

Resource Allocation Algorithm for Optimizing User Fairness in Multi-User OFDMA System

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ABSTRACT

This paper proposed a novel resource allocation based on iterative water-filling subcarrier allocation algorithm in multi-user OFDMA system. The algorithm updated the transmit power of each subcarrier in each iterative by improve the water-filling algorithm, which could more accurately calculate the capacity of subcarrier, rather than compute the channel capacity with average power of traditional water-filling subcarrier allocation algorithm. In this paper, a power line is proposed as a reference which varies according to the allocated subcarriers. We compute the corresponding reference power line by the minimum noise-to-signal ratio first, then compare the sub-carrier to be allocated with the reference power line to use iterative water-filling, until all subcarriers allocated. The algorithm is to solve the problem of fairness among users based on guaranteeing the total system capacity. Simulation results show that the system capacity of the system capacity close to the optimal algorithm, but greatly improves the user fairness.

Categories and Subject Descriptors

H.4 [Information Systems Applications]: Miscellaneous;

General Terms

Algorithms

Keywords

OFDMA, iterative water-filling, power allocation; capacity, user fairness

1. Introduction

With the development of wireless communication, spectrum, one of significant resource in communication system, is in shortage obviously. In order to solve the spectrum utilization and the communication quality of service (Qos) and other issues, many solutions have been proposed. Orthogonal Frequency Division Multiplexing (OFDM) becomes the core technology in 4G systems, because of its superior performance in numerous aspects. Resource allocation [1]-[3] in OFDMA system has become a research hotspot in recent years.

In OFDMA system, efficiency and fairness [4]-[6] are two important issues that need to be considered in resource allocation. Spectral efficiency is defined as transmission rate per unit bandwidth, which is equal to the total bandwidth divided by the total system throughput. When spectral efficiency is highest, the system can achieve maximum throughput. However, it will be unfair for the users who are far away from the base station or whose channel condition is not good. Therefore, besides the rate of users, the total rate of system also need to be considered. Fairness can be measured through different perspectives. On the other hand, fairness can be defined by the bandwidth occupied by users when every user gets the same number of carriers [7]. The users' rate can also indicate the fairness between users, the target of these rates is to allocate resources to the users, so that all those users achieve the same data transfer rate. To get satisfactory system performance, resource allocation of the wireless systems should find out the compromise of system efficiency and users' fairness.

To solve this problem, in [8]-[10], compromise strategies are proposed between resource efficiency and users fairness. Then to define a fairness factor according to the proportional rate [11]. The maximum of this fairness factor is 1, meanwhile, it is most equitable when every user in the system get the same rate. Based on this, a novel parameter is defined to indicate system performance when the user fairness is met [12]. This parameter is values real (0,1) based on proportional rate constraint and users' attainable rates, when value is 1, it represents achievable rates of users are the same. In [13], the carriers are redistributed among users which have the minimum total capacity loss and the maximum fairness gain to reach the compromise of system capacity and users' fairness. In [14] a dynamic digital control technology is raised to greatly improve user fairness, simultaneously minimize transmission power. In [15], a resource allocation algorithm based on new proportional rate constraint is proposed. It allocates subcarriers and power respectively, which makes the complexity greatly reduce. The subcarriers are assigned

by max-min criterion, considering the compromise of capacity and fairness under different rate constraint

Many others in [16]-[18] adopt average power algorithm to allocate subcarriers, which can't maximize system capacity and guarantee user fairness. Here we propose a novel resource allocation algorithm, it guarantees system capacity and also maximizes user fairness.

The rest of this paper is organized as follows. In section II, introduce OFDMA optimization model. In section III, proportional allocates subcarriers and the number of bits per symbol to the users. Then these bits will be modulated, equivalently, Inverse Fast Fourier Transform (IFFT), after that, parallel-to-serial(P/S) conversion, and add a guard interval to each OFDM symbol. Assume $P_{k,j}$ represents the power allocated to subcarrier $j \in \{1,2,\dots,N\}$ of user $k \in \{1,2,\dots,K\}$. The signal user k receives from subcarrier j can be expressed by the formula as follow:

$$y_{k,j} = h_{k,j} p_{k,j} s_j + v \quad (1)$$

Where $y_{k,j}$ is the receive signal, $h_{k,j}$ means the channel gain of the k -th user on the j -th subcarrier, which is Rayleigh distributed with unitary variance i.e. $E\{|h_{k,j}|^2\} = 1$. v is an additive white Gaussian noise (AWGN), and its mean is zero and variance is $\sigma^2 = N_0 \frac{B}{N}$ (B is the system bandwidth, N_0 is the noise power spectral density). The corresponding sub-channel Signal-To-Noise Ratio (SNR) is $\gamma_{k,j} = h_{k,j}^2 / \sigma^2$, and Noise-To-Signal Ratio is $\chi_{k,j} = 1 / \gamma_{k,j}$. The target of OFDMA resource allocation is maximize system capacity and guarantee user fairness.

The objective of the resource allocation can be formulated as

$$\begin{aligned} & \max_{c_{k,j}, p_{k,j}} \frac{B}{N} \sum_{k=1}^K \sum_{j=1}^N c_{k,j} \log_2(1 + p_{k,j} \gamma_{k,j}) \\ \text{subject to} \quad & \text{C1: } c_{k,j} \in \{0,1\}, \forall k, j \\ & \text{C2: } \sum_{k=1}^K c_{k,j} = 1, \forall j \\ & \text{C3: } p_{k,j} \geq 0, \forall k, j \\ & \text{C4: } \sum_{k=1}^K \sum_{j=1}^N c_{k,j} p_{k,j} \leq P_{\text{tot}} \\ & \text{C5: } R_1 : R_2 : \dots : R_K = \lambda_1 : \lambda_2 : \dots : \lambda_K \end{aligned} \quad (2)$$

where $c_{k,j} \in \{0,1\}$ is the subcarrier allocation indicator, $c_{k,j}$ indicates whether the j th subcarrier is assigned to the k th user.

If the j th subcarrier is assigned to the k th user, $c_{k,j} = 1$,

otherwise $c_{k,j} = 0$. The constraints C1 and C2 in (2) limit the subcarrier allocation indicator and require each subcarrier can only be allocated to one user. The constraints C3 and C4 ensure

rate constraint resource allocation is described. Section IV provides performance analysis and simulation results. Section V gives conclusions.

2. Multi-User OFDMA Optimization Model

The OFDMA system is assumed to have K users and N subcarriers. Based on the estimated channel state, the base station

the subcarriers' powers must be non-negative and the total power must be lower or equal to the total transmit power. C5 is user fairness constraints, where R_i is the rate of the i th user, λ_i is the rate constraint of the i th user.

3. Proportional Rate Constraint Resource Allocation

The target formulate of maximize total rate is given by (2). The matter about C1-C4 has been solved in [19], which maximizes the system capacity, but the user fairness isn't taken into consideration. And this will make the system hard to assure the communication performance of users who have bad channel conditions.

To get highest system capacity and guarantee user fairness at the same time, proportional rate constraint resource allocation has been proposed in [14]-[16], which assumes that the power allocated to each subcarrier is identical, and use average power to calculate the channel capacity, as show in Fig.1(a), where $p_{k,j} + \chi_{k,j}, k = 1, \dots, K, j = 1, \dots, N$ is called power baseline. However, this power baseline is not inconsistent with the one after actually water-filling (as show in Fig. 1(b)), so it make that the capacity calculated very inaccurate. Therefore, this algorithm cannot maximize the system capacity under ensuring user fairness. To meet the fairness requirements and maximize the system capacity, this paper proposes a novel subcarrier and power allocation algorithm which based on proportional rate constraint. In the subcarrier allocation process, according to current subcarrier allocation and user fairness constraint, improving the water-filling algorithm, and changing the power allocated to the subcarrier. The algorithm maximizes the system capacity, also guarantees the user fairness.

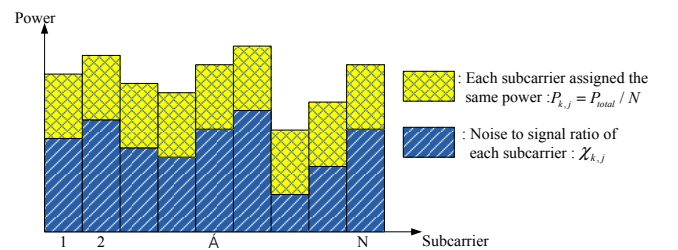


Fig.1(a) Equal power distribution

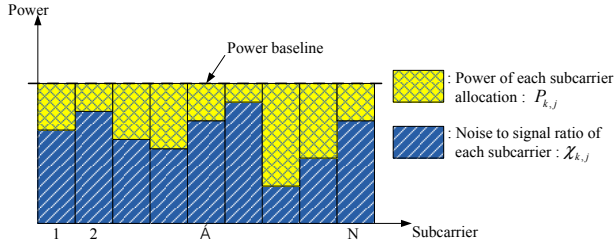


Fig.1(b) Power water-filing situation

3.1 Average power algorithm

During the allocation of subcarriers using the average power, average power allocation greedy algorithm is described below.

Algorithm 1: Average power algorithm

1. Initialization

$$\kappa \leftarrow \{1, 2, \dots, K\}, \zeta \leftarrow \{1, 2, \dots, N\}, p = P_{tot} / N, R_k = 0, \forall k \in \kappa$$

2. assign to each user one subcarrier

for $k=1$ **to** K

$$\kappa^* \leftarrow \kappa$$

$$j = \arg \min_{j \in \zeta} \chi_{k,j}$$

$$\kappa^* \leftarrow \kappa^* \setminus \{k\}, \zeta \leftarrow \zeta \setminus \{j\}$$

$$R_k = R_k + \log_2(1 + p / \chi_{k,j})$$

end for

3. assign unallocated subcarriers to user according to the greedy policy.

while $\zeta \neq \emptyset$

$$k = \arg \min_{k \in \kappa} (R_k / \lambda_k)$$

$$j = \arg \min_{j \in \zeta} (\chi_{k,j})$$

$$\zeta \leftarrow \zeta \setminus \{j\}$$

$$R_k = R_k + \log_2(1 + p / \chi_{k,j})$$

end while

The first step of the algorithm initializes all the variables. κ is the set of users, ζ is the set of subcarriers, p is the average power for each subcarrier, R_k keeps track of the capacity for each user.

The second step assigns to each user one subcarrier, calculate corresponding capacity.

The third step proceeds to assign unallocated subcarriers to user according to the greedy policy.

3.2 Our Improved Water-Filling Algorithm

General water-filling algorithm, as shown in the Fig. 1(b), the power baseline is formulated as follow:

$$w = (P_{tot} + \sum_{k=1}^K \sum_{j=1}^N \chi_{k,j}) / N. \quad (3)$$

The capacity required for each user is

$$R_k = \sum_{j=1}^N \log_2(1 + p_{k,j} \chi_{k,j}), \quad (4)$$

$$\text{Where } p_{k,j} = \max((w - \chi_{k,j}), 0).$$

It is optimal to calculate the capacity using the final power allocation, however we can only determine the subcarrier allocation after the process is done. So it is infeasible to calculate $p_{k,j}$ and system capacity R_k by (3) and (4). In order to solve this problem, many papers assume the power is constant in the whole process, which formulate as $p_{k,j} = P_{tot} / N$. This paper improves the water-filling algorithm. First set the noise baseline is b , as shown in Fig. 2, Δ is the difference between current subcarrier's noise-to-signal ratio and noise baseline. When water-filling to the j th subcarrier, the power baseline raise to w' from w , where $w' = w + \Delta / N$. From Fig. 2, the power baseline rises totally, and update the power of each subcarrier, repeat this process until all subcarriers are allocated.

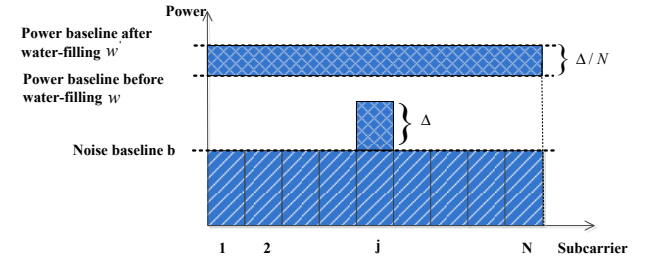


Fig.2. Power update of water-filling diagram

For the convenience of description, a single user and multi-subcarrier is chosen for example. Omitting the subscript i , the specific steps of this novel water-filling algorithm is describe as follows.

Algorithm 2: Improved water-filling algorithm

1: $\zeta \leftarrow \{1, 2, \dots, N\}$ //Initialize subcarriers set

2: $b = \min_{j \in \zeta} \chi_j$ //Find subcarrier with minimal noise-to-signal ratio

3: $w = P_{tot} / N + \min_{j \in \zeta} \chi_j$ //calculate the power baseline

4: **for** $j=1$ **to** N

5: $\Delta \chi_j = \chi_j - b$ // χ_j is the noise-to-signal ratio of current subcarrier

6: $\Delta\chi_j = N(w-b)/(N-1)$ // calculate the threshold when the power baseline reach to χ_j , the critical situation is shown as Fig. 3.

7: **if** the updated power baseline w is below χ_j after the above water-filling, namely $\Delta\chi_j > N(w-b)/(N-1)$, then regulate the increasing value to $\Delta w = N(w-b)/(N-1)$

8: $w = w + \Delta w / N$ //update the power baseline

9: **end if**

10: **if** the updated power baseline is above χ_j

11: $w = w + \Delta\chi_j / N$ // update the power baseline

12: **end if**

13: **end for**

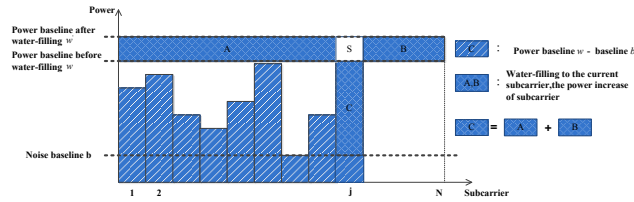


Fig. 3 water-filling threshold condition

3.3 Proportional Rate Constraint Resource Allocation Based on Improved Water-Filling Algorithm

Proportional rate constraint resource allocation of this paper is based on the improved water-filling algorithm mentioned in the previous section. According to the improved water-filling algorithm, optimize the subcarrier and power allocation. During the subcarrier allocation, constantly correct the power allocated to the subcarriers, make the user capacity calculated accurately. According to user fairness constraint, find the next user to allocate subcarrier, achieve maximum fairness among users. The simplified block steps are as follows while its pseudo-code is presented in Algorithm 3.

Step 1 Determine the set of users κ , the set of subcarriers ζ and the index of the subcarriers allocated to user k ;

Step 2 Each user is assigned to one subcarrier, calculate corresponding power and capacity;

Step 3 Define fairness measurement criteria which means the fairness is better when the value is smaller, and calculate the degree of user fairness;

Step 4 Suppose for each user redistribute a unallocated subcarrier, but not to remove it from the subcarriers;

Step 5 Calculate the difference of the total system capacity and the degree of users fairness between the user which add a subcarrier again and the original user;

Step 6 Calculate the proportional values between the difference of the total system capacity and the degree of users fairness;

Step 7 Find the user who has the maximum ratio of system capacity and user fairness;

Step 8 For this user assigned a unallocated subcarrier which has minimum Noise-To- Signal Ratio;

Step 9 Repeat until all available subcarriers are allocated

Algorithm 3: Proportional rate constraint resource allocation based on improved water-filling algorithm.

1: $\kappa \leftarrow \{1, 2, \dots, K\}$; $\zeta \leftarrow \{1, 2, \dots, N\}$; $F_k \leftarrow \emptyset$; $F_k^* \leftarrow F_k$
//Initialize users set, subcarriers set and the index of the subcarriers allocated to user k

Proportional rate constraint resource allocation based on improved water-filling algorithm

2: $\chi_j = \min_{k \in \kappa} \{\chi_{k,j}\}$, $j \in \zeta$ //Find the minimize noise-to-signal ratio of each subcarrier

3: $w = ((\sum_{j=1}^N \chi_j) + P_{tot}) / N$ //Calculate the corresponding water baseline

4: **if** $w - \chi_j \leq 0$ ($j \in \zeta$), then

Remove subcarrier j from ζ : $\zeta \leftarrow \zeta \setminus \{j\}$, and recalculate the water baseline

end if

5: **for** $ii=1$ to K //Firstly, each user is assigned to one subcarrier, calculate corresponding power

6: $\kappa^* \leftarrow \kappa$, $\zeta^* \leftarrow \zeta$ //Reset users set, subcarriers set

7: $\chi_j^* = \min_{k \in \kappa^*, j \in \zeta^*} \{\chi_{k,j}\}$, $F_k^* \leftarrow F_k^* \cup \{j\}$ //Find the minimal noise-to-signal ratio in noise-to-signal ratio matrix, and allocate subcarrier j to user k

8: $\kappa^* \leftarrow \kappa^* \setminus \{k\}$, $\zeta^* \leftarrow \zeta^* \setminus \{j\}$ //Remove the user k which has been allocated the subcarrier j , and remove the allocated subcarrier j

9: According to improved water-filling algorithm, update power baseline w^*

10: **end for**

11: $p_j^* = \max((w^* - \chi_j^*), 0)$, $j \in F_k^*$ // Calculate the transmit power demand of allocated subcarrier

12: $R_k^* = \sum_{j \in F_k^*} \log_2(1 + p_j^* \gamma_{k,j})$ // Calculate the capacity demand of each user

13: $R^* = \sum_{k=1}^K \sum_{j \in F_k^*} \log_2(1 + p_j^* \gamma_{k,j})$ // Calculate the total capacity

14: $\mu^* = \left\| \bar{\mathbf{R}} - \bar{\boldsymbol{\lambda}} \right\|$, $\bar{\mathbf{R}} = [R_1^*, R_2^*, \dots, R_K^*]$, $\bar{\boldsymbol{\lambda}} = [\lambda_1^*, \lambda_2^*, \dots, \lambda_K^*]$

//Define fairness measurement criteria which means the fairness is better when the value is smaller, and calculate the degree of user fairness

15: $\kappa^* \leftarrow \kappa$ //Reset users set

16: **for** $ii=1$ to K // Suppose for each user redistribute a unallocated subcarrier, but not to remove it from the subcarriers

17: $\chi_j^* = \min_{k \in \kappa, j \in \zeta^*} \{\chi_{k,j}^*\}$, $F_k^* \leftarrow F_k^* \cup \{j\}$ //Find the minimal noise-to-signal ratio in unallocated subcarriers

18: $\kappa^* \leftarrow \kappa^* \setminus \{k\}$ //Remove the user k which has been allocated the subcarrier j

19: According to improved water-filling algorithm, update power baseline w^*

20: $p_j^* = \max((w^* - \chi_j^*), 0)$, $j \in F_k^*$ // Calculate the transmit power demand of allocated subcarrier

21: $R_k^* = \sum_{j \in F_k^*} \log_2(1 + p_j^* \gamma_{k,j})$ // Calculate the capacity demand of each user

22: $R_u^* = \sum_{k=1}^K \sum_{j \in F_k^*} \log_2(1 + p_j^* \gamma_{k,j})$ // Calculate the total capacity

23: $\mu_{ii}^* = \left\| \bar{\mathbf{R}} - \bar{\boldsymbol{\lambda}} \right\|$, $\bar{\mathbf{R}} = [R_1^*, R_2^*, \dots, R_K^*]$, $\bar{\boldsymbol{\lambda}} = [\lambda_1^*, \lambda_2^*, \dots, \lambda_K^*]$

// Calculate the degree of user fairness

24: $F_k^* \leftarrow F_k^* \setminus \{j\}$ //Remove the subcarrier j from F_k^*

25: **end for**

26: $\Delta R_{ii} = R_{ii}^* - R^*$, $\Delta \mu_{ii} = \mu_{ii}^* - \mu^*$, $ii \in \kappa$ //Calculate the difference of the total system capacity and the degree of users fairness between the user which add a subcarrier again and the original user

27: $\bar{\mathbf{R}} = [\Delta R_1, \Delta R_2, \dots, \Delta R_K]$, $\bar{\boldsymbol{\mu}} = [\Delta \mu_1, \Delta \mu_2, \dots, \Delta \mu_K]$ //Calculate the proportional values

28: $k = \arg \max_{k \in \kappa} (\bar{\mathbf{R}} / \bar{\boldsymbol{\mu}})$ //Find the user who has the maximum ratio of system capacity and user fairness

29: $\chi_j^* = \min_{j \in \zeta^*} \{\chi_{k,j}^*\}$, $F_k^* \leftarrow F_k^* \cup \{j\}$, $\zeta^* \leftarrow \zeta^* \setminus \{j\}$ //For this user assigned a unallocated subcarrier

30: According to improved water-filling algorithm, update power baseline w^*

31: Repeat step 11 to 27 until $\zeta^* = \phi$

32: $R = \sum_{k=1}^K R_k^*$ //After completing subcarrier allocation, calculate the total capacity

4. Simulation and Performance Analysis

In this section, the computer simulation are given about our proposed algorithm. Simulation platform parameters using IEEE802.16a standard, the system parameters are assumed as follows: the system bandwidth is $B=1\text{MHZ}$, number of subcarriers is $N=1024$, the total power is $P_{tot}=7.5*10^{-6}$, the

noise density is $N_0=10^{-9}$, constraint of each user's rate is λ , value random integer from 1 to 9, the channel model is Rayleigh fading channel. Here a measurement standard is given for user fairness, which defined as $\mu = \left\| \bar{\mathbf{R}} - \bar{\boldsymbol{\lambda}} \right\|$, where $\bar{\mathbf{R}} = [R_1, R_2, \dots, R_K]$, $\bar{\boldsymbol{\lambda}} = [\lambda_1, \lambda_2, \dots, \lambda_K]$. If the result meets the proportional rate limits, $\mu=0$ which means the fairness is better when the value is smaller.

Fig.4 shows the comparison of the total system capacities between average power algorithm and proposed algorithm when the SNR is 6dB and 16dB. As can be seen from the figure, as the number of user increases, the system capacities also increase slowly. This is the effect of multiuser diversity gain. The system capacity of proposed algorithm is similar to the one of average power algorithm for all the numbers of users for this set of simulation parameters.

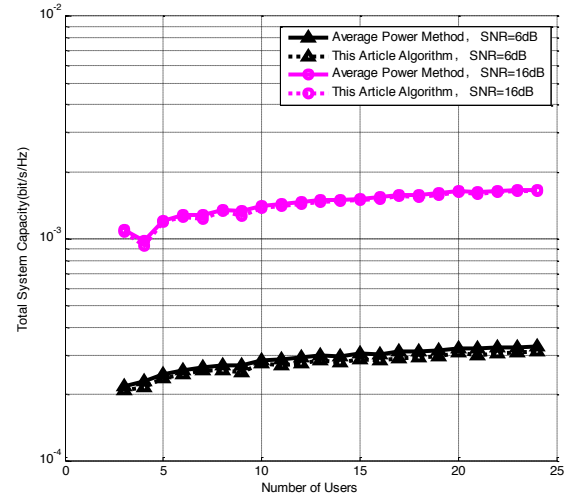


Fig. 4. Comparison of total system capacity when SNR is 6dB and 16dB.

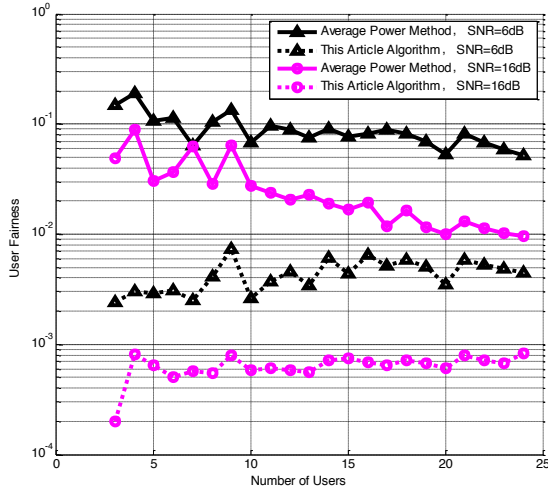


Fig. 5. Comparison of user fairness when SNR is 6dB and 16dB.

Fig.5 depicts the user fairness as a function of the number of users for the average power algorithm and proposed algorithm when the SNR is 6dB and 16dB. It is observed that the proposed algorithm outperforms the average power algorithm, because the smaller the value, the better the fairness.

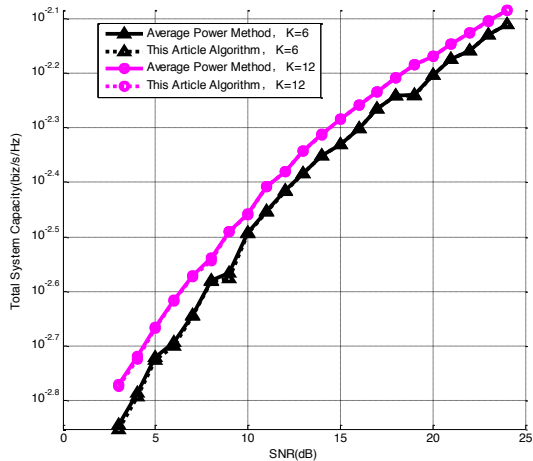


Fig. 6. Comparison of total system capacity when number of user is 6 and 12.

Fig.6 shows the comparison on the total system capacities as a function of the SNR, when the number of user is 6 and 12. It can be seen from the figure, that, the total system capacities increase as the SNR increases. Furthermore, it is noticeable that the system capacities of the proposed algorithm is very close to the average power algorithm, which the highest reduce is 2.25%.

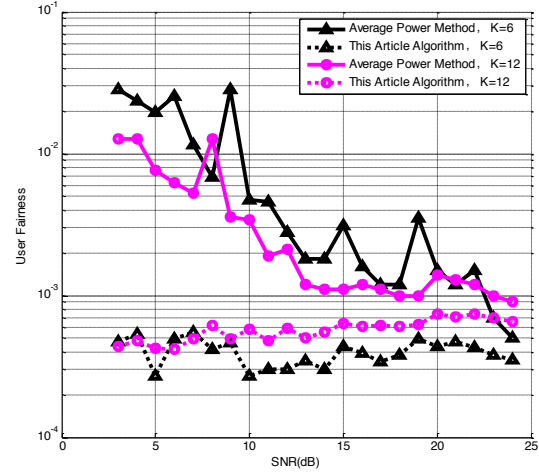


Fig. 7. Comparison of User fairness when number of user is 6 and 12.

Fig.7 illustrates the comparison of user fairness between average power algorithm and proposed algorithm, as a function of the different SNR, when the number of users, K , is 6 and 12. It can be seen that in the low SNR, the user fairness of the proposed algorithm outperforms the average power algorithm. With increasing SNR, the user fairness for both algorithms are getting closer. It implies that at high SNR, the power assigned to each subcarrier is close to the average power, thus improving its fairness is not very obvious.

In summary, the proposed algorithm improves user fairness significantly while keep the system capacity at a high level, particularly evident when the SNR is low.

5. Conclusion

In this paper, a novel optimize user fairness scheme is proposed in multi-OFDMA system. This scheme adopts an improved water-filling algorithm, fixed the capacity and fairness measure during the subcarrier allocation. System capacity is guaranteed and user fairness is greatly improved. Simulation results show that capacity of proposed algorithm is close to average power algorithm, system capacity declines by only about 3%, but the fairness raises 99.20%

6. ACKNOWLEDGMENTS

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