An Efficient Resource Allocation Algorithm for OFDM-Based NOMA in 5G Systems

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Abstract: Non-orthogonal multiple access (NOMA) has become the key technology in the future 5G wireless networks. It can achieve multi-user multiplexing in the transmit power domain by allocating different power, which can effectively improve the system capacity and spectral efficiency. Aiming at the problem of high computational complexity and improving system capacity in non-orthogonal multiple access (NOMA) based on orthogonal frequency division multiple access (OFDMA) for 5G wireless cellular networks, this paper proposes an improved low complexity radio resource allocation algorithm for user grouping and power allocation optimization. The optimization model is established with the goal of maximizing system capacity. Through the step-by-step optimization idea, the complex non-convex optimization problem is decomposed into two sub-problems to be solved separately. Firstly, all users are grouped based on the greedy method, and then the power allocation is performed on the sub-carriers of the fixed group. Simulation results show that the proposed algorithm has better system capacity than the existing state-of-the-art algorithms and reduced complexity performance.

Keywords: 5G; NOMA; OFDMA; optimization; algorithms

1. Introduction

The rapid development of the mobile Internet and the Internet of Things and the popularization of the application of intelligent terminals have placed higher demands on future wireless networks. The new generation of mobile communication systems (5G) needs to further expand the system capacity to meet the emerging new business [1–5]. In the face of increasingly tight spectrum resources, the traditional multiple access method has got difficulties to meet the demand, so the industry proposes to adopt a new type of multiple access mode in 5G, namely non-orthogonal multiple access (NOMA) [6–9]. NOMA technology can significantly improve system spectral efficiency and support large-scale user access and has become one of the key technologies of 5G [10,11]. For traditional orthogonal multiple access (OMA) technology, a single user is allocated a single radio resource, such as frequency division or time division, and NOMA technology introduces a power domain, which can allocate the same resource to multiple users, that is, multiple users can share the same resource block so that the system can accommodate users, regardless of the number of system orthogonal resource blocks [11]. The NOMA technology adopts superposition coding at the transmitting end, and allocates less power to users with good channel conditions through the power division multiplexing technology, and allocates
more power for users with poor channel conditions, thereby achieving better user fairness [12–14]. Compared with OMA, the complexity of the receiver of the NOMA system will increase, but its biggest advantage is that it can obtain higher spectral efficiency, which is equivalent to increasing the complexity of the receiver in exchange for spectral efficiency [15–17]. As processor performance continues to increase, more advanced receivers can be used on the device, and the implementation of NOMA technology in real-world systems is also possible using multi-user separation via a successive interference cancellation (SIC) technique at the receiver. In the NOMA system, it is impractical to superimpose all users on the same resource block because of the large decoding delay and serious error propagation [18,19]. Therefore, it is necessary to reduce the number of users superimposed on the same resource block by means of user grouping. Reasonable user grouping and power allocation algorithms can reduce the interference between user signals and improve system capacity. Many scholars have conducted related research. Reference [20] proposes an exhaustive search user grouping scheme, which selects the best-performing user group by traversing all candidate user combinations. However, the complexity of the algorithm increases exponentially with the increase in the number of users. When the number of users is large, the algorithm is impractical. Reference [21] introduced a random user grouping algorithm, which first randomly divides users into groups, and then extracts one user from each group for pairing according to the channel gain difference. The algorithm can guarantee large differences between user channels using the same resource, but the users extracted from each group are randomly selected, and thus cannot get better system performance. In the study of power allocation, the reference [22] analyzed and compared the effects of three power allocation algorithms on user performance under the proportional fairness user matching scheme, including iterative water-filling method (IWF), fractional power allocation (FPA) and fixed power allocation (FPA). Reference [23] uses a method combining Lagrangian duality and dynamic programming to jointly optimize the user grouping and power allocation problem, although the optimal solution of the approximate full search algorithm can be obtained, the algorithm complexity is high. Reference [24] studies the power allocation problem of the NOMA system with the goal of maximizing system throughput. First, the base station transmits power equally distributed to each subcarrier, and then the power is allocated to the superimposed users on each subcarrier by FPA. This method ignores the channel transient characteristics in the power allocation between subcarriers and cannot achieve the best performance. Therefore, in [25] considering the influence of channel gain difference, it is proposed to use the iterative water-filling algorithm to allocate power between subcarriers, and achieve better system throughput, but in the process of power allocation. It takes several iterations, and each iteration will cause the power allocation scheme of the user on the same subcarrier to be invalid, which needs to be redesigned, so it still has a certain complexity.

In view of the problems in the above research, this paper proposes an improved user grouping and power allocation scheme, aiming to further reduce the complexity of the algorithm and optimize the system capacity. The optimization model is established with the goal of maximizing system capacity. Through the step-by-step optimization idea, the complex non-convex optimization problem is decomposed into two sub-problems to be solved separately. Firstly, all users are grouped based on the greedy method, and then the power allocation is performed on the sub-carriers of the fixed group. Considering that the linear water filling algorithm [26] does not need iteration, but the performance of the iterative water-filling algorithm can be obtained, this paper uses the linear water filling algorithm for all subcarriers having power allocated, and the total multiplexing power of each subcarrier is obtained; The FPA method is used to allocate power to the subcarrier superimposed users. The simulation results show that the proposed algorithm can obtain the throughput performance similar to the existing optimal algorithm under the condition of greatly reducing the complexity.

The rest of the paper is organized as follows. In Section 2, the system model is described. In Section 3, the proposed algorithms and their principles are analyzed. In Section 4, the complexity analysis is described. Section 5 provides the simulation results, while Section 6 concludes the paper.
2. System Model

Consider a single-cell multi-user downlink orthogonal frequency division multiplexing (OFDM)-NOMA cellular system, assuming that there is one base station in the cell, $K$ users, and each user is equipped with one antenna, as shown in Figure 1.

![Proposed system model for orthogonal frequency division multiplexing (OFDM)-based Downlink non-orthogonal multiple access (NOMA).]

Figure 1. Proposed system model for orthogonal frequency division multiplexing (OFDM)-based Downlink non-orthogonal multiple access (NOMA).

The total system bandwidth is $B$, the number of orthogonal subcarriers used for transmission is $N$, and the bandwidth of each subcarrier is $B_k = \frac{B}{N}$. On each subcarrier, the base station transmits a multi-user superposition signal, and the total transmission power of the base station is $P_T$. If the number of superimposed users on the $n$-th subcarrier is $k_n$, the superimposed signal $s_n$ transmitted by the base station on the subcarrier $n$ can be expressed as

$$s_n = \sum_{k=1}^{k_n} \sqrt{p_{k,n}} x_{k,n}, \quad (1)$$

where $p_{k,n}$ represents the power allocated by the $k$-th user on the $n$-th subcarrier and $x_{k,n}$ represents the transmission signal of the $k$-th user on the $n$-th subcarrier. On the $n$-th subcarrier, the received signal obtained by superimposing the user signal through the channel transmission to the receiving end of the $k$-th user can be expressed as

$$y_{k,n} = h_{k,n} \sum_{i=1}^{k_n} \sqrt{p_{i,n}} s_{i,n} + \omega_{k,n} = \sqrt{p_{k,n}} h_{k,n} s_{k,n} + \sum_{i=1, i \neq k}^{k_n} \sqrt{p_{i,n}} h_{k,n} s_{i,n} + \omega_{k,n}, \quad (2)$$

where $h_{k,n}$ represents the channel gain of the base station to the $k$-th user on the $n$-th subcarrier and $\omega_{k,n}$ represents the additive white Gaussian noise with a mean of 0 and a variance of $\sigma_n^2$.

It can be seen from Equation (2) that at the receiving end, the signal received by the user includes its desired signal and interference signals from other users. To obtain the desired signal, the receiver can use the successive interference cancellation (SIC) technique [27–29] for signal detection. For users with the lowest signal-to-noise ratio (SNR), other users’ signals can be directly detected as noise to demodulate their own signals; for users with high SNR, the signals of all users whose signal-to-noise ratio is lower than their own are demodulated and removed from the received superimposed signals to eliminate the interference, and then detects its own desired signal. Assume that on the $n$-th subcarrier,
the user sorts according to the signal to interference and noise ratio (SINR) from large to small: 
\[ \varphi_{1,n} \geq \varphi_{2,n} \geq \cdots \geq \varphi_{k,n}, \] where \[ \varphi_{k,n} = \frac{|h_{k,n}|^2}{\sigma_n^2}. \] Then, after SIC detection processing, the SINR of the \( k \)-th user on the \( n \)-th subcarriers

\[ \gamma_{k,n} = \frac{p_{k,n}|h_{k,n}|^2}{\sum_{i=1}^{k-1} p_{i,n}|h_{i,n}|^2 + \sigma_n^2} = \frac{p_{k,n} \varphi_{k,n}}{\sum_{i=1}^{k-1} p_{i,n} \varphi_{k,n} + 1}. \] (3)

Using the Shannon formula, the capacity of the \( k \)-th user on the \( n \)-th subcarrier can be expressed as

\[ R_{k,n} = B_s \log_2 \left( 1 + \gamma_{k,n} \right). \] (4)

Then the total capacity on the \( n \)-th subcarrier is

\[ R_n = B_s \sum_{k=1}^{K} \log_2 \left( 1 + \gamma_{k,n} \right). \] (5)

As can be seen from Equation (5), user throughput is closely related to user grouping and power allocation. Therefore, in order to improve user throughput, research on user grouping and power allocation is necessary. In this system model, the user grouping and power allocation schemes on the subcarriers with the total throughput of the NOMA system under the total power constraint are optimized. The optimization problem studied in this paper was

\[ \max_p \sum_{n=1}^{N} \sum_{k=1}^{K} \rho_{k,n} R_{k,n}, \] (6)

Subject to

\[ \sum_{n=1}^{N} \sum_{k=1}^{K} p_{k,n} \leq P_T, \quad \forall k, n, \] (7)

\[ p_{k,n} \geq 0, \quad \forall k, n, \] (8)

\[ \rho_{k,n} \in \{0, 1\}, \quad \forall k, n, \] (9)

\[ \sum_{k=1}^{K} \rho_{k,n} = k_n, \quad \forall k, n, \] (10)

wherein, the Equation (7) represents the total power constraint, that is, the sum of the user powers on all subcarriers is not greater than the total transmit power \( P_T \); Equation (8) indicates that the power allocated by each user superimposed on the \( n \)-th subcarrier is not less than 0; Equations (9) and (10) refer to the case where the user is superimposed on each subcarrier, denoted by \( \rho_{k,n} \), if the \( k \)-th user is on the \( n \)-th subcarrier, then \( \rho_{k,n} = 1 \), otherwise \( \rho_{k,n} = 0 \). The optimization problem of Equations (6) to (10) is a joint optimization problem that combines user grouping and power allocation on subcarriers, which is obviously non-convex, and it is difficult to directly obtain an optimal solution. In addition, in the NOMA system, multiple users are superimposed on one subcarrier, which increases the computational complexity of joint optimization to solve the global optimal solution is added. In order to reduce the complexity of resource allocation in the NOMA system, this paper decomposes it into two sub-problems of user grouping and power allocation on sub-carriers and uses the step-by-step solution to obtain the sub-optimal solution of the optimization problem.
3. Proposed Algorithm

3.1. User Grouping Scheme

In the NOMA system, the sender superimposes the signals of multiple users on the power domain and transmits them simultaneously. Therefore, different user grouping schemes have a great impact on system performance. An exhaustive algorithm is used to traverse the search for all possible user combinations, and then the system performance under different user grouping results is compared to obtain the best user grouping. However, the exhaustive algorithm has a high degree of complexity and is not applicable in practice. In order to reduce the complexity of the exhaustive search, this paper considered the greedy algorithm to perform user selection on each subcarrier. The basic idea of the greedy algorithm is to always use the best choice in the current step as the optimal strategy when solving the problem. In the process of user grouping, it is assumed that the average power allocated to the subcarriers is $P = P_T / N$, and the FPA algorithm or the FTPA algorithm is used on each subcarrier to perform power allocation on the superposed users. When user grouping is performed on a single subcarrier, the user with the largest weighted sum rate is selected as the first user on the subcarrier, and the user who can better improve the system and capacity is selected from the remaining users to join the packet. Since the power distribution between the sub-carriers is evenly distributed, the user selection is performed for all sub-carriers without considering the sub-carrier order. The specific steps of the greedy algorithm (GA) scheme are as follows in Algorithm 1.

**Algorithm 1 Proposed GA Based User Grouping**

**Initialization.** Set of subcarriers $C = \{1, 2, \cdots, N\}$, set of users $U = \{1, 2, \cdots, K\}$, set of superimposed users on each subcarrier $\Lambda_n = \emptyset$, let $p_{k,n} = 0$, the $k$-th user average data rate is $T_k = 0$, where subcarrier $n \in C$, user $k \in U$, number of iterations $n = 1$

1. Select the first user on the $n$-th subcarrier
2. If there is a user with a capacity of 0 in the user set $U$
3. The user $k_{\text{NOPT}}$ with the highest channel gain among the users is selected
4. Otherwise, select the user with the largest $R_k / T_k$ from the user set $U$, i.e., $k_{\text{NOPT}} = \arg \max \left( R_k / T_k \right)$, $k \in U$
5. Group $k_{\text{NOPT}}$ into the $\Lambda_n$ set
6. Remove the user from the user set $U$, that is, $U \leftarrow U \setminus k_{\text{NOPT}}$, and update the corresponding $T_k$, $p_{k,n} = 0$.
7. Select other $k_n - 1$ superimposed users on the $n$-th subcarrier.
8. Select the user $m$ ($m \in U$) is arbitrarily selected from the user set $U$
9. Calculate the total capacity $R_n$ of the user $m$ and all users in the set $\Lambda_n$ on the subcarrier according to Equation (5)
10. Determine the user who takes the maximum value of $R_n$
11. For $\hat{m}$, the user $\hat{m}$ is grouped into the set $\Lambda_n$, and simultaneously removed from the set $U$, that is, $U \leftarrow U \setminus \hat{m}$, and update the corresponding $T_k$, $p_{k,n} = 0$
12. If the number of elements in the set $\Lambda_n < k_n$
13. return to step 1
14. Otherwise, continue with the steps below
15. The user group is completed on the $n$-th subcarrier, so that $n = n + 1$, $U = \{1, 2, \cdots, K\}$
16. If $n \leq N$, return to step 2
17. Otherwise, the iteration is jumped out and the user group is completed

3.2. Power Allocation Scheme

After determining the user grouping on the subcarriers, this section studies the power allocation problem combines the water filling principle with the FTPA method and further optimizes the objective
function. First, a linear water filling algorithm is used between subcarriers to complete power allocation, and each subcarrier power $p_n$ is obtained, and then the FTPA method is used to allocate power to the superimposed users on a single subcarrier. After determining the user grouping, the optimization problem of Equation (6) can be rewritten as

$$\max_{p_n} \sum_{n=1}^{N} B_s \log_2 (1 + p_n H_n),$$

Subject to $\sum_{n=1}^{N} p_n \leq P_T$, (12)

where $H_n = \frac{h_n}{N_0 B_s}$, $h_n$ represents the equivalent channel gain of the $n$-th subcarrier, and a better value can be determined by simulation, that is, the channel gain of the user with the best channel condition in the user group is superimposed on the $n$-th subcarrier, $N_0$ represents the noise power spectral density.

Obviously, Equation (11) is a convex optimization problem, which can be solved by a Lagrangian algorithm to construct a Lagrangian function

$$L = \sum_{n=1}^{N} B_s \log_2 (1 + p_n H_n) + \lambda \left( P_T - \sum_{n=1}^{N} p_n \right),$$

where $\lambda$ is the Lagrangian multiplier.

On both sides of Equation (13), $p_n$ and $\lambda$ are respectively derived, and then

$$\frac{\partial L}{\partial p_n} = \frac{1}{\ln 2} \times \frac{H_n}{1 + H_n p_n} - \lambda.$$ (14)

Let the derivative of Equation (14) be 0, which gives

$$\lambda \ln 2 = \frac{H_n}{1 + H_n p_n},$$ (15)

Since the left side of the equation is a non-negative constant, it can be obtained from Equation (15)

$$\frac{H_n}{1 + H_n p_n} = \frac{H_m}{1 + H_m p_m},$$ (16)

where $m, n = \{1, 2, \cdots, N\}$. It can be deduced by Equation (16)

$$p_n = p_m + \frac{1}{H_m} - \frac{1}{H_n}.$$ (17)

Equation (17) shows the relationship between the powers of the subcarriers. If the power of one of the subcarriers is known, the power of the other subcarriers can be obtained. In addition, the power sum of all subcarriers should meet the total power constraint, i.e.,

$$\sum_{n=1}^{N} p_n = N \left( p_m + \frac{1}{H_m} \right) - \sum_{n=1}^{N} \frac{1}{H_n} \leq P_T.$$ (18)

Then Equation (18) can be further derived

$$p_m \leq \frac{1}{N} \left( P_T - \frac{N}{H_m} + \sum_{n=1}^{N} \frac{1}{H_n} \right).$$ (19)
If the channel gains $H_n$ of the subcarriers are arranged in a specific order, the order of arrangement of the corresponding subcarrier powers $p_n$ can be obtained. The subcarrier is removed while the subcarrier power $p_j$ in which one of the $H_n$ values is small is set to 0, that is, its channel gain is removed from $\sum_{n=1}^{N} \frac{1}{H_n}$, and replaced by $\sum_{n=1}^{N} \frac{1}{H_n} - \frac{1}{H_j}$. Assuming that the sub-carrier channel gains are arranged in ascending order, that is, $H_1 \leq H_2 \leq \cdots \leq H_N$, the order of the corresponding sub-carrier powers is $p_1 \leq p_2 \leq \cdots \leq p_N$. According to Equation (19)

$$p_1 = \frac{1}{N} \left( P_T - \frac{N}{H_1} + \sum_{n=1}^{N} \frac{1}{H_n} \right).$$

If $p_1 \leq 1$, set $p_1$ to 0 and remove it from the assignable subcarrier set, and then assign power to the second subcarrier.

$$p_2 = \frac{1}{N} \left( P_T - \frac{N-1}{H_2} + \sum_{n=2}^{N} \frac{1}{H_n} \right).$$

Until $p_j > 0$ is found, then the power of the remaining subcarriers is sequentially determined according to Equation (17). So far, the power allocation on the subcarriers is completed. After the linear water filling power distribution, the user on the subcarrier that actually participates in the water filling is further allocated power, and the packet user on the removed subcarrier is ignored, and the sub-optimal solution of the power allocation is obtained, and the joint optimization user packet and power allocation problem are obtained most.

After linear water-filling power allocation is performed on the subcarriers, the power $p_n$ on each subcarrier is obtained. Then use the FTPA method [10] to allocate power to the superimposed users on the subcarriers, according to the following Equation

$$p_{k,n} = \frac{p_n}{\sum_{i \in \Lambda_n} h_i^{-2\alpha_{\text{FTPA}}}} h_{k,n}^{-2\alpha_{\text{FTPA}}}. \tag{22}$$

where $\Lambda_n$ represents the superimposed user set on the $n$-th subcarrier, $\alpha_{\text{FTPA}}$ represents the attenuation factor ($0 \leq \alpha_{\text{FTPA}} \leq 1$), and when $\alpha_{\text{FTPA}} = 0$, the average power distribution between users is superimposed. As $\alpha_{\text{FTPA}}$ increases, users with small channel gains will be allocated more power.

Based on the above analysis, the specific process of the power allocation algorithm (PAA) is as follows in Algorithm 2.

**Algorithm 2 Proposed PAA**

1. Arrange the channel state values $H_n$ of the subcarriers and the power $p_n$ in ascending order,
2. Select the first user on the $n$-th subcarrier
3. for $n = \{1, 2, \cdots , N\}$
4. Count $p_n$ using Equation (19)
5. if $p_n \leq 0$
6. let $p_n = 0, 1/H_n = 0, N \leftarrow N - 1$, remove this subcarrier
7. Until $p_n > 0$ jump out of the loop.
8. Determine the power of the remaining subcarriers using Equation (17)
9. Calculate the power $p_{k,n}$ of the superimposed user on each subcarrier using Equation (22), and complete the entire power allocation.

**4. Complexity Analysis**

In this paper, the proposed user grouping method based on the GA scheme was mainly used in the user grouping on the subcarrier. For the convenience of discussion, only the complexity analysis of the
user grouping situation on a single subcarrier was performed, and the number of user combinations on the subcarrier was considered. Assuming that the number of users superimposed on the \( n \)-th subcarrier was \( k_n \) and the number of candidate users was \( K \), then the user combination mode existing on the \( n \)-th subcarrier had \( \sum_{k=0}^{k_n} \binom{K}{k} = k_n (N - k_n + 1) \). There were \( \binom{K}{k_{n+1}} \) combinations in the algorithm, so the proposed method effectively reduced the computational complexity. In the power distribution process, the proposed linear water filling algorithm needed \( 2N - M + MN \) sub-additions and \( 2 + M \) multiplications, the operation amount was \( O(N) \) and the iterative water-filling algorithm required \( 2kN \) additions and \( K(N + 2) \) multiplications, and the operation amount was \( O(kN) \), where \( M \) represents the number of subcarriers removed and \( k \) represents the number of iterations. It can be seen that the linear water filling algorithm is equivalent to the iterative computation of the iterative water-filling algorithm, but the total complexity was significantly lower than in the iterative water-filling algorithm.

5. Simulation Results and Performance Analysis

This section mainly simulated the downlink NOMA system and used MATLAB software to verify the performance of the proposed algorithm. In the simulation process, the user grouping on the subcarrier adopts a GA based user grouping method and compared it with other user grouping algorithms. The proposed PAA uses the linear water-filling power allocation (LWF-FTPA) and compared it with the iterative water-filling power allocation (IWF-FTPA) [30], equal power allocation between subcarriers (EPA) [31] and the FTPA algorithm was used between overlay users. In the simulation, the base station transmit power was set to 30 dBm, and the number of superimposed users in the power domain was two. The main simulation parameters are shown in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>System bandwidth</td>
<td>10 MHz</td>
</tr>
<tr>
<td>Wavenumber of subcarriers</td>
<td>64</td>
</tr>
<tr>
<td>Delay extension</td>
<td>5 ( \mu )s</td>
</tr>
<tr>
<td>Base station transmit power</td>
<td>30 dBm</td>
</tr>
<tr>
<td>Channel model</td>
<td>Rayleigh fading channel</td>
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<tr>
<td>Number of overlay users</td>
<td>2</td>
</tr>
<tr>
<td>Maximum Doppler shift</td>
<td>30 Hz</td>
</tr>
<tr>
<td>Noise power spectral density</td>
<td>(-174 \text{ dBm/Hz})</td>
</tr>
<tr>
<td>Channel attenuation factor (a_{\text{FTPA}})</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Figure 2 compares the total system throughput of the proposed user grouping algorithm with the reference [29] algorithm, exhaustive grouping algorithm of [20] and the random grouping algorithm of [21]. After using these four algorithms to group users of all sub-carriers in the cell, combined with the linear water filling-based power allocation algorithm proposed in this paper, the power allocation was performed on the users on each sub-carrier, and the total cell throughput obtained by the four algorithms was compared. Among them, take \(a_{\text{FTPA}} = 0.2\). It can be seen from Figure 2 that the throughput performance of the proposed algorithm was better than that of the references [20,29], and also the search range was reduced and the complexity was greatly reduced. In addition, compared with the reference [21] algorithm, the proposed algorithm could effectively improve the total cell throughput. This is because the user grouping algorithm of the reference [21] completely separates the users into several sets, and does not take into account the influence of the channel state information (CSI) of each user, resulting in poor system throughput performance.
Figure 2. Comparison of total system throughput obtained by four user grouping algorithms.

Figure 3 shows the relationship between total cell throughput and the number of cell users under three different power allocation algorithms when $\alpha_{\text{FTP}} = 0.2$. The proposed user grouping selects the GA based user grouping scheme (LWF-FTPA). As can be seen from Figure 3, the total cell throughput increased with the number of cell users. In addition, when the number of users was fixed, the performance of the proposed algorithm and IWF-FTPA algorithm was completely closed, and it was obviously better than the performance of the EPA-FTPA algorithm. Compared with the EPA-FTPA algorithm, the performance of the proposed algorithm was improved by about 8.8%. The EPA-FTPA algorithm had poor performance due to the fact that the actual channel conditions were not considered when the power was initially allocated. Although the IWF-FTPA algorithm could obtain better system throughput than EPA-FTPA, the algorithm needed to go through multiple iterations and the computational complexity was high. In this paper, the LWF algorithm avoided the multiple iterations of the iterative water-filling algorithm, the complexity was reduced, and the better throughput performance could be obtained.

Figure 4 is a graph showing the relationship between system throughput and power allocation factor $\alpha_{\text{FTP}}$ when $K = 10$, where the user group selects the greedy algorithm based user grouping scheme herein. It can be seen from Figure 4 that with the increase of $\alpha_{\text{FTP}}$, the total throughput of the cell shows a downward trend, mainly because the larger the $\alpha_{\text{FTP}}$, the greater the difference in the power allocated by each user, and the edge users with poor channel conditions will be allocated. Moreover, all will sacrifice part of the system capacity, but to a certain extent to ensure user fairness.

The achievable sum rate was compared with the total power to noise ratio under different algorithms in Figure 5. As can be seen from Figure 5, the achievable sum-rate increased with increasing the total power to noise ratio for all algorithms. The results also indicate that the proposed algorithm effectively showed better overall sum rate performance as compared with the references [20,21,29] algorithms. The results also gave important information that the proposed algorithm was more robust in noisy environments than the existing state-of-the-art schemes.
Figure 3. Relationship between total cell throughput and the number of users for different algorithms.

Figure 4. Comparison of the total system throughput against the power allocation factor. The achievable sum rate was compared with the total power to noise ratio under different algorithms in Figure 5. As can be seen from Figure 5, the achievable sum rate increased with increasing the total power to noise ratio for all algorithms. The results also indicate that the proposed algorithm effectively showed better overall sum rate performance as compared with the references [20, 21, 29] algorithms. The results also gave important information that the proposed algorithm was more robust in noisy environments than the existing state-of-the-art schemes.
Figure 5. Comparison of the achievable sum-rate against the total power to noise ratio.

Figure 6 compares the sum rate against the number of iterations of the proposed algorithm and the references [20,21,29] and OMA algorithms. As can be seen from Figure 6 the sum-rate increased with an increasing number of iterations for all the algorithms. However, it is clear from the results that the proposed algorithm achieved the maximum sum rate value earlier than the competing alternatives. The other schemes took a large number of iterations to reach their maximum values but they were still lower than the proposed algorithm’s.

Figure 6. Comparison of the sum-rate against the number of iterations under different algorithms.
6. Conclusions

In this paper, the problem of downlink resource allocation in the OFDM-NOMA system was studied with the goal of maximizing system capacity. Through the idea of step-by-step optimization, the optimization problem was decomposed into two sub-problems: user grouping and power allocation. Firstly, a subcarrier user grouping strategy based on GA was adopted. When the performance better to the exhaustive algorithm was obtained, the required number of iterations decreases, and the computational complexity was effectively reduced. Secondly, a low-complexity power allocation algorithm was proposed. The linear water filling algorithm was combined with the FTPA method. The linear water filling algorithm was used to allocate power to all sub-carriers, and the sub-carrier superimposed users were allocated power by FTPA. The linear water-filling power allocation algorithm did not need to perform multiple iterations, but its capacity performance was completely close to the iterative water-filling algorithm. The simulation results show that the proposed user grouping and power allocation scheme could further reduce the complexity based on the optimization of the capacity of the NOMA system. A further extension of this study is to consider the MIMO integration and analyze various important parameters.

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