TELKOMNIKA, Vol.14, No.2, June 2016, pp. 574~587
ISSN: 1693-6930, accredited **A** by DIKTI, Decree No: 58/DIKTI/Kep/2013
DOI: 10.12928/TELKOMNIKA.v14i1.3299

A Combined User-order and Chunk-order Algorithm to Minimize the Average BER for Chunk Allocation in SC-FDMA Systems

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Abstract

A Chunk by chunk-based allocation is an emerging subcarrier allocation in Single Carrier Frequency Division Multiple Access (SC-FDMA) due to its low complexity. In this paper, a combined user-order and chunk-order allocation for solving chunk allocation problem which minimizes the average BER of all users while improving the throughput in SC-FDMA uplink is proposed. The subcarrier grouping into a chunk of all users on both-order allocations are performed by averaging the BER of a contiguous subcarriers within a chunk. The sequence of allocation is according to the average of users' BER on user-order allocation and the average of chunks' BER on chunk-order allocation. The best allocation is determined by choosing one of both-order allocations which provides the smaller BER systems. The simulation results showed that the proposed algorithm can outperform the previous algorithms in term of average BER and throughput without increase the time complexity.

Keywords: *Combined, BER, allocation, SC-FDMA, uplink*

1. Introduction

SC-FDMA (Single Carrier Frequency Division Multiple Access) is an uplink technique used for 4G Long Term Evolution (LTE) wireless systems [1-2]. It is designed in uplink regarding to multicarrier technique for multiuser transmission using OFDM (Orthogonal Frequency Division Multiple)-based technique. SC-FDMA performs precoded-DFT (Discrete Fourier Transform) to decrease the PAPR (Peak to Average Power Ratio) which is an advantage due to power constraint on users' terminal [1-2].

In wireless channel, all users experience the time and frequency varying fading due to their mobility and the change of propagation environment. Multiuser diversity is an impact of uncorrelated fading channels among users at an instantaneous time [3-4]. By exploiting the instantaneous fading condition among users, base station may schedule the radio resources to all users independently to improve the overall quality of services [3-4]. As an attractive of uplink transmission method, the resource allocator of LTE system is deployed by dynamically scheduling different subcarriers to different users at each time transmission interval (TTI) where in its TTI could be modeled as an optimization problem to achieve the quality of service with a lot of constraints [3-4].

In [3-8], the downlink greedy-based resource allocations of OFDMA are deployed. The linearly complexity of optimum power and subcarrier allocations is investigated in [5] for maximazing the capacity. In order to reduce the complexity, chunk-based for subcarrier allocations in [3-4], [6-8] are deployed by scheduling the different of a contiguous subcarriers to each user. In [7], chunks are allocated to all users based on their Signal to Noise Ratio (SNR) within each chunk, where in [3-4], [6, 8] BER constraint within each chunk are considered in allocation. In [5], power allocation is performed to each allocated chunks using lagrangian method. While in [3-4], [6-8], these are performed using equal power allocation.

On the uplink, there are power and subcarrier adjacency constraints of each user on allocation[9]. In [10-13], subcarrier and power allocations are proposed by maximazing the

Received December 20, 2015; Revised April 25, 2016; Accepted May 8, 2016

efficiency of spectral [10-11], fairness [12] and utility [13]. They have optimum performance despite having the high complexity. To reduce the complexity, the subcarrier allocation using equal power allocation is proposed in [9], [14-22]. In [9, 17], subcarrier allocations are developed on subcarrier by subcarrier based while in [14-16], [18-22] are developed on chunk by chunk based which could impact the decrease of complexity. In [9,14], [16-17], [19-21], the spectral efficiency are maximized while in [15, 18], data rate fairness are maximized. In [20], chunk by chunk based using waterfilling power allocation are developed while fractional power control is implemented for limiting the user’s transmit power. It could reaches the significantly improved of spectral efficiency and fairness as well but it increases the time complexity. Chunk-based allocation in [22] can balances among spectral efficiency and fairness by introducing the weighting factor between them. For solving chunk allocation problem, the allocation in [9-17], [20-21] are performed using greedy-based while in [18-19], [22] are deployed based on mean-greedy algorithms. Considering the time complexity, solving the chunk allocation problem based on mean greedy algorithm is preferable than conventional greedy-based algorithm due to the lower of its time complexity. Hence, designing an allocation scheme based on mean greedy algorithm is our focus in this work.

The mean-greedy based algorithms in [18-19], [22] are the attractive chunk-based allocation since the allocator search the optimum user-chunk pairs using the average of certain quality of service. The mean greedy (MEG) [18], single mean greedy(SMEG) [18] and multi-criteria ranking based greedy (MCRG) [19] algorithms perform a user-order allocation regarding to the mean of users’ utility performance. The subcarriers grouping into a chunk are obtained based on their SNR and chunks are allocated to users regarding to their average of spectral efficiency achieved. Comparing to MEG algorithm, SMEG algorithm uses a single average calculation which calculate it on every allocation. In MCRG algorithm, users are sorted regarding to a lot of criteria such as mean, standard deviation and an utility threshold based on the concordance value of the promethee method [19].

In [22], the allocation is performed considering user-order and chunk-order allocations where both order perform chunk grouping based on their SNR. Then the allocation on each order is obtained based on the sequence of users’ spectral efficiency average and chunks’ spectral efficiency average, respectively. The best allocation is determined based on their score which according to the weighting factor of decision criteria.

In this paper, chunk allocation algorithm based on a combined user-order and chunk-order using the BER consideration is proposed. The objective of this scheme is to minimize the average BER of all users. We denote it as BER system which are not considered in [18-19], [22]. Due to adjacency subcarrier restriction on the uplink, subcarriers grouping into a chunk is performed according to L-FDMA (Localized Frequency Divisio Multiple Access) rule using the average BER of subcarriers within a chunk. The sequence of allocation is according to the average of users’ BER and chunks’ BER on user-order and chunk-order allocation, respectively. The final allocation is determined by selecting one of both order which reaches the smaller BER system. Regarding to the given chunk allocation result, the spectral efficiency on each chunk is obtained by finding the highest spectral efficiency on all subcarriers within a chunk. Consequently, the proposed algorithm can minimizes the BER system while keeps the throughput maximization without increases the time complexity.

2. Model and Formulation of Research

The SC-FDMA model system used in this work is same with in [22] which is shown in Figure 1. In this system, there are N available subcarriers and K active users within a cell. The channel state information (CSI) which consists the uplink channel gain of all K users on all N subcarriers are sent by all users through the uplink signalling transmisson. It is sent periodically at the beginning of the time transmission interval without error condition. All subcarriers are grouped into a chunk by collecting a contiguous subcarriers. It is denoted that number of available chunks is C. The base station handles the subcarrier grouping according to L-FDMA rule and allocates them to the suitable users based on the chunk allocation scheme. The chunk allocated for all users are sent to all users periodically in every TTI through the downlink signalling transmission without error condition. They are used by all users to transmit traffic information in the uplink transmission. In this work, we propose on developing chunk allocation problem by shaping n_c contiguous subcarriers of all users into a chunk and allocate them to the suitable users using BER-based consideration.

The channel state information of user-k on subcarrier-n is modeled as the channel gain of user-k on subcarrier-n and it is expressed by [14-15], [22] :

$$H_{n,k}[dB] = 10\log R_{n,k} - L_p - 10\delta \log d_k - \varepsilon_{n,k} \tag{1}$$

Where L_p is propagation loss; d_k is the distance of user-k from the base station in kilometers; δ is pathloss exponent; $\varepsilon_{n,k}$ is the lognormal shadowing deviation; $R_{n,k}$ is the rayleigh fading. Signal to noise ratio of user-k on subcarrier-n ($SNR_{n,k}$) can be expressed as [14-15], [22]:

$$SNR_{n,k} = \frac{p_{n,k} H_{n,k}}{\sigma_n} = p_{n,k} CNR_{n,k} \tag{2}$$

Where $p_{n,k}$ is power allocated of user-k on subcarrier-n ; σ_n is the noise power; $CNR_{n,k}$ is the channel to noise power ratio of user-k on subcarrier-n. Since power allocated to each subcarrier within a chunk is equal, it means that $p_{n,k} = P_k/n_c$ and P_k is the transmit power of user-k. The BER of user-k on subcarrier-n can be approximated as follow [3-4], [6-8]:

$$BER_{n,k} = 0.2\exp\left(-\frac{1.6 SNR_{n,k}}{M_{n,k} - 1}\right) \tag{3}$$

Where $M_{n,k}=2^r$. $M_{n,k}$ is the modulation level of user-k on subcarrier-n and $M_{n,k}$ is M-ary QAM with the number of bits per symbol $r \geq 2$ with BER is less than 10^{-3}. The achievable of data rate of user-k on subcarrier-n has the upper bound as [14]:

$$R_{n,k} = b_s \log_2\left[1 + SNR_{n,k}\right] \tag{4}$$

Where b_s is bandwidth per subcarrier. It is denoted the SNR gap (Γ). It is the difference between the SNR needed to reach a certain data rate in a practical system and the theoretical threshold as [23]:

$$\Gamma = \frac{-\ln(5BER)}{1.5} \tag{5}$$

Considering the SNR gap, the achievable of data rate if subcarrier-n is allocated to user-k may yields [24]:

$$R_{n,k} = b_s \log_2\left[1 + \frac{SNR_{n,k}}{\Gamma}\right] \tag{6}$$

We denote the spectral efficiency if subcarrier-n is allocated to user-k as:

$$r_{n,k} = \frac{R_{n,k}}{b_s} = \log_2\left[1 + \frac{SNR_{n,k}}{\Gamma}\right] \tag{7}$$

In [3-4], [6-8], BER-based chunks forming of all users are provided where equation (3) is used to find n_c such that $BER_{c,k}$ is less than the BER requirement. n_c is a number of subcarrier within a chunk and $BER_{c,k}$ is bit error rate of user-k on chunk-c. In those works, (3) is used to form a chunk without considering the subcarriers contiguity since its restriction is not necessary in the downlink [2, 9].

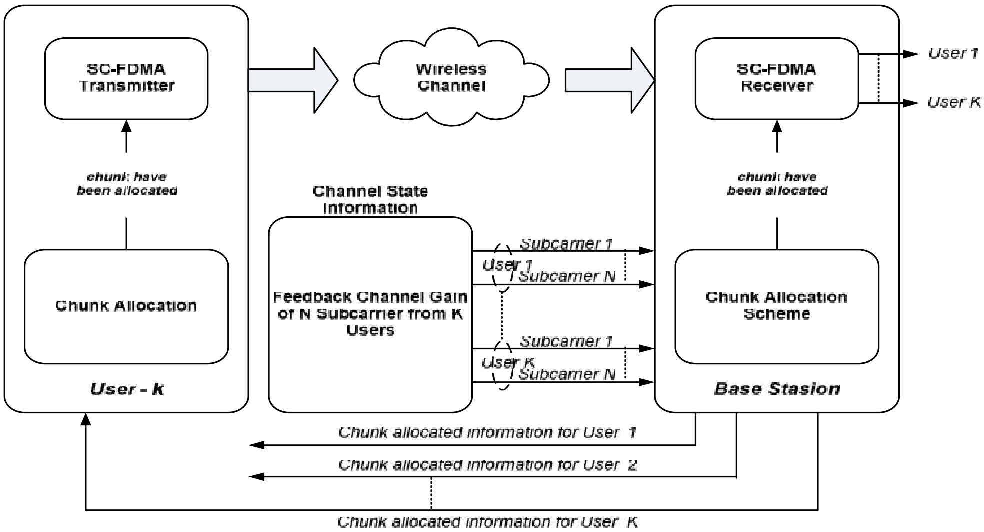

Figure 1. Uplink SC-FDMA Systems

In this work, n_c contiguous subcarriers of all users are grouped into a chunk based on the L-FDMA (Localized-Frequency Division Multiple Access) rule to exploit the multiuser diversity [2, 9, 22]. There is a subcarrier contiguity restriction in the uplink[9]. In this paper, another point of view in using (3) is reformulated. According to the given n_c, the average BER of all n_c contiguous subcarriers are obtained using (3). BER-based subcarriers grouping is performed by averaging the BER of all n_c contiguous subcarriers to meet the L-FDMA rule as:

$$\begin{aligned} BER_{c,k} &= \underset{n=(c-1)n_c+1,\dots,c.n_c}{mean}\left(BER_{n,k}\right),\ c=1:C,\ \forall k\in K \\ &= \frac{1}{n_c}\sum_{n=(c-1)n_c+1}^{n=c.n_c} BER_{n,k},\ c=1:C,\ \forall k\in K \\ &= \frac{1}{n_c}\sum_{n=(c-1)n_c+1}^{n=c.n_c} 0.2\exp\left(-\frac{1.6SNR_{n,k}}{M_{n,k}-1}\right),\ c=1:C,\ \forall k\in K \end{aligned} \tag{8}$$

In order to maintain fairness between users, a chunk is allocated to a user and could not be used by other users. It indicates that bit error rate of user-*k* is given by:

$$\begin{aligned} &BER_k = \frac{1}{C_k}\sum_{c=1}^{C} S_{c,k} BER_{c,k},\ \forall k\in K \\ &subject\ to\ :\sum_{c=1}^{C} S_{c,k}=1 \end{aligned} \tag{9}$$

Where BER_k is the bit error rate of user-*k*, $S_{c,k}$ is the chunk assignment index denoting which chunk-*c* is allocated to user-*k*. If the chunk-*c* is allocated to user-*k*, $S_{c,k}$=1, otherwise $S_{c,k}$=0. It is denoted that C_k is a number of chunk allocated to the user *k*. Since C_k=1 [22], from (9) one obtains:

$$\begin{aligned} &BER_k = \sum_{c=1}^{C} S_{c,k} BER_{c,k},\ \forall k\in K \\ &subject\ to\ :\sum_{c=1}^{C} S_{c,k}=1 \end{aligned} \tag{10}$$

The BER system is found by averaging the BER of all users and it is given by:

$$\begin{aligned} BER_T &= \underset{k=1,\dots K}{mean}\left(BER_k\right) \\ &= \frac{1}{K}\sum_{k=1}^{K} BER_k \\ &= \frac{1}{K}\sum_{k=1}^{K}\sum_{c=1}^{C} S_{c,k} BER_{c,k}, \forall k \in K \\ subject\ to\ &: \sum_{c=1}^{C} S_{c,k} = 1 \end{aligned} \tag{11}$$

In order to keep a high sum of data rate of all users, the spectral efficiency of each user-chunk pair should be maximized. To maximize each user-chunk pair, the spectral efficiency of user-*k* on chunk-*c* is obtained by finding the highest spectral efficiency on all subcarriers within a chunk. It can be expressed as:

$$r_{c,k} = \max_{n=(c-1)n_c+1,\dots,c.n_c} \left\{r_{n,k}\right\},\ c = 1:C\ , \forall k \in K \tag{12}$$

Where $r_{n,k}$ is spectral efficiency of user-*k* on subcarrier-*n*. The achievable of the spectral efficiency of user-*k* has the upperbound as follow:

$$\begin{aligned} r_k &= \sum_{c=1}^{C} S_{c,k} r_{c,k} \\ subject\ to &: \sum_{c=1}^{C} S_{c,k} = 1 \end{aligned} \tag{13}$$

where $S_{c,k}$ is chunk assignment index. The spectral efficiency of system (throughput system) can be obtained by adding (13) over all *K* users:

$$\begin{aligned} r_T &= \sum_{k=1}^{K} r_k \\ &= \sum_{k=1}^{K}\sum_{c=1}^{C} S_{c,k} r_{c,k} \\ subject\ to &: \sum_{c=1}^{C} S_{c,k} = 1 \end{aligned} \tag{14}$$

Jain's fairness index is used to determine the fairness among users as follow [22, 25]:

$$F = \frac{\left(\sum_{k=1}^{K} r_k\right)^2}{K\sum_{k\in K} r_k^{\ 2}} \tag{15}$$

The problem of chunk allocation become the determining the elements of matrix $\boldsymbol{S_{c,k}}$ which mean the chunk assignment index. It denotes which chunk should be allocated to which user so that the BER of systems is minimized. The optimization of chunk allocation could be written as:

$$\begin{aligned} &\text{Objective :} \\ &Min : BER_T = \frac{1}{K}\sum_{k=1}^{K}\sum_{c=1}^{C} S_{c,k} BER_{c,k} \\ &subject\ to\ : \\ &C1\ :\ \sum_{c=1}^{C} S_{c,k} = 1 \\ &C2\ :\ \sum_{k=1}^{K} S_{c,k} = 1 \\ &C3\ :\ S_{c,k} \in \{0,1\} \\ &C4 :\ p_{n,k} = \frac{P_k}{n_c} \\ &C5 : r_{c,k} = \max_{n=(c-1)n_c+1,\dots,c.n_c} \left\{r_{n,k}\right\} \end{aligned} \tag{16}$$

Constraints (C4) and (C5) are done for *c=1:C* and *k=1:K*. Constraint (C1) to (C3) are used to ensure that each user in the systems only has a chunk and could not be allocated by other users. Constraint (C4) implements equal power allocation to each subcarrier within a chunk while constraint (C5) keep the high throughput in the system.

In this paper, a proposed allocation is proposed to fix the allocation problem in (16) with some constraints of optimization.

3. The Proposed Allocation

Based on Equation (3), the BER of user-*k* on subcarrier-*n* could be denoted as a matrix of size *N x K*:

$$\mathrm{BER}_N = \begin{bmatrix} BER_{1,1} & BER_{1,2} & .... & .... & BER_{1,K} \\ BER_{2,1} & BER_{2,2} & .... & .... & BER_{2,K} \\ .... & .... & .... & .... & .... \\ .... & .... & .... & .... & .... \\ BER_{N,1} & BER_{N,2} & .... & .... & BER_{N,K} \end{bmatrix} \tag{17}$$

The subcarriers grouping is performed according to (8) by averaging the BER of n_c contiguous subcarriers within a chunk. The BER of the user-*k* on chunk-*c* could be seen as a matrix of size *C x K*:

$$\mathrm{BER}_C = \begin{bmatrix} BER_{1,1} & BER_{1,2} & .... & .... & BER_{1,K} \\ BER_{2,1} & BER_{2,2} & .... & .... & BER_{2,K} \\ .... & .... & .... & .... & .... \\ .... & .... & .... & .... & .... \\ BER_{C,1} & BER_{C,2} & .... & .... & BER_{C,K} \end{bmatrix} \tag{18}$$

The idea of this paper is to search the user-chunk pairs using combined-order allocation with BER average consideration when determining the allocation sequence on both allocation orders. The first use of combined-order allocation is introduced in [22] by using promethee method to determine the allocation sequence on each order according to the spectral efficiency achieved by all possible user-chunk pairs. In this work, the promethee method is also used to determine the allocation sequence on each order based on the bit error rate achieved by all possible user-chunk pairs. On this method, a number of alternatives which have a number of criteria decision are compared with each other according the deviation and weighting factor among each criteria. In general, the aggregated preference indices of two alternatives can be expressed as follow [22], [26-27]:

$$\text{®}(a,b) = \sum_{j=1}^{J} w_j \left(F_j\left[g_j(a) \right] - F_j\left[g_j(b) \right] \right), \forall a \neq b, a, b \in A \tag{19}$$

π(a,b) is denoting the degree *a* is preferred to *b* over all *J* criterias. w_j is a weighting factor of criteria-*j*. *π(a,b)* provides the preference of *a* over *b* for observed deviations between their evaluation function $F_j(.)$ on criteria $g_j(.)$. In [22], the aggregated preference indices has been used to compare the alternatives with each other in term of spectral efficiency function. While in this work, it is used to compare the alternatives with each other in term of bit error rate.

In order to rank the alternatives on both orders allocation, the negative outrangking flow of the promethee method is also used by facing an alternative to the other alternatives as follow [22], [26-27]:

$$\text{¤}^-(a) = \frac{1}{A-1} \sum_{b=1, b \neq a}^{A} \text{®}(b,a), \; for \; a = 1 : A \tag{20}$$

Where *$\phi^{-}(a)$* is the negative outranking flow of an alternative-*a* and *A* is a number of alternative. It expresses an alternative-*a* is outranked by the other alternatives. An alternative which has the highest ϕ has the best choice and is given by [22]:

$$n = \arg \ \max \left\{ \phi(n) \right\}_{n=1,2,\dots,A} \tag{21}$$

In this paper, the bit error rate is used as an evaluation function to perform the pairwise comparison among alternatives on both allocation orders. On each order, the negative outrangking flow of the promethee method in [22], [26-27] are also used to obtain the allocation sequence according to the bit error rate. The utilization of promethee method on the combined-order allocation with BER consideration are derived in the next section.

3.1. User-order Allocation using BER-based

Based on $\boldsymbol{BER_C}$ of (16), each column has a *C* number of BER from all chunks. It means that each user has a *C* number of criteria comparison. The goal is to obtain the allocation sequence of users by comparing their BER on each chunk. The BER of user-*k* on chunk-*c* is denoted by $BER_{c,k}$ which means that $F_j[(g_j(a)]=BER_{c,k}$. Since $a=1:K$ and $j=1:C$, the aggregated preference indices of (19) becomes:

$$\pi(k,k') = \sum_{c=1}^{C} w_c \left[BER_{c,k} - BER_{c,k'} \right], k \neq k' \ and \ k,k' \forall K \tag{22}$$

$\pi(k,k')$ is denoting the degree user *k* is preferred to user *k'*. w_c is weighting factor of the BER on chunk-*c* expressing the priority of BER on chunk-*c*. Since the priority of BER on all chunks are same, the weighting factor are also the same. It can be stated as [22]:

$$w_c = \frac{1}{C} \ and \ \sum_{c=1}^{C} w_c = 1 \tag{23}$$

Using (23) , from (22) one obtains:

$$\begin{aligned} \pi(k,k') &= \frac{1}{C}\sum_{c=1}^{C} \left[BER_{c,k} - BER_{c,k'} \right], k \neq k' \ and \ k,k' \forall K \\ &= \frac{1}{C}\sum_{c=1}^{C} BER_{c,k} - \frac{1}{C}\sum_{c=1}^{C} BER_{c,k'} \\ &= \overline{BER_k} - \overline{BER_{k'}} \end{aligned} \tag{24}$$

Where $\overline{BER_k}$ and $\overline{BER_{k'}}$ are the bit error rate average over *C* chunks on user-*k* and user-*k'*, respectively. Based on (24), the pairwise comparison among *K* users is depend on their BER average from *C* chunks.

To rank all *K* users, the negative outrangking flow of each user is performed based on the pairwise comparison to the other users. Each *BER* of user is facing to other *(K-1)* BER. Since *A*=*K*, the negative outrangking flow of a user-*k* of (20) becomes:

$$\begin{aligned} \phi^{-}(k) &= \frac{1}{K-1} \sum_{x=1, x\neq k}^{K} \pi(x,k), \ for \ \mathrm{k} = 1:K \\ &= \frac{1}{K-1} \sum_{x=1, x\neq k}^{K} \overline{BER_x} - \overline{BER_k}, \ for \ \mathrm{k} = 1:K \end{aligned} \tag{25}$$

It denotes a user-*k* is outranked by all other users. All *K* users are sorted according to their *$\phi^{-}(k)$* in term of descending order. A user who has the highest *$\phi^{-}(k)$* is choosed to obtain a chunk using (21) as [22]:

$$\hat{k} = \arg \ \max \left\{ \phi(k) \right\}_{k=1,2,\dots,K} \tag{26}$$

Index $\hat{k}$ is a user who has the highest ϕ. Choosing the highest $\phi^{-}(k)$ means that a user who has the smallest average of BER is choosed to obtain a chunk since it can achieve the minimum of BER system.

Futhermore, a chunk allocated to user-$\hat{k}$ is obtained by finding a chunk which provides the smallest BER on user-$\hat{k}$ to achieve the minimum of BER system. It is given by:

$$\hat{c} = \arg \min_{c=1,2,\ldots,C} \left\{ BER_{c,\hat{k}} \right\} \quad (27)$$

Index $\hat{c}$ is a chunk which has the smallest BER on user-$\hat{k}$.

3.2. Chunk-order Allocation using BER-based

In (18), each row has a K number of BER from all users. It means that each chunk has a K number of criteria comparison. The goal is to obtain the allocation sequence of chunks by comparing their BER on each user. The BER of chunk-c on user-k is denoted by $BER_{k,c}$ which means that $F_j[(g_j(a)]=BER_{k,c}$. The aggregated preference indices of (19) becomes:

$$\pi(c,c') = \sum_{k=1}^{K} w_k \left[BER_{k,c} - BER_{k,c'} \right], c \neq c' \ and \ c,c' \forall C \quad (28)$$

$\pi(c,c')$ is denoting the degree chunk-c is preferred to chunk-c'. w_k is weighting factor of the BER on user-k. Since the priority of BER on all users are same, the weighting factor are also the same. It could be written as [22]:

$$w_k = \frac{1}{K} \ and \ \sum_{k=1}^{K} w_k = 1 \quad (29)$$

Using (29), from (28) one obtains:

$$\begin{aligned} \pi(c,c') &= \frac{1}{K}\sum_{k=1}^{K}\left[BER_{k,c} - BER_{k,c'} \right], c \neq c' \ and \ c,c' \forall C \\ &= \frac{1}{K}\sum_{k=1}^{K} BER_{k,c} - \frac{1}{C}\sum_{c=1}^{C} BER_{k,c'} \\ &= \overline{BER_c} - \overline{BER_{c'}} \end{aligned} \quad (30)$$

Where $\overline{BER_c}$ and $\overline{BER_{c'}}$ are the bit error rate average over K users on chunk-c and chunk-c' which mean that the pairwise comparison among C chunks depend on their BER average from K users.

Each BER of chunk is facing to other $(C-1)$ BER. Since A=C, the negative outrangking flow of a chunk-c of (20) becomes:

$$\begin{aligned} \phi^{-}(c) &= \frac{1}{C-1}\sum_{x=1,x\neq c}^{C} \pi(x,c), \ for \ \mathrm{c}=1:C \\ &= \frac{1}{C-1}\sum_{x=1,x\neq c}^{C} \overline{BER_x} - \overline{BER_c}, \ for \ \mathrm{c}=1:C \end{aligned} \quad (31)$$

It denotes a chunk-c is outranked by all other chunks. All C chunks are sorted according to their $\phi^{-}(c)$ in term of descending order. A chunk which has the highest $\phi^{-}(c)$ is allocated to a user using (21) as:

$$\tilde{c} = \arg \max \left\{ \phi^{-}(c) \right\}_{c=1,2,\ldots,C} \quad (32)$$

Index $\tilde{c}$ is a chunk which has the highest ϕ. Choosing the highest $\phi^{-}(c)$ means that a chunk which has the lowest average of BER is allocated to a user.

Futhermore, a user who obtains a chunk-$\tilde{c}$ is determined by searching a user which provides the smallest BER on chunk-$\tilde{c}$ as follow:

$$\tilde{k} = \arg \min_{k=1,2,\ldots,K} \left\{ BER_{\tilde{c},k} \right\} \tag{33}$$

Index $\tilde{k}$ is a user which has the smallest BER on chunk-$\tilde{c}$.

3.3. A Combined-order using BER-based Algorithm

The combined allocation performs user-based allocation and chunk-based allocation at the same time. The result of each allocation has a chunk assignment index $S_{c,k}$ with the objective is BER system minimization according to optimization problem in (14). The final allocation is obtain by determining one of both allocations which raises the smaller BER system. The combined algorithm are as follow:

Initialization:

Step 1 : Calculate BER and spectral efficiency achieved by all users on all subcarrier using (3) and (7), respectively.
Step 2 : Perform BER-based subcarriers grouping and determine the spectral efficiency of all users on all chunks using (8) and (12), respectively.

User-order allocation using BER-based :

Step 1 : Find the average BER of all users using:

$$BER_k = \frac{1}{C}\sum_{c=1}^{C} BER_{c,k},\ k \in K$$

Step 2 : Perform the aggregated preference indices of each user to other users using (24).
Step 3 : Determine the negative outrangking flow of all users using (25).
Step 4 : Find a user who obtains a chunk using (26).
Step 5 : Find a chunk which allocated to a user using (27).
Step 6 : A user on step 4 obtains a chunk on step 5 and update chunk assignment index ($S_{c,k,uo}$).
Step 7 : Calculate the BER achieved by its pair using (10).
Step 8 : Remove a user on step 4 and a chunk on step 5 from process and repeat step 4 to 7 until all users have obtained the chunks.
Step 9 : Calculate the BER system using (11).

Chunk-order allocation using BER-based:

Step 1 : Find the average BER of all chunks using:

$$BER_c = \frac{1}{K}\sum_{k=1}^{K} BER_{c,k},\ \mathrm{c} \in C$$

Step 2 : Perform the aggregated preference indices of each chunk to other chunks using (30).
Step 3 : Determine the negative outrangking flow of all chunks using (31).
Step 4 : Find a chunk which is allocated to a user using (32).
Step 5 : Find a user who obtains a chunk using (33).
Step 6 : A user on step 5 obtains a chunk on step 4 and update chunk assignment index ($S_{c,k,co}$).
Step 7 : Calculate the BER achieved by its pair using (10).
Step 8 : Remove a user on step 4 and a chunk on step 5 from process and repeat step 4 to 7 until all chunks are allocated.

Step 9 : Calculate the BER system using (11).

Final decision:

Step 1 : Compare the resulting BER system of both allocations and select a smaller.
Step 2 : Select a chunk assignment index which produces a smaller BER system based on step 1.
Step 3 : Calculate the sum of spectral efficiency and the fairness index based on chunk assignment index in step 2 using (14) and (15), respectively.

The complexity based on asymtotic approach is applied to quantify the proposed allocation due to the limitation of time duration within a time transmission interval. In initialization process, calculating the BER and The efficiency of spectral reached by all users on all chunks (step 1) need *O(KN)* operations. Then, on subcarriers grouping and calculating the BER and spectral efficiency of all users on all chunks (step 2) need *O(KN)* operations. The time complexity of initialization process needs *O(KN)*.

In proposed allocation has the similar step with the previous work in [22] and it is different in term of Qos considered. Thus, the complexity of combined-order allocation using BER-based is *O(KC)*. In final decision process, It consist of comparing the resulting BER system by both allocation orders and select a chunk assignment index which produces a smaller BER as well as calculate its performances. Hence, this step can be avoided since there is no iteration. Thus, the time complexity of combined-order using BER-based is *O(KC)*.

In MEG [18], SMEG [18], iterative swapping chunk [16] and combined-order[22] algorithms also perform the subcarrier allocation in term of chunk. They perform subcarriers grouping before allocation process which have the similar process with our proposed algorithm in initialization process. Thus, we only compare the time complexity in main allocation algorithm.

In MEG, SMEG and iterative swapping chunk algorithms have the time complexity as $O(KC^2)$ [18], *O(KC)* [18] and *O(KClogC)* [16], respectively. The comparison of the combined order allocation using BER-based with some previous works is presented on Table 1.

Table 1. The complexity comparison

Algorithms	Time Complexity
Mean Enhanced Greedy[18]	$O(KC^2)$
Single Mean Enhanced Greedy[18]	O(KC)
Iterative Swapping Chunk[16]	O(KClogC)
Combined-order Allocation[22]	O(KC)
Combined Allocation using BER-based	O(KC)

Table 1 shows that the proposed algorithm has the same complexity with the combined-order [22] and SMEG [18] algorithms. It has less time complexity than MEG [18] and iterative swapping chunk [16] algorithms due to the use of single average calculation on each time transmission interval. Regarding to the asymtotic approach, the complexity of them is obtained based on their iterations number however they implement two orders allocation at the same time.

4. Results and Discussion

In order to evaluate the proposed algorithm, the computer simulations are performed using montecarlo method. The number of simulation trial is equal to the number of TTI. The channel gain per subcarrier of all users are according to the model in [14-15], [22]. Using $\sigma_n^2=N_o.b_s$, Channel to Noise ratio (CNR) per subcarrier of each user can be written [14-15], [22]:

$$CNR_{n,k}\left[dB\right]=10\log R_{n,k}-L_p-10\delta\log d_k-\varepsilon_{n,k}-N_o b_s \quad (34)$$

L_p is the propagation loss, d_k is user-*k* distance from base stasion, δ is pathloss exponent, $\varepsilon_{n,k}$ is lognormal shadowing. $R_{n,k}$ is the rayleigh fading with rayleigh parameter τ such that $E[\tau^2]=1$. N_o is noise spectral density per subcarrier and b_s is bandwidth per subcarrier. The complete parameters of simulation are presented in Table 2.

Table 2. The simulation parameters

Parameter	Setting
Frequency (f)	2 Ghz
Distribution of Users	uniform
Number of users (K)	10 - 50
Number of subcarrier per chunk (n_c)	3 - 12
Radius of cell (D)	1 – 2 km
Noise spectral density(N_o)	-174 dBm/hz
Bandwidth per subcarrier(b_s)	15 khz [14-15,22]
Modulation Level ($M_{n,k}$)	≥ 4
Propagation loss (L_p)	128.1 dB [14-15,22]
Pathloss exponent (δ)	3.76 [14-15,22]
Fading parameter ($R_{n,k}$)	Rayleigh with $E[\tau^2]=1$
Shadowing deviation ($\varepsilon_{n,k}$)	1 dB [28]
Number of TTI	5000

The throughput, fairness index and BER system of the proposed algorithms were evaluated by varying the number of subcarriers per chunk and the number of users. The BER system performances are presented in Figure 2 and 3, respectively. While throughput performances are showed in figure 4 and 5, respectively. Finally, the fairness performances are viewed in Figure 6 and 7, respectively. At each simulation, the performances of proposed algorithm are compared with those of MEG [18], SMEG [18], iterative [16], combined-order with w_{se}=1 and combined-order with w_{se}=0 [22] algorithms.

Figure 2 shows the effect of subcarriers number per chunk on BER system. It can be seen that the BER system of all schemes degraded due to the increase in number of subcarrier per chunk. This was caused by the higher bit error rate of each user-chunk pair. It makes the BER system is degraded since it averages all users' BER that have been allocated. The proposed algorithm achieves smaller BER system comparing to previous algorithms. It gives in average of BER system improvement as 60%, 63.7%, 82.6%, 70.4% and 49.1% against comb-order with w_{se}=1, comb-order with w_{se}=0, MEG, SMEG and iterative algorithms, respectively.

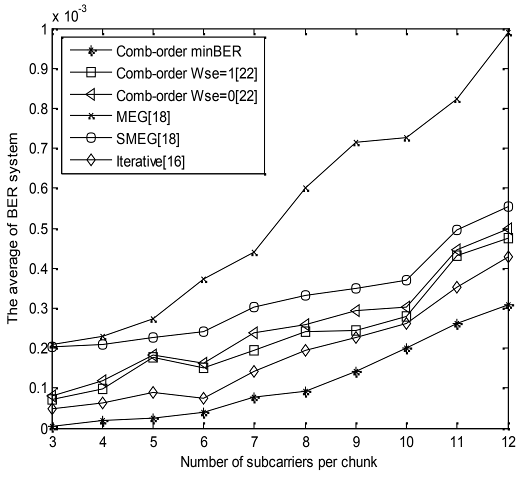

Figure 2. The average of BER system versus the number of subcarriers per chunk with K=40, D=2 km

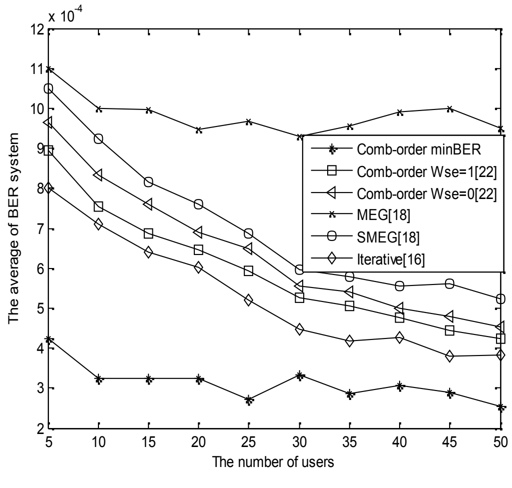

Figure 3. The average of BER system versus the number of users with n_{c}=12, D=2 km

By varying users number as viewed in Figure 3, It can be seen that the BER system of all schemes improved due to the increase in number of user. This was caused by the lower bit error rate of each user-chunk pair. It makes the BER system is improved since it averages all users' BER that have been allocated. The proposed algorithm also gives the average of BER system improvement as 45.6%, 49.5%, 68.1%, 54.1% and 38.7% against comb-order with w_{se}=1, comb-order with w_{se}=0, MEG, SMEG and iterative algorithms, respectively.

Regarding to the results on Figure 2 and 3, the BER system performances of the proposed algorithms has the same behaviour where it has the smallest BER system comparing to previous algorithms. These results are in accordance with the objective which minimizes the BER system. It takes into account the search a user-chunk pair which gives the smallest BER ($BER_{c,k}$) on each allocation iteration on user-based and chunk-based allocations. Choosing the smallest BER system between user-based and chunk-based allocation can improves the BER system.

Figure 4 presents the impact of the number of subcarriers per chunk on throughput system. It can be seen that the throughput all schemes degraded due to the increase in number of subcarrier per chunk. This result correlates with those of Figure 2 where the throughput is proportional to the BER system. The degradation of BER system causes the decrease of throughput. The proposed algorithm achieves greater throughput system comparing to previous algorithms. It gives in average of improvement as 10.7%, 16.3%, 78.7%, 68.1% and 7.4% against comb-order with w_{se}=1, comb-order with w_{se}=0, MEG, SMEG and iterative algorithms, respectively.

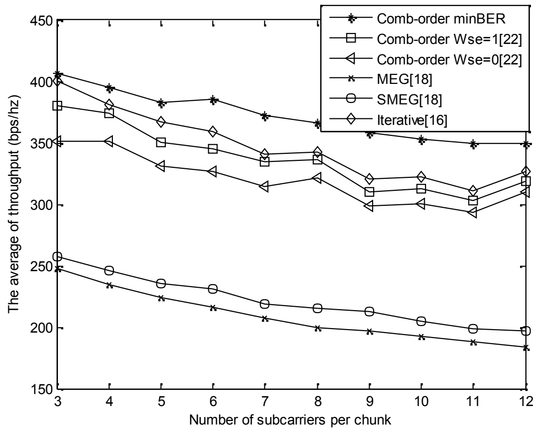

Figure 4. The average of throughput versus the number of subcarriers per chunk with K=40, D=2 km.

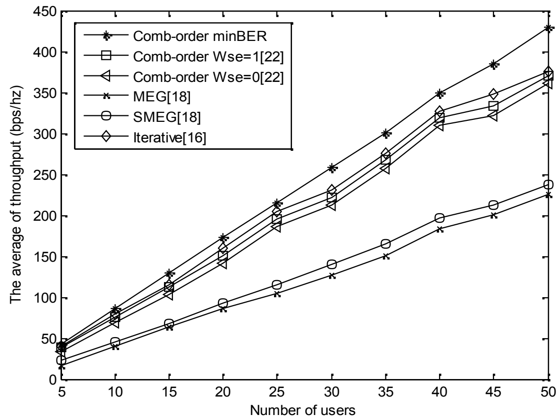

Figure 5. The average of throughput versus the number of users with n_{c}=12, D=2 km

Varying the number of users as shown in Figure 5, it can be seen that the throughput all schemes improved due to the increase in number of user. This result correlates with those of Figure 3 where the throughput is proportional to the BER system. The improvement of BER system causes the increase of throughput. The proposed algorithm gives the average of improvement as 13.3%, 20.7%, 104.9%, 84.9% and 9.1% against comb-order with w_{se}=1, comb-order with w_{se}=0, MEG, SMEG and iterative algorithms, respectively.

Based on results as seen in Figure 4 and 5, the throughput system of the proposed algorithm has the best peformance on both scenarios. Although it minimizes the BER system on optimization problem, by selecting the highest spectral efficiency on all subcarriers within a chunk is also able to improve the throughput system.

Figure 6 shows the effect of the subcarriers number per chunk on fairness system. It can be seen that the proposed algorithm gives the fairness reduction when it compares against comb-order with w_{se}=1, comb-order with w_{se}=0, MEG and SMEG algorithms. Otherwise, it gives in average of fairness improvement as 5.5% against iterative algorithm. Its result also correlates with Figure 7 where by increasing the number of users, the proposed algorithm gives in average of fairness improvement as 9.3% against the iterative algorithm.

Considering the results on Figure 6 and 7, the proposed algorithm gives the average of fairness improvement against iterative algorithm but it gives in average of fairness reduction against combined-order, MEG and SMEG algorithms. The combined-order with w_{se}=0 has the highest fairness performances since it chooses either user-order or chunk-order allocation which gives the higher fairness system on solving the chunk allocation problem.

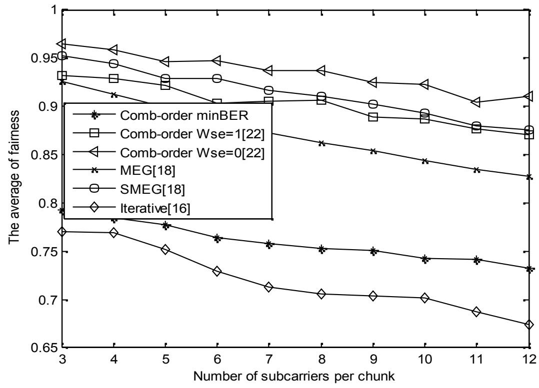

Figure 6. The average of fairness index versus the number of subcarriers per chunk with K=40, D=2 km

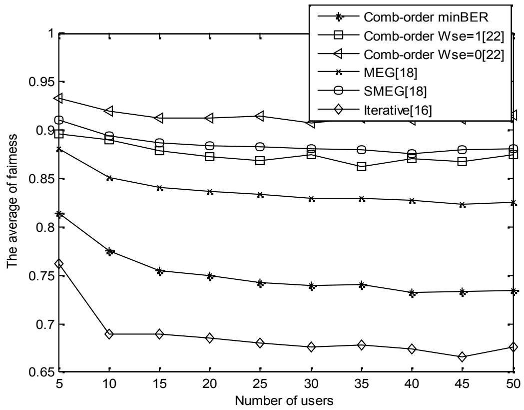

Figure 7. The average of fairness index versus the number of users with $n_{c=}12$, D=2 km

Considering the results altogether, it can be concluded that the proposed algorithm outperform the previous algorithms in both BER and throughput. It also outperform iterative algorithm in term of fairness. Comparing to MEG, SMEG and Combined-order algorithm, there is a fairness reduction since the proposed algorithm optimizes BER system while keeps the high throughput. Its fairness reduction as a consequence if throughput is pursued in an optimization constraint. In other word, the proposed scheme not only improves the BER but also improves throughput system. Hence, it can be considered to be applied in multimedia services which observes BER and throughput system.

5. Conclusion

In this work, a combined-order allocation algorithm using BER-based consideration for SC-FDMA uplink systems is proposed. The objective of this algorithm is to minimizes the BER system while keeps the high throughput. Varying the number of subcarriers per chunk and the number of users, the proposed algorithm gives the same trend on simulation results. Comparing the proposed algorithm with iterative algorithm, it achieves the smallest average of BER and throughput improvement as 38.7% and 7.4% when varying the number of users and the number of subcarriers per chunk, respectively.

By selecting the highest spectral efficiency on all subcarriers within a chunk and choosing a user-chunk pair which has the smallest BER on every allocation of both orders allocation can improve the performance in both BER and throughput. Although, there is a fairness reduction as consequence of pursuing the throughput when comparing with algorithms in [18] and [22]. This suggests that the proposed scheme not only improves the BER average but also improves throughput system.

Using both-orders allocation at the same time do not increase the time complexity due to asymtotic approximation. It has the same time complexity with the combined-order and SMEG algorithms and has less time complexity compared to MEG and iterative swapping chunk algorithms. Therefore, it can be considered to be applied in practical implementation especially in multimedia services.

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