Uplink Resource Allocation Algorithms with Fractional Power Control as Power Constraints for OFDMA System

Arfianto Fahmi, Muhamad Asvial, Dadang Gunawan
Electrical Engineering Department
University Of Indonesia
Depok, Indonesia
arfianto.fahmi@ui.ac.id, asvial@ee.ui.ac.id, guna@eng.ui.ac.id

***Abstract*—In this paper, two algorithms in resource allocation with fractional power control scheme are proposed and evaluated. In these algorithms, we joint chunk allocation and unequal power allocation in one chunk by considering fractional power control scheme as power constraint on each user to improve the sum of spectral efficiency of users and fairness among users. In order to evaluate our proposed algorithms, we compare the performances of our proposed algorithms with those of the previous algorithms with fractional power control scheme as power constraint in each user. From the simulation results are shown that our proposed algorithms can improve the sum of spectral efficiency and fairness among users in macrocell urban and suburban condition.**

Keywords – chunk allocation; unequal power allocation; fractional power control; resource allocation; OFDMA; uplink

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing Access (OFDMA) is one of the access technology solutions that have been widely adopted as a standard in the 3GPP LTE physical layer and IEEE 802.16 to accommodate high-speed service. 3GPP-LTE has chosen SC-FDMA (Single Carrier Frequency Division Multiple Access) as uplink access scheme in OFDMA systems, because it has a lower peak to average power ratio (PAPR) and higher frequency diversity since it assigns a consecutive subcarriers to a user[1][2][3].

In OFDMA uplink system, the radio resources used by each user can be adjusted and changed depending on channel conditions of each user. The process of adaptation is performed every 1 time transmission interval (TTI) and to reduce the complexity of algorithm, resource allocation is performed based on a chunk (set of subcarriers) [3][4][5].

There are two types of subcarriers grouping in OFDMA uplink to form a chunk : Localized-FDMA (L-FDMA) and Distributed-FDMA (D-FDMA), where the subcarriers grouping in one chunk are either consecutive or distributed, respectively. Both of them have almost the same levels of PAPR and from [1] showed that L-FDMA achieves higher throughput than D-FDMA with the slightly weaker of PAPR. So, most of the previous works consider L-FDMA as subcarriers grouping in OFDMA uplink system.

In every TTI, each user get a different chunk to each other to keep the orthogonality among users so that the intracell interference can be avoided using a certain distributed resource allocation algorithm in each cell. In order to maximize spectral efficiency, frequency reuse factor of one is used in OFDMA uplink and downlink direction. With frequency reuse factor of one, one cell will experience the interference from or to other cells especially for users at the cell edge. In order to reduce the intercell interference from or to other cells, 3GPP LTE has recommended fractional power control (FPC) as power control scheme to reduce intercell interference. This power control scheme provides better tradeoff between cell edge performance and overall spectral efficiency [6][7].

In the previous works of uplink single cell resource allocation focus on chunk allocation with equal power allocation [8-10] and with unequal power allocation [11] in each subcarrier of one chunk without considering fractional power control scheme. In those works are assumed that user's power constraints are constant in all TTIs. So, in this work we consider FPC which is used to determine the user's power constraints in every TTI and these power constraints will change in every TTI based on the each user's distance to base stasion.

In [8] propose chunk allocation algorithm using mean enhanced greedy (MEG) algorithm by considering L-FDMA scheme as subcarriers grouping and equal power allocation in one chunk. This algorithm allocate a chunk to the user by finding a user who has the smallest average of chunk gain then this user will get a chunk which has the biggest average of user channel gain.

In [9] propose chunk allocation scheme by considering L-FDMA scheme as subcarrier grouping and equal power allocation in one chunk. The channel gain in each chunk per user is calculated based on the equalization method used (Minimum Mean Square Error and Zero Forcing). This algorithm will choose the biggest quality of chunk and this chunk will be allocated to a user who has the biggest quality on that chunk and an iteration is used by swapping allocated chunks between user to improve the capacity.

In [10], resource allocation algorithm by modifying the obilor's algorithm is proposed. In this algorithm, it considers L-FDMA scheme as subcarriers grouping and equal power allocation in one chunk. The channel gain in each chunk per user is calculated based on the equalization method used (MMSE and ZF). This algorithm allocate a chunk to a user by finding a chunk which has the smallest average of user gain and this chunk will allocate to a user who has the biggest average of chunk channel gain.

In [11], resource allocation algorithms by combining chunk allocation and unequal power allocation on each subcarrier in one chunk are proposed to improve the performances. It considers L-FDMA and MMSE as subcarriers grouping and equalization method respectively. These algorithms are divided into two process, there are power allocation and chunk allocation, where waterfilling power scheme is used as power allocation.

In this work, two algorithms in resource allocation with fractional power control scheme are proposed. In these algorithms, we joint chunk allocation and unequal power allocation in one chunk by considering fractional power control scheme as power constraint on each user to improve the sum of spectral efficiency of users and fairness among users. The user's power constraints in each TTI are changed based on fractional power control scheme in [7] and the unequal power allocation in each subcarrier of one chunk is based on the waterfilling power scheme in [12].

In order to evaluate our proposed algorithms, we compare the performances of our proposed algorithms with those of the previous algorithms in [8-10] with fractional power control scheme as power constraint in each user.

II. PROBLEM FORMULATION

In the uplink system there are K users and N available subcarriers. The available subcarriers are divided into several chunks where each chunk contains n_c consecutive subcarriers. We consider L-FDMA as subcarriers grouping in one chunk with the number of consecutive subcarriers per chunk is $n_c = N/K$ and the number of subcarriers in one chunk is fixed in all TTIs. A chunk is similar with a fraction of the total transmission bandwidth which is allocated to user. In order to maintain fairness among users, we consider that one chunk is only allocated to one user and can not be shared by other users. So, we can assume that the number of available chunks are equal to the number of users (C=K) and we can define that C_k is a chunk allocated to the user k.

By allowing one chunk is only allocated to one user, intracell interference can be avoided because each user get a chunk that is different from other users and fractional power control is performed to reduce intercell interference by limiting each user's power spectral density (PSD) rather than total power in each TTI[6][7].

We consider that in base stasion has known the channel gain ($H_{n,k,csi}$) of subcarrier-n of user k as CSI in each TTI. And we can define channel to noise ratio ($CNR_{n,k,csi}$) of subcarrier-n of user-k before allocation :

$$CNR_{n,k,csi} = \frac{H_{n,k,csi}}{\sigma_n^2} \qquad (1)$$

σ_n^2 is the noise power of subcarrier n.

In order to allocate unequal power to each subcarrier in one chunk, we consider to use waterfilling power scheme in [12] and extend that power allocation scheme into our proposed algorithms, so the amount of power allocated to subcarrier-n of user-k in one chunk can be expressed as :

$$p_{n,k} = \frac{P_k + \sum_{n=cn_c-n_c+1}^{kn_c} \frac{1}{CNR_{n,k,csi}}}{n_c} - \frac{1}{CNR_{n,k,csi}} \qquad (2)$$

$p_{n,k}$ is performed for $k=1,..,K$, $n=1,..,N$ and $c=1,..,C$ where a chunk containts n_c consecutive subcarriers, and P_k is power constraint of user k based on fractional power control.

Fractional Power Control is performed to reduce intercell interference by limiting each user's power spectral density (PSD) rather than total power in each TTI. The user's transmit PSD (in dBm/chunk) can be defined as transmit power per chunk as follow [7]:

$$PSD = P_o + \alpha.Lp \qquad (3)$$

P_o (in dBm/chunk) is chunk spesific constant, α is a parameter representing the fraction of path-loss that we aim at compensating for and Lp (in dB) is pathloss to the base stasion. The user's transmit power k is determined by multiplying equation (3) with the number of chunk allocated to each user (C_k) and will be :

$$P_k = \min\,(P_{max}, PSD + 10logC_k) \qquad (4)$$

Where P_{max} is maximum power of user. In our proposed algorithms are assumed that each chunk will be allocated to only one user, it's mean that power constraint of each user is equal with power constraint of each chunk and we can note that $C_k = 1$. So the user's transmit power k (in dBm) will be :

$$P_k = \min\,(P_{max}, P_o + \alpha.L_p) \qquad (5)$$

In receiver, frequency Domain Equalizer using Minimum Mean Square Equalizer (MMSE) is performed as ISI equalization method, and from [2] the SNR of one chunk with MMSE can be written as (6), $\gamma_{n,k}$ is the SNR of subcarrier-n of user-k which already have power allocation.

$$\gamma_k^{MMSE} = \left(\frac{1}{\frac{1}{n_c}\sum_{n\in C_k}\frac{\gamma_{n,k}}{\gamma_{n.k}+1}} - 1\right)^{-1}, \gamma_{n,k} = \frac{p_{n,k}\,H_{n,k,csi}}{\sigma_n^2} \qquad (6)$$

Chunks that already have power allocation will be allocated to user based on proposed allocation algorithms and the spectral efficiency after power and chunk allocation of user-k can be expressed as :

$$eff_k^{MMSE} = log_2\left[1 + \left(\frac{1}{\frac{1}{n_c}\sum_{n\in C_k}\frac{\gamma_{n,k}}{\gamma_{n.k}+1}} - 1\right)^{-1}\right] \qquad (7)$$

The aim of chunk allocation algorithm in each TTI is to maximize the sum of spectral efficiency of users and can be expressed as :

$$Max_{(C_k)} \quad \sum_{k=1}^{K} eff_k^{MMSE} \tag{8}$$

With the constraints of allocation are subject to :

$$\sum_{n=1}^{n_c} p_{n,k} = P_k, \quad for\ k = 1,..,K \tag{9}$$

$$P_k = \min\left(P_{max}, P_o + \alpha . L_p\right), \ for\ k = 1,..,K \tag{10}$$

$$n_{c1} = n_{c2} = \cdots = n_{cK} = N/K \tag{11}$$

$$\sum_{i=1}^{K} n_{ci} = n_{c1} + n_{c2} + \cdots + n_{cK} = N \tag{12}$$

$$C_1 \cup C_2 \ \cup \ldots..\cup C_K \in C \tag{13}$$

$$\sum_{k=1}^{K} S_{kc} = 1, \ \ for\ c = 1,..,C \tag{14}$$

$$\sum_{c=1}^{C} S_{kc} = 1, \ \ for\ k = 1,..,K \tag{15}$$

$$S_{kc} \in \{0,1\} \tag{16}$$

The Optimization of resource allocation is performed by maximizing the sum of spectral efficiency users (8) with the optimization constraints are (9) to (16). Constraint (9) is used because there are multiple power constraints based on number of user and constraint (10) are considered to limit user's power transmit based on FPC. Constraint (11) is used to maintain fairness of each user's spectral efficiency. It means that the number of subcarriers in one chunk of each user is equal and the number of subcarriers in one chunk are constant in every TTI. S_{kc} are binary variables that denote whether a chunk is allocated (S_{kc} = 1) to a user or not (S_{kc} = 0). Constraints (14), (15) and (16) allows users to use only 1 unique chunk (subcarriers or chunks cannot be shared). Our proposed resource allocation algorithms are solution to solve those allocation problem in multiuser system by considering over all chunk allocation after power allocation are performed in each chunk.

III. THE PROPOSED ALGORITHM

A. Proposed Algorithm 1

In this proposed algorithm, our work in [10] is extended by using unequal power allocation in one chunk based on waterfilling power scheme in [12] and also consider fractional power control scheme in [7] as user's power constraints. This algorithm can be explained as follow :

Step 1 : Channel to noise ratio of subcarrier-n of user-k is determined using equation (1).

Step 2 : Fractional power control is performed to determine each user's power constraint using equation (5) .

Step 3 : Power allocation is performed on each subcarrier of each user considering user's power constraint based on FPC using equation (2) .

Step 4 : SNR per subcarrier of each user after power allocation ($\gamma_{n,k}$) is obtained using equation (3).

Step 5 : SNR per chunk using MMSE (γ_{ck}^{MMSE}) of each user is determined using equation (6). The equation (6) is performed for *c=1,.., C* of each *k* where *k = 1,.., K.*

Step 6 : Select a chunk which will be allocated by selecting a chunk which has the smallest average of SNR in order to maintain fairness among users. This step can be expressed as :

$$mean_c = \frac{1}{K}\sum_{k=1}^{K} \ \gamma_{ck}^{MMSE} \tag{17}$$

$$\tilde{c} = min(mean_c) \tag{18}$$

$\tilde{c}$ is a chunk to be allocated. The next step is to find a user who will get a chunk $\tilde{c}$.

Step 7 : Choose a user who has the largest SNR in chunk $\tilde{c}$ (from step 6) and can be expressed :

$$\tilde{k} = \max(\ \gamma_{\tilde{c}k}^{MMSE}) \tag{19}$$

So chunk $\tilde{c}$ is allocated to user $\tilde{k}$.

Step 8 : Determine the spectral efficiency is achieved by user $\tilde{k}$ who get chunk $\tilde{c}$ using equation (7).

Step 9 : The chunk that already allocated and the user who already get a chunk are removed from the process and repeat step 6 through step 9 until all chunks are allocated and all users are got the chunk.

B. Proposed Algorithm 2

In this proposed algorithm, we design new chunk algorithm and apply unequal power allocation in one chunk based on waterfilling power scheme in [12] and also consider fractional power control scheme in [7] as user's power constraints. We choose allocation based on user or chunk in such a way to obtain the biggest spectral efficiency after power allocation are performed. The complete algorithm is explained as follow :

Step 1 : Channel to noise ratio of subcarrier-n of user-k is determined using equation (1).

Step 2 : Fractional power control is performed to determine each user's power constraint using equation (5) .

Step 3 : Power allocation is performed on each subcarrier of each user considering user's power constraint based on FPC using equation (2) .

Step 4 : SNR per subcarrier of each user after power allocation ($\gamma_{n,k}$) is obtained using equation (3).

Step 5 : SNR per chunk using MMSE (γ_{ck}^{MMSE}) of each user is determined using equation (6). The equation (6) is performed for *c=1,.., C* of each *k* where *k = 1,.., K.*

Step 6 : Find a user and a corresponding chunk that will give the smallest γ_{ck}^{MMSE} in order to maintain fairness among users and can be expressed as follow :

$$\left[\tilde{c}, \tilde{k}\right] = arg\ min\, \gamma_{ck}^{MMSE} \tag{20}$$

Step 7 : Find a chunk that will give the biggest (γ_{ck}^{MMSE}) which corresponding to user $\tilde{k}$.

$$\dot{c} = arg\, max(\ \gamma_{c\tilde{k}}^{MMSE}) \qquad (21)$$

Step 8 : Find a user that will give biggest (γ_{ck}^{MMSE}) which corresponding to chunk $\tilde{c}$.

$$\dot{k} = arg\, max(\ \gamma_{\tilde{c},k}^{MMSE}) \qquad (22)$$

Step 9 : **C**ompare between $\gamma_{\dot{c},\tilde{k}}^{MMSE}$ and $\gamma_{\tilde{c},\dot{k}}^{MMSE}$ and choose the maximum value between them.

$$[\overline{c}, \overline{k}] = max[\ \gamma_{\dot{c},\tilde{k}}^{MMSE}, \ \gamma_{\tilde{c},\dot{k}}^{MMSE}] \qquad (23)$$

It means that user $\overline{k}$ will get chunk $\overline{c}$.

Step 10: Calculate the spectral efficiency is achieved by user $\overline{k}$ who get chunk $\overline{c}$ using equation (7).

Step 11 : The chunk that already allocated and the user who already get a chunk are removed from the process and repeat step 6 through step 11 until all chunks are allocated and all users are got the chunk.

IV. RESULTS AND DISCUSSIONS

In this section, we present and compare the performances of our proposed algorithms with the previous algorithms by considering the fractional power control as user's power constraint in previous works [8-10]. We consider the sum of the spectral efficiency users and fairness index among users as parameter performances to be evaluated based on equation (7) and jain's fairness index [13] :

$$FI_{jain} = \frac{[\sum_{k \in K} eff_k]^2}{K\ x\ \sum_{k \in K} eff_k^2} \qquad (24)$$

TABLE I. SIMULATION PARAMETERS

Parameters	**Setting**
Frequency	2 Ghz
Type of system	Macrocell
Number of available subcarriers	1024
Bandwidth per subcarrier	15 Khz
Number of users	4,8,16,32
Distribution of users	Uniform
Number of subcarriers per chunk	128, 64, 32, 16
Radius of Cell in km	1 ;1.5 ;2 ;2.5
Channel gain model	Urban, suburban
Chunk specific constant (P_o) for 12 subcarriers	-57 dBm/hz
Pathloss compensation in FPC (α)	0.6
Noise spectral density	-174 dBm/hz
Number of CSI	100 TTI
Number of simulation repetitions	50 times

The allocation process is performed in every TTI, so we calculate the overall sum of spectral efficiency users and fairness index among users by averaging over 100 TTI. The simulation is also repeated over 50 times. The channel gain of each subcarrier per user as CSI ($H_{n,k,csi}$) in each TTI are determined based on the macrocell model for urban and suburban area used in [2][4][5]:

$$H_{n,k,csi}[dB] = 10 log R_{n,k} - L_p - 10\delta\ log d_k - \varepsilon_{n,k} \quad (25)$$

Where L_p is the propagation loss chosen to be 128.1 dB, d_k is user-k distance from base stasion in kilometers, δ is pathloss exponent set to 3.76, $\varepsilon_{n,k}$ is lognormal shadowing with 2 dB as standard deviation and $R_{n,k}$ is the rayleigh fading with rayleigh parameter τ such that $E[\tau^2]=1$. The simulation parameters we used to evaluate our proposed algorithms are shown in table I.

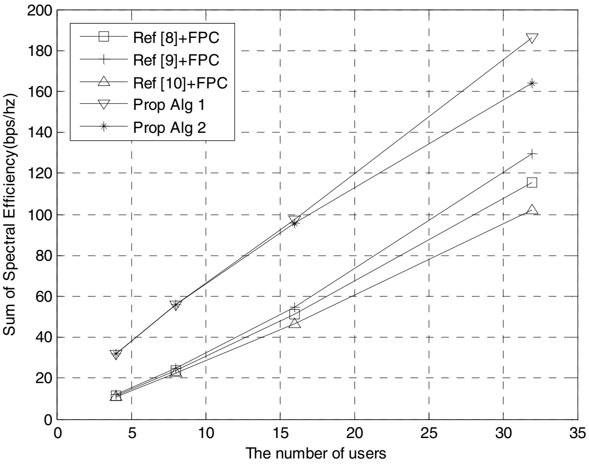

Figure 1. Sum of spectral efficiency users with the number of subcarriers are 1024, user distribution is uniform and radius of cell is 2 kilometers

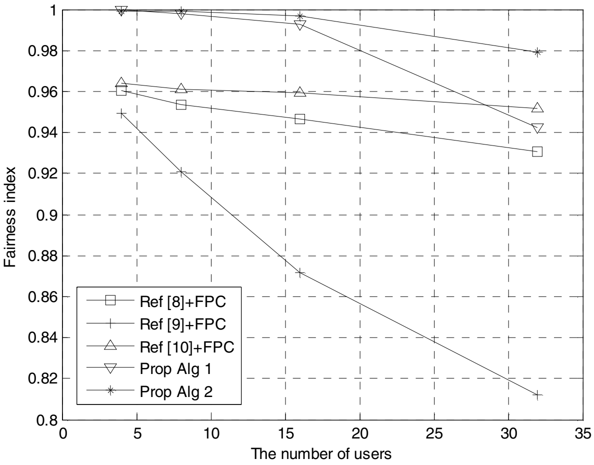

Figure 2. Fairness index among users with the number of subcarriers are 1024, user distribution is uniform and radius of cell is 2 kilometers

In figure 1 is shown that the proposed algorithms can improve the sum of spectral efficiency users over the previous work with FPC scheme at the number of user is 16 and 32. In figure 2 is shown that the proposed algorithms can improve fairness index over previous work with FPC scheme except in algorithm 1 at the number of user is 32. In figure 3 and 4 are shown that the proposed algorithms can outperform the previous work with FPC scheme and also shown that the proposed algorithm 1 has higher sum of spectral efficiency users achievement than algorithm 2 and the proposed algorithm 2 has higher fairness index achievement than the proposed algorithm 1.

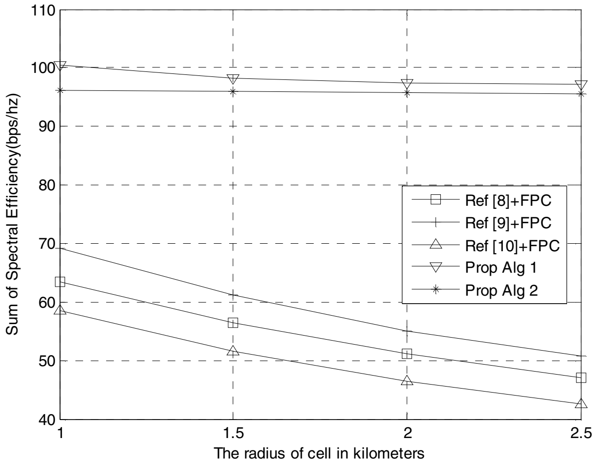

Figure 3. Sum of spectral efficiency user with the number of subcarrier is 1024, the number of user is 16 and user distribution is uniform.

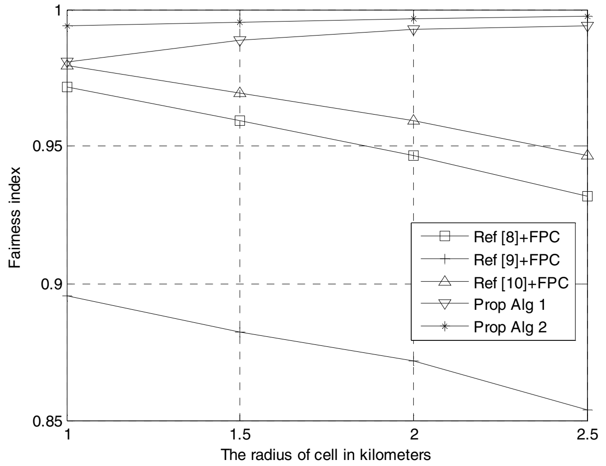

Figure 4. Fairness Index among user with the number of subcarrier is 1024, the number of user is 16 and user distribution is uniform.

The proposed algorithms can improve sum of spectral efficiency because of performing unequal power allocation in one chunk by allocating different subcarrier power's based on channel gain of each subcarrier and its difference with those of previous algorithms where subcarrier's power in one chunk are equal. In the proposed algorithm 1, resource allocator choose a chunk first which has the smallest user's average of SNR, and assign it to a user who has the biggest SNR on that chunk. So, it can achieves fairness improvement over previous algorithms. In the proposed algorithm 2, resource allocator choose a pair of user and corresponding chunk which has the smallest SNR, and find a user-chunk which has the biggest SNR by searching the biggest chunk on that user and searching the biggest user on that chunk. The final allocation is performed by selecting the biggest among them and it can also achieves fairness improvement over the previous algorithms.

In this work, we put in fractional power control to limit user's power on our optimization constraints which are not done in previous algorithms. So, it can be proved that our proposed algorithms can improve the performances in other condition which are not discussed in previous algorithms.

V. CONCLUSIONS

Two resource allocation algorithms by combining chunk allocation and unequal power allocation with fractional power control scheme as user's power constraint for multiuser OFDMA uplink are proposed and investigated. These proposed algorithms offer performance improvement over the previous works in [8-10] with fractional power control scheme as power constraints to limit user's power transmit.

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