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Proportional 자원할당을 위한 OFDMA 시스템에서 채널 용량을 증대시키기 위한 향상된 전력 할당 기법

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Improved Power Allocation to Enhance the Capacity in OFDMA System for Proportional Resource Allocation

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요 약

Orthogonal Frequency Division Multiple Access(OFDMA)는 4세대 무선 통신을 위해 고려되는 변조와 다중 접속 기술이다. 본 논문에서는, OFDMA 시스템에서 더 나은 proportional rate의 자원할당 기법을 위해 전체 전력, 비트 오류율, 유저 간의 rate proportionality에 대한 제한 조건을 만족시키면서, 유저의 전송률을 최대화 시키는 전략 할당 알고리즘에 대해 기술하였다. 그리고 subcarrier 할당의 비율과 유저의 정규화된 proportionality 조건에 기반을 둔 전력 할당 방식을 제안하였다. 유저에게 subcarrier 할당을 위한 방법으로는 greedy 알고리즘과 waterfilling 기술이 적용되었다. 제안된 알고리즘에 대한 평가는 시뮬레이션을 통해서 이루어졌으며, 시뮬레이션을 통해서 제안된 알고리즘이 유저 간의 rate proportionality를 유지하면서 더 높은 시스템 채널 용량과 적은 소요 시간을 보인다는 것을 확인할 수 있었다.

Key Words : OFDMA, resource allocation, power allocation, subcarrier allocation, proportionality, waterfilling

ABSTRACT

The Orthogonal Frequency Division Multiple Access (OFDMA) is considered as a novel modulation and multiple access technique for 4th generation wireless systems. In this paper, we formulate a base station's power allocation algorithm for each user to maximize the user's sum rate, subject to constraints on total power, bit error rate, and rate proportionality among the users for a better proportional rate adaptive (RA) resource allocation method for OFDMA based system. We propose a novel power allocation method based on the proportion of subcarrier allocation and the user's normalized proportionality constant. We adapt a greedy algorithm and waterfilling technique for allocating the subcarriers among the users. In an end-to-end simulation, we validate that the proposed technique has higher system capacity and lower CPU execution times, while maintaining the acceptable rate proportionality among users.

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Ⅰ. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) system, the benefit of orthogonality in subcarrier frequency, is used to divide a broadband channel into a large number of parallel narrowband subchannels for the desirable information transmission. In OFDM system, each subchannel, a large number of closely-spaced orthogonal subcarriers, is robust to intersymbol interference (ISI) and inter-carrier interference (ICI). OFDM is an effective way to deal with multi-path selective fading channel. Before transmission, the signal is encoded, modulated with quadrature amplitude modulated (QAM) mapping, and operated by the inverse fast Fourier transform (IFFT) to convert the signal from a frequency domain to a time domain. Then, a cyclic prefix (CP) is added to each OFDM symbol [1], which is the best technique to deal with the multi-path delay spread. On the receive side, we remove the CP, and reverse the techniques of the transmit side.

In OFDM, because all the subcarriers are used by a user in a given time, Orthogonal Frequency Division Multiple Access (OFDMA) or Multiuser-OFDM (MU-OFDM) [2] serves as an extended technique that enables the system capable of achieving multiple-access operation through different subcarriers in the same given amount of time. That is, to achieve multiple-access operation in an OFDMA system, a subset of subcarriers called subchannel is assigned to each user separately. OFDMA, which reportedly takes advantage of the OFDM and code division multiple access (CDMA) scheme is now widely used in wireless communications and mobile communications [3] such as mobile WiMax, Mobile Broadband Wireless Access (MBWA), and the downlink of the 3rd Generation Partnership Project Long Term Evolution (3GPP LTE) [4].

Among the advantages of OFDMA, the most interesting one, as mainly discussed in this research, is the dynamic resource allocation. This research topic has been investigated by many researchers in an effort to improve its performance and capacity. The dynamic resource allocation in the OFDMA system is divided into two categories of the optimization problems. The rate adaptive (RA) technique seeks to maximize the data rate subject to the transmission power constraint. The other technique seeks to minimize the system's transmission power subject to the total data rate; it is known as the margin adaptive (MA) technique.

There have been several schemes proposed so far in OFDMA system based on the resource allocation problem, assigning subcarrier and power to each user. An effective scheme developed by Wong et al. in [5], solving the MA resource allocation problem, provides a synergistic subcarrier and power allocation algorithm to minimize the total transmitted power subject to a fixed user's rate. Furthermore, in rate adaptive optimization, Jang et al. in [6] developed an algorithm, which maximizes the total user's rate subject to the transmitted power constraint. Yin et al. in [7] extended the work of [6] while keeping the transmitted power at a minimum rate. Working on rate adaptive optimization, Rhee et al. in [8] created an effective subcarrier allocation algorithm which ensures the fairness in resource allocation problems. Because the proposed subcarrier algorithm is adaptive, Shen et al. in [9] used this advantage to create an extension to the fairness by developing a novel power allocation algorithm that maximizes the total capacity subject to user's rate proportionality constraint. In spite of this achievement, the algorithm of Shen et al. in [9] is highly complex in its computation of non-linear equations. Therefore, it fails to meet the requirement of real-time implementation. Wong et al. in [10] proposed an enhanced algorithm which modified Rhee's subcarrier algorithm in [8] using a greedy algorithm and developed Shen's proposed power algorithm in [9]. In their study, Wong et al. in [10] achieved a better capacity using linear computation to solve the resource allocation problem. Later, Falahati et al. in [11] improved the low-complexity resource allocation algorithm of Wong et al. in [10] by iteratively attempting to satisfy only the proportionality constraint. Their result is less complex and show a slight improvement in the system capacity. There are many other works from different researchers [12]-[14] which do not focus on system capacity but the fairness among users, the optimization, and the channel state information instead.

This paper aims to improve overall capacity with low computational complexity of the system. We introduce a novel power allocation method based on the user's allocated subcarriers and normalized proportionality constant. Depending on the number of allocated subcarriers for each user, better capacity is provided to each user. For subcarrier allocation, we adapt the effective algorithm proposed by Rhee et al. in [8] to allocate the subcarrier among the users, which is also mentioned in the other aforementioned studies in [9]-[11]. We also follow Wong's proposed subcarrier allocation algorithm in [10]. As a result, we can illustrate the tradeoff between both the subcarrier allocation algorithms using the proposed power allocation method. We also present a detailed analysis of the resource allocation technique. We believe that this novel method achieves higher system capacity, reduces the execution time compared to the existing techniques of the root-finding scheme by Shen et al. in [9] and the linear scheme by Wong et al. in [10], while satisfying the user's rate proportionality constraint within the acceptable range.

This paper is divided into several sections and is organized as follows. The introduction is given in section I. In section II, the system model with the optimization problem in an OFDMA system is formulated. The resource allocation technique is presented in section III, while an analysis of an important parameter, alpha (α) is described in detail in section IV. Additionally, section V illustrates the simulation analysis and results. Eventually, the paper is concluded in section VI.

Ⅱ. System Model

In this section, we consider the structure of OFDMA based system's downlink transmission and the optimization problem for proportional resource allocation as shown in Fig. 1. The figure shows that each of the different K users is allocated to different subcarriers. It should be noticed that each subcarrier is allocated to one user at any given time. The transmitted bits of information are allocated into a number of different subcarriers. Next, these allocated subcarriers are modulated into M-ary QAM (M-QAM) symbols and operated with IFFT and CP addition processes before the signal is broadcast. After transmitting through a frequency selective Rayleigh fading channel, the CP is removed from the OFDMA symbol and FFT is then applied at the receive side. Furthermore, the channel state information (CSI) feedback is sent from each user's channel estimator to the base station (BS) using different feedback channels. By observing the CSI feedback, the resource allocation (RA) sub-system at the BS is able to analyze it in a better way to serve the user at the next time interval. At the kth user's receive side $(1 \le k \le K)$, after transmitting the feedback signal, the subchannel selector observes every subchannel and chooses an appropriate one for the decoder in order to obtain the kth user's data perfectly.

In this system, we assume each user observes an OFDMA narrowband channel H_k with an independent fading channel. The subchannel signal-to-noise ratio (SNR) for the kth user in the nth subcarrier $(1 \le n \le N)$ is given by $H_{k,n} = g_{k,n}^2/\sigma^2$, where $g_{k,n}$ implies the channel gain of the kth user at the nth subcarrier, and $\sigma^2 = N_0(B/N)$ is the additive white Gaussian noise (AWGN); N is the number of subcarriers, while N_0 and B are the noise power spectral density and the total bandwidth, respectively. We also know that the received SNR for the nth subcarrier of the kth user is denoted by $\gamma_{k,n} = p_{k,n}H_{k,n}$ where $p_{k,n}$ denotes the allocated power. Therefore, the number of bits for the kth user in the nth subcarrier, $r_{k,n}$, can be expressed by the following equation.

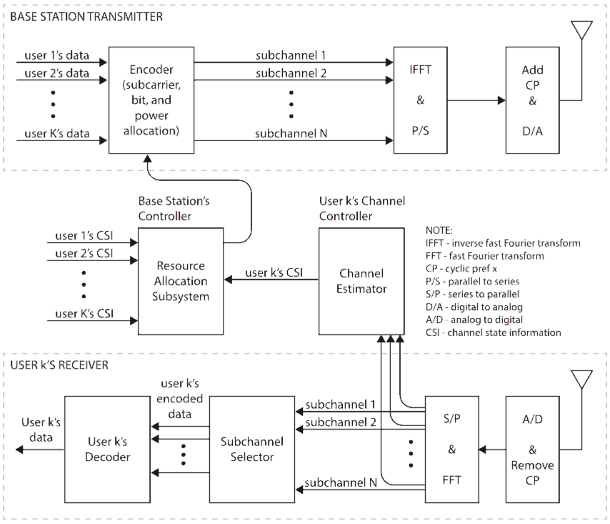


Fig. 1. The resource allocation scheme of Orthogonal Frequency Division Multiple Access (OFDMA) based downlink system block diagram.

$$r_{k,n}=\log_2\left(1+\frac{\gamma_{k,n}}{\Gamma}\right) \tag{1}$$

According to Chung et al. in [15], the received SNR gap Γ can be obtained by the gap-approximation analysis in the form of $\Gamma=-\ln(5BER)/1.6$ based on the bit error rate (BER) constraint, the applied coding, and the system margin performance.

The objective for optimizing resource allocation problem is to maximize the sum of the average user's rate subject to the following equation below.

$$\max_{c_{k,n}p_{k,n}}\frac{B}{N}\sum_{k=1}^{K}\sum_{n=1}^{N}c_{k,n}\log_2\left(1+p_{k,n}\frac{H_{k,n}}{\Gamma}\right) \tag{2}$$

subject to :

1). $c_{k,n}\in\{0,1\}\ \forall k,n$
2). $p_{k,n}\geq 0\ \forall k,n$

3). $\sum_{k=1}^{K}c_{k,n}=1\ \forall n$
4). $\sum_{k=1}^{K}\sum_{n=1}^{N}c_{k,n}p_{k,n}\leq P_{tot}$
5). $R_i : R_j=\phi_i:\phi_j\ \forall i,j\in\{1,\cdots,K\},\ i\neq j$

Here, $c_{k,n}$ is the subcarrier allocation indicator, such that, $c_{k,n}=1$ if and only if the nth subcarrier is assigned to the kth user. P_{tot} denotes the total transmit power constraint, ϕ_k is the normalized proportionality constant of the kth user where $\sum_{k=1}^{K}\phi_k=1$, and R_k is the total sum rate for the kth user, given by

$$R_k=\sum_{n=1}^{N}c_{k,n}r_{k,n} \tag{3}$$

In (2), constraint 1 provides a simple value to use to use regardless of whether each subcarrier allocation indicator is assigned or not. Constraint 2 confirms that there is no negative value to be assigned to the power. Constraint 3 ensures that each subcarrier can only be assigned to one user. Constraint 4 keeps the sum of the power from all subcarriers in the given limited total power, and constraint 5 declares the default value for users' proportional data rate constraints.

For the optimization problem, it is difficult to enhance both subcarrier and power allocation at the same time due to the non-linear constraints problem. Therefore, in order to retain a better executing speed and higher level of performance, it is profoundly recommended to break the problem into two different sections. One is subcarrier allocation and the other is power allocation. Thus, the complexity is decreased and the optimization problem in (2) is lessened, as shown below,

$$\max_{p_{k,n}}\frac{B}{N}\sum_{k=1}^{K}\sum_{n\in\zeta_k}\log_2\left(1+p_{k,n}\frac{H_{k,n}}{\Gamma}\right) \tag{4}$$

subject to :

1). $p_{k,n}\geq 0\ \forall k,n$
2). $\sum_{k=1}^{K}\sum_{n\in\zeta_k}p_{k,n}\leq P_{tot}$
3). $R_i : R_j=\phi_i:\phi_j\ \forall i,j\in\{1,\cdots,K\},\ i\neq j$

In this equation, ζ_k refers to the set of subcarriers to be allocated to the kth user. Therefore, the kth user's sum data rate $r_{k,n}$ becomes

$$R_k = \sum_{n \in \zeta_k} r_{k,n} \tag{5}$$

In (4), the problem becomes easier to solve. Following the simple algorithmic structure given in [9] and [10], we can obtain ζ_k from a subcarrier allocation algorithm, and P_k from a power allocation algorithm. We eventually are able to distribute the suitable power across each subcarrier among the users using waterfilling technique, defined as

$$p_{k,n} = p_{k,1} + \frac{H_{k,n} - H_{k,1}}{H_{k,n} H_{k,1}} \tag{6}$$

where

$$p_{k,1} = \frac{P_k - V_k}{N_k} \tag{7}$$

for $n \in \{1,2,...,N_k\}$ as well as $k \in \{1,2,...,\mathrm{K}\}$. Also, N_k is the number of subcarriers in ζ_k, and V_k is a variable that is used to solve P_k using Lagrangian multiplier.

Ⅲ. Resource Allocation

In this section, we present in details the subcarrier allocation methods proposed by Rhee et al. in [8] and by Wong et al. in [10], and the proposed power allocation method.

3.1. Subcarrier Allocation

Rhee et al. in [8] derived a multiuser convex optimization problem in order to find the optimal subcarrier allocation, and had proposed a low-complexity adaptive subchannel allocation algorithm. In their work, each subchannel is assigned to each user whose channel gain is qualified for it. In their algorithm, which assigns subcarriers among the users, an equal amount of power (P_{max}/N) is allocated to each subcarrier while $C(h_{k,n})$ is defined by the equation below.

$$C(h_{k,n}) = \frac{B}{N}\log_2\left(1 + \frac{(P_{max}/N)h_{k,n}^2}{N_0 \frac{B}{N}}\right) \tag{8}$$

Here, R_k represents the zero-margin data rate of the kth user for the assigned subcarrier. The effective subcarrier allocation algorithm is described as shown bellow.

```
1) Initialize parameters
    a) set $R_k = 0,\ \forall k = \{1,2,...,K\}$ and
       $A = \{1,2,...,N\}$
2) Allocate the best subcarrier for each user
   for $k = 1$ to $K$
    a) find $n$ satisfying
       $|h_{k,n}| \geq |h_{k,j}|,\ \forall j \in A$
    b) update $R_k$ and $A$ with the $n$ from a)
       $R_k = C(h_{k,n}),\ A = A - n$
3) Distribute of the remain unallocated
   subcarrier while $A \neq 0$
    a) find $k$ satisfying
       $R_k \leq R_i, \forall i,\ 0 \leq i \leq K$
    b) for the found $k$, find $n$ satisfying
       $|h_{k,n}| \geq |h_{k,j}|,\ \forall j \in A$
    c) update $R_k$ and $A$ with the $k$ from $n$
       $R_k = R_k + C(h_{k,n}),\ A = A - n$
```

The first step is the initialization step. Data rates are set for all users to zero and the vector A determines the available subcarriers. In this case, we define A as ranging from 1 to N subcarrier.

In the second step, we allocate the nth subcarrier to the kth user, which has the largest channel gain. When one subcarrier is allocated by the kth user, the amount of available subcarriers in A is reduced by 1. At the end of the loop, we note that the number of subcarriers in A has been reduced by K. Also, the users' rates are assigned at every loop based on the kth user.

The remaining $A-K$ unallocated subcarriers are used for the third step, where it is necessary to distribute the best subcarrier to each user based on the users' rates from the second step. During the iteration of each loop, we check if the number of available subcarriers in A is not zero or if there are still subcarriers available for users. If either is true, we need to find the user who has the lowest data rate to receive one subcarrier during each turn. To allocate the subcarriers, we use the same algorithm referred to in the second step.

Wong et al. in [10] developed the subcarrier allocation algorithm by Rhee et al. in [8] using a greedy algorithm. First, they initialized the number of subcarriers per user based on the reasonable assumption of Yin et al. in [7]. Then, after the power allocation, the proportion of subcarriers for each user become nearly equal to the normalized proportionality constants. Here, N_k is defined as follows.

$$N_1 : N_2 : \cdots : N_K = \phi_1 : \phi_2 : \cdots : \phi_K \qquad (9)$$

Therefore, we have the number of subcarriers of the kth user $N_k = \phi_k N$ along with the remaining unallocated subcarriers defined as $N^* = N - \sum_{k=1}^{K} N_k$. Below is the effective subcarrier allocation algorithm modified using the greedy algorithm by Wong et al. in [10].

```
1) Initialize parameters
    a) Set $c_{k,n} = 0,\ \forall k \in \{1,2,...,K\}$ and $\forall n \in \{1,2,...,N\}$
       $R_k = 0,\ \forall k = \{1,2,...,K\}$ and $p = P_{tot}/N$
    b) Define the set of available subcarrier $M = \{1,2,...,N\}$
2) Allocation the best subcarrier for each user $k = 1$ to $K$
    a) Sort $H_{k,n}$ in ascending order
    b) Find $n = \arg max_{k \in M} |h_{k,n}|$
    c) Set $c_{k,n=1}$
    d) Reduce $N_k = N_k - 1$
    e) Subtract the $nth$ subcarrier from $M = M \setminus \{n\}$
    f) Update $R_k = R_k + \frac{B}{N}\log_2(1 + pH_{k,n})$
3) Apply the greedy algorithm to achieve $N^*$ while $\| M \| > N^*$
    a) $L = \{1,2,...,K\}$
    b) $k = \arg max_{k \in L} \frac{R_k}{\phi_k}$
    c) $n = \arg max_{k \in M} |h_{k,n}|$
    d) if $N_k > 0$
        i) Set $c_{k,n} = 1$
        ii) Reduce $N_k = N_k - 1$
        iii) Subtract the $nth$ subcarrier from $M = M \setminus \{n\}$
        iv) Update
            $R_k = R_k + \frac{B}{N}\log_2(1 + pH_{k,n})$
    e) else
        i) Subtract the $kth$ user from $L = L \setminus \{k\}$
4) Distribute the unallocated subcarrier $N^*$ to users
    a) Define $L = \{1,2,...,K\}$
    b) For each subcarrier $n = 1$ to $N^*$
        i) Find $k = \arg max_{k \in L} \frac{R_k}{\phi_k}$
        ii) Set $c_{k,n} = 1$
        iii) Update
            $R_k = R_k + \frac{B}{N}\log_2(1 + pH_{k,n})$
        iv) Subtract the $kth$ user from $L = L \setminus \{k\}$
```

In a brief description of this algorithm, all the variables are initialized in step 1, During step 2, each user can gain one of the available subcarriers from the position where the effective subchannel SNR is the highest. The remaining available subcarriers need to achieve the same value of the defined unallocated subcarriers N^*, which can be determined using the greedy algorithm during step 3. Finally, the unallocated subcarriers are distributed to all users during step 4.

After each subcarrier has been assigned to users, the next part will illustrate how to allocate power to users fairly.

3.2. Power Allocation

In pervious section, after all the subcarriers are assigned to each user, the resource allocation problem is reduced to an optimal power allocation in (4). In this part, we introduce the proposed power allocation method to allocate the power among the users. To do this, we use the number of subcarriers allocated to a user and its proportionality constant. In our method, we are interested in two main parameters, which are used accordingly in order to achieve the best power for all users. Those two parameters are S_k, the number of allocated subcarriers for the kth user, and ϕ_k, the normalized proportionality constant for the kth user. The parameter S_k can be formulated as

$$S_k = \sum_{n=1}^{N_k} c_{k,n} \tag{10}$$

where N_k, the number of subcarriers, is distributed to the kth user. In addition, $c_{k,n}$ is the subcarrier indicator for the assignment of the nth subcarrier to the kth user.

In order to use these two parameters, we need to study on another parameter called α (alpha). The α parameter is used for obtaining the portion from the total power P_{tot} according to S_k. Thus, the remaining power is given to ϕ_k as in the following equations.

$$\lambda_{S_k} = \alpha P_{tot} \tag{11}$$

$$\lambda_{\phi_k} = (1-\alpha) P_{tot} \tag{12}$$

The variables λ_{S_k} and λ_{ϕ_k} are the portions of the total power derived using S_k and ϕ_k, respectively. Thus, λ_{S_k} and λ_{ϕ_k} have to satisfy a condition $\lambda_{S_k} + \lambda_{\phi_k} = P_{tot}$. Because α is the important parameter in this power allocation method for achieving high system capacity, we are going to discuss about the α parameter in details in the next section.

Next, we can use the portions defined above to find the power for the kth user.

$$P_{S_k} = \frac{S_k \lambda_{S_k}}{\sum_{k=1}^{K} S_k} = \frac{\alpha S_k P_{tot}}{N} \tag{13}$$

$$P_{\phi_k} = \frac{\phi_k \lambda_{\phi_k}}{\sum_{k=1}^{K} \phi_k} = (1-\alpha)\phi_k P_{tot} \tag{14}$$

$$P_k = P_{S_k} + P_{\phi_k} \tag{15}$$

The variable P_{S_k} and P_{ϕ_k} are defined as the power of the kth user obtained from S_k and ϕ_k, respectively. Also, $\sum_{k=1}^{K} S_k$ is equal to N, $\sum_{k=1}^{K} \phi_k$ is equal to 1, and P_k is the total power that the kth user can achieve. In this case, the total power is

$$P_{tot} = \sum_{k=1}^{K} P_k \tag{16}$$

Therefore, the algorithm for the proposed power allocation method is illustrated as below.

```
1) Initialize parameters
   a) Initialize $\alpha$
   b) Retain $\phi_k$
   c) Find $S_k$
2) Find $\lambda_{S_k}$ and $\lambda_{\phi_k}$; equations (11) and (12)
3) Find $P_{S_k}$ and $P_{\phi_k}$; equations (13) and (14)
4) For the capacity for each user from $k=1$ to $K$
   Compute $P_k$ in equation (15)
```

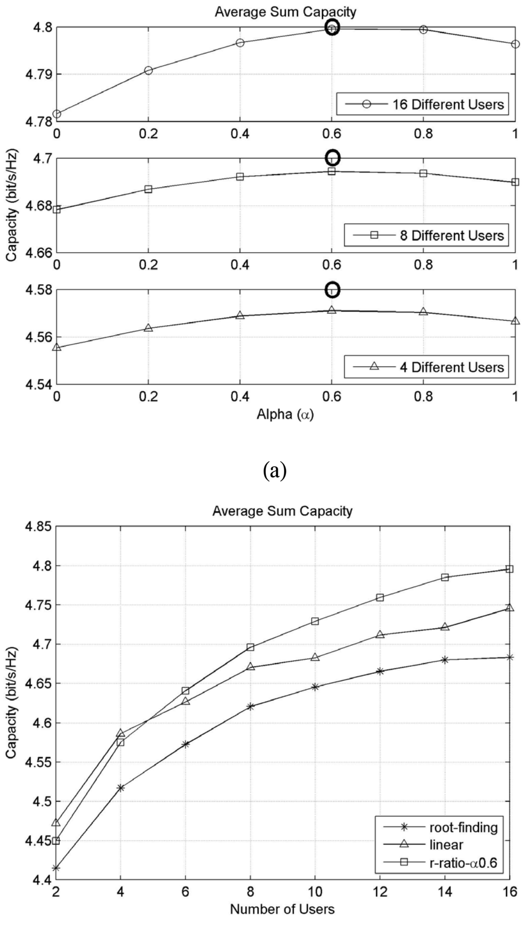
After power allocation among the users, waterfilling is applied to allocate the power among the subcarriers allocated to each user.

Ⅳ. Alpha (α) Parameter Analysis

In the previous section, we note that the alpha (α) parameter is the important parameter as it provides the portions of the total power derived using S_k and ϕ_k. In this section, we determine the best α value for the proposed power allocation method in order to achieve the highest average sum capacity among a number of different users. We set the range of α from 0 to 1 with an increment of 0.2. We choose 4, 8 and 16 different users for our experiment.

We simulate an OFDMA downlink system with 64 subcarriers and the total power of $1W$ in the channel bandwidth $1MHz$. Also, we assume that the maximum delay spread is $5\mu s$ and the maximum Doppler shift is $30Hz$. Updating the subcarrier and power allocation, we sample the channel state information (CSI) at every $0.5ms$ while the average subchannel SNR is assumed to be $38dB$. We use 1000 different channel realizations and 100 sampling times for each channel realization process. With an increment of 2, the system is alternately changed from 2 to 16 users.

In this analysis, we use Rhee’s subcarrier allocation algorithm as the effective subcarrier allocation method developed by Rhee et al. in [8], Wong’s subcarrier allocation algorithm as the subcarrier allocation method, as improved by Wong et al. in [10]. The alpha (α) parameter simulation process is divided into two parts. The first is for using Rhee’s subcarrier allocation algorithm with the proposed method, called *r-ratio*. The second is Wong’s subcarrier allocation algorithm with the proposed method, called *w-ratio*. Additionally, we compare with two different pervious techniques: the *root-finding* technique is the proposed scheme by Shen et al. in [9], while the *linear* technique is the proposed scheme by Wong et al. in [10].



(a)

(b)

Fig. 2. The experiment of Rhee’s subcarrier allocation algorithm in [8] and the proposed power allocation method (*r-ratio*). (a) An observation of the average sum capacity over range of alpha. (b) A comparison of the average sum capacity between the *r-ratio* when $\alpha = 0.6$ scheme and the previous preposed techniques, the *root-finding* and *linear*

4.1. Rhee's Subcarrier and the Proposed Power Allocation Algorithms (*r-ratio*)

Fig. 2(a). shows the average sum capacity curves for the system using Rhee’s subcarrier allocation algorithm and the proposed power allocation method with 4, 8 and 16 users. All three capacity curves look similar because the capacity keeps increasing as the value of the alpha increases. However, these curves reaches the peak when $\alpha = 0.6$, for 4, 8 and 16 users, respectively. Then these graphs go down slightly and when $\alpha = 1.0$, the achieved capacity at that point is changed to just slightly below the peak.

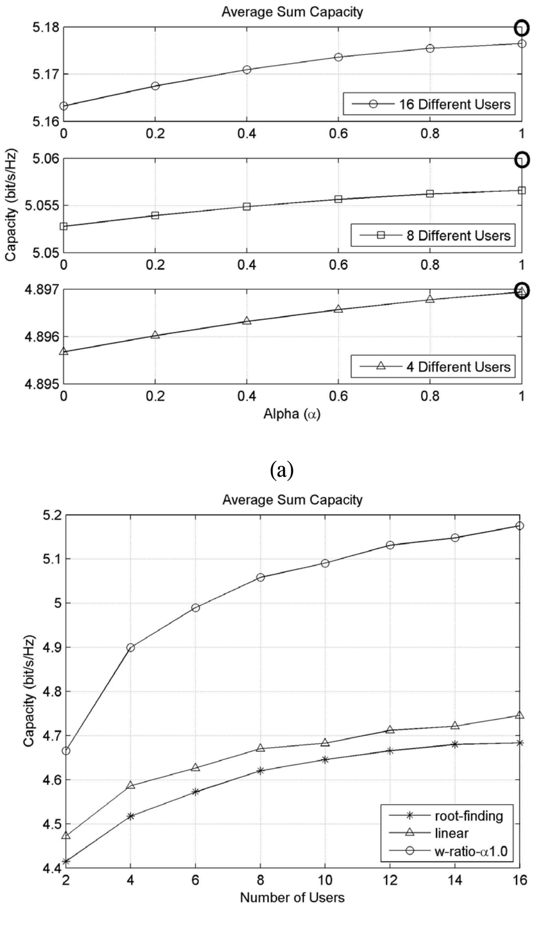
In this case, we can achieve the highest average sum capacity for different users when $\alpha=0.6$. Additionally, we note that the curve for 4 users arches more than it does for 16 users. Therefore, when α ranges from 0.6 to 1, the greater numbers of different users leads to a steadier curve.

After we found the best value for the α parameter, we make a comparison between $r-ratio$ with $\alpha=0.6$ ($r-ratio-\alpha 0.6$), the *root-finding*, and the *linear* techniques as shown in Fig. 2(b). In general, the $r-ratio-\alpha 0.6$ scheme provides the best capacity among them. Compared to the *root-finding* technique, the gap between different capacities becomes wider as number of the users increase. It was noted that both of them use the same subcarrier allocation but different power allocation algorithms. Compared to the *linear* technique, we noted that the $r-ratio-\alpha 0.6$ scheme stays below a range from 2 to 5 users, and keeps increasing significantly above the technique. Thus, the result is still better than the *linear* technique.

To sum up, the $r-ratio-\alpha 0.6$ scheme is better than both the *root-finding* and the *linear* techniques with the highest value, $4.795\,bit/s/Hz$ for the 16 different users.

4.2. Wong's Subcarrier and the Proposed Power Allocation Algorithms (*w-ratio*)

Fig. 3(a) shows the average sum capacity curves for the system using Wong's subcarrier allocation algorithm and the proposed power allocation method with the alpha value ranging from 0 to 1. The figure shows that the curves look different from that shown in Fig. 2(a). Again, we analyze the same three different numbers of users, 4, 8 and 16. With the alpha value ranging from 0 to 1, we noted that the capacity curves continue to increasing constantly, reaching a peak at $\alpha=1.0$. It is also noted that we obtain different values of the alpha parameter for the highest capacity with different subcarrier allocation algorithms. For this experiment, the value $\alpha=1.0$ is the best value considering the system capacity.



(a)

(b)

Fig. 3. The experiment of Wong's subcarrier allocation algorithm in [10] and the proposed power allocation method (*w-ratio*). (a) An observation of the average sum capacity over the range of alpha. (b) A comparison of the average sum capacity between the *w-ratio* when $\alpha=1.0$ scheme and the pervious proposed techniques, the *root-finding* and *linear*

Surprisingly, we obtained a better result after we made the comparison of the $w-ratio$ when $\alpha=1.0$ ($w-ratio-\alpha 1.0$) scheme and the *root-finding* and *linear* techniques. The result shows that the $w-ratio-\alpha 1.0$ scheme is far higher than what the other two can achieve. For 16 users, the $w-ratio-\alpha 1.0$ capacity is $5.175\,bit/s/Hz$, following by *linear* 4.746 $bit/s/Hz$, and *root-finding* $4.683\,bit/s/Hz$ at the bottom. We also noted the gap between the $w-ratio-\alpha 1.0$ scheme and their techniques become larger as the number of users increase.

Overall, the $w-ratio-\alpha 1.0$ scheme gives the highest average sum capacity compared to the *root-finding* and *linear* techniques.

V. Simulation Results

The simulation results of the proposed power allocation method with Rhee and Wong's subcarrier allocation algorithms ($r-ratio-\alpha 0.6$ and $w-ratio-\alpha 1.0$) for solving the resource allocation problem are illustrated in this section in a comparison with the *root-finding* technique presented by Wong et al. in [10], and the *linear* technique presented by Shen et al. in [9] with three different aspects of the overall capacity, the CPU execution time, and the rate proportionality. A set of proportionality constants $\Delta_k = \phi/\min\phi$ as assigned to each user for each channel realization, is assumed to the following probability mass function, as shown below.

$$\Delta_k\begin{cases}1 \in the\,probability\,of\;0.5\\ 2 \in the\,probability\,of\;0.5\end{cases} \qquad (17)$$

We divide the results into three different parts according to the three different aspects above.

5.1. Overall Capacity

Fig. 4. depicts the comparison of the average sum capacity of the different resource allocation schemes, as previously discussed. Since the effect of multi-user diversity gains, more users lead to better capacity. In brief, we noted that the $w-ratio-\alpha 1.0$ scheme provides the best average sum capacity among all. However, because the curves for the two experiment schemes are high than the *root-finding* and *linear* techniques, we still need them in the comparisons in the next parts of the CPU computing time and the rate proportionality.

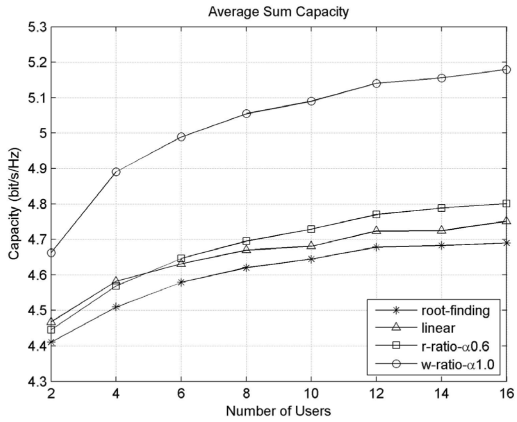


Fig. 4. A comparison of the average sum capacity of the four different resource allocation schemes

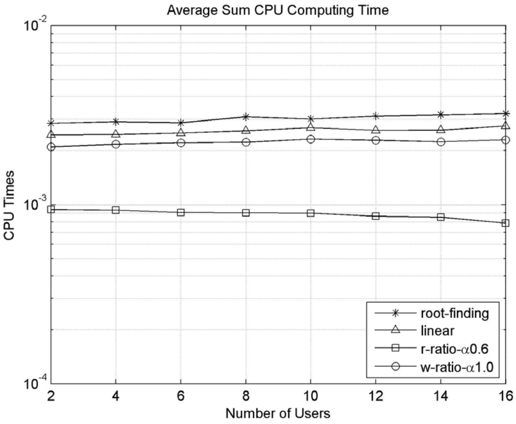


Fig. 5. A comparison of the average sum CPU computation time of the four different resource allocation schemes

5.2. CPU Execution Time

Fig. 5. illustrates the second aspect in the comparison of the average sum CPU execution times for these schemes. The average CPU execution time is the simulation time for both subcarrier and power allocation computation times, while in earlier work [10], the author compared the computing time for power allocation only. We conducted the simulation using Matlab 2012 on a personal computer running the Windows 7 64-bit Operating System with an Intel Core 2 Duo 2.93 GHz CPU processor with 2 GB of RAM. In the figure, the computation time of $r-ratio-\alpha 0.6$ scheme is the fastest, while the $w-ratio-\alpha 1.0$ scheme remains in the second place with a computation time below that of the *root-finding* and *linear* techniques. It is desired for the real-time implementation that the less computation time is the best. Thus, there is a tradeoff in which the $r-ratio-\alpha 0.6$ scheme provides the lowest CPU execution time while the

$w-ratio-\alpha1.0$ scheme provides the best overall capacity in the system.

5.3. Rate Proportionality

Fig. 6. depicts the normalized capacity ratios per user for the case of 16 users. The leftmost bar (phi) is the required proportion ϕ_k. The comparison is made between the normalized proportionality constraints given by $\{\phi_k\}_{k=1}^{16}$ and the normalized rate proportionality of the *root-finding*, *linear*, $r-ratio-\alpha0.6$ and $w-ratio-\alpha1.0$ techniques given by $R_k/\sum_{k=1}^{16} R_k$. We can note that *root-finding* technique can achieve a nearly identical required proportion, while the others appear to swing around the required point. The *linear* technique also provides better normalized rate proportionality than the $r-ratio-\alpha0.6$ and $w-ratio-\alpha1.0$ schemes; though they cannot provide the ideal required amount, they still stay close to the bar, and would be acceptable in the real system.

Ⅵ. Conclusion

This paper presents a new rate adaptive resource allocation technique with a novel power allocation method in an OFDMA based system. By combining the proposed power allocation method with the subcarrier allocation algorithm from Rhee et al. [8] and another subcarrier allocation algorithm from Wong et al. [10], we are able to present better schemes to solve the resource allocation problem. Both achieve better results in terms of a higher average sum capacity, and lower average CPU computation times compared to the *root-finding* and *linear* techniques. However, there is a weakness that we cannot achieve better normalized proportionality among the users, as in the *root-finding* and *linear* techniques. To sum up, we select the $w-ratio-\alpha1.0$ scheme as it provides higher average sum capacity and better performance, which are applicable for general real-time implementation in the OFDMA based systems.

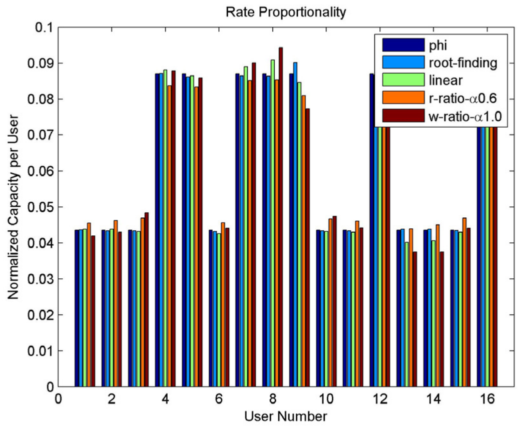


Fig. 6. Normalized rate proportionality per user for 16 users with the required portions ϕ_k shown as the leftmost bar for each user. A comparison of the four techniques is shown

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