With the explosive growth of mobile data traffic in the past decades, heterogeneous network (HetNet) has been regarded as a promising solution for future wireless communication. By deploying small cells (micro/pico/femto cells) or relays in macrocells, the network capacity can be significantly improved due to the reduced transmitter receiver distance. However, since the cells at different tiers usually share the same spectrum to achieve a high spectral efficiency, cross-tier cochannel interference is a critical issue for HetNets preventing the further performance improvements.

Coordinated multipoint (CoMP) is a technique for mitigating cochannel interference by means of combing a cluster of base stations (BSs) to simultaneously serve the selected user. It has been widely studied in macrocell-only networks to enhance the signal quality of cell edge users. The BS cooperation may range from coordinated scheduling and beamforming to full joint transmission (JT) . Deploying CoMP in HetNets, benefits will be brought together with challenges. For example, the macrocell is overlaid by entire small cells in HetNets and thus all the users in small cells may benefit from BS cooperation rather than cell edge users only. In another word, more users and BSs need to be jointly considered by resource allocation schemes in HetNets to fully exploit the benefits of CoMP.

Although combining CoMP with HetNets has attracted much research attention in most recent years, the published works addressing a variety of objectives and deployment scenarios are not yet fully developed, especially for the JT scenarios. In [2] and [3], the coverage probability of HetNets deploying CoMP JT was analyzed. In [1], the power consumption was minimized by determining the optimal received signal strength thresholds to form user's serving BS set. The resource allocation was studied in [4], where a cumulative distribution function (CDF)-based subchannel assignment scheme was designed without considering power allocation jointly, which will limit the performance gain. In this paper, we propose a joint subchannel and power allocation scheme for HetNets with CoMP JT support, by which a set of BSs possibly belonging to different tiers can transmit the same data of a single user simultaneously to avoid cochannel interference. To the best of our knowledge, it is the first piece of work jointly considering the issues of subchannel assignment and power allocation in such deployment scenario. Our objective is to maximize the overall network throughput subject to the transmit power budgets at BSs. To find the optimal solution, an iterative algorithm is first developed which decomposes the subchannel assignment and power allocation in each iteration to reduce computational complexity. Then, a greedy-based algorithm and an iterative waterfilling-based algorithm are designed, respectively, to solve the subchannel assignment and power allocation subproblems. The remainder of this letter is organized as follows. Section II introduces the system model and formulates the scheme to an optimization problem. Then Section III proposes the algorithms for solving the problem. Simulation results are presented in Section IV and the letter is finally concluded in Section V.

We consider the downlink of an orthogonal frequency division multiple access (OFDMA)-based HetNet composed of one macro BS and B small BSs as shown in Figure 1. Without loss of generality, the macro BS is indexed by 0 and small BSs are indexed from 1 to B. They cooperatively serve U users and share C subchannels. The power budget of BS b is max Pb . With JT, each subchannel may be used by multiple BSs to transmit the data of one user. However, it can be assigned to at most one user at a given time to avoid 493 2017 17th IEEE International Conference on Communication Technology 978-1-5090-3942-5/17/$31.00

©2017 IEEE interference.

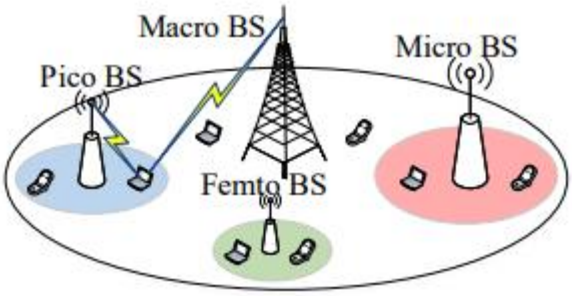


Figure 1. Typical structure of HetNets with CoMP JT.

We assume that the channel state information is known by BSs, which is a common condition for CoMP transmission [5]. Let , c bu g denote the channel gain of the link from BS b to user u on subchannel c. Then the transmission rate of user u achieved from these cooperative BSs on subchannel c is

$$\gamma_u^c = \Delta f \log_2\left(1 + \frac{\sum_{b=0}^{B} p_b^c g_{b,u}^c}{N_0}\right),$$

The constraint (2b) ensures that the allocated power cannot exceed the transmit power budget at each BS and (2d) ensures that each subchannel is assigned to at most one user. Here, BSs and user devices are supposed to be equipped with a single antenna. But it is straightforward to extend our work to multiple antennas scenarios because these cooperative BSs form a distributed multiple antennas system in nature.

Problem (2) is a mixed-integer nonlinear programming (MINLP) problem which is known to be computationally intractable. An effective way is to decompose the MINLP into the subproblem with integer variables and the subproblem with real variables to reduce the computational complexity [5]-[7]. Thus, we employ an iterative approach in this paper, by which the subchannel assignment and power allocation are decoupled and the solutions of these two simpler subproblems are adjusted alternatively until convergence. The main procedure is summarized in Algorithm 1。

| Algorithm 1 – iterative algorithm for joint subchannel and power allocation |
|---|
| 1. **Initialization**: |
| • Set iteration index $i=1$, initial overall throughput $T(0)=0$. |
| • Set initial power $p_b^c(0)=\mathrm{P}_b^{\max}/C, \forall b,c$. |
| 2. **Iteration $i$**: |
| • Compute $\boldsymbol{\rho}(i)$ by Algorithm 2 under $\boldsymbol{p}(i-1)$. |
| • Compute $\boldsymbol{p}(i)$ by Algorithm 3 under $\boldsymbol{\rho}(i)$ and $\boldsymbol{p}(i-1)$. |
| 3. Compute $T(i)$ using (2a) and increase $i$. |
| Go back to step 2 until $i=\mathrm{I}^{\max}$ or $T(i)=T(i-1)$. |
| 4. Output $\boldsymbol{\rho}$ and $\boldsymbol{p}$. |

Based on the power allocation solution p( 1) i – obtained in the last iteration, subchannel assignment is performed following Algorithm 2. Although strictly speaking, each subchannel could be allocated to one user or remain unused, maximizing the overall throughput results in the use of all subchannels. Therefore, we allocate each subchannel c to the user with the maximum transmission rate. Such greedy based approach can thus achieve a local optimal subchannel assignment solution.

| Algorithm 2 – greedy algorithm for subchannel assignment |
|---|
| 1. For $c = 1$ to $C$ |
| • Select the user with the maximum transmission rate, i.e., $u_c^* \equiv \arg\max_u \left\{ \sum_{b=0}^{B} p_b^c g_{b,u}^c \right\}$. |
| • Set $\rho_{u_c^*}^c = 1$ and $\rho_{u \neq u_c^*}^c = 0, \forall u$. |
| Endfor. |
| 2. Output $\boldsymbol{\rho}$. |

To evaluate the performance of the proposed scheme and algorithms, a downlink HetNet with Long Term Evolution (LTE) technology shown in Figure 1 has been simulated. There are C = 50 subchannels, each of which has a bandwidth of Δf = 180 kHz. 15 hot spots are uniformly located in the macrocell. 10 and 5 users are uniformly distributed in the macrocell and each hot spot, respectively. The macro BS has a power budget of max P0 = 46 dBm. The maximum numbers of iterations are set to be max max I K= = 10. The large-scale distance-dependent path loss is expressed as L = 122.85 + 34.88log10(d), where d is the distance measured in Km. The lognormal shadowing is applied with a standard deviation of 10 dB and the penetration loss is 20 dB. The small-scale fading is modeled as the normalized Rayleigh fading and the noise power density is –174 dBm/Hz.

First, the proposed joint subchannel and power allocation scheme is compared with two reference schemes. One is the CDF-based scheduling scheme designed in [4] for the joint transmission in HetNets. It is the most related work to ours that we could find. The other is the classical round-robin (RR) scheme which allocates both subchannels and power to users in an average manner. The schemes are compared in two types of scenarios. One is macro-pico HetNet where the power budget of pico BSs is max Pb = 30 dBm. Another is macro-femto HetNet where max Pb = 20 dBm. The number of small BSs is changed from 3 to 15 by adding small BSs to the hot spots. The results presented in Figure 2 are obtained by averaging over 5000 channel realizations.

It is clear in Figure 2 that our scheme can always achieve the best performance. Since the channel conditions of users are not differentiated by RR scheme, it can only obtain the lowest throughput. By CDF scheme, the subchannel is assigned based on the user's cumulative rate distribution function while the power is still equally allocated. Although its performance is much better than RR, the improvements achieved are still limited compared to our scheme since which jointly optimize the subchannel and power allocation. Besides, the convergences of the proposed iterative algorithms (i.e., Algorithm 1 and Algorithm 3) have also been examined. We observed the overall throughputs obtained in each iteration process and found that both Algorithm 1 and Algorithm 3 generally converged within five iterations.

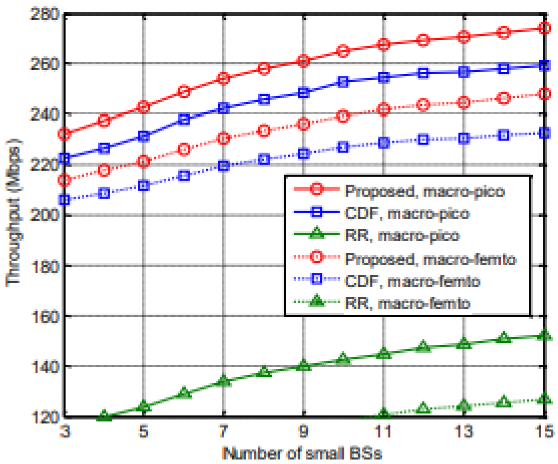


Figure 2. Overall throughput comparison under macro-pico/femto scenarios.