Multi-Carrier ICI Coordination in Heterogeneous Networks Based on Han-Kobayashi Coding

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***Abstract*—With rapid growing of wireless data service, heterogeneous network (HetNet) has evolved as a basic cellular architecture because of its high spectrum and energy efficiency. However, due to the transmit power difference among the macro base station and various low power nodes and the randomness of small cell deployment, the inter-cell interference (ICI) between the macro-cell and small cells might demonstrate strong, weak or mixed features. To reduce its severe impact, in this paper we propose a Han-Kobayashi (H-K) coding based ICI coordination scheme. Furthermore, for multi-carrier interference networks, each subcarrier may encounter different interference scenario due to frequency-selective fading. With the known achievable rates of H-K coding, we study an optimized power allocation method to coordinate the transmit powers of two users on each subcarrier and maximize the network throughput. The optimization problem is generally non-convex, we propose an iterative convex approximation (ICA) method to maximize a concave lower bound and iteratively approach the optimum of the throughput function. Simulation results verify the superiority of the optimization method, and show that the proposed ICI coordination scheme can provide substantial throughput gain over other transmission schemes.**

***Index Terms*—Han-Kobayashi coding, heterogeneous network, inter-cell interference, multi-carrier system, power allocation**

I. Introduction

Heterogeneous network (HetNet), which consists of the macro base station (BS) and a mix of lower power nodes in the coverage of macro-cell, is a new way to deal with the explosive wireless traffic demand. By improving the spatial spectrum efficiency as well as the energy efficiency, HetNet has the potential to provide the next significant performance leap in cellular networks [1].

However, in HetNets new challenges of cochannel interference management are created. When full spectrum reuse is implemented, the cross-tier inter-cell interference (ICI) might be severe because of the big difference of transmit powers and BS-user link distances [2]. If a pico-cell is located in the central area of the macro-cell, the pico-user will encounter strong downlink interference from the macro-BS; if a pico-cell is located in the macro-cell edge and there is a macro-user close by, the pico-BS will encounter strong uplink interference from the macro-user. There will be various other interference scenarios considering the randomness of user locations and the consumer deployment feature of small cells. Orthogonal multiplexing, such that the macro-BS transmits almost blank subframe (ABSF) when the pico-BS works, is proposed in LTE-A systems to avoid the cross-tier ICI. But the spectrum efficiency is reduced by using only half of the time or frequency resources. Therefore, advanced ICI coordination schemes are eagerly solicited in system design for HetNets.

Power control is often used to coordinate the ICI in homogeneous networks, and power allocation across the subcarriers is further considered in multi-carrier interference networks to optimize the network throughput [3–6]. Reference [3] and [4] introduced iterative water-filling (IWF) schemes to balance the transmit spectrum of multiple users with mutual interference, where each user repeatedly measures the aggregate interference received from all other users, then greedily water-pours their own power without considering the impact on other users. Since every user is selfish, the IWF scheme can only lead to a competitive Nash equilibrium. Reference [5] proposes an optimal spectrum balancing (OSB) algorithm to maximize the network throughput by joint coordinating the spectrum of all users, but it suffers from an exponential complexity in the number of users. Reference [6] proposes a low complexity joint optimization method by involving a series of relaxations in the optimization process. However, these works only consider weak interference scenarios, and the ICI is simply treated as noise.

For two-user interference channel, Han-Kobayashi (H-K) coding is the best known transmission scheme to achieve the maximal sum-rate [7], and is proved that can approach the capacity region to within 1 bit [8]. H-K coding divides the transmit information into private and common portions, where private information can only be decoded at the intended receiver but common information can be decoded at both receivers. By decoding the common information, part of the interference can be canceled off. For different interference scenarios, such as strong, mixed or weak interference, H-K coding has different work modes and different achievable sum-rate expressions.

For multi-carrier transmission in HetNets, each subcarrier in each link is subject to frequency-selective fading, thus may encounter different interference scenarios. We can apply H-K coding on each subcarrier, but the transmission power on each subcarrier of the two BSs (in downlink) or two users (in uplink) should be optimized with the power constraint of each node. The optimization problem is generally non-convex since the achievable sum-rate of H-K coding is non-convex in mixed and weak interference scenarios. In this paper, we propose an iterative convex approximation (ICA) method to solve this non-convex optimization problem. Through relaxation and transformation, we first construct a concave lower-bound of the achievable sum-rate function for each of the interference scenarios, and then maximize the network throughput by standard convex program. Sequentially, the optimized power allocation results are used to update the lower bound. Through several times of iterations, the algorithm will converge to at least a local optimum of the original problem.

The performance of ICI coordination through H-K coding and jointly optimized power allocation is verified through simulations, where the performance of H-K coding based IWF scheme, orthogonal multiplexing, and treating interference as noise are also compared. We can see substantial gain of the proposed scheme over other transmission schemes.

The rest of this paper is organized as follows. In Section II, we introduce the system model and problem formulation. In Section III, we propose the ICA algorithm to solve the non-convex optimization problem. Simulation results are provided in Section IV, and finally Section V concludes the paper.

II. System Model and Problem Formulation

Consider a multi-carrier interference network, where two users transmit their signals at all subcarriers simultaneously. We consider there is a central unit who has all channel information and coordinate the transmission of the two users. In this section, we will first give some results on the achievable rates of H-K coding under different interference scenarios, and then we will formulate the network throughput optimization problem for multi-carrier transmissions.

A. Single-Carrier Interference Network

The basic model of two-user interference channel is

$$y_1 = x_1 + \sqrt{a}x_2 + n_1 \tag{1}$$
$$y_2 = \sqrt{b}x_1 + x_2 + n_2 \tag{2}$$

where x_i and y_i are the transmit and received symbols, respectively, for user $i \in \{1, 2\}$, and the power of x_i is P_i; the direct-link channel gains are normalized to 1, and the cross-link channel gains are $\sqrt{a}$ and $\sqrt{b}$, respectively; the noise n_i is circular symmetric complex Gaussian with zero mean and unit variance.

The sum-capacity of two-user Gaussian interference channel is known in most of the interference scenarios, i.e., when both interference are strong, one is strong and the other is weak, or both interference are very weak [9]. In these scenarios, the capacity-achievable transmission scheme is simplified H-K coding. For each user, only one portion of information, either common or private, need to be transmitted. That means, in different interference scenarios, H-K coding has different simplified work mode. The sum-capacity in general weak interference scenario is still open. However we can use the work mode in very weak interference to obtain an achievable sum-rate for this scenario. For the convenience of readers, we list the known achievable sum-rates for various interference scenarios in Table I.

TABLE I
Achievable Sum-Rates of H-K Coding

Scenario	(a, b)	Sum-Rate
strong	$a \geq 1$ $b \geq 1$	$\min \begin{cases} \log(1+P_1) + \log(1+P_2) \\ \log(1+P_1+aP_2) \\ \log(1+bP_1+P_2) \end{cases}$
mixed 1	$ab \geq 1$ $a \leq 1$	$\log(1+\frac{P_1}{1+aP_2}) + \log(1+P_2)$
mixed 2	$ab \leq 1$ $b \geq 1$	$\min \begin{cases} \log(1+\frac{P_1}{1+aP_2}) + \log(1+P_2) \\ \log(1+bP_1+P_2) \end{cases}$
mixed 3	$ab \geq 1$ $b \leq 1$	$\log(1+P_1) + \log(1+\frac{P_2}{1+bP_1})$
mixed 4	$ab \leq 1$ $a \geq 1$	$\min \begin{cases} \log(1+P_1) + \log(1+\frac{P_2}{1+bP_1}) \\ \log(1+P_1+aP_2) \end{cases}$
weak	$a \leq 1$ $b \leq 1$	$\log(1+\frac{P_1}{1+aP_2}) + \log(1+\frac{P_2}{1+bP_1})$

B. Multi-Carrier Interference Network

Consider two-user multi-carrier interference network, where K subcarriers are simultaneously allocated to two users. Assuming that the direct-links and cross-links channel fading are independent over different subcarriers, a two-user interference channel is formed on every subcarrier. The input-output equations on the k-th subcarrier can be expressed as

$$y_1^k = h_{11}^k x_1^k + h_{12}^k x_2^k + n_1^k \tag{3}$$
$$y_2^k = h_{21}^k x_1^k + h_{22}^k x_2^k + n_2^k \tag{4}$$

where x_i^k and y_i^k are transmit and received symbols on subcarrier k, h_{ij}^k denotes the subcarrier channel gain from Tx_j to Rx_i, $i, j \in \{1, 2\}$, the transmit power of user i on subcarrier k is p_i^k, and the noise $n_i^k \sim \mathcal{CN}(0, \sigma_i^2)$ is circular symmetric complex Gaussian with zero mean and variance σ_i^2.

To obtain the achievable sum-rates of H-K coding on every subcarrier, we define the normalized direct-link and cross-link channel gains as

$$g_1^k = \frac{|h_{11}^k|^2}{\sigma_1^2},\ g_2^k = \frac{|h_{22}^k|^2}{\sigma_2^2},\ a^k = \frac{|h_{12}^k|^2\sigma_2^2}{|h_{22}^k|^2\sigma_1^2},\ b^k = \frac{|h_{21}^k|^2\sigma_1^2}{|h_{11}^k|^2\sigma_2^2}.$$

Then the sum-rates can be expressed appropriately following Table I, for example, the sum-rate in weak interference scenario is

$$R_{\text{sum}}^k = \log\left(1 + \frac{g_1^k p_1^k}{1 + a_k g_2^k p_2^k}\right) + \log\left(1 + \frac{g_2^k p_2^k}{1 + b_k g_1^k p_1^k}\right). \tag{5}$$

Since each user has a sum-power constraint, the transmit power on each subcarrier should be allocated under some rules. In weak interference channel, the interference is treated as noise, thus the transmit powers of two users are competing. One user increases its transmit power will definitely reduce the SINR of the other user. However, in strong interference channel, one user increases power may increase the SINR of both users after interference cancelation. Taking into account various interference scenarios on all subcarriers, it is hard to have an intuitive conjecture on how to balance the transmit spectrums of two users to maximize the network throughput. Therefore, we must resort to optimization techniques to solve this problem.

With sum-power constraint, the maximal network throughput is the summation of the achievable sum-rates of all subcarriers with optimized power allocations, i.e.,

$$\begin{aligned} \max_{\mathbf{p}_1,\mathbf{p}_2} \; & \sum_{k=1}^{K} R_{\text{sum}}^k(p_1^k, p_2^k) \\ \text{s.t. } & p_1^1 + ... + p_1^K \le P_1 \\ & p_2^1 + ... + p_2^K \le P_2 \\ & p_i^k \ge 0 \end{aligned} \tag{6}$$

where $\mathbf{p}_i = [p_i^1, \cdots, p_i^K]$, $i = 1, 2$.

As we can see from Table I, only the values of (a, b) affect the work-mode of H-K coding, that means power allocation does not impact the work-mode. Thus we can determine the H-K coding work mode before allocating the power.

III. Network Throughput Optimization

As listed in Table I, there are two types of logarithm functions in the sum-rate expressions. Type I is that, the power variables only appear on the numerators inside the logarithm, this type of function is naturally concave. Type II is that, inside the logarithm, power variables appear both on the numerators and denominators, this type of function is non-convex. Actually type II logarithm term is a difference of concave functions. It is well known that this form of optimization problem is NP-hard and does not have efficient solution to obtain global optimum. In this section, we will first introduce the basic idea of the iterative convex approximation algorithm to find a local optimum of this kind of non-convex problems, and then extend the idea to maximize the network throughput.

A. Iterative Convex Approximation Algorithm

The basic idea of the iterative convex approximation algorithm is proposed in [6]. Define a simple non-convex logarithm optimization problem as

$$\begin{aligned} \max_{p_1,p_2} \; & \log\left(1 + \frac{p_1}{1+p_2}\right) \\ \text{s.t. } & p_1 + p_2 \le P. \end{aligned} \tag{7}$$

First, a lower bound of the logarithm function is introduced, i.e.,

$$\alpha \log z + \beta \le \log(1+z) \tag{8}$$

where

$$\alpha = \frac{z_0}{1+z_0}, \quad \beta = \log(1+z_0) - \frac{z_0}{1+z_0}\log z_0$$

and z_0 is an arbitrary positive number. The approximation is tight when $z = z_0$. Thus we can obtain a relaxation of the optimization problem,

$$\max_{p_1,p_2} \; \alpha \log\left(\frac{p_1}{1+p_2}\right) + \beta. \tag{9}$$

Then an exponential form of variable replacement is introduced, i.e., $p_1 = \exp(\tilde{p}_1)$, $p_2 = \exp(\tilde{p}_2)$, and we will find that

$$\log\left(\frac{e^{\tilde{p}_1}}{1+e^{\tilde{p}_2}}\right) = \tilde{p}_1 - \log(1+e^{\tilde{p}_2}) \tag{10}$$

is a concave function over $\tilde{p}_1$ and $\tilde{p}_1$ (where we can easily prove that the log-sum-exp function is convex).

After the relaxation and variable replacements, the original problem (7) is transformed as

$$\begin{aligned} \max_{\tilde{p}_1,\tilde{p}_2} \; & \alpha\left[\tilde{p}_1 - \log(1+e^{\tilde{p}_2})\right] + \beta \\ \text{s.t. } & e^{\tilde{p}_1} + e^{\tilde{p}_2} \le P \end{aligned} \tag{11}$$

where the objective function is concave and the constraint is convex.

Given an arbitrary initial values of α and β, such as $\alpha = 1$ and $\beta = 0$, (11) can be solved by any standard convex optimization program like CVX. Then the optimized results are used to update the values of α, β and the lower bound function. The sequence of iterations produces a monotonically increasing objective and will converge to at least a local optimum of the original problem [6].

B. Sum-Rate Relaxation in Different Interference Scenarios

1) Strong Interference: Under the scenario of strong interference, the sum-rate is a minimal of three type I logarithm functions. We know that taking the minimum of multiple concave functions is still a concave function. Therefore, maximizing the sum-rate in this mode is achieved by standard convex optimization method.

2) Mixed Interference 1: The sum-rate expressions in mixed interference scenario 1 and 3 are similar, thus we only take scenario 1 as an example to discuss. The achievable sum-rate in this scenario is

$$R_{\text{sum}}^k(p_1^k, p_2^k) = \log\left(1 + \frac{g_1^k p_1^k}{1 + a_k g_2^k p_2^k}\right) + \log\left(1 + g_2^k p_2^k\right) \tag{12}$$

where p_1^k and p_2^k are transmit powers on subcarrier k that to be optimized. For conciseness, we will drop the dependency of R_{sum}^k on p_1^k and p_2^k in the following.

Applying the approximation method to the first logarithm term and after exponential transformation, we get a lower bound of (12), i.e.,

$$\bar{R}_{\text{sum}}^k = \alpha_1^k \log\left(\frac{g_1^k e^{\tilde{p}_1^k}}{1 + a_k g_2^k e^{\tilde{p}_2^k}}\right) + \beta_1^k + \log\left(1 + g_2^k e^{\tilde{p}_2^k}\right) \tag{13}$$

where the first logarithm term is concave, but the second logarithm term becomes convex. Thus we use another approximation for the second term, and obtain

$$\bar{R}_{\text{sum}}^k = \alpha_1^k \log\left(\frac{g_1^k e^{\tilde{p}_1^k}}{1 + a_k g_2^k e^{\tilde{p}_2^k}}\right) + \beta_1^k + \alpha_2^k \log\left(g_2^k e^{\tilde{p}_2^k}\right) + \beta_2^k. \tag{14}$$

The obtained lower bound is the sum of a concave function and a linear function, thus is concave over $\tilde{p}_1^k$ and $\tilde{p}_2^k$.

3) Mixed Interference 2: The sum-rate expressions in mixed interference scenario 2 and 4 are similar, thus we take scenario 2 as an example to discuss. The achievable sum-rate in this scenario is

$$R_{\text{sum}}^k = \min \begin{cases} \log\left(1 + \frac{g_1^k p_1^k}{1 + a_k g_2^k p_2^k}\right) + \log\left(1 + g_2^k p_2^k\right) \\ \log(1 + b_k g_1^k p_1^k + g_2^k p_2^k) \end{cases} \tag{15}$$

where the first function in the minimum is non-convex, so that R_{sum}^k is non-convex as well.

To maximize R_{sum}^k, we can split (15) into two optimization problems with additional constraints. That means, we can first maximize the first function with constraint that the first one is smaller, and then maximize the second function with constraint that the second one is smaller. After optimization the larger sum-rate result will be chosen as the maximum of R_{sum}^k.

If we require

$$\log\left(1 + \frac{g_1^k p_1^k}{1 + a_k g_2^k p_2^k}\right) + \log\left(1 + g_2^k p_2^k\right) < \log(1 + b_k g_1^k p_1^k + g_2^k p_2^k)$$

the only condition is that

$$p_2^k < \frac{b_k - 1}{g_2^k (1 - a_k b_k)}. \tag{16}$$

Therefore, the optimization problem becomes

$$\begin{aligned} \max_{p_1^k, p_2^k} \ & \log\left(1 + \frac{g_1^k p_1^k}{1 + a_k g_2^k p_2^k}\right) + \log\left(1 + g_2^k p_2^k\right) \\ \text{s.t. } & p_2^k < \frac{b_k - 1}{g_2^k (1 - a_k b_k)} \end{aligned} \tag{17}$$

and

$$\begin{aligned} \max_{p_1^k, p_2^k} \ & \log(1 + b_k G_1^k p_1^k + G_2^k p_2^k) \\ \text{s.t. } & p_2^k \geq \frac{b_k - 1}{g_2^k (1 - a_k b_k)}. \end{aligned} \tag{18}$$

The optimization of (17) follows the procedure in mixed scenario 1, and the optimization of (18) is a standard convex problem.

Since (15) is the sum-rate of one subcarrier, if there are m subcarriers work in mixed interference scenario 2 or 4, the expression of the network throughput will have 2^m possible combinations under different additional power constraints. The computational complexity is forbidden if m is large. Therefore, in practical, we can first determine a minimum function of (15), for example, by checking the condition (16) with a uniformly allocated power $p_2^k = P_2/K$. Although this method will lose some optimality, the complexity is dramatically reduced.

4) Weak Interference: In weak interference scenario, the interference is treated as noise, and the achievable sum-rate is given in (5). After relaxation and exponential transformation, the optimization problem becomes

$$\begin{aligned} \max_{\tilde{p}_1^k, \tilde{p}_2^k} \ & \alpha_1^k \left[\log g_1^k + \tilde{p}_1^k - \log(1 + a_k g_2^k e^{\tilde{p}_2^k})\right] + \beta_1^k \\ & + \alpha_2^k \left[\log g_2^k + \tilde{p}_2^k - \log(1 + b_k g_1^k e^{\tilde{p}_1^k})\right] + \beta_2^k \end{aligned} \tag{19}$$

where the objective function is concave over $\tilde{p}_1^k$ and $\tilde{p}_2^k$.

C. Optimization of the Network Throughput

According to the sum-rate relaxation results in each interference scenario, the multi-carrier network throughput optimization problem (6) can be transformed as

$$\begin{aligned} \max \ & \sum_{k \in \mathcal{C}_1} R_{\text{sum}}^k(p_1^k, p_2^k) + \sum_{k \in \mathcal{C}_2} \bar{R}_{\text{sum}}^k(\tilde{p}_1^k, \tilde{p}_2^k) \\ \text{s.t. } & \sum_{k \in \mathcal{C}_1} p_1^k + \sum_{k \in \mathcal{C}_2} e^{\tilde{p}_1^k} \leq P_1 \\ & \sum_{k \in \mathcal{C}_1} p_2^k + \sum_{k \in \mathcal{C}_2} e^{\tilde{p}_2^k} \leq P_2 \\ & p_i^k \geq 0, \quad \text{for } k \in \mathcal{C}_1, \ i = 1, 2 \\ & \tilde{p}_i^k \geq 0, \quad \text{for } k \in \mathcal{C}_2, \ i = 1, 2 \end{aligned} \tag{20}$$

where $\mathcal{C}_1$ denotes the subcarrier set that the interference scenario is strong, or the second cases of mixed 2 and 4; $\mathcal{C}_2$ denotes the subcarrier set that the interference scenario is mixed 1 or 3, weak, or the first cases of mixed 2 and 4.

Given a set of initial values of α_1^k, β_1^k, α_2^k, β_2^k, the problem (20) can be solved by standard convex optimization program. Then the values of α_1^k, β_1^k, α_2^k, β_2^k are updated according to the optimized power allocation results. After several times of iterations, the network throughput will converge to at least a local optimum.

IV. Simulation Results

In this section, we evaluate the performance of the proposed H-K coding based multi-carrier joint optimization method (HK-ICA) in heterogeneous networks. We consider a downlink interfering scenario where a macro-BS serves a macro-user and a pico-BS serves a pico-user. The transmit power of the macro-BS is 46 dBm and the transmit power of the pico-BS is 30 dBm. Single antenna is used both in BS and user sides, and 16 subcarriers are considered in simulations.

The path loss models for macro-BS and pico-BS are from 3GPP specification [10], i.e.,

$$PL_{\text{MBS-UE}} = 15.3 + 37.6 \log_{10}(D)$$
$$PL_{\text{PBS-UE}} = 30.6 + 36.7 \log_{10}(D)$$

where D is the distance between BSs and users. Assume that the coverage of the macro-BS is 500 m and the cell-edge SNR is 5 dB. The noise power, including the background ICI from other macro-cell and small cells, can be calculated by the path loss model and cell-edge SNR value. Independent and identically distributed small-scale Rayleigh fading are considered on each subcarrier. The results are averaged over 100 channel realizations.

For comparisons, we also evaluate the performance of H-K coding based iterative water-filling scheme (HK-IWF), treating interference as noise (I/N-ICA), and orthogonal multiplexing scheme. In HK-IWF scheme, H-K coding is applied on every subcarrier but the power allocation is implemented by IWF algorithm. In I/N-ICA scheme, on every subcarrier the interference is treated as noise, but the power allocation

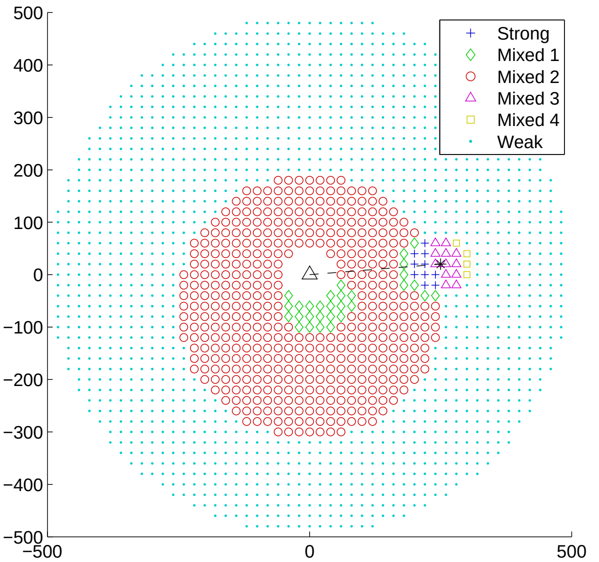

Fig. 1. Various interference scenarios when pico-BS is deployed at different positions. The central '△' denotes the macro-BS, the middle-right '∗' denotes the macro-user, the pico-user is 60 m above the pico-BS.

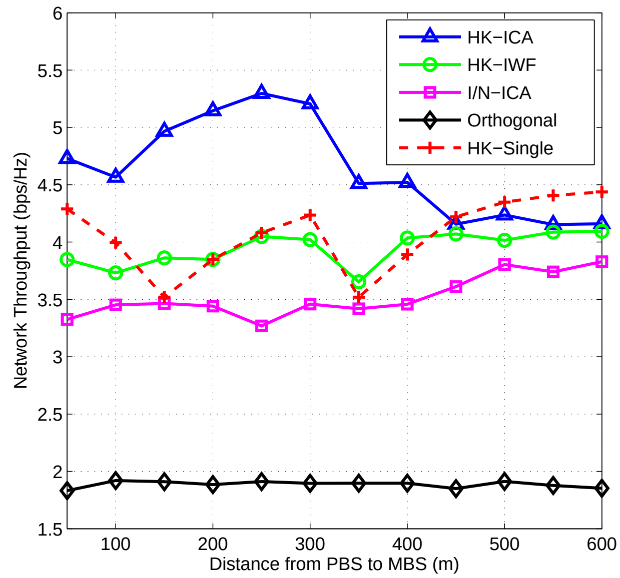

Fig. 2. Network throughput comparisons when the pico-BS moves from macro-cell center to macro-cell edge while the macro-user is fixed.

is optimized by ICA algorithm. In orthogonal multiplexing, each user occupies half of the time, and power allocation is implemented by single-user water-filling algorithm.

Fig. 1 demonstrates the relationship between interference scenarios and network deployments. Set the position of macro-BS at the coordinate origin, and a macro-user fixed at (250,20). Change the position of the pico-cell all around within the macro-cell, and keep the relative position of the pico-BS and pico-user fixed (the pico-user is always 60 m above the pico-BS). Fig. 1 marks the interference scenarios when the pico-BS is deployed at corresponding positions. We can see that all six interference scenarios appear but mixed 2 and weak have the largest probability. In this figure, only the impact of path loss is considered, with frequency-selective fading each subcarrier might encounter different interference scenarios.

Fig. 2 shows the simulated network throughput when the pico-BS moves from the macro-cell center (50, 0) to outside the macro-cell edge (600, 0), while the other topology is the same with in Fig. 1. Along with the moving of pico-BS, we know from Fig. 1 that mixed 2, mixed 1, strong, mixed 3, mixed 4 and weak interference scenarios are sequentially encountered. But due to frequency-selective fading, this is in average sense, actually we observe that even when the pico-BS moves to the cell-edge there are still several subcarriers not working in weak scenarios. For comparison, we also provide the achievable sum-rate of H-K coding with single subcarrier (HK-Single) where there is no fading and power allocation.

Simulation results show that both ICA and IWF algorithms converge in about 10 times of iterations. Due to the lack of space, we do not provide figure here. In Fig. 2, we can see that the HK-ICA scheme achieves substantial throughput gain than the HK-IWF, I/N-ICA, and orthogonal multiplexing schemes. In multi-carrier interference network, the H-K coding based schemes, i.e., HK-ICA and HK-IWF, still demonstrate some similarity with the "W" curve (see the curve of HK-Single). That means H-K coding based schemes can accommodate various interference scenarios. When the distance of pico-BS and macro-BS is less than 400 m, i.e., when the pico-cell is deployed in most areas of the macro-cell, HK-ICA scheme performs much better than HK-IWF scheme thanks to the benefit of centralized joint optimization. But when the distance is over 450 m, i.e., the pico-cell is deployed in macro-cell edge, HK-IWF can achieve almost the same performance of HK-ICA. In this scenario, HK-IWF is more preferred since it has lower computational complexity and can be implemented in a distributed manner. Due to frequency-selective fading and ICA optimization, the scheme that treating interference as noise is not as bad as we expected. Moreover, at macro-cell edge, the I/N-ICA scheme is not overlapped with the HK-ICA scheme, this is because there are still several subcarriers not working in weak interference scenario. The orthogonal multiplexing scheme, as standardized in LTE-A, has the worst performance, but on the contrast this result show us how much potential the new ICI coordination scheme can provide.

V. Conclusions

In this paper, a new ICI coordination scheme in multi-carrier heterogeneous network was provided. The scheme combines H-K coding and multi-carrier joint transmit power optimization, and demonstrate substantial performance gain than other power allocation and transmission schemes. The proposed optimization algorithm first constructs a concave lower bound of the original non-convex throughput function, and then gradually tightens the lower bound by solving the relaxed convex problem and iterations. The ICI coordination scheme can be extended to multi-antenna scenarios and that will be our future research topic.

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