

Energy efficient resources allocations for wireless communication systems

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Abstract

The energy consumption level of the telecommunication process has become a new consideration in resource management scheme. It is becoming a new parameter in the resource management scheme besides throughput, spectral efficiency, and fairness. This work proposes a power control scheme and user grouping method to keep the rational energy consumption level of the resource management scheme. Inverse water-filling power allocation is a power allocation scheme that optimizes the energy efficiency by giving the power to the user which have good channel conditions. The user grouping method becomes the solution for carrier aggregation (CA) scheme that prevents edge cell user get the resources from the high-frequency carrier. This can prevent energy wastage in the transmission process. This power control scheme and user grouping method can optimize the spectral and energy efficiency without increasing the time complexity of the system.

Keywords: energy efficient, mean-greedy, user grouping, water-filling

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1. Introduction

Background on data transmission process, LTE systems use OFDMA technique which divides one frequency band into several subcarriers (chunk/physical resources block (PRB)) that will be allocated to several users [1, 2]. This is a system that can achieve higher data rate, and seamless mobility across several distinct technologies [3]. In recent works, the purpose of resource management scheme (RMS) is not only to achieve a higher throughput, but it is starting to achieve a higher level of energy efficiency. Energy efficiency is becoming a new performance parameter on wireless network, as observed in [4]. Energy consumption level become a new consideration in resource management scheme (RMS). The most popular way to reduce the energy consumption level is power control scheme, which allocates and controls the transmitted power that being used, to avoid energy wastage. This scheme exploits the multi-user diversity on OFDMA system [5]. Inverse water-filling power control is one of power control schemes that try to optimize the energy efficiency level by giving more power to user with good channel conditions.

The new LTE-A system uses Carrier Aggregation (CA) to get additional bandwidth for the system. It is possible to use several adjacent frequency carriers [6]. To improve the energy efficiency in CA, user grouping method is proposed. User grouping will divides each user depends on the distance and carriers coverage. This method will give the resources from the lowest frequency to the furthest user in the cell (edge cell user), and give the resources from the highest frequency to the nearest user. This can improve the energy efficiency in the system.

In [7-9], RMS on the downlink side of LTE systems with single carrier (without CA) is proposed. It is assumed all users can be scheduled on the same carrier. Works [7, 8] proposed the proportional fair algorithm, while [9] proposed the modified greedy (mean-greedy) algorithm. Work [10] tries to improve the RMS by using QoS provisioning. The modified greedy algorithm also tried on uplink side in [11-13]. Work [14] tries RMS on LTE-A downlink system with CA scheme, works [15, 16] proved that the CA scheme makes the proportional fair algorithm not optimal because there are some problem caused by CA and its different fading on each component carrier. To overcome this new problem, user grouping (UG) method was proposed.

In [15], UG process only applied on the user side, while in [16], UG process applied both on user side and chunk side of each carrier. This process increases the fairness among users, but decrease average user throughput.

Work [17] try to implement grouping process in [16] on mean-greedy-based algorithm. Simulation process shows that the result is same between mean-greedy algorithm with grouping and without grouping. Then the grouping process is modified in work [18] to improve the performance of mean-greedy algorithm process on LTE-A with inter band non-contiguous CA scheme. In terms of energy saving, work [19] tries to use fractional power control, and works [20, 21] proposed power control process to meet the energy saving issue on LTE heterogeneous network. While [22] tries to propose the power allocation on CA system. Water-filling power control scheme discussed in [23]. This principle is being used in this work to create a proper water-filling method to be implemented on the system as in [24]. This works try to analyze the performances of mean-greedy algorithm [9] on LTE-A system with CA by combining user grouping on [18] and power control principle method on [23]. By the simulation, the ombined scheme has better energy and spectral efficiency, but the fairness will be lower compared with the original mean-greedy algorithm.

Model System Design

This work tries to observe the performance of the proposed algorithm through simulation process, that will be conducted at LTE-A system's downlink path. The cell that being observed is a single cell environment, using three aggregated component carriers with the same amount of bandwidth, same transmit power. The Carrier Aggregation (CA) schemes that being used is non-contiguous CA, which aggregated several carriers on different band. The allocation process performed only in observed cell, without handover or user movement. There are no interference parameters from the other cells. The observed cell condition explained in Figure 1. A group of aggregated carrier can be defined as [15]:

$$F = f_1, f_2, \dots, f_K; \quad f_1 < f_2 < \dots < f_K \quad (1)$$

the path loss value for a carrier can be calculated by the spatial channel model:

$$PL_k = 58.83 + 37.6 \log(R_{k(\text{km})}) + 21 \log(f_{k(\text{MHz})}) \quad (2)$$

according to (1), for a constant value of PL, the coverage of f_3 must be smaller than f_2 and so on. The coverage of each carrier can be formulated by:

$$R_1 > R_2 > \dots > R_K \quad (3)$$

According to Figure 1, user 3 is in the coverage of all carriers, so user 3 can use the resource from all carriers, while user 1 only can use the resources from f_1 because it is only in coverage of f_1 . This condition will be the basic condition for the grouping process.

Problem Formulation

The main purpose of this work are to analyze the performance of the proposed algorithm. To analyze the performance, there are several constraints that have to be fulfilled:

$$\sum_{n=1}^N \alpha_{n,v} = 1; \quad \forall v \in V \quad (4)$$

$$\sum_{n=1}^N \sum_{v=1}^V \alpha_{n,v} = V \quad (5)$$

$$\beta_{n,v} \in [0, x] \mid x \leq P_t; \quad \forall v \in V; \quad \forall n \in N \quad (6)$$

$$\sum_{n=1}^N \sum_{v=1}^V \beta_{n,v} \leq P_t \quad (7)$$

$$\alpha_{n,v} \neq 0 \rightarrow \beta_{n,v} \neq 0; \quad \forall v \in V; \quad \forall n \in N \quad (8)$$

α represents a chunk allocation matrix, $\alpha_{n,v} = 1$ if v-th chunk is allocated to n-th user (n, v is user-chunk pair), otherwise $\alpha_{n,v} = 0$. β represents power allocation matrix. (4) explains that each chunk only assigned for 1 specific user, cannot be shared with another, while (5) makes sure all chunks have to be allocated to a specific user. (6) and (7) are constraint that

the total power allocated to each chunk cannot exceed the total power from eNB, and (8) is to make sure all chunks get power to transmit.

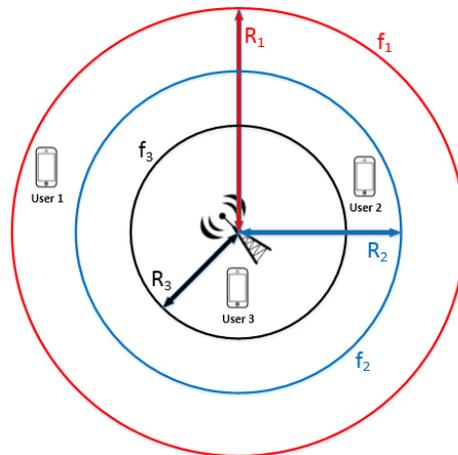


Figure 1. Observed cell condition

2. The Proposed Algorithm

This work tries to combine the User Chunk Grouping (UCG) method and Inverse-Water-filling (IWF) power control on mean-greedy (MG) algorithm. At first, the UCG method will be performed to divide the users to several groups, depends on each user location on cell. Then, the MG algorithm on [9] and [13] will be performed with Equal Power Allocation (EPA) scheme. After all resources are allocated to a specific user, IWF power control will be take place in order to manage the power that being used by each resource/chunk. The flowchart of the proposed algorithm can be seen on Figure 2.

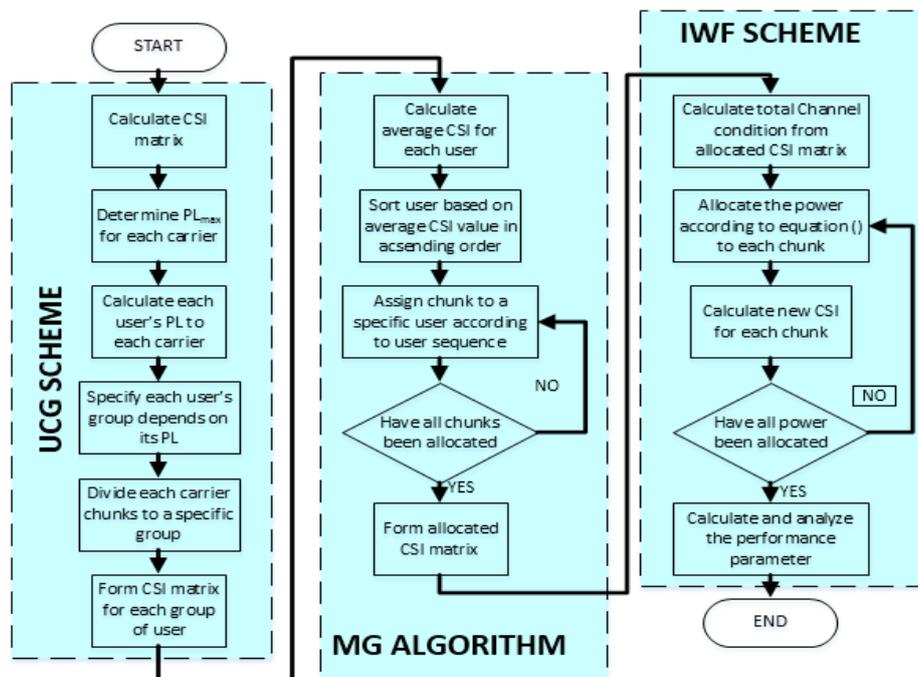


Figure 2. Proposed algorithm's flowchart

2.1. User Chunk Grouping (UCG) Method

User Chunk Grouping method is a modified user grouping method that divided both the resources and users on a specified group. Resources and users from each group will be managed independently on the allocation process. UCG method performed based on the maximum path loss (PL_{max}) for each carrier. This work uses non-contiguous CA scheme that aggregated several carriers on different band frequencies. There are some differences in fading characteristic from each carrier. To maintain the system performances, the path loss for each carrier cannot exceed PL_{max} value. The value of PL_{max} can be calculated by [15]:

$$PL_{max} = 58.83 + 37.6 \log(R_{k(\text{km})}) + 21 \log(f_{k(\text{MHz})}) \quad (9)$$

the same value of PL_{max} will result different coverage for each carrier (as in (1)-(3)). The higher frequency will have smaller coverage and vice versa. Users will be divided into several groups according to the location of each user on the cell. The formulation is [15]:

$$\beta_n = \{\beta_k | PL_k^n < PL_{max}, 1 \leq k \leq K\}; 1 \leq n \leq N \quad (10)$$

thus, $\beta_n = \beta_k$ means that the n-th user is the member of group β_k . It also means the n-th user is on the k-th carrier coverage and can use k carrier(s). The pseudocode algorithm of this process can be seen on Table 1.

Table 1. Algorithm of User-Grouping Method

Pseudocode for User Grouping Method		
Give each user to a specific group		
1	G=0	// G = group for each user
2	for n=1 to N	
3	if d(n) ≤ R1	// d = user distance
4	G(n)=1	// R1 = max coverage of carrier 1
5	else if d(n) ≤ R2	// R2 = max coverage of carrier 2
6	G(n)=2	
7	else if d(n) ≤ R3	// R3 = max coverage of carrier 3
8	G(n)=3	
9	end if	

Each group will get chunks from the corresponding component carrier(s). Group 3 (user 3 on Figure 1) is the nearest user group because they are on carrier 3 coverage as well as carrier 2 and 1, so group 3 can use chunk from all carrier. Group 2 (user 2 on Figure 1) is on carrier 2 coverage, but on the outside of carrier 3, so they cannot use resources from carrier 3. So that group 1 (user 1 on Figure 1), they only can use resources from carrier 1, because they are on the outside of carrier 2 and 3. Thus, carrier 1 has to divides its chunk to 3 different groups proportionally, and carrier 3 only distributes its chunk to 1 group. β_j is one of the group in the system ($j \leq K$). The resource distribution process to group β_j can be performed based on:

$$\partial_j = \{\sum_{n=1}^N PL_n^n | \beta_n = \beta_j\} \quad (11)$$

where ∂_j is the total value of PL from carrier k=j on group j. To distribute chunk to each group can be formulated by:

$$[C_j] = \frac{\partial_j}{\sum_{k=1}^K \partial_k} \cdot V \quad (12)$$

$$\sum_{j=1}^K C_j \leq V \quad (13)$$

the output from this process is a separated CSI matrix for each group. This separated CSI matrix will be processed independently with MG algorithm and IWF scheme.

2.2. Mean-Greedy (MG) Allocation Algorithm

Mean-Greedy allocation algorithm is a modified greedy algorithm that tries to maximize both spectral efficiency and fairness [9]. On each TTI, before the chunk allocation takes place, this algorithm tries to sort each user based on average CSI the system. This average CSI value will be sorted from the smallest to be used as a sequence number for each user. A user with the smallest average CSI value will have first chance to get the best chunk for itself, followed by the second user and so on [9]. The chunk selection by each user are based on greedy principal. User n^* will choose v -th chunks which have the best CSI value based on [9]:

$$n^* = \arg \max_v r_{n,v}(s) \quad (14)$$

where $r_{n,v}(s)$ is the CSI value for n -th user and v -th chunk pair on the s -th TTI. This process will be executed repeatedly until all chunks are allocated to a specific user. If there are unallocated chunks when all users got at least 1 chunk, the user with the smallest sequence number can get chunk again, followed by the second sequence number, and so on. This process explained by Table 2.

Table 2. Algorithm of Mean-Greedy Process

Pseudocode for Mean-greedy Algorithm	
Calculate each user average CSI	
1	for $n=1$ to N // N = total user
2	$C_{av}(n)$ =average CSI for n -th user
3	Q -number(n)= n // queuing number of each user
4	end for
Sort average user CSI from the lowest	
5	for $i=1$ to $(N-1)$
6	for $j=1$ to $(N-1)$
7	if $C_{av}(j) < C_{av}(j+1)$
8	interchange Q -number(j) and Q -number($j+1$)
9	end if
10	end for
11	end for
Allocates the chunk to a specific user	
12	$C'=0$ // C' = allocated CSI matrix
13	for $n=1$ to N
14	$a=Q$ -number(n), $x=0$, $y=0$
15	for $v=1$ to V // V = total chunk
16	if $x < C(a, j)$ // C = CSI matrix
17	$X=C(a, j)$, $y=j$
18	end if
19	end for
20	$C(:, y)=0$, $C'(a, y)=x$
21	end for

2.3. Inverse Water-filling Power Control

Inverse Water-filling (IWF) power control is a water-filling scheme that gives more power transmit to chunks with better channel condition, and reducing the power on chunks with bad channel condition. This scheme can improve the spectral efficiency on the system, but will disrupt the system's fairness [23]. This scheme will maximize the energy efficiency by not wasting a lot power on worse chunks. The transmitted power will be distributed to each user-chunk pair according to:

$$P_{n,v}(s) = \frac{H_{n,v}(s)}{\sum_{n=1}^N \sum_{v=1}^V H_{n,v}(s)} \cdot P_t \quad (15)$$

where $H_{n,v}(s)$ is a channel condition on n -th user and v -th chunk set on s -th TTI, and P_t is total power from eNB. The process of Inverse Water-filling power control explained by Table 3.

2.4. The Proposed Algorithm Flow

At first, each chunk will calculate all CSI to each user to form a CSI matrix. This process will assume the power allocated equally to each chunk (EPA). This CSI matrix will be used as

where b is chunk bandwidth and Γ called SNR gap. The spectral efficiency (SE) and energy efficiency (EE) of the system be calculated by:

$$SE_{\text{system}} = \frac{\sum_{n=1}^N \sum_{v=1}^V \mu_{n,v}}{B} \tag{18}$$

$$EE_{\text{system}} = \frac{\sum_{n=1}^N \sum_{v=1}^V \mu_{n,v}}{P_t} \tag{19}$$

where B is bandwidth system. There are 2 simulation scenario. The first is a simulation on a varied number of user, and the other one is a simulation on varied cell coverage.

4. Results and Discussion

4.1. Results on Varied Number of User

For a varied number of users, the proposed algorithm (UCG-MG-IWF) has the best spectral and energy efficiency, but has the worst fairness index. The addition of UCG and IWF scheme can increase the energy and spectral efficiency, because this two scheme prioritize user with the best channel condition. But this constraint will decrease the system fairness because user with bad channel condition will get less power which makes that user quality will drop drastically.

The proposed algorithm can improve spectral efficiency up to 1.507 bps/Hz and can improve energy efficiency up to 188.21 kbps/Watt. This means the proposed algorithm works well in terms with the energy efficient scheme. But the proposed algorithm's fairness index decreased 29.52% compared with the original one. Individually, UCG scheme (UCG-MG) will increase more energy and spectral efficiency, and decrease less fairness index compared with IWF scheme (MG-IWF). It means, the performances of UCG scheme is better than IWF scheme. The simulation results for varied number of users can be seen in Figures 3-5.

4.2. Results on Varied Cell Coverage

On varied cell coverage, the proposed algorithm improved the energy efficiency up to 121.24 kbps/Watt and spectral efficiency up to 0.97 bps/Hz. The fairness index will decrease up to 27.08% compared with the original MG algorithm. Individually, UCG scheme still a better scheme than IWF scheme. UCG scheme improves the efficiencies more than IWF, and decrease the fairness index less than IWF. This scenario's results explained by Figures 6-8. Overall results of the simulation can be seen in Table 5.

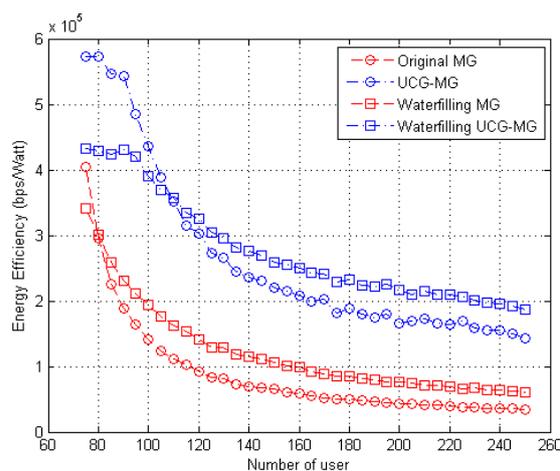


Figure 3. Energy efficiency of each algorithm on varied number of users

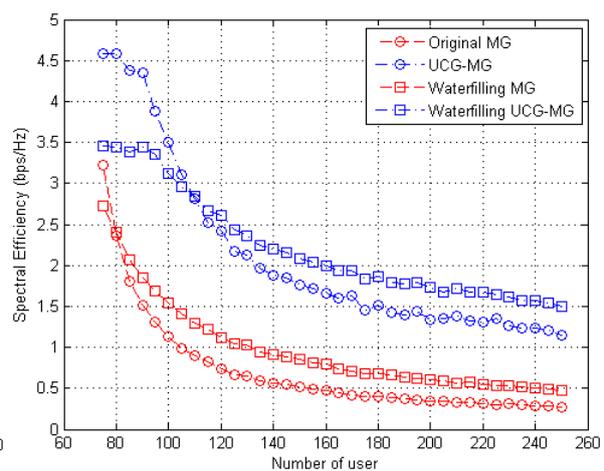


Figure 4. Spectral efficiency of each algorithm on varied number of users

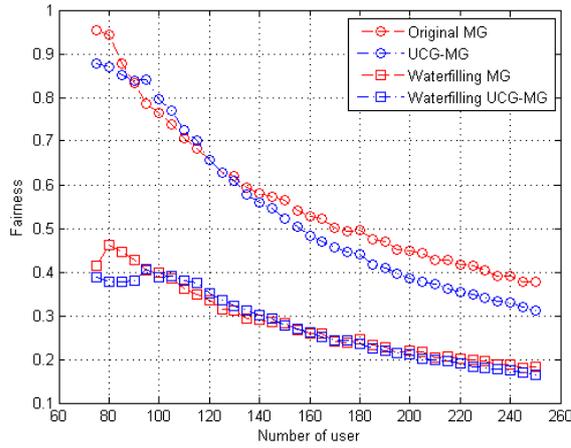


Figure 5. Fairness index of each algorithm on varied number of users

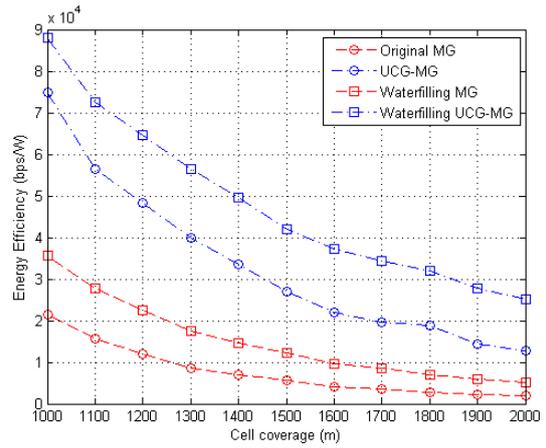


Figure 6. Energy efficiency of each algorithm on varied cell coverage

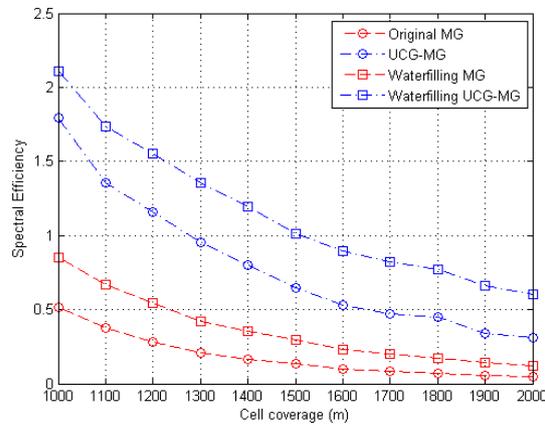


Figure 7. Spectral efficiency of each algorithm on varied cell coverage

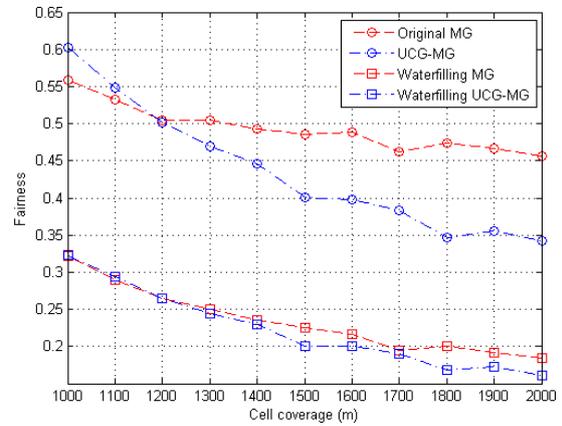


Figure 8. Fairness index of each algorithm on varied cell coverage

Table 5. Simulation Results

VARIED NUMBER OF USER				
Algorithm	Fairness Index	Energy Efficiency (kpbs/Watt)	Spectral Efficiency (bps/Hz)	
Original MG	0.5695	88.35	0.7068	
UCG-MG	0.5343	263.58	2.1086	
MG-IWF	0.2815	122.48	0.9799	
UCG-MG-IWF	0.2743	276.56	2.2125	
VARIED CELL COVERAGE				
Algorithm	Fairness Index	Energy Efficiency (kpbs/Watt)	Spectral Efficiency (bps/Hz)	
Original MG	0.4934	23.237	0.185	
UCG-MG	0.4359	100.153	0.801	
MG-IWF	0.2339	45.374	0.362	
UCG-MG-IWF	0.2226	144.482	1.155	

4.3. Time Complexity

To quantify the complexity of the proposed algorithm, time complexity with asymptotic approach is used. This approach depends on the time restriction within time transmission interval [12]. The complexity is determined by the number of iterations. The proposed algorithm consists of 3 stages of allocation: UCG scheme, MG algorithm, and IWF power control. UCG scheme divides users and chunks into several groups based on the carrier's coverage, it needs $O(N)$. The MG algorithm sorts the user and allocate chunks to a specific user, it needs $O(NV)$. The IWF power control allocates the power for each chunk, it needs $O(NV)$.

Then, the total complexity is $O(NV) + O(NV) + O(NV) \approx O(NV)$. This means, the proposed algorithm's time complexity is almost the same with the original MG algorithm. This caused by the number of iteration of the proposed algorithm and the original MG algorithm is of the same value. The comparison between each algorithm shown in Table 6.

Table 6. Time Complexity on Each Algorithm

Algorithm	Process Complexity			Total
	UCG	MG	IWF	
Original MG	-	$O(NV)$	-	$\approx O(NV)$
UCG-MG	$O(N)$	$O(NV)$	-	$\approx O(NV)$
MG-IWF	-	$O(NV)$	$O(NV)$	$\approx O(NV)$
UCG-MG-IWF	$O(N)$	$O(NV)$	$O(NV)$	$\approx O(NV)$

5. Conclusion

This work proposed an allocation algorithm that tries to maximize the energy efficiency. By the simulation results, the proposed algorithm can improve both energy efficiency and spectral efficiency. The proposed algorithm improves spectral efficiency by 1.507 bps/Hz and improve energy efficiency by 188.21 kbps/Hz. This condition happens because UCG tries to limit the transmit distance for each carrier, so the system quality can be maintained. Meanwhile IWF try to maximize the energy and spectral efficiency by adding more power to user with better channel conditions. In contrary, the proposed algorithm reduces fairness index by 29.51% in average. This caused by the UCG limit the transmit distance so user in the cell edge will get less chunk. IWF will reduce allocated power for user with bad channel condition, so it cannot maintain its quality and reduce the fairness index overall.

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