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Weighted Sum Throughput Maximization in Heterogeneous OFDMA Networks

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***Abstract*—We formulate the resource allocation in the downlink of heterogeneous orthogonal frequency division multiple access (OFDMA) networks. Our primary objective is to maximize the system sum throughput subject to service and system constraints, including maximum transmit power, quality of service and per-user subchannel allocation. Due to the inter-cell interference, the corresponding optimization problem is, in fact, nonconvex, that cannot be solved using standard convex optimization techniques. Here we propose an algorithm based on local search method and use of penalty function to approximate the formulated constrained optimization problem by an unconstrained one. To approximate a global optimal, we set escaping procedure from the critical point based on constraint function conditions. The result shows that the proposed method might achieve optimum conditions by a hybrid of split and shared spectrum allocation. Numerical analysis indicates that the proposed algorithm outperform the other conventional methods in the scenario of the high level of inter-cell interference. Moreover, the proposed method approximates the global optimum by considering both channel gain and inter-cell interference with a fast rate of convergence.**

I. INTRODUCTION

According to market report [1], mobile subscriptions all over the world grew around seven % per year during Q1 2014. Over the same period, mobile broadband subscriptions grew even faster at a rate of 35 % per year, reaching 2.3 billion. Smartphones dominate the mobile phones selling in Q1 2014 at around 65 %. Moreover, data usage per subscription continued to grow, which is dominated by video (40%) and followed by social network (10%) (in 2013). These factors have contributed to a 65 % growth in mobile data traffic in the period between Q1 2013 and Q1 2014. This report noted that most data traffic is generated indoors by users, either from indoor solutions or by outdoor solutions that provide radio access for indoor users. One solution to increase capacity and coverage is heterogeneous networks (HetNets) that complement existing networks with small cells.

A femtocell is a small and underlying cell in HetNets. The network is designed to cover indoor or very small areas and connected to the main cellular network through internet backbone provided by a user. Moreover, these kinds of networks can be randomly deployed by users without centralized network coordination in many aspects such as frequency and location plan, a maximum transmission power adjustment or time access scheduling [2]. Considering the flexibility, economic aspects and market trend, it might be the most cellular networks that co-exist with larger existing cellular networks in the future, such as macrocell or microcell. These situations make femtocells have a potency of interfering adjacent femtocells and the main macrocell networks. Instead of improving network performance, the presence of interference in HetNets can dismiss the expectation of cellular providers as well as their subscribers to have the performance improved.

Because of inter-cell interference, sum rate optimization in multi-cells is a nonconvex problem [3]. There are some researches with different approaches to solving these kinds of problems. Currently, the widely used strategies for resolving the problem are using convex optimization approach to solve nonconvex problems [4]. To achieve the maximum capacity of the secondary service for HetNets, reference [5] develops a mixed access strategies for spectrum sharing based on overlay and underlay strategies. In cognitive radio, the secondary service is the service provided for users with less priority for spectrum access. Using an approach of Jensen's inequality [4] to simplify the problem and subsequently solve it using Lagrange duality, this method is simple and achieves the capacity that is close to the maximum achievable capacity of the secondary service. However, this work focuses on the secondary network. It does not maximize the total capacity of HetNets.

To optimize data rate in digital subscriber line systems, reference [6] developed distributed power control based on iterative water-filling technique. In this paper, interference channel is modeled as a non-cooperative game. The method can be implemented distributively without centralized control. It results in competitive optimal power allocation by offering an opportunity to negotiate the best use of power and frequency between two edges of the system.

To maximize the throughput of HetNets, reference [7] proposed spectrum splitting-based cognitive interference management in two-tier LTE networks using a Monte Carlo simulation. The results were achieved by allocating transmit power, frequency spectrum and time slot based on pilot signals from base stations (BSs) and control channel information. Power is assigned to each subchannel equally. Subchannels are allocated separately to each tier network by considering the best gain and the best trial number of subchannels for each BS. Thus, the method is still away from the optimal result.

In this paper, a method of suboptimal resource allocation in OFDMA HetNets is proposed to maximize sum throughput of HetNets with the constraints of maximum transmit power and quality of service (QoS). As the optimization problem is nonlinear and nonconvex [3] that cannot be solved using standard convex method [4], we propose an approximation using a local search strategy that considers the global optimal condition for critical-point escaping procedure [8]. As optimal power allocation at fading channel assumes average power constraint [9], we approximate to solve the problem using local search method by assigning average power allocation in each

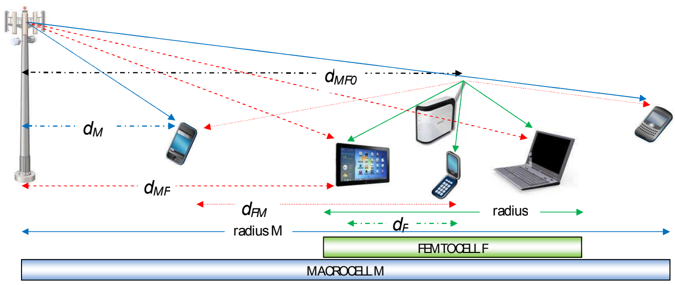

Fig. 1. System model.

subchannel, which is the spectrum and power allocation for each BS in HetNets.

The remaining of this paper is organized as follows. Section II presents System Model and Problem Formulation. Section III elaborates the proposed method, i.e. Suboptimal Spectrum and Power Allocation. Results and Analysis are discussed in Section IV. Finally, Section V concludes this paper.

II. System Model and Problem Formulation

A. System Model

In this work, downlink transmission in sectorized OFDMA cellular HetNets is considered. Networks are modeled in one dimension as having been done in [3] to ease identification, analysis and solving the problem. However, the model still captures most important aspects of the real issues in cellular HetNets as described in Fig. 1. The radius of coverage areas is 500 m for macrocell (r_M) and 40 m for femtocell (r_F). Same numbers of user terminals (UTs), k_M for macrocell and k_F for the femtocell, are uniformly distributed in each cell. These networks share the same spectrum. System parameters are presented in Table I. Data rate (bits per second) of selected UT in cell A (k^A) on subchannel n is:

$$R_{k^A}^{A,n} = B \times log_2 \left(1 + \frac{P_{k^A}^{A,n} G_{k^A}^{A,n}}{N_0 B + P_{k^A}^{B,n} G_{k^A}^{B,n}} \right), \tag{1}$$

where $P_{k^A}^{A,n}$ and $P_{k^A}^{B,n}$ are the power transmitted on subchannel n by cell A and cell B, respectively, to user k^A. $G_{k^A}^{A,n}$ and $G_{k^A}^{B,n}$ denote the channel gain on subchannel n from serving-BS A and interfering-BS B, respectively, to user k^A. For propagation path losses, 3GPP's path-loss models [11] for outdoor and indoor femtocells are used.

B. Problem Formulation

In this paper, we propose our method to maximize sum throughput of wireless OFDMA HetNets (2) under some constraints, i.e. (3) to (6). The optimization variables are the set of allocated power at each subchannel of each BS. Reference [12] has showed that the maximum data rate of an OFDMA system is achieved when each subcarrier is allocated to one UT with the best channel gain on that subcarrier. However, in HetNets, performing only the same approach above to each network may not lead the best capacity because of the interference. To optimize the capacity of these networks, in addition to the best channels of allocated users [12], resource allocation also needs to consider the channels has low interference power. Thus, power allocation in HetNets must take into account properly both high transmit power for high capacity and interference avoidance to adjacent interfered networks caused by this resource allocation. The constrained optimization problem can be formulated as follows:

$$\begin{aligned} f(P_k^{M,n}, P_{k'}^{F,n}) = \max_{P_k^{M,n}, P_{k'}^{F,n}} \sum_{k}^{K} \sum_{n \in \mathcal{N}_k} w_k^{M,n} R_k^{M,n} \\ + \sum_{k'}^{K'} \sum_{n \in \mathcal{N}_{k'}} w_{k'}^{F,n} R_{k'}^{F,n}, \end{aligned} \tag{2}$$

subject to power constraints:

$$C_1: \quad \sum_{k}^{K} \sum_{n \in \mathcal{N}_k} P_k^{M,n} \le P_{tot}^M, \tag{3}$$

$$\sum_{k'}^{K'} \sum_{n \in \mathcal{N}_{k'}} P_{k'}^{F,n} \le P_{tot}^F,$$

$$C_2: \quad P_k^{M,n} \ge 0; P_{k'}^{F,n} \ge 0, \tag{4}$$

subject to QoS and subchannel allocation constraints:

$$C_3: \quad \frac{P_k^{M,n} G_k^{M,n}}{N_0 B + P_k^{F,n} G_k^{F,n}} - \gamma_{th} \ge 0, \forall k \in \{1, \cdots, K\}, \tag{5}$$

$$\frac{P_{k'}^{F,n} G_{k'}^{F,n}}{N_0 B + P_{k'}^{M,n} G_{k'}^{M,n}} - \gamma_{th} \ge 0, \forall k' \in \{1, \cdots, K'\},$$

$$C_4: \quad \mathcal{N}_k^M \cap \mathcal{N}_{k'}^M = \varnothing, \mathcal{N}_k^F \cap \mathcal{N}_{k'}^F = \varnothing, \forall k \ne k', \tag{6}$$

where M and F indicate symbols for macro and femto cells, respectively. K and K' are total user number of macro and femto cells. $w_k^{A,n} \in [0,1]$ is the weight of UT-k of cell A on subchannel n, which is set as '1'. P_{tot}^A is the total power of cell A. γ_{th} is the signal-to-interference-plus-noise ratio (SINR) threshold; expressing the minimum QoS level that causes subchannel having SINR $< \gamma_{th}$ will be avoided. $\mathcal{N}_k^A$ is the number of allocated subchannels to k^A, in which each subchannel is allocated for each different user at the same time. It is assumed that channel states have been known before resource allocation.

We consider the optimization problem as weighted sum throughput maximization problem which evaluates power and QoS constraints as weighted factors for each network. The objective function is nonlinear and non concave in (P_n^M, P_n^F), because of the inter-cell interference term [3]. However, the nonlinear optimization problem can be solved using different approaches that involve some compromises, such as global optimization [4]. To improve the efficiency of the global search, [8] proposes the usage of a local search at each iteration. [13] describes the usage of a mathematical apparatus to make possible to escape a local solution. This approach helps to find the global solution in game equilibrium problems, hierarchical optimization problems, and other nonconvex optimization problems. In this paper, we propose a suboptimal resource allocation method for HetNets based on a *local search* method. This approach is suitable for unconstrained optimization problem and finding a local minimum of an objective function [4]. It needs modification to solve the constrained global optimization problem. We use a *penalty function* method to approximate a constrained optimization problem using an unconstrained one [10]. To approximate the global optimum, we set an escaping procedure from the critical point based on constraint function conditions.

TABLE I. System Parameters

Symbol	Parameter (Unit)	Value
f_c	carrier frequency (GHz)	2
B_{sc}	freq. bandwidth per-subchannel (kHz)	180
N_{sc}	number of subchannels	25
N_0	thermal noise density (W/Hz)	$5.556 \cdot 10^{-21}$
fd	channel fading per-subchannel	Rayleigh
fs	channel fading in all spectrum	frequency selective
L_w	wall penetration loss (dB)	13
P_{tot}^M	macro base-station (BS) total power (dBm)	48
P_{tot}^F	femto-BS total power (dBm)	30
d_u^M	minimum distance to macro-BS (m)	50
d_u^F	minimum distance to femto-AP (m)	3

III. Suboptimal Spectrum and Power Allocation

This section elaborates a suboptimal spectrum and power allocation algorithm (OSPA) for OFDMA HetNets based on local search and penalty function methods. Radio resources are allocated to the best gain channels among all UTs' for each subchannel of each cell. We use a local search strategy and set critical point escaping procedure based on some constraint functions.

Local Search: The local search algorithm is used to find the power allocated to each subchannel. At first, total power is equally distributed to each subchannel. Then, iteratively this allocated power is reduced by a step size matrix $\mathbf{A}$ multiplied by $\boldsymbol{\nabla} f$. By setting the proper step size $\mathbf{A}$, then we have an equation for variable updating.

$$\mathbf{X}^{i+1} = \mathbf{X}^{i} - \mathbf{A} \circ \boldsymbol{\nabla} f(\mathbf{X}^{i}), \tag{7}$$

where $\mathbf{X}$ is an $N \times 2$ matrix of variables of the objective function, i.e. the power allocated for each subchannel. N is the total number of subchannels. i is the iteration index. $\boldsymbol{\nabla} f$ is the gradient of the objective function (2), not the variable updating function (7), which is used as a multiplier of iterative searching of the allocated power in each subchannel of each cell. $\circ$ is the Hadamard product operator. $\mathbf{A}$ is an $N \times 2$ matrix that obtained as follows.

$$\mathbf{A} = \begin{cases} \epsilon \cdot \mathbf{J} \div \boldsymbol{\nabla} f, & \text{if } \boldsymbol{\nabla} f > 0, \\ 0, & \text{otherwise,} \end{cases} \tag{8}$$

where ϵ is a small value constant. $\mathbf{J}$ is an $N \times 2$ matrix of ones. $\div$ is an element-wise matrix division notation.

Penalty Function: The penalty function $\mathcal{V}(\mathbf{X})$ is designed for relieving the impact of power allocation on subchannel n of cell A whose constraints are violated. This function is developed based on constraint formulas as follows.

$$\mathcal{C}_{n,1}^{A} = \frac{P_{tot}^{A}}{N} - P_{n}^{A}, \quad \forall n \in \{1, \cdots, N\}, \tag{9}$$

$$\mathcal{C}_{n,2}^{A} = \frac{P_{n}^{A} \cdot G_{kA}^{A,n}}{N_0 B + P_{n}^{B} \cdot G_{kA}^{B,n}} - \gamma_{th}, \quad \forall n \in \{1, \cdots, N\}, \tag{10}$$

$$\boldsymbol{\mathcal{C}} = \left\{ \boldsymbol{c}_1^{M}, \boldsymbol{c}_1^{F}, \boldsymbol{c}_2^{M}, \boldsymbol{c}_2^{F} \right\}, \tag{11}$$

where $\mathcal{C}_{n,1}^{A}$ and $\mathcal{C}_{n,2}^{A}$ are the values of constraint functions of cell A on subchannel n above, i.e. (9) and (10). $\boldsymbol{c}_m^{A} = \{\mathcal{C}_{1,m}^{A}, \mathcal{C}_{2,m}^{A}, \cdots \mathcal{C}_{N,m}^{A}\}^{T}$ is an N-element column vector of constraint function values of cell A. $m \in \{1, 2\}$ is the index of constraint functions above. $\boldsymbol{\mathcal{C}}$ is an $N \times 4$ matrix of constraint function values.

Step size vector ($\boldsymbol{\delta}$) of the penalty function is set to gradually vanish power allocation on subchannels whose constraints are violated; so the rate of convergence is set faster than $\mathbf{A}$ (8). The 1×4 row vector $\boldsymbol{\delta}$ is obtained as follows.

$$\boldsymbol{\delta} = \left| \overline{\boldsymbol{\mathcal{C}}_0} \right| / N, \tag{12}$$

where

$$\boldsymbol{\mathcal{C}}_0 = \begin{cases} \boldsymbol{\mathcal{C}}, & \boldsymbol{\mathcal{C}} < 0, \\ 0, & \text{otherwise.} \end{cases}$$

Then penalty function multiplier ($\boldsymbol{\Omega}$) is an $N \times 2$ matrix:

$$\boldsymbol{\Omega} = \begin{cases} \beta \cdot |\boldsymbol{\nabla} f_{neg}| \div \boldsymbol{\Omega}_2, & \text{if } \boldsymbol{\nabla} f < 0, \\ 1, & \text{otherwise,} \end{cases} \tag{13}$$

where

$$\boldsymbol{\nabla} f_{neg} = \begin{cases} \boldsymbol{\nabla} f, & \text{if } \boldsymbol{\nabla} f < 0, \\ 0, & \text{otherwise.} \end{cases}$$

$$\boldsymbol{\Omega}_2 = |\min(\boldsymbol{\nabla} f_{neg})| \otimes \mathbf{I}.$$

β is set to make the penalty function gradually eliminates power on subchannels having violated constraints. $\otimes$ is the Kronecker product operator. $\mathbf{I}$ is an N-element vector of ones.

Then, the penalty function is obtained as follows.

$$\mathcal{V}(\mathbf{X}) = \left\{ \boldsymbol{\rho}^{M} + \boldsymbol{\mu}^{M}, \boldsymbol{\rho}^{F} + \boldsymbol{\mu}^{F} \right\}, \tag{14}$$

where

$$\boldsymbol{\rho}^{A} = \begin{cases} -\delta_1^{A} \cdot \frac{P_{tot}^{A}}{N} \cdot \boldsymbol{c}_1^{A}, & \text{if } \mathcal{C}_{n,1}^{A} < 0, \\ 0, & \text{otherwise.} \end{cases}$$

$$\boldsymbol{\mu}^{A} = \begin{cases} -\delta_2^{A} \cdot \frac{P_{tot}^{A}}{N} \cdot \boldsymbol{c}_2^{A}, & \text{if } \mathcal{C}_{n,2}^{A} < 0, \\ 0, & \text{otherwise.} \end{cases}$$

$\delta_m^{A} \in \{\boldsymbol{\delta}\},\ m \in \{1, 2\}$, is a step size variable for cell A (12).

Then (7) will be rewritten as follows.

$$\mathbf{X}^{i+1} = \mathbf{X}^{i} - \mathbf{A} \circ \boldsymbol{\nabla} f(\mathbf{X}^{i}) - \boldsymbol{\Omega} \circ \mathcal{V}(\mathbf{X}^{i}). \tag{15}$$

Stopping Condition: Stopping condition is set to approach the global optimum by considering constraint functions as follows.

$$0 \leq \mathcal{C}_{n,1}^{A/B} \leq \frac{P_{tot}^{A/B}}{N}, \quad \forall n \in N, \tag{16}$$

$$\mathcal{C}_{n,2}^{A/B} \geq -\gamma_{th}, \quad \forall n \in N, \tag{17}$$

$$\frac{\Delta f}{f} \leq \epsilon, \tag{18}$$

where f is the objective function as presented in (2).

Algorithm Summary: In general, the proposed method is summarized as follows.

1) Initially, for each subchannel of each network, the best channel among all users' is selected, and power allocation is set equally.
2) Transmit power of each subchannel of each BS is iteratively reduced using local search method (7) with very small step size till optimum power allocation for interfering cells is achieved while maintaining the global optimum objective.
3) For subchannels with violated constraints, power reduction is set faster using penalty function.
4) Evaluate the stopping condition to ensure the global optimum objective is approached.

At the end of an iteration cycle, spectrum allocation for both networks can be a hybrid of split and shared spectrum. In general, the algorithm can be written as follows.

Initialization:
$P_{tot}^{M}, P_{tot}^{F}, P_{n}^{M}, P_{n}^{F}, d_{MF0}, N_{k}^{M}, N_{k}^{F}, channel\_type$;
$(d_M, d_F, d_{MF}, d_{FM}) \leftarrow$ load *distance_vector*;
$(G^{M}, G^{F}, G^{MF}, G^{FM}) \leftarrow$ generate *channel_gain*;
$\max\limits_{k} (G_k^{Mn}, G_k^{Fn}, G_k^{MFn}, G_k^{FMn}), \forall n \in N, \forall k \in K$
$\leftarrow$ find the best gain of each subchannel;
$f(P_k^{M,n}, P_{k'}^{F}, n) \leftarrow$ set the *objective function* (2);
$\boldsymbol{\nabla} f \leftarrow$ set the *gradient function*;
$\boldsymbol{\mathcal{C}} \leftarrow$ set *constraint functions and matrix* (9 - 11);
while NOT stopping condition **do**
  $\mathbf{A} \leftarrow$ set the step size matrix (8);
  Calculate the penalty function: $\boldsymbol{\delta}, \boldsymbol{\Omega}$ and $\mathcal{V}(\mathbf{X})$ (12 - 14)
  Update $\mathbf{X}^{i+1}$; (15)
  Evaluate variable bounds,
  e.g. $P \geq 0, \sum P_n \leq P_{tot}$;
  $count(N_k^{M}, N_{k'}^{F})$;
  $set(P_{tot}^{M,n}, P_{tot}^{F,n})$
  Evaluate stopping conditions (16 - 18)
end while

IV. Numerical Results and Analyses

In this section, we present the results of the proposed method using numerical analysis to find the optimum result for each iteration cycle. Moreover, then repeat the algorithm for different network configurations to get the final average results. We compare and analyze the performance of the proposed algorithm with the following algorithms:

- Multicells iterative water-filling (IWF) algorithm [6]: An optimal multi-channel power allocation method that is implemented in distributed manner.
- Equal power allocation (EPA): Total transmit power is divided and distributed evenly into all subchannels.
- Split spectrum allocation (SSA): Total spectrums is divided equally for each cell.

The average sum throughput is obtained by simulating the method in many repetitions that parameters, i.e. UT's positions, are set randomly.

Fig. 2 shows the average sum throughput of OSPA with different scenarios when γ_{th} is selected differently. The different scenarios are separating distances between cells (d_{MF0}) and channel models, i.e. 3GPP's path losses for outdoor and indoor femtocells. k^M and k^F are 6 UTs for each network. The other parameters are elaborated in Section II-A above. The figure shows that the differences of cells' distances d_{MF0} and thresholds γ_{th} effect to the differences of average sum throughput and peak rate for each scenario. For outdoor femtocell scenario, OSPA with d_{MF0} 100 m reaches a peak rate at γ_{th} 4 dB. Whereas, OSPA with d_{MF0} 250 m and for the same scenario reaches a peak rate at γ_{th} 0 dB. It reveals that OSPA with the appropriate selection of γ_{th} can optimize average sum throughput of HetNets. When using 3GPP's indoor channel model, wall penetration loss is assigned. This kind of path loss can reduce interference power significantly from outside cells depend on wall material [9], [11]. However, when implemented in indoor femtocell with d_{MF0} 100 m, OSPA has decreasing trend for the increasing of γ_{th}. It reveals that this method is not suitable to optimize the throughput of HetNets in low interference scenario.

Fig. 3 shows average sum throughput of HetNets with a varied number of users. d_{MF0} is 100 m. Path loss channel model is outdoor, i.e. femtocell without surrounding wall. In this figure, the proposed method (OSPA with γ_{th} 4 dB) is compared with IWF, EPA, and SSA 50%. In general, sum throughput of all methods increases with increasing number of UTs. The proposed method outperforms all others. OSPA allocates transmit power in each subchannel of each cell by iteratively reducing the power of each cell to reduce inter-cell interference and to avoid violated constraints. Using this approach, OSPA occupies the best subchannels and releases the worse ones, which lets the other BS occupy. Whereas, EPA distributes transmit power equally to each subchannel. Using EPA, high gain inter-cell subchannels will interfere to adjacent BS; while the low ones reduce power efficiency.

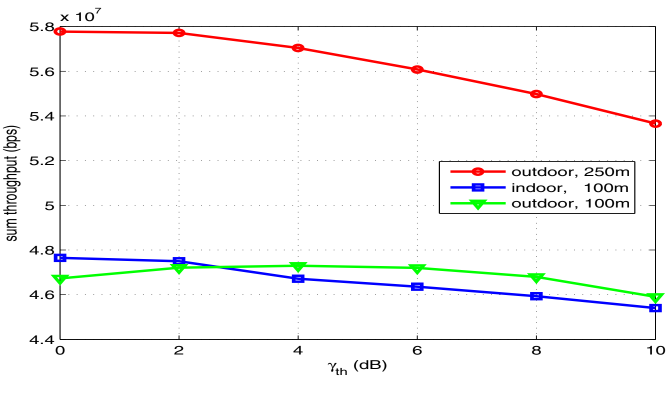

Fig. 2. OSPA with varied threshold γ_{th} for different scenarios.

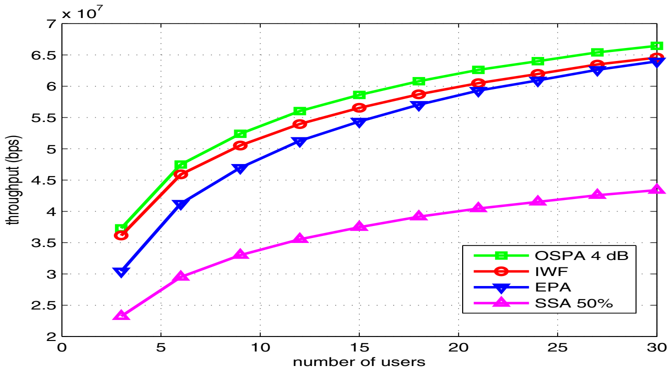

Fig. 3. Average sum throughput of HetNets (outdoor femtocell, d_{MF0} = 100m) with varied user number.

Comparing to IWF, OSPA has better sum throughput of HetNets. Water-filling power allocation, the core algorithm of IWF, is built by assuming Gaussian channel with no interference power [9]. It allocates more power to higher gain channels, less power to lower gain channels, and no power to channels which results in lower SINR compared to the threshold. In this case, IWF allocates power optimally to each subchannel based on the water-filling algorithm. When implemented in an interference environment such as HetNets, IWF will look for optimal equilibrium between all BSs using competition approach [6]. Speed convergence of this method is paid off by the loss of optimal point. Meanwhile, OSPA approximates optimum conditions iteratively, gradually and in parallel for all subchannels and multicells. Thus, OSPA outperforms IWF in multichannel HetNets.

Comparing to SSA, OSPA results in higher sum throughput of HetNets. SSA selects the best half spectra for the macrocell and leaves the rest ones for the femtocell. Then the pre-assigned power in each network is distributed entirely to the spectra using EPA. By using this approach, there is no interference among different network tiers. However, fewer spectra for each network reduce the benefit of frequency diversity in a multicarrier system. Moreover, the EPA will distribute transmission power uniformly in each subchannel regardless of channel conditions. It leads to the high channel gain occupied by the same transmission power as the weak one. So the power allocation on each subchannel is less optimal.

Fig. 4 shows the portion of average allocated power for each subchannel over the total (maximum) power of each network for each iteration step. d_{MF0} is 150 m. Channel model is 3GPP's outdoor propagation path loss. γ_{th} is 2 dB. The number of UTs is 6 units. The average allocated power tends to decrease as iteration steps increase. In femtocell, there is a slightly decrease allocated power. While, in the macrocell, the decrease of transmission power is sharper. It happens because the average distance of the macro UTs and the macro BS is greater than the one of the FAP and fUTs. So propagation path losses in the macrocell are larger than the femtocell. Also, the random spread of macro UTs in HetNets more likely interfered by femtocell than a limited distribution around the UTS femto AP. Assuming the noise power is constant, the determining factor of the channel quality is the channel gain and the received interference power. The combination of high propagation path losses and the high probability of getting interfered in the downlink transmission leads channel in the macrocell is worse than the one of the femtocell.

Fig. 5 shows the average sum throughput of the propose method for each iteration step, in which uses the same scenari as the previous one. Compared to Fig. 5, Fig. 4 shows tha decreasing allocated power in the macrocell from iteration ste 1 to 2 results in decreasing throughput of the macrocell, bu increasing throughput of the femtocell and entire network: It reveals that limiting transmission power in the macroce can improve the capacity of the femtocell and entire network: For step 2 to 4, decreasing allocated power in the macroce and slightly decrease allocated power in the femtocell lead to slightly decreasing the macrocell's sum throughput an followed by slightly increasing sum throughput in the femtoce and entire networks. It reveals that proper power allocation i.. each subchannel of each cellular network leads to decreasing interference power as well as increasing sum throughput of the network. Moreover, it also shows both networks seek equilibrium out for these steps. For step 4 to 6, the transmission power for femtocell remain unchanged and for macrocell is decreasing. It resulted in slightly decreasing throughput in macrocell and followed by slightly increasing throughput in the femtocell. For entire networks, sum throughput achieves steady state condition. It reveals that the system has achieved equilibrium points and also approximates the global optimum of the objective function. To conclude, the proposed method approach optimum points, i.e. suboptimal power allocation in each network, by considering channel gain and inter-cell interference. Moreover, the proposed method has a fast rate of convergence that shown by small step to stop.

V. Conclusion

In this paper, our investigation on sum throughput maximization in downlink heterogeneous OFDMA networks has been elaborated. The proposed method approximates the global optimum using a local search and a penalty function iteratively and simultaneously through power allocation for each subchannel of HetNets. By using the proposed method, optimum conditions might be achieved by a hybrid of split and shared spectrum allocation, which also might be achieved by IWF. IWF achieves optimum by iteratively allocating resources of each network using water-filling algorithm after getting channel state information; while the proposed method achieves optimum by finding out equilibrium of equal power allocation in each subchannel of each network and set less or even no power for violated subchannels. In the high-interference environment, the proposed method with the right selection of γ_{th} achieves higher throughput than the other conventional methods. Moreover, the proposed method approximates the global optimum by considering both channel gain and inter-cell interference power with a fast rate of convergence.

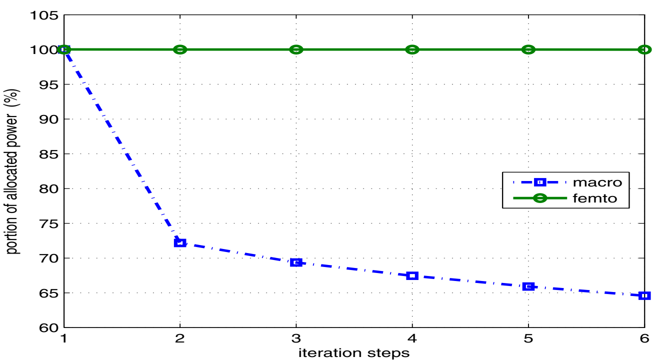

Fig. 4. The portion of average allocated power over the total power for each iteration step.

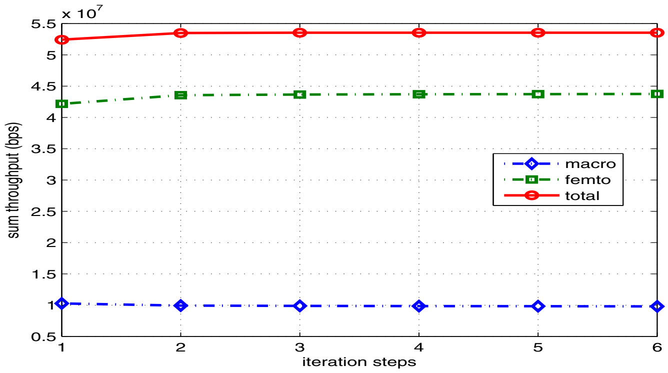

Fig. 5. Average sum throughput of OSPA method for each iteration step.

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