M.S. THESIS

Downlink Resource Allocation for a Network using Femto-Base Stations as Relays to Macro-Users

펨토 기지국을 대형셀 사용자의 중계기로 사용하는 네트워크를 위한 하향링크 자원 할당 기법

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지도교수 이 재 홍

이 논문을 공학석사 학위논문으로 제출함

2013 년 5 월

서울대학교 대학원

전기 정보공학부

아 유 쉬

아유쉬의 공학석사 학위논문을 인준함

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Abstract

Downlink Resource Allocation for a Network using Femto-Base Stations as Relays to Macro-Users

We propose a resource allocation scheme for the downlink of a two-tier wireless network in which femto-base stations are used as relays to macro-users. In the proposed scheme, subcarriers and relays are assigned and power is allocated to macro- and femto-users such that their total net utility is maximized. Simulation results show that the proposed scheme has higher fairness index and lower total power consumption than the greedy and the random subcarrier assignment schemes.

Keywords: Downlink, femtocell, relay, resource allocation.

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Chapter 1

Introduction

In a wireless network, femtocells increase capacity and reduce the traffic load of macro-base station (MBS) by using low-cost femto-base stations (FBSs) to serve dedicated femto-users (FUs) [1, 2]. However, MBS and FBSs cause inter-tier interference to FUs and macro-users (MUs), respectively, if FUs use the same spectrum as MUs [3–5].

In [6, 7], it was shown for a network with one femtocell and one MU that the interference from a FBS to a MU is eliminated if the FBS is used as a relay to the MU. If the schemes in [6, 7] are used in a network with multiple femtocells and MUs, relay assignment and subcarrier and power allocation to MUs and FUs are required to maintain their quality-of-service requirements. The problem of resource allocation to MUs and FUs has not been investigated for a network where FBSs are used as relays to MUs.

We consider the downlink of a two-tier network where FBSs are used as relays to MUs. An optimization problem is formulated to maximize the total net utility of all users under power constraints of base stations and a resource allocation scheme is proposed to solve the formulated problem.

The rest of this thesis is organized as follows. We describe the system model in chapter 2, formulate the optimization problem in chapter 3, and propose the resource allocation scheme to solve it in chapter 4. We present computer simulation results in chapter 5 and draw conclusions in chapter 6.

Chapter 2

System Model

2.1 Two-tier Network Model

Consider the downlink of a two-tier wireless network with a macrocell in the first tier and J femtocells in the second tier. Suppose that there are K MUs in macrocell and $L_j,\ j = 1 \ldots J$, FUs in femtocell j. Assume that femtocells do not overlap with each other and that interference from a FBS to a MU outside its coverage is negligible [2,8,9]. Assume that MUs and FUs share spectrum of bandwidth W which is divided into M subcarriers of bandwidth $B = W/M$ each. Assume that MBS and FBSs are synchronized and transmit in time-slots of duration T.

2.2 Transmission scheme

Suppose that MBS assigns subcarrier m to MU k. If MBS assigns FBS j as a relay to MU k, data is transmitted to MU k in two phases of equal duration $T/2$. In the first phase, MBS transmits data to MU k and FBS j over subcarrier m with transmit power P_m^{M}. In the second phase, FBS j decodes and forwards the data received from the MBS to MU k over subcarrier m with transmit power $P_m^{\mathrm{F}_j}$. MU k combines data received in the first and second phases by maximal ratio combining (MRC) [10]. If MBS does not assign any FBS as a relay to MU k, it transmits data to MU k in a single phase of duration T over subcarrier m with transmit power P_m^{M}.

Suppose that the subcarrier m is assigned by FBS j to FU l_j. FBS j transmits data to FU l_j in a single phase of duration T over subcarrier m with transmit power $\tilde{P}_m^{\mathrm{F}_j}$.

Chapter 3

Problem Formulation

The utility function of a user is defined as $\mathrm{U}(r) = \dfrac{r^{1-\alpha} - 1}{1-\alpha}$ where $\alpha \in [0, \infty)$ is a fairness parameter and the utility function represents the utility of data rate r to the user. A higher value of α leads to more fair resource allocation to all users but lower sum rate, and vice versa [11]. The cost function of a user is defined as $\mathrm{C}\left(P\right) = P$ and represents the cost incurred by all the base stations in transmitting data to a user with a total transmit power P. The net utility of a user is defined as $\mathrm{U}_{\mathrm{net}}\left(r, P\right) = \mathrm{U}\left(r\right) - \mu \mathrm{C}\left(P\right)$ where μ is the weight of the cost function of the user [12–14].

Let δ_{km}^{M}, $\pi_{km}^{\mathrm{F}_j}$, and $\delta_{l_j m}^{\mathrm{F}_j}$ denote binary indicator variables. If MBS assigns subcarrier m to MU k, $\delta_{km}^{\mathrm{M}} = 1$, and $\delta_{km}^{\mathrm{M}} = 0$, otherwise. If MBS assigns FBS j as a relay to transmit data to MU k over subcarrier m, $\pi_{km}^{\mathrm{F}_j} = 1$, and $\pi_{km}^{\mathrm{F}_j} = 0$, otherwise. If

FBS j assigns subcarrier m to FU l_j, $\delta_{l_j m}^{\mathrm{F}_j} = 1$, and $\delta_{l_j m}^{\mathrm{F}_j} = 0$, otherwise. Then, the optimization problem to maximize the total net utility of users is formulated as

$$\max_{\left(\boldsymbol{\Delta}^{\mathbf{M}},\boldsymbol{\Pi}^{\mathbf{F}},\boldsymbol{\Delta}^{\mathbf{F}},\mathbf{P}^{\mathbf{M}},\mathbf{P}^{\mathbf{F}},\widetilde{\mathbf{P}}^{\mathbf{F}}\right)} \Bigg\{ \sum_{k=1}^{K}\sum_{m=1}^{M} \delta_{km}^{\mathrm{M}} \left(1-\pi_{km}^{\mathrm{F}_j}\right) \mathrm{U}_{\mathrm{net}}\left(r_{km}^{\mathrm{M}}, P_m^{\mathrm{M}}\right)$$
$$+\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M} \delta_{km}^{\mathrm{M}}\pi_{km}^{\mathrm{F}_j}\mathrm{U}_{\mathrm{net}}\left(r_{km}^{\mathrm{M},\mathrm{F}_j}, P_m^{\mathrm{M}} + P_m^{\mathrm{F}_j}\right)$$
$$+\sum_{j=1}^{J}\sum_{l_j=1}^{L_j}\sum_{m=1}^{M} \delta_{l_j m}^{\mathrm{F}_j}\mathrm{U}_{\mathrm{net}}\left(r_{l_j m}^{\mathrm{F}_j}, \tilde{P}_m^{\mathrm{F}_j}\right) \Bigg\} \tag{3.1}$$

subject to:

$$\sum_{k=1}^{K} \delta_{km}^{\mathrm{M}} \le 1,\ \forall m, \tag{3.2}$$

$$\sum_{l_j=1}^{L_j} \delta_{l_j m}^{\mathrm{F}_j} \le 1,\ \forall j, m, \tag{3.3}$$

$$\sum_{k=1}^{K} \delta_{km}^{\mathrm{M}}\pi_{km}^{\mathrm{F}_j} \le 1,\ \forall j, m, \tag{3.4}$$

$$\sum_{j=1}^{J} \delta_{km}^{\mathrm{M}}\pi_{km}^{\mathrm{F}_j} \le 1,\ \forall k, m, \tag{3.5}$$

$$\pi_{km}^{\mathrm{F}_j}\left(1-\delta_{km}^{\mathrm{M}}\right) = 0,\ \forall j, k, m, \tag{3.6}$$

$$\delta_{l_j m}^{\mathrm{F}_j}\sum_{k=1}^{K} \delta_{km}^{\mathrm{M}}\pi_{km}^{\mathrm{F}_j} = 0,\ \forall j, l_j, m, \tag{3.7}$$

$$\delta_{km}^{\mathrm{M}},\ \pi_{km}^{\mathrm{F}_j},\ \delta_{l_j m}^{\mathrm{F}_j}\ \in \{0,1\},\ \forall j, l_j, k, m, \tag{3.8}$$

$$\sum_{k=1}^{K}\sum_{m=1}^{M} \delta_{km}^{\mathrm{M}} P_m^{\mathrm{M}} \le P_{\mathrm{tot}}^{\mathrm{M}}, \tag{3.9}$$

$$\sum_{k=1}^{K}\sum_{m=1}^{M}\delta_{km}^{\mathrm{M}}\pi_{km}^{\mathrm{F}_j}P_m^{\mathrm{F}_j}+\sum_{l_j=1}^{L_j}\sum_{m=1}^{M}\delta_{l_jm}^{\mathrm{F}_j}\tilde{P}_m^{\mathrm{F}_j}\leq P_{\mathrm{tot}}^{\mathrm{F}},\ \forall j, \tag{3.10}$$

$$\mathbf{P^M}\succeq 0,\mathbf{P^F}\succeq 0,\widetilde{\mathbf{P}}^{\mathbf{F}}\succeq 0 \tag{3.11}$$

where $\mathbf{\Delta^M}=\left\{\delta_{km}^{\mathrm{M}},\ \forall k,m\right\}$, $\mathbf{\Pi^F}=\left\{\pi_{km}^{\mathrm{F}_j},\ \forall j,k,m\right\}$, $\mathbf{\Delta^F}=\left\{\delta_{l_jm}^{\mathrm{F}_j},\ \forall j,l_j,m\right\}$, $\mathbf{P^M}=\left\{P_m^{\mathrm{M}},\ \forall m\right\}$, $\mathbf{P^F}=\left\{P_m^{\mathrm{F}_j},\ \forall j,m\right\}$, $\widetilde{\mathbf{P}}^{\mathbf{F}}=\left\{\tilde{P}_m^{\mathrm{F}_j},\ \forall j,m\right\}$, r_{km}^{M} is the data rate of MU k over subcarrier m if no FBS is assigned as a relay to MU k, $r_{km}^{\mathrm{M},\mathrm{F}_j}$ is the data rate of MU k over subcarrier m if FBS j is assigned as a relay to MU k, $r_{l_jm}^{\mathrm{F}_j}$ is the data rate of FU l_j in femtocell j over subcarrier m, $P_{\mathrm{tot}}^{\mathrm{M}}$ is the maximum total transmit power of MBS, and $P_{\mathrm{tot}}^{\mathrm{F}}$ is the maximum total transmit power of each FBS. The constraints (3.2) and (3.3) imply that a subcarrier is assigned to at most one user in a cell. The constraint (3.4) implies that a FBS is assigned as a relay to at most one MU over each subcarrier. The constraint (3.5) implies that at most one FBS is assigned as a relay to a MU over a subcarrier. The constraint (3.6) implies that if a subcarrier is not assigned to a MU, then, that MU is not assigned any FBS as a relay over that subcarrier. The constraint (3.7) implies that subcarrier m is not assigned to any FU of a femtocell whose FBS is assigned as a relay to a MU over subcarrier m.

Chapter 4

Proposed Resource Allocation Scheme

High computational complexity is required to find the optimal resource allocation to users by an exhaustive search over all possible subcarrier assignments to MUs and FUs and relay assignments to MUs. So, a suboptimal resource allocation scheme is proposed in which the resource allocation is performed in two stages. In the first stage, subcarriers are assigned to MUs and FUs and relays are assigned to MUs. In the second stage, power is allocated to MUs and FUs.

4.1 Subcarrier Assignment to MUs and FUs and Relay Assignment to MUs

Let Y_k denote a variable having the value Y_k=j if MU k is in coverage of femtocell j and the value Y_k=0, otherwise. Let $\mathrm{U}_{\mathrm{tot}_{km}^{(1)}}$ denote the total net utility of all users over subcarrier m for the case that subcarrier m is assigned to MU k, $Y_k = 0$, and no FBS is assigned as a relay to MU k over subcarrier m. If $Y_k \neq 0$, $\mathrm{U}_{\mathrm{tot}_{km}^{(1)}}$=0. Let $\mathrm{U}_{\mathrm{tot}_{km}^{(2)}}$ denote the total net utility of all users over subcarrier m for the case that subcarrier m is assigned to MU k and to a FU in femtocell Y_k and no FBS is assigned as a relay to MU k over subcarrier m. Let $\mathrm{U}_{\mathrm{tot}_{km}^{(3)}}$ denote the total net utility of all users over subcarrier m for the case that subcarrier m is assigned to MU k but not to any FU in femtocell Y_k and no FBS is assigned as a relay to MU k over subcarrier m. Let $\mathrm{U}_{\mathrm{tot}_{km}^{(4)}}$ denote the total net utility of all users over subcarrier m for the case that subcarrier m is assigned to MU k but not to any FU in femtocell Y_k and FBS Y_k is assigned as a relay to MU k over subcarrier m. If Y_k=0, $\mathrm{U}_{\mathrm{tot}_{km}^{(2)}}$=0, $\mathrm{U}_{\mathrm{tot}_{km}^{(3)}}$=0, and $\mathrm{U}_{\mathrm{tot}_{km}^{(4)}}$=0.

Considering equal power allocation by all base stations to all subcarriers, an algorithm is proposed to assign subcarriers to MUs and FUs and assign relays to MUs. The proposed algorithm is shown in Algorithm 1. All variables are initially set to 0. Each subcarrier is assigned in two steps which are described for subcarrier m and are repeated for the remaining subcarriers. In the first step, the net utility of each FU

Algorithm 1: Proposed algorithm for subcarrier assignment to MUs and FUs and relay assignment to MUs

```
1  Initialize $\delta_{km}^{\mathrm{M}} = \pi_{km}^{\mathrm{F}_j} = \delta_{l_j m}^{\mathrm{F}_j} = 0,\ \forall j, k, l_j, m$.
2  for $m = 1 : M$ do
3      Step 1:
4      Compute $\mathrm{U}_{\mathrm{net}}\left(r_{l_j m}^{\mathrm{F}_j}, \tilde{P}_m^{\mathrm{F}_j}\right),\ \forall l_j, j$ considering inter-tier interference from
       MBS to FUs over subcarrier $m$.
5      for $j = 1 : J$ do
6          $l_j^* = \underset{(l_j)}{\mathrm{argmax}} \left\{\mathrm{U}_{\mathrm{net}}\left(r_{l_j m}^{\mathrm{F}_j}, \tilde{P}_m^{\mathrm{F}_j}\right)\right\}$.
7          if $\mathrm{U}_{\mathrm{net}}\left(r_{l_j^* m}^{\mathrm{F}_j}, \tilde{P}_m^{\mathrm{F}_j}\right) > 0$ then $\delta_{l_j^* m}^{\mathrm{F}_j} = 1$.
8      $\mathrm{U}_{\mathrm{tot}_m}^{\mathrm{F}} = \sum_{j=1}^{J} \delta_{l_j^* m}^{\mathrm{F}_j} \mathrm{U}_{\mathrm{net}}\left(r_{l_j^* m}^{\mathrm{F}_j}, \tilde{P}_m^{\mathrm{F}_j}\right)$.
9      Step 2:
10     $\mathrm{U}_{\mathrm{max}_m} = \max\left\{\max_{(i,k)}\left\{\mathrm{U}_{\mathrm{tot}_{km}^{(i)}}\right\}, \mathrm{U}_{\mathrm{tot}_m}^{\mathrm{F}}\right\}$.
11     if $\mathrm{U}_{\mathrm{max}_m} > \mathrm{U}_{\mathrm{tot}_m}^{\mathrm{F}}$ then
12         $k^* = \underset{(k)}{\mathrm{argmax}}\left\{\max_{(i)}\left\{\mathrm{U}_{\mathrm{tot}_{km}^{(i)}}\right\}\right\}$.
13         $\delta_{k^* m}^{\mathrm{M}} = 1$.
14         if $\mathrm{U}_{\mathrm{max}_m} = \mathrm{U}_{\mathrm{tot}_{k^* m}^{(2)}}$ then retain subcarrier assignment to FUs in
           femtocell $Y_{k^*}$ in Step 1.
15         if $\mathrm{U}_{\mathrm{max}_m} = \mathrm{U}_{\mathrm{tot}_{k^* m}^{(3)}}$ then $\delta_{l_{Y_{k^*}} m}^{\mathrm{F}_{Y_{k^*}}} = 0,\ \forall l_{Y_{k^*}}$.
16         if $\mathrm{U}_{\mathrm{max}_m} = \mathrm{U}_{\mathrm{tot}_{k^* m}^{(4)}}$ then
17             $\pi_{k^* m}^{\mathrm{F}_{Y_{k^*}}} = 1$.
18             $\delta_{l_{Y_{k^*}} m}^{\mathrm{F}_{Y_{k^*}}} = 0,\ \forall l_{Y_{k^*}}$.
19     else
20         Compute $\mathrm{U}_{\mathrm{net}}\left(r_{l_j m}^{\mathrm{F}_j}, \tilde{P}_m^{\mathrm{F}_j}\right),\ \forall l_j, j$ not considering inter-tier interference
           from MBS to FUs over subcarrier $m$.
21         Repeat 5-7.
```

over subcarrier m is computed considering inter-tier interference from MBS to FUs over that subcarrier. In each femtocell, subcarrier m is assigned to the FU having the largest positive net utility over that subcarrier. The subcarrier m is not assigned to any FU in a femtocell if no FU in the femtocell has a positive net utility over that subcarrier. Then, the total net utility of all FUs over subcarrier m, $\mathrm{U}^{\mathrm{F}}_{\mathrm{tot}_m}$, is computed.

In the second step, the maximum total net utility of all users over subcarrier m is computed as $\mathrm{U}_{\mathrm{max}_m}{=}\max\left\{\max\limits_{(i,k)}\left\{\mathrm{U}_{\mathrm{tot}^{(i)}_{km}}\right\}, \mathrm{U}^{\mathrm{F}}_{\mathrm{tot}_m}\right\}$. If $\mathrm{U}_{\mathrm{max}_m}{>}\mathrm{U}^{\mathrm{F}}_{\mathrm{tot}_m}$, subcarrier m is assigned to the MU k^* such that the total net utility of all users over subcarrier m is maximized. If $\mathrm{U}_{\mathrm{max}_m}{=}\mathrm{U}_{\mathrm{tot}^{(2)}_{k^*m}}$, subcarrier assignment to FUs in femtocell Y_{k^*} in the first step is retained. If $\mathrm{U}_{\mathrm{max}_m}{=}\mathrm{U}_{\mathrm{tot}^{(3)}_{k^*m}}$, subcarrier m is not assigned to any FU in femtocell Y_{k^*}. If $\mathrm{U}_{\mathrm{max}_m}{=}\mathrm{U}_{\mathrm{tot}^{(4)}_{k^*m}}$, FBS Y_{k^*} is assigned as a relay to MU k^* over subcarrier m and subcarrier m is not assigned to any FU in femtocell Y_{k^*}. If $\mathrm{U}_{\mathrm{max}_m}{\leq}\mathrm{U}^{\mathrm{F}}_{\mathrm{tot}_m}$, subcarrier m is not assigned to any MU. The net utility of each FU over subcarrier m is re-computed not considering inter-tier interference from MBS to FUs over subcarrier m. The subcarrier assignment to FUs, as described in the first step, is repeated using the re-computed values of net utilities of FUs over subcarrier m.

4.2 Power Allocation to MUs and FUs

The problem for power allocation to MUs and FUs is formulated as

$$\begin{aligned}\max_{\left(\mathbf{P^M},\mathbf{P^F},\widetilde{\mathbf{P}}^{\mathbf{F}}\right)} \Bigg\{ & \sum_{k=1}^{K}\sum_{m=1}^{M}\delta_{km}^{\mathrm{M}}\left(1-\pi_{km}^{\mathrm{F}_j}\right)\mathrm{U}_{\mathrm{net}}\left(r_{km}^{\mathrm{M}},P_m^{\mathrm{M}}\right)\\ &+\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M}\delta_{km}^{\mathrm{M}}\pi_{km}^{\mathrm{F}_j}\mathrm{U}_{\mathrm{net}}\left(r_{km}^{\mathrm{M},\mathrm{F}_j},P_m^{\mathrm{M}}+P_m^{\mathrm{F}_j}\right)\\ &+\sum_{j=1}^{J}\sum_{l_j=1}^{L_j}\sum_{m=1}^{M}\delta_{l_jm}^{\mathrm{F}_j}\mathrm{U}_{\mathrm{net}}\left(r_{l_jm}^{\mathrm{F}_j},\tilde{P}_m^{\mathrm{F}_j}\right)\Bigg\}\end{aligned} \tag{4.1}$$

$$\text{subject to:}\quad \sum_{k=1}^{K}\sum_{m=1}^{M}\delta_{km}^{\mathrm{M}}P_m^{\mathrm{M}}\leq P_{\mathrm{tot}}^{\mathrm{M}}, \tag{4.2}$$

$$\sum_{k=1}^{K}\sum_{m=1}^{M}\delta_{km}^{\mathrm{M}}\pi_{km}^{\mathrm{F}_j}P_m^{\mathrm{F}_j}+\sum_{l_j=1}^{L_j}\sum_{m=1}^{M}\delta_{l_jm}^{\mathrm{F}_j}\tilde{P}_m^{\mathrm{F}_j}\leq P_{\mathrm{tot}}^{\mathrm{F}},\ \forall j. \tag{4.3}$$

The Lagrangian of (4.1) is given by

$$\begin{aligned}&\mathcal{L}\left(\mathbf{P^M},\mathbf{P^F},\widetilde{\mathbf{P}}^{\mathbf{F}},\lambda^{(1)},\mathbf{\Lambda^{(2)}}\right)\\ &=\sum_{k=1}^{K}\sum_{m=1}^{M}\delta_{km}^{\mathrm{M}}\left(1-\pi_{km}^{\mathrm{F}_j}\right)\mathrm{U}_{\mathrm{net}}\left(r_{km}^{\mathrm{M}},P_m^{\mathrm{M}}\right)\\ &\quad+\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M}\delta_{km}^{\mathrm{M}}\pi_{km}^{\mathrm{F}_j}\mathrm{U}_{\mathrm{net}}\left(r_{km}^{\mathrm{M},\mathrm{F}_j},P_m^{\mathrm{M}}+P_m^{\mathrm{F}_j}\right)\\ &\quad+\sum_{j=1}^{J}\sum_{l_j=1}^{L_j}\sum_{m=1}^{M}\delta_{l_jm}^{\mathrm{F}_j}\mathrm{U}_{\mathrm{net}}\left(r_{l_jm}^{\mathrm{F}_j},\tilde{P}_m^{\mathrm{F}_j}\right)-\lambda^{(1)}\left(\sum_{k=1}^{K}\sum_{m=1}^{M}\delta_{km}^{\mathrm{M}}P_m^{\mathrm{M}}-P_{\mathrm{tot}}^{\mathrm{M}}\right)\end{aligned}$$

$$-\sum_{j=1}^{J}\lambda_j^{(2)}\left(\sum_{k=1}^{K}\sum_{m=1}^{M}\delta_{km}^{\mathrm{M}}\pi_{km}^{\mathrm{F}_j}P_m^{\mathrm{F}_j}+\sum_{l_j=1}^{L_j}\sum_{m=1}^{M}\delta_{l_jm}^{\mathrm{F}_j}\tilde{P}_m^{\mathrm{F}_j}-P_{\mathrm{tot}}^{\mathrm{F}}\right). \tag{4.4}$$

where $\lambda^{(1)}$ and $\lambda_j^{(2)}$ are non-negative Lagrange multipliers, and $\mathbf{\Lambda^{(2)}} = \left\{\lambda_j^{(2)},\ \forall j\right\}$. The Lagrange dual function of (4.1) is given by

$$\mathcal{D}\big(\lambda^{(1)},\mathbf{\Lambda^{(2)}}\big)=\sum_{m=1}^{M}\mathcal{D}_m\big(\lambda^{(1)},\mathbf{\Lambda^{(2)}}\big)+\lambda^{(1)}P_{\mathrm{tot}}^{\mathrm{M}}+\sum_{j=1}^{J}\lambda_j^{(2)}P_{\mathrm{tot}}^{\mathrm{F}} \tag{4.5}$$

where

$$\begin{aligned}
&\mathcal{D}_m\big(\lambda^{(1)},\mathbf{\Lambda^{(2)}}\big)=\\
&\max_{\left(\mathbf{P^M}\succeq 0,\ \mathbf{P^F}\succeq 0,\ \widetilde{\mathbf{P}}^{\mathbf{F}}\succeq 0\right)}\left\{\sum_{k=1}^{K}\delta_{km}^{\mathrm{M}}\left(1-\pi_{km}^{\mathrm{F}_j}\right)\mathrm{U}_{\mathrm{net}}\left(r_{km}^{\mathrm{M}},P_m^{\mathrm{M}}\right)\right.\\
&\qquad+\sum_{j=1}^{J}\sum_{k=1}^{K}\delta_{km}^{\mathrm{M}}\pi_{km}^{\mathrm{F}_j}\mathrm{U}_{\mathrm{net}}\left(r_{km}^{\mathrm{M,F}_j},P_m^{\mathrm{M}}+P_m^{\mathrm{F}_j}\right)\\
&\qquad+\sum_{j=1}^{J}\sum_{l_j=1}^{L_j}\delta_{l_jm}^{\mathrm{F}_j}\mathrm{U}_{\mathrm{net}}\left(r_{l_jm}^{\mathrm{F}_j},\tilde{P}_m^{\mathrm{F}_j}\right)-\lambda^{(1)}\left(\sum_{k=1}^{K}\delta_{km}^{\mathrm{M}}P_m^{\mathrm{M}}\right)\\
&\qquad\left.-\sum_{j=1}^{J}\lambda_j^{(2)}\left(\sum_{k=1}^{K}\delta_{km}^{\mathrm{M}}\pi_{km}^{\mathrm{F}_j}P_m^{\mathrm{F}_j}+\sum_{l_j=1}^{L_j}\delta_{l_jm}^{\mathrm{F}_j}\tilde{P}_m^{\mathrm{F}_j}\right)\right\}
\end{aligned} \tag{4.6}$$

The dual problem of (4.1) is formulated as

$$\min_{\left(\lambda^{(1)}\geq 0,\ \mathbf{\Lambda^{(2)}}\succeq 0\right)}\left\{\mathcal{D}\big(\lambda^{(1)},\mathbf{\Lambda^{(2)}}\big)\right\}. \tag{4.7}$$

It is known that, if the number of subcarriers is sufficiently large, the duality gap of (4.1) reduces to zero [15]. So, the optimal solution of (4.1) is obtained by solving (4.7) using the subgradient method [16].

Chapter 5

Simulation Results

Suppose that 10 femtocells are uniformly distributed in a macrocell and that there are 300 subcarriers with bandwidth of 1kHz each. Suppose that the maximum total transmit power of MBS is 46dBm and that of each FBS is 20dBm. The path-loss model recommended by 3GPP LTE group [17] is adopted. Jain's fairness index is used to compare the fairness of resource allocation to users [18]. The performance of the proposed scheme is compared with the greedy scheme [19] and the random subcarrier assignment (RSA) scheme.

Figs. 5.1 and 5.2 show sum rate of users vs. number of users for $\alpha = 0$ and $\alpha = 10$, respectively. It is shown that sum rate of users under the proposed scheme is higher than that under the RSA scheme and almost the same as that under the greedy scheme. It is shown that, for a given value of μ, sum rate of users under the proposed scheme is higher for $\alpha = 0$ than for $\alpha = 10$. It is shown that, with increasing values of μ, sum rate of users under the proposed scheme decreases faster for $\alpha = 10$ than for $\alpha = 0$.

Figs. 5.3 and 5.4 show total power consumption by BSs vs. number of users for $\alpha = 0$ and $\alpha = 10$, respectively. It is shown that total power consumption by BSs under the proposed scheme is lower than that under the greedy and the RSA schemes. It is shown that, for a given value of μ, total power consumption by BSs under the proposed scheme is higher for $\alpha = 0$ than for $\alpha = 10$. It is shown that, with increasing values of μ, total power consumption by BSs under the proposed scheme decreases faster for $\alpha = 10$ than for $\alpha = 0$.

Figs. 5.5 and 5.6 show Jain's fairness index vs. number of users for $\alpha = 0$ and $\alpha = 10$, respectively.It is shown that fairness index under the proposed scheme is higher than that the greedy scheme. It is shown that fairness index under the proposed scheme is higher than that under the RSA scheme except when $\alpha = 0$ and $\mu = 0.1$. It is shown that, for a given value of μ, fairness index under the proposed scheme is lower for $\alpha = 0$ than for $\alpha = 10$. It is shown that, with increasing values of μ, fairness index under the proposed scheme decreases faster for $\alpha = 0$ than for $\alpha = 10$.

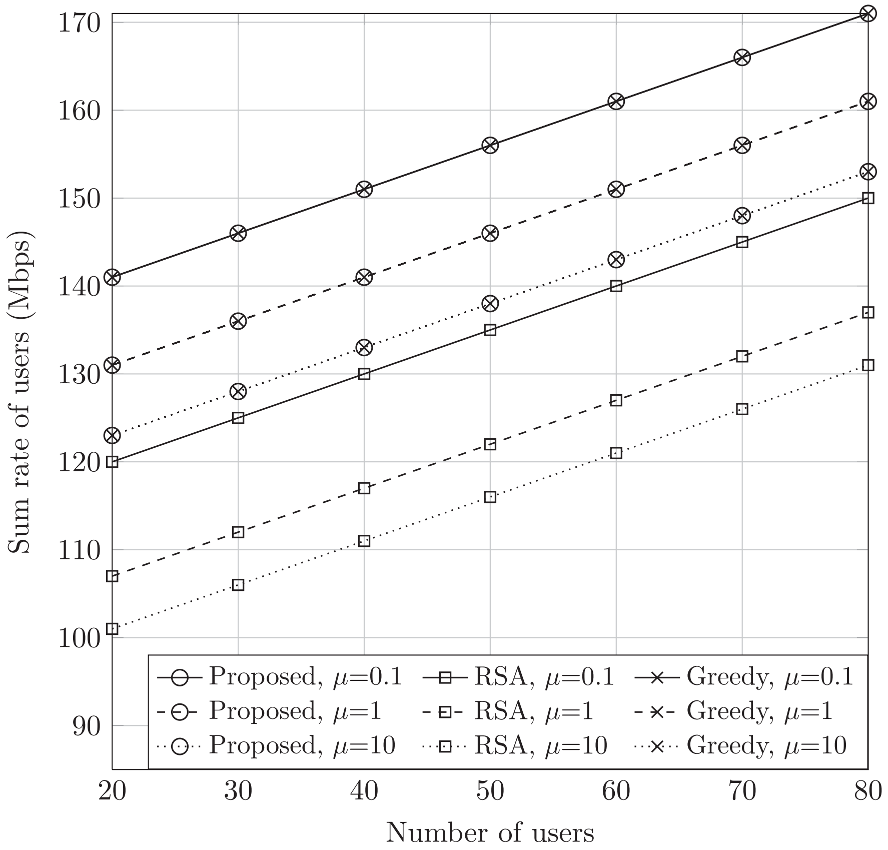

Figure 5.1. Sum rate of users vs. number of users. $J = 10$ and $\alpha = 0$.

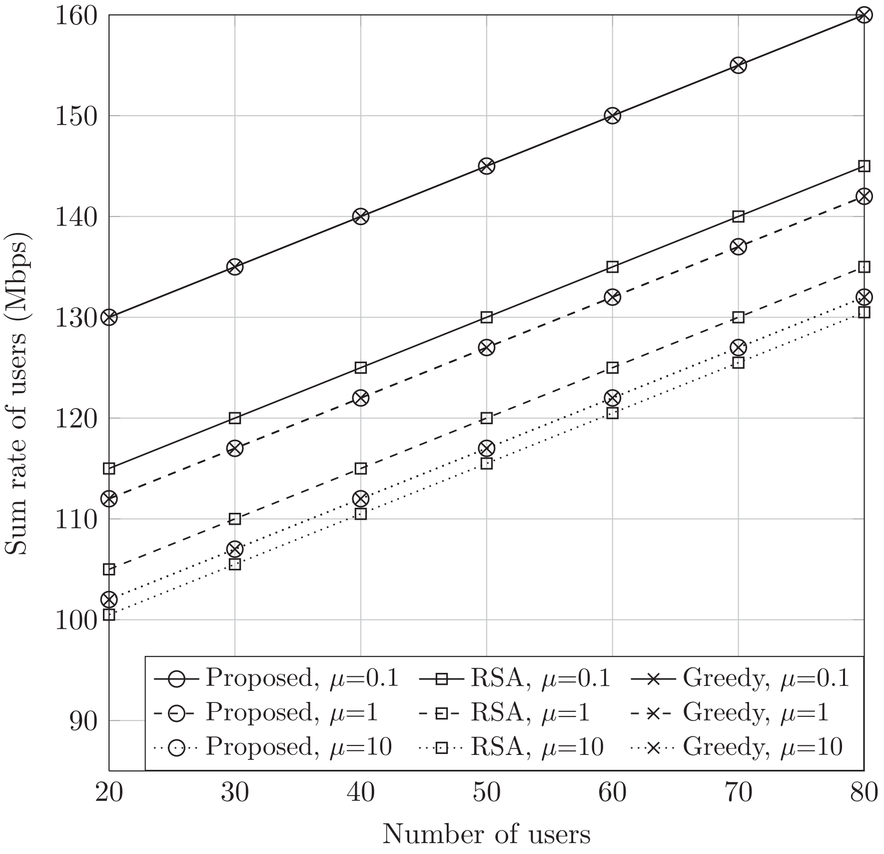

Figure 5.2. Sum rate of users vs. number of users. $J = 10$ and $\alpha = 10$.

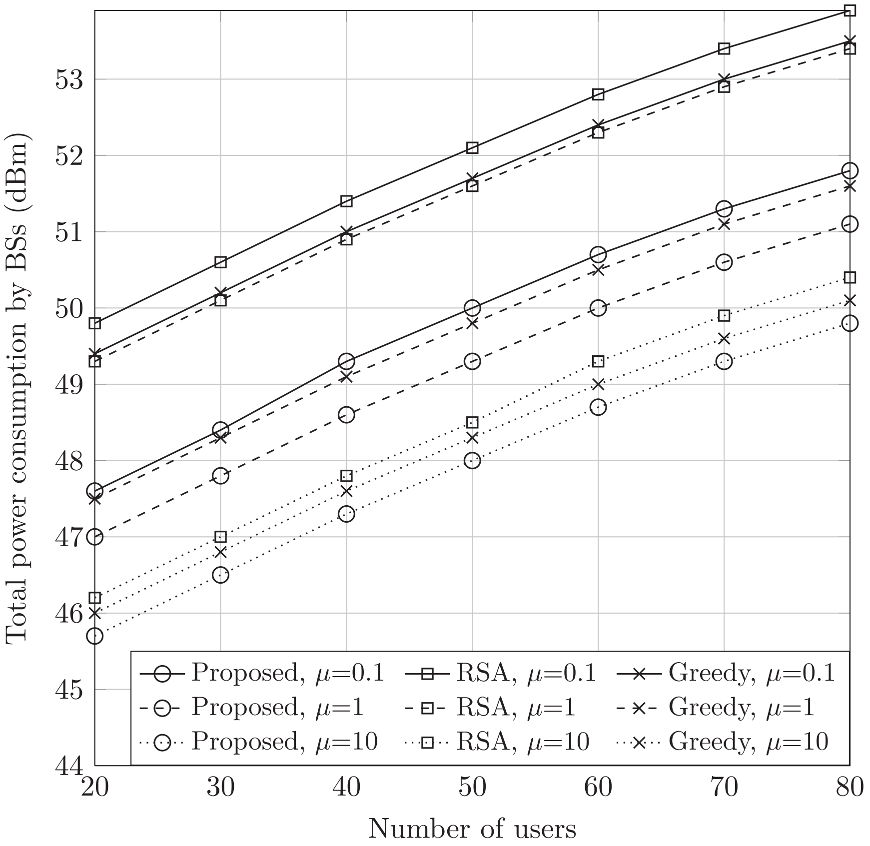

Figure 5.3. Total power consumption by BSs vs. number of users. $J = 10$ and $\alpha = 0$.

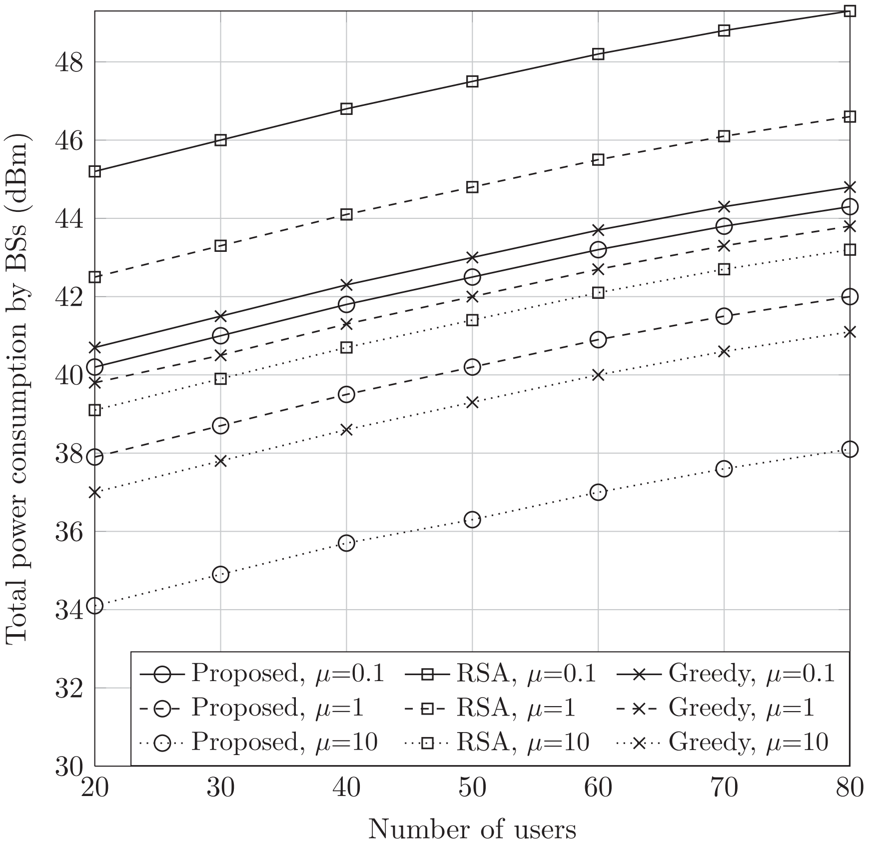

Figure 5.4. Total power consumption by BSs vs. number of users. $J = 10$ and $\alpha = 10$.

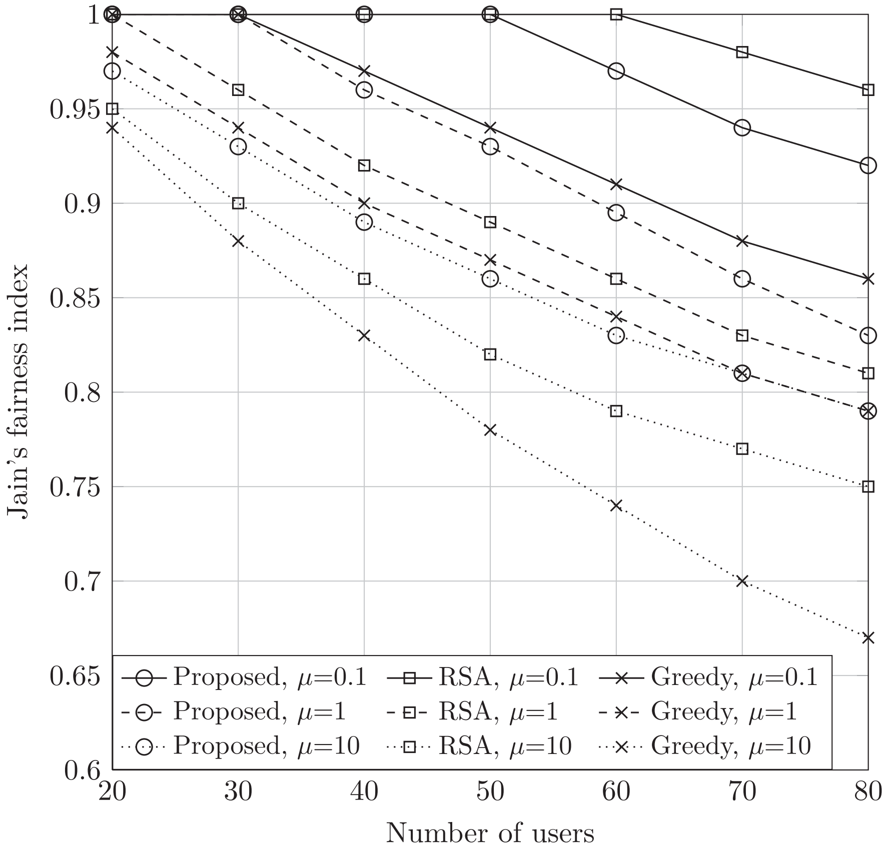

Figure 5.5. Jain's fairness index vs. number of users. $J = 10$ and $\alpha = 0$.

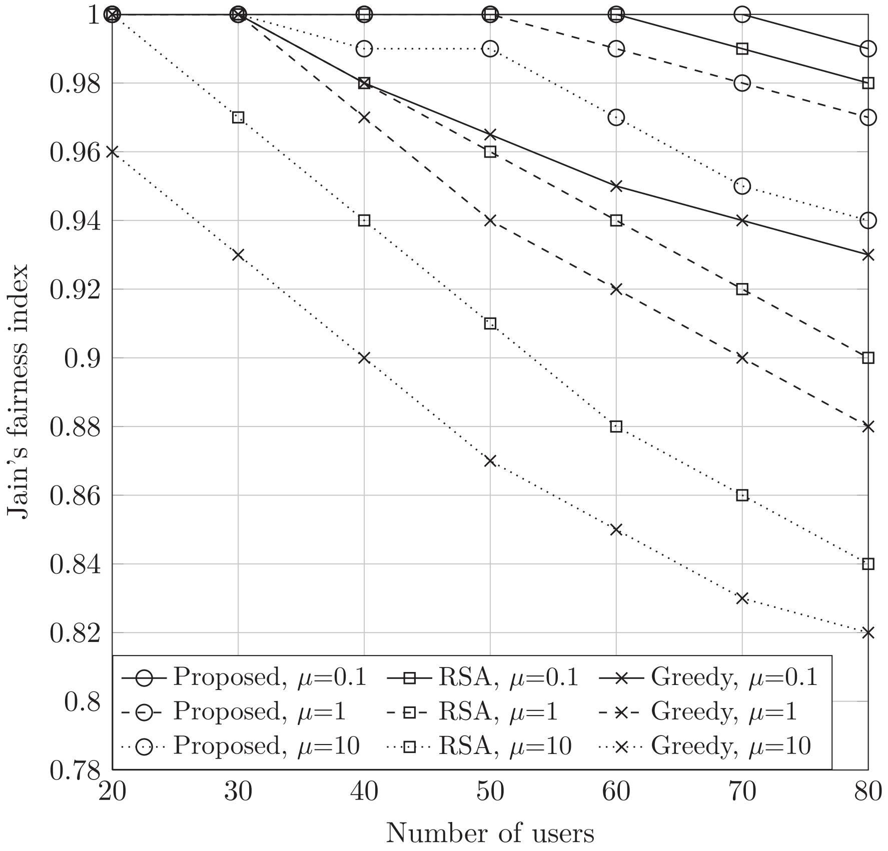

Figure 5.6. Jain's fairness index vs. number of users. $J = 10$ and $\alpha = 10$.

Chapter 6

Conclusion

We consider the downlink of a two-tier network in which femtocells are used as relays to MUs. We formulate an optimization problem to maximize the total net utility of all users. We propose a resource allocation scheme to solve the formulated problem. Simulation results show that the proposed scheme has higher fairness index and lower total power consumption than the greedy and the random subcarrier assignment (RSA) schemes. Simulation results also show that the proposed scheme has higher sum rate of users than the RSA scheme and almost the same sum rate of users as the greedy scheme.

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한글초록

본 논문에서는 펨토셀 기지국이 매크로셀 사용자를 위한 중계기로 사용되는 2 계층 무선 네트워크 하향링크를 위한 자원 할당 기법을 제안한다. 제안된 기법에서, 매크로셀 사용자와 펨토셀 사용자의 순효용을 최대화시키도록 부반송파 및 중계기를 지정하고 전력을 할당한다. 제안된 기법이 그리디 (greedy) 기법 및 무작위 부반송파 할당 기법에 비해 공평성 지수는 더 높으며 총 소모전력은 더 낮음을 컴퓨터 모의실험을 통해 확인하였다.

주요어: 하향링크, 펨토셀, 중계기, 자원 할당.

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