Antenna Selection and Resource Allocation in Downlink MISO OFDMA Femtocell Networks

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***Abstract*—In this paper, the problem of joint sub-channel assignment, antenna selection, and power control in the downlink (DL) of an orthogonal frequency division multiple access (OFDMA) femtocell network is investigated in order to maximize system throughput. This problem, due to its discrete nature and the interference, is modeled as a mixed integer non-linear programming (MINLP) optimization problem, which is complicated to solve. To deal with this complexity, the problem is decomposed into three subproblems: 1) sub-channel assignment, 2) antenna selection, and 3) power control. We then present an iterative algorithm for these subproblems resulting in an optimized network throughput. The superiority of our proposed method compared to other existing works is demonstrated through simulation results.**

I. Introduction

Spectral efficiency, flexibility in resource allocation, and low implementation cost have contributed to the deployment of orthogonal frequency division multiple access (OFDMA) systems as the main trend for the broadband wireless industry [1]. In this regard, power control and sub-channel assignment are some of the most challenging problems for the success of OFDMA femtocells networks, where femtocells are being considered as a potential approach to improve the capacity and coverage for indoor wireless users. These challenges have led many researchers to investigate the idea of the sub-channel and power allocation optimization problem in OFDMA cellular networks [2]-[11].

For instance, [2]-[6] consider the sub-channel assignment problem together with power control in wireless OFDMA networks. In [2], sub-channel assignment, and power control are investigated in terms of maximizing the minimum rate of the network. Then an iterative algorithm is proposed to solve this problem. In [4]-[5], the problem of subcarrier and power allocation for maximizing the sum rate of a heterogeneous network is investigated under the maximum transmit power and users' quality of service (QoS) constraints. The modeled problems are then solved by decoupling the power allocation and subcarrier assignment problem and solving each separately. The authors of [6] propose a coordinated joint uplink user scheduling and power control algorithm for maximizing system throughput of a multi-cell cellular network. This work reformulates the original problem in a fractional problem (FP) form, and is subsequently solved through a distributed suboptimal iterative algorithm. In [7], downlink (DL) beamforming, antenna selection, and uplink power allocation are considered in order to minimize the total transmit power of the network. For the DL of a multiuser OFDMA network with distributed antenna systems (OFDM-DAS), a joint antenna, subcarrier, and power allocation scheme for maximizing energy efficiency is studied in [8]. Moreover, in [8], in order to avoid the complexity of considering the SINR of the users in the rate function, an upper bound on the maximum allowed interference is calculated.

Recently, systems with multiple-input multiple-output (MIMO) have become a promising approach to enhance the capacity and reliability of wireless communication systems. However, in this technology, the separation of radio frequency (RF) chains for each antenna branch causes an increase in complexity and cost of the device, which makes it prohibitive for practical purposes. It is proven that through antenna selection, we can exploit the benefits of a MIMO system in terms of achieving a diversity gain with a much lower complexity since no pre- and post-processing is required [12]-[14].

Nonetheless, to the best of our knowledge, the joint problem of sub-channel allocation, antenna selection and power control in the DL of an OFDMA femtocell network for maximizing system throughput has not been addressed in the existing literature. In [2]-[6], transceivers are equipped with only one antenna and in [7], the objective function is to minimize the system's power consumption in a full-duplex multi-cell network while neglecting the subcarrier allocation. Furthermore, [8] considers the problem of the antenna selection in the DL of a single cell network, without proper consideration of interference in the rate function. This motivates us to focus on solving the problem of joint sub-channel assignment, antenna selection and power control under the transmit power feasibility constraint in the DL of an OFDMA femtocell network to maximize system throughput. This problem is modeled as an optimization problem, which due to its discrete nature of sub-channel and antenna selection variables as well as the presence of co-channel interference is a non-convex mixed integer non-linear programming (MINLP). In order to solve this complex problem, we first decompose it into three subproblems, i.e. sub-channel assignment, antenna selection, and power allocation. In the first step, for a fixed transmit power and a given antenna selection scheme, the optimal sub-channel assignment is obtained. Then, for the obtained sub-channel allocation, the best antenna selection assignment is determined and finally, based on the obtained sub-channel and antenna selection policies, the power allocation problem

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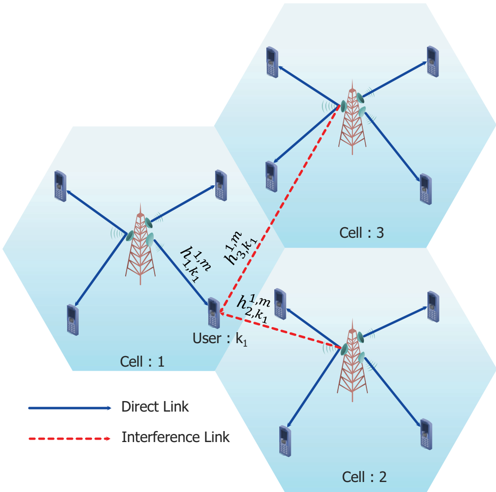

Fig. 1. System model of the OFDMA networks consisting of C=3 femtocells, where there are K = 4 users in each femtocell. In this figure, the blue arrow shows the direct transmission link between the base station and the users, while the dotted line indicates the undesired interference link.

is solved using an augmented penalty method [15]. The aforementioned algorithms are then incorporated into a three-step iterative method that uses the outcome of one step as the input of the next one. This process is continued until convergence is achieved.

The rest of this paper is organized as follows: the system model is introduced in Section II. In Section III, the solution methodology is investigated. The sub-channel assignment, antenna selection, and power allocation subproblems are discussed in sub-Section III-A, B, and C, respectively. In Section IV, the complexity of our solution methodology will be illustrated. Section V presents the simulation results and Section VI concludes the paper.

II. System Model and Problem Formulation

We consider a DL of an OFDMA femtocell network where each femtocell is sharing the same sub-channels with other femtocells under a co-channel deployment. The set of all femtocells is represented by $\mathcal{C} = \{1, 2, ..., C\}$. Each femtocell is serving K users with N available sub-channels. Each BS is equipped with M antennas and the set of BSs' antennas is denoted by $\mathcal{M} = \{1, 2, ..., M\}$. We further assume that $\mathcal{N} = \{1, 2, ..., N\}$ is a fixed set of available sub-channels at each femtocell. We denote $h^{n,m}_{c,k_c}$ as the direct DL channel coefficients from the c^{th} BS to the k^{th} user in cell c over the n^{th} sub-channel from the m^{th} antenna. Similarly, $h^{n,m}_{c',k_c}$ represents the cross DL channel coefficients from another femtocell c' to the k^{th} user in the cell c over the n^{th} sub-channel from the m^{th} antenna. Let $p^{n,m}_{c,k}$ denote the transmit power of the c^{th} BS to the k^{th} user over the n^{th} sub-channel from the m^{th} antenna. Furthermore, $s^{(n)}_{k,c}$ is a binary subcarrier variable that would be 1 if the n^{th} subcarrier is assigned to the k^{th} user in the c^{th} cell and 0, otherwise, and $x^{(m)}_{k,c}$ is a binary antenna selection indicator variable that would be 1 if the m^{th} antenna from the c^{th} cell is assigned to the k^{th} user and 0, otherwise. The data rate of the k^{th} user in the c^{th} cell over the n^{th} sub-channel when the m^{th} antenna is selected is written as

$$r^{n,m}_{c,k} = \log_2\left(1 + \frac{x^{(m)}_{k,c} s^{(n)}_{k,c} p^{n,m}_{c,k} |h^{n,m}_{c,k_c}|^2}{\sigma^2 + \sum\limits_{c' \neq c} \sum\limits_{k' \neq k} \sum\limits_{m' \in \mathcal{M}} x^{(m')}_{k,c'} s^{(n)}_{k,c'} p^{n,m'}_{c',k'} |h^{n,m'}_{c',k_c}|^2}\right), \quad (1)$$

where σ^2 is the variance of additive white Gaussian noise. Since $x^{(m)}_{k,c}$ and $s^{(n)}_{k,c}$ are binary variables, we can rewrite (1) as:

$$r^{n,m}_{c,k} = x^{(m)}_{k,c} s^{(n)}_{k,c} R^{n,m}_{c,k}, \quad (2)$$

where, $R^{n,m}_{c,k}$ is:

$$R^{n,m}_{c,k} = \log_2\left(1 + \frac{p^{n,m}_{c,k} |h^{n,m}_{c,k_c}|^2}{\sigma^2 + \sum\limits_{c' \neq c} \sum\limits_{k' \neq k} \sum\limits_{m' \in \mathcal{M}} x^{(m')}_{k,c'} s^{(n)}_{k,c'} p^{n,m'}_{c',k'} |h^{n,m'}_{c',k_c}|^2}\right). \quad (3)$$

To simplify the notation, we define the vectors of transmit power, sub-channel and antenna variables as, $\mathbf{p}_{c,k} = [p^{(1)(1)}_{c,k}, ..., p^{N,M}_{c,k}]$, $\mathbf{s}_{k,c} = [s^{(1)}_{k,c}, ..., s^{(N)}_{k,c}]$, and $\mathbf{x}_{k,c} = [x^{(1)}_{k,c}, ..., x^{(M)}_{k,c}]$, respectively, and denote $\mathbf{p} \triangleq [\mathbf{p}_{1,1}, ..., \mathbf{p}_{c,|\mathcal{K}_c|}]$, $\mathbf{s} \triangleq [\mathbf{s}_{1,1}, ..., \mathbf{s}_{c,|\mathcal{K}_c|}]$ and $\mathbf{x} \triangleq [\mathbf{x}_{1,1}, ..., \mathbf{x}_{c,|\mathcal{K}_c|}]$ where $|\mathcal{K}_c| = K$.

Now, we can formally state the problem of sub-channel allocation, antenna selection, and power control for maximizing system throughput in an OFDMA femtocell network under transmit power feasibility constraint as[1]:

$$\begin{aligned}
&\max_{\mathbf{x},\mathbf{s},\mathbf{p}} \sum_{c \in \mathcal{C}} \sum_{k \in \mathcal{K}_C} \sum_{n \in \mathcal{N}} \sum_{m \in \mathcal{M}} r^{n,m}_{c,k}(\mathbf{x}, \mathbf{s}, \mathbf{p}) \\
&\text{s.t.} \\
&C_1: \sum_{n \in \mathcal{N}} \sum_{m \in \mathcal{M}} \sum_{k \in \mathcal{K}_c} x^{(m)}_{k,c} s^{(n)}_{k,c} p^{n,m}_{c,k} \leq p_{\max}, \quad \forall c \in \mathcal{C}, \\
&C_2: p^{n,m}_{c,k} \geq 0, \quad \forall c \in \mathcal{C}, \forall k \in \mathcal{K}_c, \forall n \in \mathcal{N}, \forall m \in \mathcal{M}, \\
&C_3: \sum_{k \in \mathcal{K}_c} s^{(n)}_{k,c} \leq 1, \quad \forall c \in \mathcal{C}, \forall n \in \mathcal{N}, \\
&C_4: \sum_{m \in \mathcal{M}} x^{(m)}_{k,c} = 1, \quad \forall c \in \mathcal{C}, \forall k \in \mathcal{K}_c, \\
&C_5: x^{(m)}_{k,c} \in \{0, 1\}, \ \forall c \in \mathcal{C}, \forall k \in \mathcal{K}_c, \forall m \in \mathcal{M}, \\
&C_6: s^{(n)}_{k,c} \in \{0, 1\}, \ \forall c \in \mathcal{C}, \forall k \in \mathcal{K}_c, \forall n \in \mathcal{N}.
\end{aligned} \quad (4)$$

In the optimization problem above, constraint C_1 indicates that the total transmit power of each femtocell is limited to a predefined threshold, given by $p_{\max}$. Constraint C_2 guarantees the positivity of the allocated power to each femtocell and constraints C_3 and C_4 ensure that each sub-channel is assigned to at most one user and each femtocell makes use of only one antenna to avoid the correlation between antennas[2] for

[1] It is worth mentioning that the extension of this proposed optimization framework can be taken into account as a minimum data rate requirement for individual DL femtocell users and that of a macrocell.

[2] This also alleviates the need for precoding at the transmitter, reducing the complexity of the system [10].

transmitting a signal to the k^{th} user, respectively. Finally, C_5 and C_6 indicate that the sub-channel indices and the antenna indicators are both binary variables. One can readily verify that the defined optimization problem (4) is a MINLP. The mixed-integer nature of this problem arises from the binary variables $s_{k,c}^{(n)}$ and $x_{k,c}^{(m)}$. Furthermore, due to the interference that is included in the rate function, the objective function is also not convex. As a result, the MINLP problem of (4) is difficult to solve. In the following sections we present our proposed method for solving this problem and obtaining a locally optimal solution.

III. Solution Methodology

To cope with the complexity of the MINLP, we decompose the optimization problem (4) into three subproblems: 1) sub-channel assignment, 2) antenna selection, and 3) power control. In order to find the locally optimal sub-channel assignment, antenna selection and power control, the following iterative procedure is employed [2], [5]. At the beginning of each iteration, the optimal sub-channel assignment is obtained from an optimal antenna selection and power allocation of previous iteration, i.e. $\mathbf{x}^{t-1}$ and $\mathbf{p}^{t-1}$, using the results of sub-Section III-A. Knowing the best sub-channel assignment, first the the best antenna for each user is selected, and then the transmission power in each sub-channel is evaluated, by incorporating the results of sub-Section III-B and sub-Section III-C respectively. The corresponding update rule is summarized as follows:

$$\underbrace{\mathbf{s}^0 \rightarrow \mathbf{x}^0 \rightarrow \mathbf{p}^0}_{\text{Initialization}} \rightarrow ... \rightarrow \underbrace{\mathbf{s}^{t-1} \rightarrow \mathbf{x}^{t-1} \rightarrow \mathbf{p}^{t-1}}_{\text{Iteration } t\text{-1}} \rightarrow \underbrace{\mathbf{s}^{t} \rightarrow \mathbf{x}^{t} \rightarrow \mathbf{p}^{t}}_{\text{Iteration } t} \rightarrow ... \rightarrow \underbrace{\mathbf{s}^{opt} \rightarrow \mathbf{x}^{opt} \rightarrow \mathbf{p}^{opt}}_{\text{Optimal Solution}}. \quad (5)$$

After solving each subproblem by algorithms that will be discussed in the following sections, an iterative procedure is employed in which the solution of the previous subproblem is used as the input of the current problem. Through this iterative procedure, we will be able to enhance the accuracy of our obtained solution. The iterative algorithm in (5) needs an initial setting for $\mathbf{s}, \mathbf{x}$ and $\mathbf{p}$. To converge to a good, locally optimal solution, these initial settings must be selected properly. To this end, we first note that the optimization problem (4) is feasible, as we can find initial settings $\mathbf{s}^0, \mathbf{x}^0$ and $\mathbf{p}^0$, satisfying all constraints. Such setting satisfying the constraints can be found as follows. First, for the initial sub-channel assignment $\mathbf{s}^0$, we assume each sub-channel is assigned to the femtocell user with the channel gain. Similarly, for the antenna selection $\mathbf{x}^0$, an antenna is allocated to the femtocell user having the highest SNR. Finally, equal power is allocated to all femtocell users across all sub-channels, i.e. $\mathbf{p}^0(i) = \frac{p_{max}}{N}$.

In the following sub-sections a tractable solution method to the original problem will be described.

A. Sub-channel assignment

In this section we will deal with the subproblem of the sub-channel assignment in order to maximize system throughput. Assuming the power and the antenna selection $(\mathbf{p}^{t-1}, \mathbf{x}^{t-1})$ from the previous iteration $t-1$, we have the following optimization problem:

$$\begin{aligned} \mathbf{s}^t = \arg\max_{\mathbf{s}} & \sum_{c\in\mathcal{C}} \sum_{k\in\mathcal{K}_c} \sum_{n\in\mathcal{N}} \sum_{m\in\mathcal{M}} x_{k,c}^{(m)} s_{k,c}^{(n)} \; R_{c,k}^{n,m}(\mathbf{p}^{t-1}, \mathbf{x}^{t-1}) \\ & \text{s.t.} \\ & C_3 : \sum_{k\in\mathcal{K}_c} s_{k,c}^{(n)} \leq 1, \quad \forall c \in \mathcal{C}, \forall n \in \mathcal{N}, \\ & C_6 : s_{k,c}^{(n)} \in \{0,1\}, \quad \forall k \in \mathcal{K}_c, \forall c \in \mathcal{C}, \forall n \in \mathcal{N}, \\ & C_1 - C_2. \end{aligned} \quad (6)$$

It can easily be demonstrated that the optimization problem (6) is convex and can be solved in each cell independently since with a known power allocation and an antenna selection scheme, interference would be a constant term. Therefore, (6) can be solved optimally as a convex optimization problem using optimization packages such as CVX.

B. Antenna selection

Here, we aim at investigating the optimal antenna selection for each user among all the available antennas. Assuming the power $\mathbf{p}^{t-1}$ is obtained from a previous iteration and the sub-channel allocation $\mathbf{s}^t$ is obtained with (6), we formulate the optimization problem as follows:

$$\begin{aligned} \mathbf{x}^t = \arg\max_{\mathbf{x}} & \sum_{c\in\mathcal{C}} \sum_{k\in\mathcal{K}_C} \sum_{n\in\mathcal{N}} \sum_{m\in\mathcal{M}} r_{c,k}^{n,m}(\mathbf{x}, \mathbf{s}^t, \mathbf{p}^{t-1}) \\ & \text{s.t.} \\ & C_4 : \sum_{m\in\mathcal{M}} x_{k,c}^{(m)} = 1, \quad \forall c \in \mathcal{C}, \forall k \in \mathcal{K}_c, \\ & C_5 : \; x_{k,c}^{(m)} \in \{0,1\}, \; \forall c \in \mathcal{C}, \forall k \in \mathcal{K}_c, \forall m \in \mathcal{M}. \end{aligned} \quad (7)$$

The solution of (7) is to give the antenna to the user that offers the highest throughput on that antenna among all other antennas. Therefore, when the power and the subchannel are fixed, the best antenna for each user can be determined as:

$$x_{k,c}^{(m)} = \begin{cases} 1, & \text{if } \; m = \arg\max_{M\in\mathcal{M}_c} R_{c,k}^{n,m}(\mathbf{p}^{t-1}, \mathbf{s}^t) \\ 0, & \text{otherwise.} \end{cases} \quad (8)$$

One may conclude that the solution of (8) would require the knowledge of all branch SNRs. However, there are various techniques to address this issue based on the quasi-stationary property of the channel gains despite the difficulty of knowing all SNRs simultaneously. For instance, one may use a training signal in a preamble. During this preamble, when the receiver scans the antennas, the highest channel gain is selected for receiving the next data burst [12]-[14].

C. Power control policy

In this section, we attempt to find the optimal power control for the sub-channel assignment and antenna selection schemes that were obtained through solving the previous two subproblems. To this end, (4) is transformed into a more mathematically tractable form given as

$$\mathbf{p}^t = \arg\max_{\mathbf{p}} \quad R(\mathbf{p}) = \sum_{c\in\mathcal{C}}\sum_{k\in\mathcal{K}_c}\sum_{n\in\mathcal{N}}\sum_{m\in\mathcal{M}} R_{c,k}^{n,m}(\mathbf{p}^{t-1},\mathbf{x}^{t-1}) \\ \text{s.t.} \\ C_1 - C_2. \tag{9}$$

Problem (9) is a non-convex optimization problem due to the presence of the interference in the rate function. While in convex optimization problems the solution of the optimization can easily be found by solving the dual problem, in non-convex optimization, there is a gap between the primal solution and the solution to the dual problem. This gap makes the ordinary Lagrangian duality approach ineffective and its result can be inaccurate. In order to handle this challenge, the augmented Lagrange method is employed in order to omit this duality gap [15]-[18]. In [15], it is proved that for a sufficiently large penalty parameter, the augmented Lagrangian is locally convex. Applying the augmented Lagrangian method to (9) transforms this optimization problem into the following form:

$$L_\gamma(\mathbf{p},\lambda) = R(\mathbf{p}) + \frac{1}{2\gamma}\left[\left(\left[\sum_{c\ \in\mathcal{C}}\lambda_c + \gamma\Big(\sum_{n\in\mathcal{N}}\sum_{m\in\mathcal{M}}\sum_{k\in\mathcal{K}_c} p_{c,k}^{n,m} - p_{\max}\Big)\right]^+\right)^2 - \sum_{c\ \in\mathcal{C}}\lambda_c^2\right], \tag{10}$$

where γ is a positive coefficient denoting the penalty parameter and λ_c is the Lagrangian dual variable.

Note that (10) is achieved by removing the constraint C_1 from (9) and adding it to the objective function. This method, which converts the inequality constraint into an equality constraint by introducing a squared additional variable, is a combination of a penalty function and the local duality methods. The augmentation method eliminates the constraints that will be added to the cost function as a penalty term. Augmented Lagrangian algorithms are based on successive minimization of the augmented Lagrangian function. Initially, penalty parameters are held fixed and the value of the multipliers are estimated proportionally. In order to estimate the value of the Lagrangian multiplier, λ, a sub-gradient method is used as below:

$$\hat{\lambda}_c^i = \lambda_c^i + \gamma^i\Big(\sum_{n\in\mathcal{N}}\sum_{m\in\mathcal{M}}\sum_{k\in\mathcal{K}_c} p_{c,k}^{n,m} - p_{\max}\Big)$$

$$\lambda_c^{i+1} = \max\ \{0, \hat{\lambda}_c^i\}, \tag{11}$$

where the superscript i indicates the iteration number. Further, the penalty parameter is updated according to the following equality [20]:

$$\gamma^{i+1} = 2\gamma^i. \tag{12}$$

The pseudo-code of the power control algorithm is given in **Algorithm 1**. The iterative procedure is summarized in **Algorithm 2**.

Algorithm 1 Proposed Power Control Method

Initialize: $i := 0$ and $\gamma^i = 1$.
Set error tolerance $\epsilon := 10^{-3}$ and $p_{c,k}^{n,m} = \frac{p_{\max}}{N}$.
while $|(p_{c,k}^{n,m})^{(i+1)} - (p_{c,k}^{n,m})^{(i)}| > \epsilon$ **do**
  Solve the unconstrained optimization problem (10) to obtain $p_{c,k}^{n,m}$.
  update λ_c^{i+1} using (11).
  update $\gamma^{i+1} = 2\gamma^i$.
  Set $i := i + 1$.
end while

Algorithm 2 Proposed Iterative Method

Initialize: $t := 1$.
Set error tolerance $\sigma := 0.1$ and $p_{c,k}^{n,m} = \frac{p_{\max}}{N}$.
while $|(R_{c,k}^{n,m})^{(t+1)} - (R_{c,k}^{n,m})^{(t)}| > \sigma$ **do**
  Subcarrier allocation:
  For a fixed power and a given antenna ($\mathbf{p}^{t-1}$,$\mathbf{x}^{t-1}$), find the optimal sub-channel assignment $\mathbf{s}^t$ based on (6).
  Antenna selection:
  For a fixed sub-channel $\mathbf{s}^t$, determine the best antenna based on (8).
  Power control policy:
  Solve the power allocation, using Algorithm. 1.
  Set $t := t + 1$.
end while

IV. Complexity Analysis

This section aims at investigating the order of complexity of the proposed solution. The evaluation of (6) for every femto user on each sub-channel in every femtocell entails KNM operations, and a worst-case complexity of searching (6) needs KNM operations in each iteration. Hence, for the optimization problem of (6) the complexity order of the sub-channel assignment is $\mathcal{O}(CKNM)$, which would be similar to the complexity order of the antenna selection subproblem. Finally, the order of complexity for the power control policy at each iteration is $\mathcal{O}(CKNM)^2$. Hence, the complexity of the iterative algorithm is $\mathcal{O}(CKNM) + \mathcal{O}(CKNM) + \mathcal{O}(CKNM)^2 \cong \mathcal{O}(CKNM)^2$ which is polynomial [20]. Additionally, **Table 1** provides a comparison of the complexity analysis between the proposed algorithm with an exhaustive search method (over all possible choices of sub-channels as well as antennas considering an equal power allocation) and with the algorithm from [5]. It is worth noting that the proposed algorithm reduces the number of variables in each optimization subproblem and changes the original problem (4) into a mathematically tractable form that can be solved.

V. Simulation Results

This section investigates the performance of the proposed algorithm for scheduling and power control in the DL direction of an OFDMA network. It is assumed that each sub-channel has a bandwidth of 180 kHz. There are K randomly located users in each femtocell, where each femtocell is equipped

TABLE I
COMPUTATIONAL COMPLEXITY OF DIFFERENT METHODS

Approach	Complexity
Our Proposed Algorithm	$\mathcal{O}(CKNM)^2$
Exhaustive Search withan Equal Power Allocation	$\mathcal{O}(C^{(KNM)}C^N C^M)$
Proposed DC Programming Method in [5]	$\mathcal{O}(CKN)^3$

TABLE II
SIMULATION PARAMETERS

Parameter	Value
Femtocell radius	100 m
Maximum power femtocell, $p_{\max}$	30 dBm
Number of users in each cell, K	4
Number of sub-channels, N	8
Number of antennas, M	4
Channel realization number	100
Variance of noise, σ^2	-120 dBm

with four antennas; i.e. $|\mathcal{M}| = 4$. The radius of a femtocell is 100 meters. The wireless channel gains are Rayleigh flat fading that include a distance dependent path-loss component of $128.1+37.6\log(d)$ dB (where d is in km) and a log normal shadowing component with 8 dB standard deviation and the PSD of the background noise at the receiver is equal to -120 dBm throughout the simulations. We conducted Monte Carlo simulations by generating random realizations of the channel gains, to obtain the average data rate of the network. The parameters for propagation modelling and simulations follow the suggestions in 3GPP evaluation methodology [23], and the setting summarized in Table II are used unless otherwise specified.

Fig. 2 illustrates the average femtocells' throughput versus the maximum transmit power of a femtocell for different methods (A-E): Method A is our proposed method, whereas Method B is the method from [5],where power control based on DC programming is employed. Method C is an exhaustive search over all possible choices for sub-channels as well as antennas, where the equality power control mechanism is employed. Method D is similar to Method A (our proposed method) but with the power equally divided across the sub-channels. Finally, Method E is similar to Method B but with random scheduling, combined with power control based on DC programming [5]. This figure illustrates that the proposed method increases the average sum rate of femtocells and reaches a larger average throughput compared to the methods considered in [5]. Moreover, it can be observed that when the proposed algorithm allocates equal power among the users (Method D), there is a small gap with Method B. This gain can be explained as Method B assigns the power to the sub-channels/antennas through some optimization algorithm, while method D assigns equal power to all antennas. This yields an extra degree-of-freedom to the resource allocation problem, leading to an enhancement of the total rate. due to its high performance while deploying the antenna selection method Additionally, it is observed that the performance of a random scheduling (when antennas and sub-channels are selected randomly; i.e. Method E) together with a DC programming power control falls below all of the aforementioned methods, indicating that proper selection of the sub-channels and antennas strongly influences the throughput.

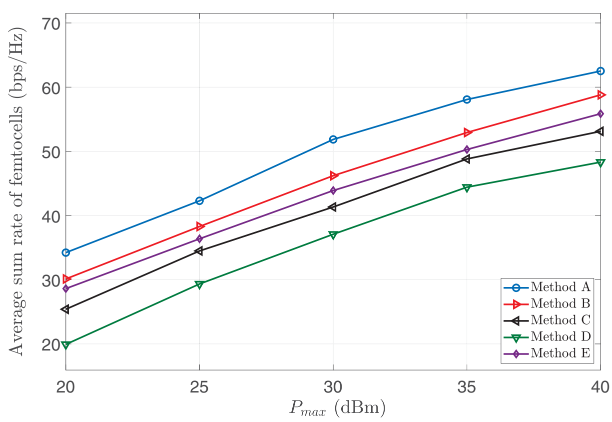

Fig. 2. Sum rate of femtocells versus $p_{\max}$

Fig. 3 illustrates the system throughput for the proposed method (Method A) versus the number of subcarriers for two different number of antennas, i.e. the $|\mathcal{M}| = 4$ and $|\mathcal{M}| = 6$, and compares it with the results of algorithm from [5], i.e. Method B. As expected, in this figure, it can be perceived that increasing the number of subcarriers in each femtocell, is an effective way to increase the system throughput. Moreover, as the number of antennas increases, the system throughput also increases accordingly. This is because of the ability of antenna selection results in a higher degree of freedom as compared to single antenna BSs. This is achieved by comparing the signal strength associated with each possible antenna choice, and selecting the best antenna, which in turn results in a better resource allocation in terms of increasing the system throughput. It is worth mentioning that although antenna selection provides diversity gain, the throughput is increased by the antenna selection due to the multiplexing

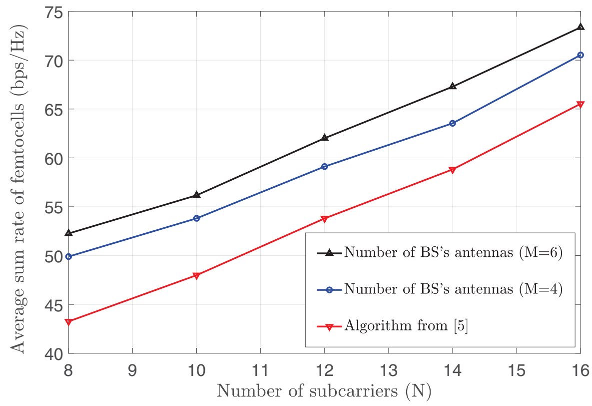

Fig. 3. Sum rate of femtocells versus number of subcarriers

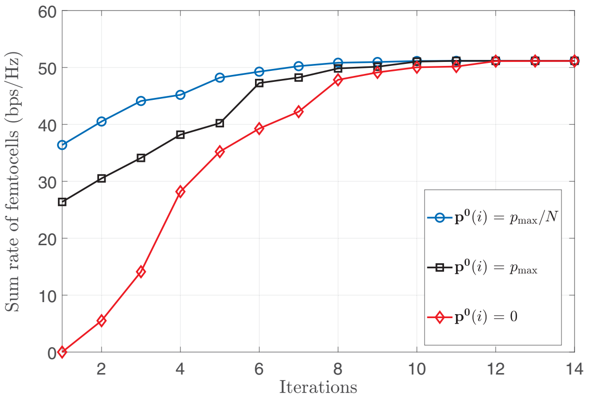

Fig. 4. Convergence of algorithm for different initialization of power allocations.

gain.

In Fig. 4, we investigate the overall convergence behaviour of the proposed iterative procedure, by showing the sum rate as function of the number of iterations. In the figure, we compare three initial selections for the power; $\mathbf{p}^0(i) = \frac{p_{max}}{N}$, i.e. equal power is assigned to all femtocell users over all sub-channels, $\mathbf{p}^0(i) = p_{max}$, i.e. all sub-channels has the maximum power, and $\mathbf{p}^0(i) = 0$, no power is assigned to the sub-channels initially. Note that the last two power assignments do not satisfy constraint C_1. As can be observed in the figure, all selected initial power allocations converge to the same sum rate for a sufficiently large number of iterations. However, the convergence rate differs for the different power allocation settings: while the initial setting $\mathbf{p}^0(i) = 0$ converges the slowest to the optimal sum rate, the setting $\mathbf{p}^0(i) = \frac{p_{max}}{N}$, which satisfies the constraints of the optimization problem, converges fast, i.e. less than 10 iterations are required.

VI. Conclusion

In this paper, the problem of sub-channel assignment, antenna selection, and power control in the DL of an OFDMA femtocell network is addressed. The corresponding optimization problem is a non-convex MINLP, which generally cannot be solved within a polynomial time complexity. Therefore, the optimization problem is reformulated as an iterative three-step problem, where in the first and second step, sub-channel assignment and antenna selection are handled through two efficient algorithms that obtain the optimal solution. In the final step, an augmented penalty method (also known as the method of multiplier) is employed to determine the locally optimal power allocation scheme. Numerical results, demonstrate our proposed method can considerably enhance networks' throughput compared to state-of-the-art methods.

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