathrm{INR}_i^{(m)}) - \log_2(\mathrm{SNR}_j^{(m)})$, respectively. If the bar of user j overlaps with the bar of user i, user j's bar will be split (separated into different layers) at the intersecting boundary positions. For each user, we can obtain at most three layers.

For simplicity, we assume that each user has three layers, the upper boundaries of user i are $P_{i,3}^{(m)}$, $P_{i,2}^{(m)}$ and $P_{i,1}^{(m)}$, and the lower boundaries are $P_{i,2}^{(m)}$, $P_{i,1}^{(m)}$ and $P_{i,0}^{(m)}$, respectively. Actually, $P_{i,0}$ is determined by the noise floor at the receiver side, i.e., $|h_{ii}^{(m)}|^2 P_{i,0}^{(m)} = N_0^{(m)}$. As shown in Fig. 2, if there are less than three layers in practice, we can set the upper and lower boundary values identical for those empty layers. For example, if the third layer is empty, we can set the boundaries as $P_{i,3}^{(m)} = P_{i,2}^{(m)}$. In this way, it is always the second layer of user j that interferes with the desired signal of user i .

The space between the upper and lower boundaries of the second interference layer is the rate of the interference information, which can be expressed as

$$R_{F,i}^{(m)} = \begin{cases} \{[\log_2(\mathrm{SNR}_i^{(m)})]^+ - [\log_2(\frac{\mathrm{INR}_i^{(m)}}{\mathrm{SNR}_j^{(m)}})]^+\}^+, & \mathrm{INR}_i^{(m)} \ge \mathrm{SNR}_i^{(m)} \\ \min\{[\log_2(\mathrm{INR}_i^{(m)})]^+, [\log_2(\mathrm{SNR}_j^{(m)})]^+\}, & \mathrm{INR}_i^{(m)} < \mathrm{SNR}_i^{(m)} \end{cases} \tag{7}$$

where $j \neq i$ and $(x)^+ = \max(x, 0)$.

Given the information bits transmitted through cross-links in group $\mathcal{C}$, each user can reconstruct the interference layer and cancel it from the received signal, and the interference-free transmission is therefore achieved. The achievable rate on the mth subcarrier is

$$R_{b,i}^{(m)} = [\log_2(\mathrm{SNR}_i^{(m)})]^+ \tag{8}$$

D. Transmission Strategy for Group $\mathcal{C}$

Remind that the conditions in (4) should be satisfied for both users simultaneously. On the subcarriers belonging to group $\mathcal{C}$, separated coding strategy is used to send the interference information. We use the orthogonal transmission strategy in time domain as an example, where the resource ratio for the first user on the subcarriers of group $\mathcal{C}$ is k ($0 \le k \le 1$). The expression of the achievable rate for each user on the mth subcarrier is

$$R_{c,1}^{(m)} = k\log_2(1+\mathrm{INR}_1^{(m)}) \tag{9}$$

$$R_{c,2}^{(m)} = (1-k)\log_2(1+\mathrm{INR}_2^{(m)}) \tag{10}$$

Then the conditions will be satisfied easily for both users at the same time simply by adjusting the value of k. The detailed design is given in the next section.

III. ALGORITHM FOR THE GROUP DIVISION

In this section, we first provide the conditions that the joint coding scheme can achieve a higher sum-rate than the conventional transmission scheme where separated coding is used on all the subcarriers. In other words, we will compare the sum-rates of the two systems with and without exploiting the cross links. Then, we will present a heuristic algorithm for dividing the groups of subcarriers based on the conditions.

A. Conditions for Providing Higher Sum-Rate

In the system with the aid of cross-links for interference cancelation, we can see from (3) that the rate of the subcarriers in group $\mathcal{C}$ contributes nothing to the system sum-rate directly. However, using the interference information transmitted in the cross-link, the receivers can decode the desired signals on the subcarriers of group $\mathcal{B}$ which are not decodable before since they are overlapped with the interference in the amplitude space. The rate of these new decodable signals is equal to that of interference information provided in the cross links.

That is to say, the data rate of two users on the subcarriers in $\mathcal{C}$, which can be expressed as $\sum_{m\in\mathcal{B}} R_{F,1}^{(m)} + R_{F,2}^{(m)}$, are included in the sum-rate implicitly.

In the system without the aid of cross-links, the direct-link transmission is also used on the subcarriers in group $\mathcal{C}$ whose sum rate can be expressed as $\sum_{m\in\mathcal{C}} R_{a,1}^{(m)} + R_{a,2}^{(m)}$.

Then, in terms of the system sum-rate, the condition that the system with the proposed joint coding scheme outperforms the system with separated coding over all the subcarriers can be written as

$$\sum_{m\in\mathcal{B}} R_{F,1}^{(m)} + R_{F,2}^{(m)} > \sum_{m\in\mathcal{C}} R_{a,1}^{(m)} + R_{a,2}^{(m)} \tag{11}$$

However, it is hard to allocate the subcarriers to the three groups according to such a condition, because $R_{F,i}^{(m)}$ cannot be determined before the subcarrier allocation. To circumvent this difficulty, we propose a sufficient condition of (11), which consists two sub-conditions as follows

$$\sum_{m\in\mathcal{C}} R_{c,1}^{(m)} + R_{c,2}^{(m)} > \sum_{m\in\mathcal{C}} R_{a,1}^{(m)} + R_{a,2}^{(m)} \tag{12}$$

$$\sum_{m\in\mathcal{C}} R_{c,i}^{(m)} = \sum_{m\in\mathcal{B}} R_{F,i}^{(m)}, \quad i = 1,2 \tag{13}$$

Condition (12) means that the sum-rate of the two users on the subcarriers in group $\mathcal{C}$ achieved by the proposed joint coding scheme should exceed that achieved by the separated coding. Condition (13) indicates that in the proposed joint coding scheme, the interference information should be transmitted with the achievable rate of the cross links.

From (9) and (10) we know that $R_{c,i}^{(c)}$ depends on the resource ratio k. Since k also cannot be determined before the subcarrier allocation, we change the condition (12) through the following proposition.

Proposition 1: The condition (12) can be satisfied if

$$\min \mathrm{INR}_i^{(m)} \geq \max \mathrm{SNR}_j^{(m)} \qquad i,j = 1,2 \tag{14}$$

is satisfied for all $m \in \mathcal{C}$.

Proof: By adding (9) with (10), we can find that $R_{c,1}^{(m)} + R_{c,2}^{(m)}$ is a linear function of k. Due to the monotonicity of a linear function, $R_{c,1}^{(m)} + R_{c,2}^{(m)}$ achieves a minimum when $k = 0$ or $k = 1$. Therefore, the following inequality is satisfied,

$$R_{c,1}^{(m)} + R_{c,2}^{(m)} \geq \log_2(1 + \min \mathrm{INR}_i^{(m)}) \tag{15}$$

Consider the received signal at Rx_i on a subcarrier m, where $i = \arg\min \mathrm{INR}_i^{(m)}$. If condition (14) is satisfied, there will exist two cases regarding the relationship between the desired signal from Tx_i and the interference signal from Tx_j, where $j \neq i, j = 1,2$. One case is that the signal transmitted by Tx_j does not overlap with the interference at Rx_i, as shown in the left part of Fig. 3. Since the maximum of $R_{a,1}^{(m)} + R_{a,2}^{(m)}$ is equal to $x + y$, where x and y are defined in the figure, the expression below is satisfied

$$R_{a,1}^{(m)} + R_{a,2}^{(m)} \leq \sum_{l=1}^{2} \log_2(1 + \mathrm{SNR}_l^{(m)}) \leq \log_2(1 + \mathrm{INR}_i^{(m)}) \tag{16}$$

The other case is that the desired signal and the interference signal overlaps in amplitude space, as shown in the right part of Fig. 3. Since the desired signal at both receivers should be decodable, the sum-rate of the two users in the direct-link follows the inequality

$$\begin{aligned} R_{a,1}^{(m)} + R_{a,2}^{(m)} &\leq \sum_{l=1}^{2} \log_2(1 + \mathrm{SNR}_l^{(m)}) - R_p \\ &= \log_2(1 + \mathrm{INR}_i^{(m)}) \end{aligned} \tag{17}$$

where R_p refers to the data rate of the overlapped layer.

Comparing (15), (16) and (17), proposition 1 can be proved. ■

The condition in (14) means that if it is satisfied, the two users will suffer from strong interference on the subcarriers of group $\mathcal{C}$.

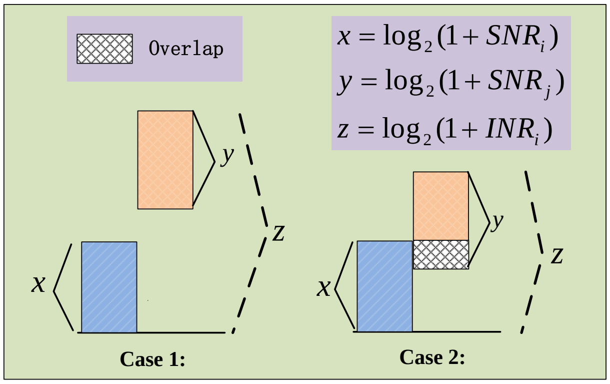

Fig. 3. Two cases of the received signal at Rx_i.

With (9) and (10), the expression of the condition in (4) can be written as

$$\frac{\sum_{m\in\mathcal{B}} R_{F,1}^{(m)}}{\sum_{m\in\mathcal{C}} \log_2(1 + \mathrm{INR}_1^{(m)})} \leq k \leq 1 - \frac{\sum_{m\in\mathcal{B}} R_{F,2}^{(m)}}{\sum_{m\in\mathcal{C}} \log_2(1 + \mathrm{INR}_2^{(m)})} \tag{18}$$

Then, condition (13) will be satisfied if and only if

$$k = \frac{\sum_{m\in\mathcal{B}} R_{F,1}^{(m)}}{\sum_{m\in\mathcal{C}} \log_2(1 + \mathrm{INR}_1^{(m)})} = 1 - \frac{\sum_{m\in\mathcal{B}} R_{F,2}^{(m)}}{\sum_{m\in\mathcal{C}} \log_2(1 + \mathrm{INR}_2^{(m)})} \tag{19}$$

Denoting

$$Q = \frac{\sum_{m\in\mathcal{B}} R_{F,1}^{(m)}}{\sum_{m\in\mathcal{C}} \log_2(1 + \mathrm{INR}_1^{(m)})} + \frac{\sum_{m\in\mathcal{B}} R_{F,2}^{(m)}}{\sum_{m\in\mathcal{C}} \log_2(1 + \mathrm{INR}_2^{(m)})} \tag{20}$$

we can rewrite the condition in (19) as

$$Q = 1 \tag{21}$$

If $Q < 1$, the resource ratio k has a lot of choices, where the cross-link is not fully utilized because the required rate of the interference information is less than the achievable rate of the cross-link. If $Q > 1$, k will not exist, such that the joint coding scheme cannot be applied in view of (4). If $Q = 1$, k is fixed and the cross-link will be fully used.

Now we can rewrite the two sub-conditions (12) and (13) into the conditions (14) and (21).

B. A Heuristic Algorithm for Subcarrier Allocation

To ensure the proposed joint coding scheme outperforms the convention scheme that using separate coding over all the subcarriers, we propose an algorithm to divide the subcarrier groups toward satisfying the conditions (14) and (21).

We initialize the three groups of subcarriers based on the condition in (14), such that both users suffer from strong interference at the subcarriers of group $\mathcal{C}$. Then, we adjust the elements in each group to make the condition in (21) satisfied, such that the cross links are fully employed to assist the interference cancelation. The detailed algorithm is shown in Table I. The set of all subcarriers is $\mathcal{U}$.

TABLE I
SUBCARRIERS ALLOCATION ALGORITHM

(1). Initialize the three groups $\mathcal{A},\mathcal{B},\mathcal{C}$: $\mathcal{C} = \{m|\min \mathrm{INR}_i^{(m)} \geq \max \mathrm{SNR}_j^{(m)}, m \in \mathcal{U}\}$, where $i,j=1,2$; $\mathcal{A}=\{m|\sum_{l=1}^{2} R_{a,l}^{(m)} \geq \sum_{l=1}^{2} R_{b,l}^{(m)}; m \in \mathcal{U}-\mathcal{C}\}$, $\mathcal{B}=\mathcal{U}-\mathcal{A}-\mathcal{C}$. Calculate Q using (20).

(2). If $Q<1$, go to step (3). If $Q>1$, jump to step (4). Otherwise, jump to the end.

(3). Move an element $J=\arg\max \sum_{l=1}^{2} R_{b,l}^{(J)}$ from $\mathcal{C}$ into $\mathcal{B}$ and calculate Q again. If $Q \leq 1$, repeat step (3). Otherwise, put J back to $\mathcal{C}$ and jump to the end.

(4). Move an element $K=\arg\min \sum_{l=1}^{2} R_{b,l}^{(K)} - R_{a,l}^{(K)}$ from $\mathcal{B}$ into $\mathcal{A}$ and calculate Q again. If $Q>1$, repeat step (4). Otherwise, jump to the end.

IV. SIMULATION RESULTS

In this section, we evaluate the sum-rate of the multi-carrier systems with and without the joint coding. For comparison, we consider two separated coding schemes, orthogonal transmission scheme and traditional interference cancelation scheme, which have been briefly introduced in Part A, Section II. In the system with joint coding, we employ these two separated coding schemes on the subcarriers of group $\mathcal{A}$. In the system without joint coding, the two separated coding schemes are used on all subcarriers.

We consider a heterogeneous network scenario where a macro-BS serves a macro-user and a pico-BS serves a pico-user. The level of mutual interference depends on the position of the pico-cell. The path loss follows the 3GPP channel model [7]: $PL_{\text{macro}} = 15.3 + 37.6\log_{10}(D)$, $PL_{\text{pico}} = 30.6 + 36.7\log_{10}(D)$, where D is the distance between base stations and users. The transmit powers of the macro-BS and pico-BS are 46 dBm and 30dBm, respectively. The noise power is determined by the cell-edge SNR of the macro-cell, which is set as 5 dB. Independent and identically distributed small-scale Rayleigh fading is considered on each subcarrier. The results are obtained over 5000 channel realizations.

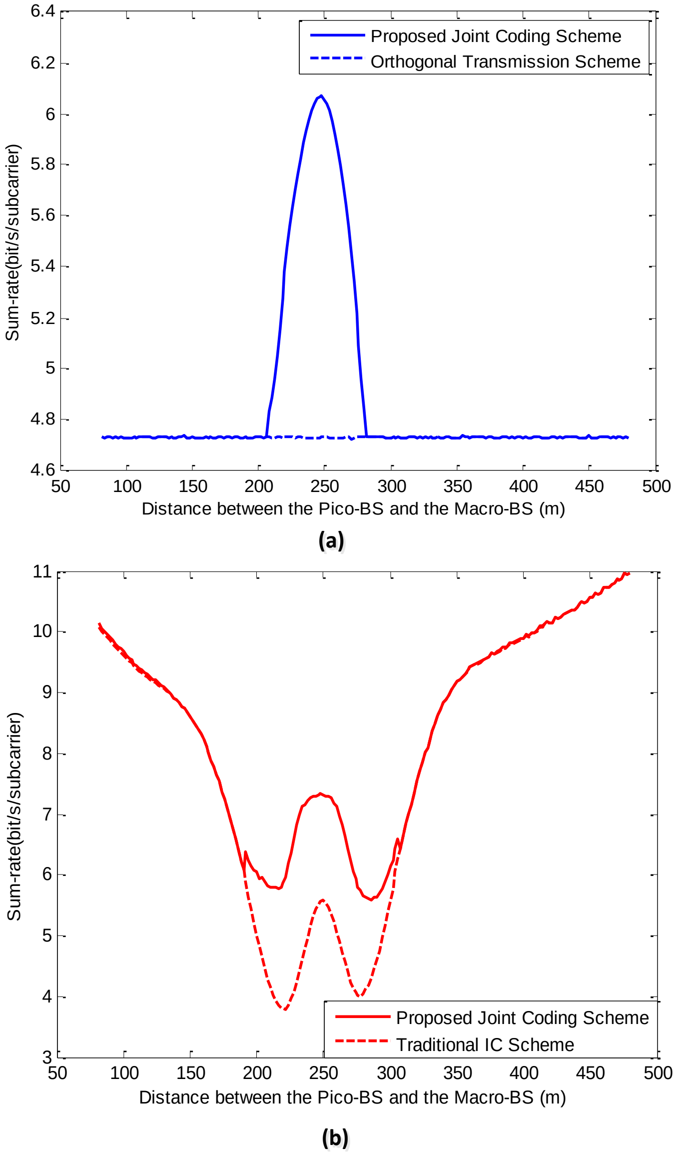

Fig. 4. Sum-rate per subcarrier achieved by the proposed joint coding scheme and separated encoding schemes.

Considering that the pico-user is fixed in the pico-cell and the macro-user is fixed in the macro-cell, we change the distance between the two BSs. When the distance is between 200 m and 290 m, both receivers suffer from strong interference. Fig. 4 (a) and (b) compare the sum-rates of the two systems with and without joint coding when two separated coding schemes are used, respectively.

Define the performance gain as $G = \frac{R_j - R_{nj}}{R_{nj}}$, where R_j and R_{nj} are the sum-rates of the systems with and without joint coding, respectively. It is shown that the system with joint coding achieves higher sum-rate despite that we sacrifice some subcarriers for the cross-link transmission. In the simulation, when the orthogonal transmission scheme is applied, the maximal gain of the proposed system is 30.2%. When the traditional interference cancelation scheme is used, the maximal gain can reach 57.9%.

V. CONCLUSION

We proposed a joint coding scheme with subcarriers cooperation to assist interference cancelation for two-user multicarrier interference systems in heterogeneous cellular networks. By taking advantage of the feature of SNRs and INRs in such kind of networks, the scheme provides higher achievable rate than that with separated coding on all the subcarriers when both users suffer from strong interference, although a few subcarriers seem to be sacrificed. The performance gain mainly comes from exploiting the strong interference in cross links and layered interference cancelation. When the interference is strong, cross-link transmission provides a higher sum rate than the direct link. With layered coding, the higher data rate in the cross-link can help increasing the rate in transmitting the desired signals.

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