LETTER

Resource Allocation for an OFDMA Relay Network with Multicells

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SUMMARY In this paper, we propose a new subcarrier allocation algorithm for a downlink OFDMA relay network with multicells. In the proposed algorithm, subcarriers are allocated to users and relays to maximize the overall sum of the achievable rate under fairness constraints. Simulation results show that the proposed algorithm achieves higher data rate than the static algorithm and reduces the outage probability compared to the static and greedy algorithms.

key words: *cooperative communication, OFDMA, fairness, resource allocation*

1. Introduction

In cooperative communication, multiple terminals, each with a single antenna, share their antennas to form a virtual multiple input multiple output (MIMO) antenna array. Cooperative communication achieves spatial diversity, reduces energy consumption, and extends its coverage area [1].

Orthogonal frequency division multiple access (OFDMA) allows terminals to share an OFDM symbol. Through adaptive subcarrier and power allocation to terminals, OFDMA provides improved spectral and power efficiency so that the capacity of OFDMA networks is increased [2].

Recently, cooperative communication and resource allocation schemes for OFDMA are combined together to achieve high data rates [3], [4]. Most of previous works on OFDMA relay networks are focused on single cell environment. However, the intercell interference (ICI) from neighboring cells affects the performance of OFDMA relay networks.

In this letter, we propose a new subcarrier allocation algorithm for an OFDMA relay network with multicells. In the proposed algorithm, subcarriers are allocated to users and relays so as to maximize the achievable rate while limiting the transmit power of each relay and providing the minimum rate required by each user. The achievable rate per subcarrier and outage probability are obtained by computer simulation.

2. System Model

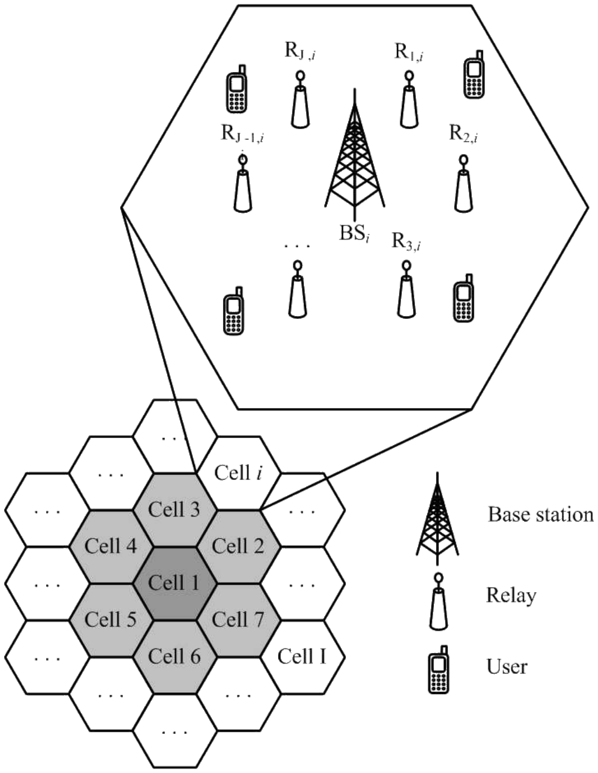

Fig. 1 OFDMA relay network with *I* cells.

Consider a downlink OFDMA relay network which consists of I omni-cells as shown in Fig. 1. Assume that the cell i has a base station (BS_i) at its center, J_i relays, and K_i users. Assume that relays in each cell are located symmetrically on a circle and users are uniformly distributed in a cell. Assume that each terminal is equipped with a single antenna and the frequency reuse factor of a downlink OFDMA relay network is one.

In a centralized network, all base stations are connected with a central unit such as the radio network controller (RNC) [5]. Assume that the central unit has the functions to not only allocate radio resources but also select combinations of relays and users and then sends the signaling messages to the related base stations, relays, and users. By using the central unit, every cell is allowed to allocate radio resources and select combinations of relays and users according to ICI.

Assume that a channel has frequency-selective fading with T independent multipaths [6]. Let $H^{\mathrm{BS}_i,(n)}_{\mathrm{U}_{k',i'}}$, $F^{\mathrm{BS}_i,(n)}_{\mathrm{R}_{j',i'}}$, and

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$$y_1^{\mathrm{R}_{j,i},(n)} = F_{\mathrm{R}_{j,i}}^{\mathrm{BS}_i,(n)} \sqrt{P_{\mathrm{BS}_i}^{(n)}}\, x_{\mathrm{BS}_i}^{(n)} + \underbrace{\sum_{\substack{i'=1\\ i'\neq i}}^{I} \sum_{j'=1}^{J_{i'}} \sum_{k'=1}^{K_{i'}} F_{\mathrm{R}_{j,i}}^{\mathrm{BS}_{i'},(n)} \rho_{\mathrm{R}_{j',i'}}^{\mathrm{U}_{k',i'},(n)} \sqrt{P_{\mathrm{BS}_{i'}}^{(n)}}\, x_{\mathrm{BS}_{i'}}^{(n)}}_{\triangleq \Gamma_1^{\mathrm{R}_{j,i},(n)}} + n_1^{\mathrm{R}_{j,i},(n)} \tag{1}$$

$$y_1^{\mathrm{U}_{k,i},(n)} = H_{\mathrm{U}_{k,i}}^{\mathrm{BS}_i,(n)} \sqrt{P_{\mathrm{BS}_i}^{(n)}}\, x_{\mathrm{BS}_i}^{(n)} + \underbrace{\sum_{\substack{i'=1\\ i'\neq i}}^{I} \sum_{j'=1}^{J_{i'}} \sum_{k'=1}^{K_{i'}} H_{\mathrm{U}_{k,i}}^{\mathrm{BS}_{i'},(n)} \rho_{\mathrm{R}_{j',i'}}^{\mathrm{U}_{k',i'},(n)} \sqrt{P_{\mathrm{BS}_{i'}}^{(n)}}\, x_{\mathrm{BS}_{i'}}^{(n)}}_{\triangleq \Gamma_1^{\mathrm{U}_{k,i},(n)}} + n_1^{\mathrm{U}_{k,i},(n)} \tag{2}$$

$$y_2^{\mathrm{U}_{k,i},(n)} = G_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)} \beta_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} y_1^{\mathrm{R}_{j,i},(n)} + \underbrace{\sum_{\substack{i'=1\\ i'\neq i}}^{I} \sum_{j'=1}^{J_{i'}} \sum_{k'=1}^{K_{i'}} G_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j',i'},(n)} \rho_{\mathrm{R}_{j',i'}}^{\mathrm{U}_{k',i'},(n)} \beta_{\mathrm{R}_{j',i'}}^{\mathrm{U}_{k',i'},(n)} y_1^{\mathrm{R}_{j',i'},(n)}}_{\triangleq \Gamma_2^{\mathrm{U}_{k,i},(n)}} + n_2^{\mathrm{U}_{k,i},(n)} \tag{3}$$

$$R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} = \frac{1}{2}\log_2\left\{1 + \frac{\left|H_{\mathrm{U}_{k,i}}^{\mathrm{BS}_i,(n)}\right|^2 P_{\mathrm{BS}_i}^{(n)}}{\left|\Gamma_1^{\mathrm{U}_{k,i},(n)}\right|^2 + N_0} + \frac{\dfrac{\left|F_{\mathrm{R}_{j,i}}^{\mathrm{BS}_i,(n)}\right|^2 P_{\mathrm{BS}_i}^{(n)}}{\left|\Gamma_1^{\mathrm{R}_{j,i},(n)}\right|^2 + N_0} \dfrac{\left|G_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)}\right|^2 P_{\mathrm{R}_{j,i}}^{(n)}}{\left|\Gamma_2^{\mathrm{U}_{k,i},(n)}\right|^2 + N_0}}{\left\{1 + \dfrac{\left|F_{\mathrm{R}_{j,i}}^{\mathrm{BS}_i,(n)}\right|^2 P_{\mathrm{BS}_i}^{(n)}}{\left|\Gamma_1^{\mathrm{R}_{j,i},(n)}\right|^2 + N_0} + \dfrac{\left|G_{\mathrm{U}_{k,i}}^{\mathrm{R}_{j,i},(n)}\right|^2 P_{\mathrm{R}_{j,i}}^{(n)}}{\left|\Gamma_2^{\mathrm{U}_{k,i},(n)}\right|^2 + N_0}\right\}}\right\} \tag{4}$$

$G_{\mathrm{U}_{k',i'}}^{\mathrm{R}_{j,i},(n)}$ denote the channel coefficients of the nth subcarrier between BS_i and the user k' in the cell i' ($\mathrm{U}_{k',i'}$), BS_i and the relay j' in the cell i' ($\mathrm{R}_{j',i'}$), and $\mathrm{R}_{j,i}$ and $\mathrm{U}_{k',i'}$, respectively.

Let $\rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)}$ denote the subcarrier assignment indicator of the nth subcarrier for $\mathrm{U}_{k,i}$ and $\mathrm{R}_{j,i}$. If the nth subcarrier is allocated to $\mathrm{U}_{k,i}$ and $\mathrm{R}_{j,i}$, $\rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} = 1$, otherwise, $\rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} = 0$. Let $P_{\mathrm{BS}_i}^{(n)}$ and $P_{\mathrm{R}_{j,i}}^{(n)}$ denote the transmit power of BS_i and $\mathrm{R}_{j,i}$ on the nth subcarrier, respectively. Assume that the transmit power of each BS and relay is equally allocated to the assigned subcarriers. Let $x_{BS_i}^{(n)}$ denote the transmit signal from BS_i on the nth subcarrier. Let $n_1^{\mathrm{R}_{j,i},(n)}$, $n_1^{\mathrm{U}_{k,i},(n)}$, and $n_2^{\mathrm{U}_{k,i},(n)}$ denote zero-mean mutually independent, circularly symmetric, complex Gaussian noises with variance N_0 on the nth subcarrier at $\mathrm{R}_{j,i}$ in the first time slot, $\mathrm{U}_{k,i}$ in the first time slot, and $\mathrm{U}_{k,i}$ in the second time slot, respectively.

Assume that relays do not transmit and receive simultaneously. By using the amplify-and-forward (AF) relaying protocol, communication between base station and users consists of two time slots. In the first time slot, base stations transmit data to relays and users. The received signal at $\mathrm{R}_{j,i}$ on the nth subcarrier is given by (1) at the top of this page. The received signal at $\mathrm{U}_{k,i}$ on the nth subcarrier is given by (2). In the second time slot, relays amplify and forward the received signals to users. The received signal at $\mathrm{U}_{k,i}$ on the nth subcarrier is given by (3) where

$$\beta_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} = \sqrt{\frac{P^{\mathrm{R}_{j,i},(n)}}{\left|y_1^{\mathrm{R}_{j,i},(n)}\right|^2}}.$$

If the nth subcarrier is allocated to $\mathrm{U}_{k,i}$ and $\mathrm{R}_{j,i}$, the achievable rate is given by (4) at the top of the page where the factor $1/2$ accounts for the fact that data is transmitted to a user over two time slots [1]. The achievable rate of the user $\mathrm{U}_{k,i}$ is given by

$$R_{\mathrm{U}_{k,i}} = \sum_{j=1}^{J_i} \sum_{n=1}^{N} \rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)}. \tag{5}$$

The overall sum of the achievable rate over all users is given by

$$R = \sum_{i=1}^{I} \sum_{k=1}^{K_i} R_{\mathrm{U}_{k,i}}. \tag{6}$$

3. Problem Formulation

To limit the power consumption of relays and achieve the target rate of users, fairness constraints are imposed on the maximum transmit power of each relay and the minimum rate required by each user. The optimization problem with fairness constraints is formulated as

$$R^* = \max \sum_{i=1}^{I} \sum_{j=1}^{J_i} \sum_{k=1}^{K_i} \sum_{n=1}^{N} \rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} \tag{7}$$

$$\text{subject to: } \rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} \in \{0,1\}, \forall\, i, j, k, n \tag{8a}$$

$$\sum_{j=1}^{J_i} \sum_{k=1}^{K_i} \rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} \leq 1, \forall i, n \tag{8b}$$

$$\sum_{n=1}^{N} P_{\mathrm{R}_{j,i}}^{(n)} \leq P_{max}, \forall i, j \tag{8c}$$

$$P_{\mathrm{R}_{j,i}}^{(n)} \geq 0, \forall i, j, n \tag{8d}$$

$$\sum_{j=1}^{J_i} \sum_{n=1}^{N} \rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} \geq R_{min}, \forall i, k \tag{8e}$$

where P_{max} is the maximum transmit power of each relay and R_{min} is the minimum rate required by each user. In this case, (8a) and (8b) correspond to the constraints on the subcarrier assignment indicator. To guarantee the exclusiveness of subcarriers, a subcarrier is not allocated to users twice. (8c) and (8d) correspond to the constraints on the maximum transmit power of each relay. The relays do not use the power over P_{max} for the network lifetime and efficiency. (8e) corresponds to the constraints on the minimum rate for each user.

The problem in (7) is a combinatorial optimization problem, containing discrete and continuous variables, which is hard to solve due to its high computational complexity [2]. Let $\rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)}$ take a real value within an interval [0, 1] to make the combinatorial optimization problem in (7) tractable. Then, the Lagrangian of the optimization problem is given by (9) at the top of the next page where $\gamma_{i,j,k,n}$, $\lambda_{i,n}$, $\nu_{i,j}$, $\eta_{n,j,i}$, and $\mu_{i,k}$ are the nonnegative Lagrange multipliers.

By taking partial derivative of the Lagrangian with respect to $\rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)}$, *Karush-Kuhn-Tucker* (KKT) conditions are obtained as follows [7]:

$$\frac{\partial L}{\partial \rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)}} = \lambda_{i,n} - (1 + \mu_{i,k}) R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} - \gamma_{i,j,k,n} = 0, \forall i, j, k, n \tag{10}$$

$$\gamma_{i,j,k,n} \rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} = 0, \forall i, j, k, n \tag{11}$$

$$\mu_{i,k} \left(\sum_{j=1}^{J_i} \sum_{n=1}^{N} \rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} - R_{min} \right) = 0, \forall i, k \tag{12}$$

$$R_{min} - \sum_{j=1}^{J_i} \sum_{n=1}^{N} \rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} \leq 0, \forall i, k \tag{13}$$

Because $\gamma_{i,j,k,n} \geq 0$, (10) becomes

$$\lambda_{i,n} \geq (1 + \mu_{i,k}) R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)}, \forall i, j, k, n. \tag{14}$$

From (10) and (11), it is obtained that

$$\left(\lambda_{i,n} - (1 + \mu_{i,k}) R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} \right) \rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} = 0, \forall i, j, k, n. \tag{15}$$

By the complementary slackness condition, if $\rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)}$ is positive, i.e., the nth subcarrier is allocated to $\mathrm{U}_{k,i}$ and $\mathrm{R}_{j,i}$, $\lambda_{i,n} - (1 + \mu_{i,k}) R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} = 0$ which implies that the equality in (14) holds. To maximize the overall sum of the achievable rate R, the user k^* and relay j^* in the cell i^* are selected for the n^*th subcarrier such that

$$(i^*, j^*, k^*, n^*) = \arg\max_{i,j,k,n} \left(1 + \mu_{i,k}\right) R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)}. \tag{16}$$

Finding the exact value of the Lagrange multiplier $\mu_{i,k}$ requires high computational complexity [2]. An approximated value of $\mu_{i,k}$ is obtained by (12). By the complementary slackness condition, if $\mu_{i,k}$ is positive, $R_{min} = \sum_{j=1}^{J_i} \sum_{n=1}^{N} \rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)}$ which implies that the equality in (13) holds. If $R_{min} < \sum_{j=1}^{J_i} \sum_{n=1}^{N} \rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)}$, i.e., $\mathrm{U}_{k,i}$ achieves higher rate than the minimum rate required by each user, $\mu_{i,k}$ is zero. Then, $\mu_{i,k}$ can be substituted as the difference between the minimum rate required by each user and the achievable rate for the user $U_{k,i}$ which is denoted $\tau_{i,k}$ and given by

$$\tau_{i,k} = R_{min} - R_{U_{k,i}}. \tag{17}$$

High computational complexity is required to find the optimal solution of the optimization problem in (7) [2]. To reduce the computational complexity, we propose a suboptimal subcarrier allocation algorithm.

4. Proposed Subcarrier Allocation Algorithm

Let $\mathcal{I}$, $\mathcal{J}_i$, $\mathcal{K}_i$, and $\mathcal{N}_i$ denote the sets of cells, relays in the cell i, users in the cell i, and subcarriers in the cell i, respectively. In the proposed algorithm, assume that the transmit power of each relay is equally allocated to the assigned subcarriers.

The proposed algorithm consists of three steps. In the first step, all sets and subcarrier assignment indicators are initialized. In the second step, each user in the set $\mathcal{K}_i$ selects the relay-subcarrier pair in the cell i that maximizes the achievable rate under the constraint on the maximum transmit power of each relay and minimum rate for each user. In the third step, if all users in the cell i achieve the minimum rate required by each user, each subcarrier in the set $\mathcal{N}_i$ is allocated to the user-relay pair in the cell i that maximizes the achievable rate under the maximum transmit power constraint of each relay.

For comparison, in the static algorithm, each user is assigned to a predetermined TDMA time slot and relay in a cooperative relay network based on OFDM-TDMA [2]. In the greedy algorithm, each subcarrier is allocated to a user, relay, and cell to maximize the overall sum of the achievable rate after an iterative search in a cooperative relay network based on OFDMA [4].

5. Simulation Results

Suppose that a downlink OFDMA relay network consists

$$\begin{aligned}L = &-\sum_{i=1}^{I}\sum_{j=1}^{J_i}\sum_{k=1}^{K_i}\sum_{n=1}^{N}\rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)}R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} - \sum_{i=1}^{I}\sum_{j=1}^{J_i}\sum_{k=1}^{K_i}\sum_{n=1}^{N}\gamma_{i,j,k,n}\rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} + \sum_{i=1}^{I}\sum_{n=1}^{N}\lambda_{i,n}\left(\sum_{j=1}^{J_i}\sum_{k=1}^{K_i}\rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} - 1\right)\\ &+\sum_{i=1}^{I}\sum_{j=1}^{J_i}\nu_{i,j}\left(\sum_{n=1}^{N}P_{\mathrm{R}_{j,i}}^{(n)} - P_{max}\right) - \sum_{i=1}^{I}\sum_{j=1}^{J_i}\sum_{n=1}^{N}\eta_{n,j,i}P_{\mathrm{R}_{j,i}}^{(n)} + \sum_{i=1}^{I}\sum_{k=1}^{K_i}\mu_{i,k}\left(R_{min} - \sum_{j=1}^{J_i}\sum_{n=1}^{N}\rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)}R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)}\right)\end{aligned} \tag{9}$$

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Algorithm: Subcarrier Allocation Algorithm
Step 1: Initialization
$\mathcal{I} = \{1, \dots I\}, \mathcal{J}_i = \{1, \dots, J_i\}, \mathcal{K}_i = \{1, \dots, K_i\}, \mathcal{N}_i = \{1, \dots, N\}$,
$\rho_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)} = 0, \forall i, j, k, n;$
Step 2: Initial Subcarrier Allocation
while $\mathcal{K}_i \neq \emptyset, i \in \mathcal{I}$ do
    $(i^*, j^*, k^*, n^*) = \arg\max_{i,j,k,n} R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)}$,
    $i \in \mathcal{I}, j \in \mathcal{J}_i, k \in \mathcal{K}_i, n \in \mathcal{N}_i.;$
    $\rho_{\mathrm{R}_{j^*,i^*}}^{\mathrm{U}_{k^*,i^*},(n^*)} = 1;$
    $\mathcal{N}_{i^*} = \mathcal{N}_{i^*} - \{n^*\};$
    If $P_{\max} - \sum_{n=1}^{N} P_{R_{j^*,i^*}}^{(n)} < 0$, then $\mathcal{J} = \mathcal{J} - \{j^*\};$
    If $\tau_{i^*,k^*} < 0$, then $\mathcal{K}_{i^*} = \mathcal{K}_{i^*} - \{k^*\};$
end
Step 3: Remaining Subcarrier Allocation
while $\mathcal{N}_i \neq \emptyset, i \in \mathcal{I}$ do
    Set $\mathcal{K}_i = \{1, \dots, K_i\};$
    $(i^*, j^*, k^*, n^*) = \arg\max_{i,j,k,n} R_{\mathrm{R}_{j,i}}^{\mathrm{U}_{k,i},(n)}$ ,
    $i \in \mathcal{I}, j \in \mathcal{J}_i, k \in \mathcal{K}_i, n \in \mathcal{N}_i.;$
    $\rho_{\mathrm{R}_{j^*,i^*}}^{\mathrm{U}_{k^*,i^*},(n^*)} = 1;$
    $\mathcal{N}_{i^*} = \mathcal{N}_{i^*} - \{n^*\};$
    If $P_{\max} - \sum_{n=1}^{N} P_{R_{j^*,i^*}}^{(n)} < 0$, then $\mathcal{J} = \mathcal{J} - \{j^*\};$
end
```

Table 1 Simulation parameters.

Parameters	Value
BS height	50 m
Relay height	50 m
User height	1.5m
Average rooftop height	25 m
Street width	12 m
Building spacing	60 m
Street orientation	90 degrees
Terrain	Medium sized cities
Center frequency	2.5 GHz
System channel bandwidth	0.3125 MHz
Subcarrier spacing	10.94 kHz
Noise figure	0 dB
Antenna gain	0 dBi
Antenna pattern	Omni-directional antenna

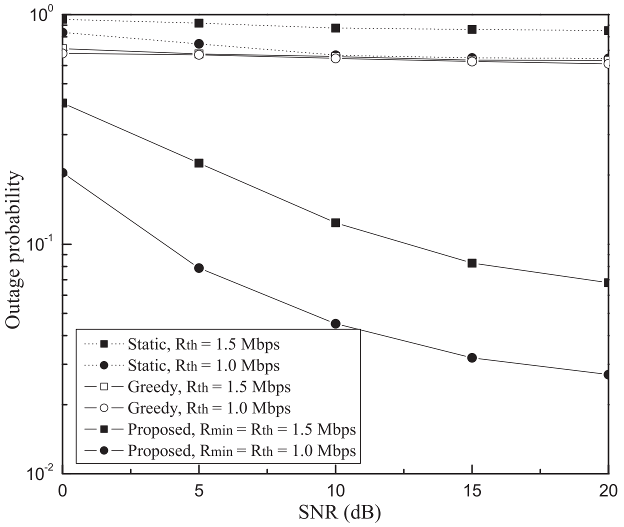

Fig. 2 Outage probability of the proposed subcarrier allocation algorithm. $I = 3$, $J_i = 5$, $K_i = 10$, and $N = 32$.

of three omni-cells. Suppose that a cell radius is 1 km and relays are located symmetrically on a circle with a radius of 0.5 km. Similar to the worst possible average signal to noise ratio (WSNR) [8], the received SNR is defined as the average received SNR of a user on the middle of the cell radius.

In base station-relay channels, the path loss model is the modified IEEE 802.16d channel model (Type D) and the multipath fading model is SUI-3 [9]. In base station-user and relay-user channels, the path loss model is the COST 231 Walfisch-Ikegami model (Type E) and the multipath fading model is SUI-4 [9]. Simulation parameters are shown in Table 1.

Figure 2 shows the outage probability of the proposed algorithm for $I = 3$, $J_i = 5$, $K_i = 10$, and $N = 32$. The outage probability is defined as the probability that a user does not meet a selected threshold rate R_{th}. It is shown that the outage probability of the proposed algorithm is lower than those of the static and greedy algorithms. It is also shown that the outage probability of the proposed algorithm decreases as the minimum rate required by each user decreases.

Figure 3 shows the achievable rate per subcarrier of the proposed algorithm for $I = 3$, $J_i = 5$, $K_i = 10$, and $N = 32$. As the SNR increases, the difference in the achievable rate between the proposed and static algorithms increases, while the difference in the achievable rate between the proposed and greedy algorithms decreases. It is shown that, as the minimum rate required by each user decreases, the achievable rate of the proposed algorithm increases. If R_{min} is low, the number of required subcarriers to achieve the minimum rate R_{min} is reduced. Then, the number of remaining subcarriers to maximize the overall sum of achievable rate is increased. Therefore the achievable rate of the proposed algorithm with $R_{min} = 1.0$ is higher than that of the proposed algorithm with $R_{min} = 1.5$. It is shown that the proposed algorithm achieves higher data rate than the static algorithm. It is shown that the achievable rate per subcarrier of the pro-

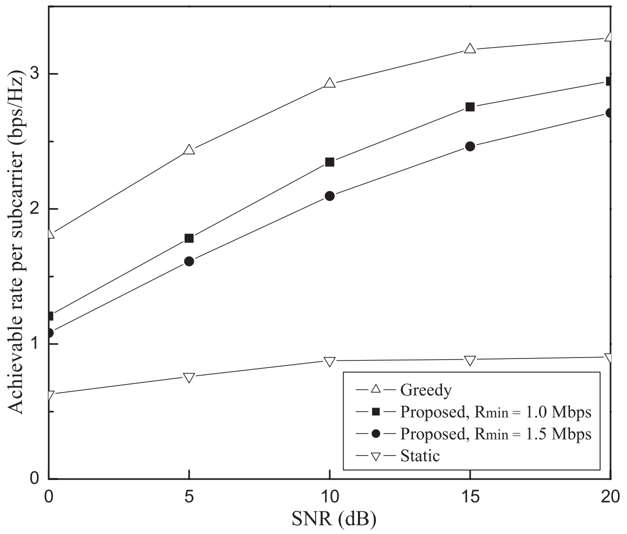

Fig. 3 Achievable rate per subcarrier of the proposed subcarrier allocation algorithm. $I = 3$, $J_i = 5$, $K_i = 10$, and $N = 32$.

posed algorithm is lower than that of the greedy algorithm without fairness constraints. However, the proposed algorithm achieves significant SNR gain in the outage probability at the expense of rate loss over the greedy algorithm.

6. Conclusion

In this paper, we propose a new subcarrier allocation algorithm to maximize the overall sum of the achievable rate under fairness constraints for a downlink OFDMA relay network with multicells. In the proposed algorithm, fairness constraints are imposed on the maximum transmit power of each relay and the minimum rate required by each user. By computer simulation, it is shown that the proposed algorithm achieves higher data rate than the static algorithm. It is also shown that the outage probability of the proposed algorithm is lower than those of the static and greedy algorithms.

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