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An Efficient Resource Allocation Algorithm for D2D Communications Based on NOMA

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ABSTRACT The performance of the future mobile communication system could greatly improve as a result of Device-to-Device (D2D) communication and Non-Orthogonal Multiple Access (NOMA). Reduction of the interference between the D2D users and cellular users is crucial in improving the overall throughput and efficiency of the D2D communication based on NOMA. This paper proposes a joint sub-channel and power allocation algorithm for D2D communication based on NOMA to maximize the uplink energy efficiency and throughput of the mobile communication system. The algorithm uses the Kuhn-Munkres (KM) technique to allocate a channel for each D2D group and formulates an optimal power allocation problem using Karush-Kuhn-Tucker (KKT) conditions. Simulations indicate that the proposed algorithm outperforms the current state-of-the-art algorithms in regards to energy efficiency and throughput under different network conditions.

INDEX TERMS Non-Orthogonal Multiple Access (NOMA), Device-to-Device (D2D), 5G, power allocation, interference management, energy efficiency.

I. INTRODUCTION

The recent unprecedented growth in the use of smart mobile devices and the increasing demand for a variety of multimedia applications in recent years, cellular networks are being greatly challenged. As one of the key technologies of the fifth-generation (5G) mobile communication [1], Device-to-Device (D2D) communication enables direct communication between adjacent devices in the communication network without the support of infrastructure such as core equipment or central equipment [2] so as to reduce the burden on the core network. Non-Orthogonal Multiple Access (NOMA) allows multiple users to share the same resources in terms of time and frequency through power-domain multiplexing and serial interference cancellation (SIC) in order to improve the system throughput and energy efficiency [3]. Therefore, combining D2D with NOMA could greatly improve the quality of service of future mobile communication systems.

In addition to increasing the efficiency, flexibility, and intelligence of the communication network system, D2D communication also introduces additional interference to the system. Therefore, one of the key problems has been how to coordinate the interference between the D2D system and the communication system [4-8]. In [9], traditional cellular users and D2D users independently determine their respective transmit power to maximize their utility. They use the game theory to model the trade-off between the two and achieve the highest system energy efficiency values. In [10], D2D users reuse resources of multiple cellular users via optimal channel selection in order to improve the throughput of the entire system. In [11], a reverse iterative combination auction technique is proposed to realize the uplink resource allocation between the D2D and cellular users so as to optimize energy efficiency. In [12], a relaxation-based algorithm is proposed to maximize the weighted energy efficiency value of the D2D link. However, these works use traditional Orthogonal Multiple Access (OMA) as the D2D access technology.

Extensive research has been conducted on the resource allocation problem of D2D communication. The works in [6-7] propose a distance-based D2D resource allocation approach. In [6], the author proposes an interference limit loop control strategy to find the appropriate cellular users to share the same spectrum resources with D2D users based on distances between users and base stations. In [7], a distance-limited resource sharing is proposed to ensure that the outage

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probability of D2D user communication is lower than the specified threshold value. However, the study only considers scenarios with only one pair of D2D users in the network. Similarly, resource allocation strategies are not based on long-term performance.

Considering multiple pairs of D2D users, the work in [8] models the resource allocation problem in the D2D network as Mixed-Integer Nonlinear Programming (MINLP) and uses a heuristic algorithm to solve the problem. In [9], D2D users are categorized into different user groups and suitably selected to minimize the impact of intra-system interference. However, the system performance still needs to be improved as the resource allocation problem in D2D communication has not yet been fundamentally solved.

In NOMA, reduction of mutual interference among users is crucial in improving the system throughput and energy efficiency. In [13], a user matching technique based on a matching degree is proposed for the downlink multiple-input multiple-output (MIMO) communication system. Here, an adaptive method is used for optimal power allocation to increase the systems' capacity. In [14-15], the power allocation of two users under large base stations is analyzed to prove that NOMA can greatly improve the systems' capacity and energy efficiency compared to the traditional OMA.

Recently, some works have applied NOMA in D2D communication systems. In [16], a new concept of *D2D group* using NOMA is proposed. In each D2D group, a D2D transmitter could simultaneously communicate with the two receivers using NOMA. In [17], multiple cellular users are multiplexed on the same channel using NOMA. This can be achieved by first obtaining the power of the cellular user based on the constraints of the continuous interference cancellation demodulation sequence and subsequently allocating designated cellular users to the D2D users through a dual iterative algorithm. However, further studies on resource allocation for D2D communications based on NOMA are required. Also, the energy efficiency of such system is yet to be investigated.

In summary, considering the interference between D2D users and traditional cellular users, and the power allocation problem in NOMA, this paper proposes a joint sub-channel and power allocation algorithm for D2D communication based on NOMA. The main objective is to guarantee the communication Quality of Service (QoS) of cellular users and D2D users and to maximize the total uplink energy efficiency and throughput of the multiple D2D groups that use NOMA. In order to solve this joint problem, multiple D2D groups multiplex sub-channels of multiple cellular users by constructing a maximum matching problem of weighted bipartite graphs in graph theory, and then Kuhn-Munkres (KM) algorithm is used to ensure the communication quality of cellular users. A channel of the corresponding cellular user is allocated to each D2D group. Also, under the premise of ensuring the communication quality and transmit power of D2D users in each D2D group, the optimal power allocation scheme is obtained using Karush-Kuhn-Tucker (KKT) conditions. To demonstrate the effectiveness of the proposed algorithm, the performance in terms of energy efficiency and throughput is compared with the current state-of-the-art algorithms [2], [17], [21] and the traditional D2D-OMA algorithm under different system parameters and conditions.

The paper is organized as follows. Section II presents D2D-NOMA system model considered for the study. Section III describes the details of the proposed resource allocation algorithm that consists of a channel allocation algorithm and a power allocation algorithm. Section IV presents simulation results and Section V provides a comparative analysis of the findings. Finally, Section VI concludes the paper.

II. SYSTEM MODEL

An uplink transmit scenario in a single cell is considered, as shown in Figure 1. The cell radius is represented by R, and the base station is located at the cell center. The cell comprises of N number of D2D groups and M number of cellular users. Each D2D group consists of one D2D transmitter and several D2D receivers where the receivers are randomly distributed. The devices are located within a circular area having a radius of d_{max}. It is assumed herein that through common control channel, the channel information of all users can be acquired via the base station while a channel allocation algorithm is performed at the base station to allocate channels for each user. The cellular user communicates with the base station in a traditional cellular mode and one channel is allocated to each cellular user. The cellular users do not have interference since each channel is orthogonal to each other. Unlike the traditional D2D pair communication, the transmitters in each D2D group uses NOMA to transmit a super-imposed mixed signal including information required by multiple receiving ends, i.e., the required transmit power when NOMA is used. To facilitate the analysis without loss of generality, each D2D group is assumed to have two receiving ends. Each D2D group can only multiplex one cellular user channel for communication, and each cellular user channel can only be multiplexed by one D2D group. Therefore, in this scenario, there is no interference between different D2D groups and interference only exists within each D2D group and cellular users of the multiplexed channel.

Let C denote a set of cellular users, $C = \{C_1, C_2, \dots, C_i, \dots, C_M\}$, where C_i represents the cellular user i. Let D denote a set of D2D groups, $D = \{D_1, D_2, \dots, D_j, \dots, D_N\}$, where D_j represents the D2D group j. The transmit power on each channel is denoted by P_c and the transmit power of the D2D transmit end in each D2D group is denoted by P_D. Let $g_{i,B}$ represent the channel gain between the base station and cellular user i. Likewise, $g_{j,1}$ and $g_{j,2}$, represent the gain between the D2D transmitter and the D2D receiver 1 and receiver 2 in D2D group j, respectively. Let $h_{i,j1}$ and $h_{i,j2}$ represent the channel gain between the receiving end 1 and the receiving end 2 of the D2D group j of the cellular user i and the shared channel thereof, respectively. Let $h_{j,B}$ represent the channel gain between the

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transmitting end and the base station in D2D group j. Let σ^2 represent the white Gaussian noise received by each user. Channel allocation is indicated using a binary variable $x_{i,j} \in \{0,1\}$ that equals one if cellular user i is multiplexed by D2D group j and equals zero otherwise.

In order to distinguish two receiving ends in a D2D group, a user with a large channel gain between the D2D transmitting end and the receiving end is known as a *strong* user and a user with a small channel gain is known a *weak* user. The assumption that $g_{j,1} > g_{j,2}$ is made, that is, the receiving end 1 is a strong user while the receiver end 2 is a weak user. Here, the power allocated to the strong user is P_d^1 and the power allocated to the weak user is P_d^2. Based on the NOMA mechanism, the strong users are allocated with low power and the weak users are allocated with high power; $P_d^1 < P_d^2$. Consequently, the weak user is less affected by the strong user and could directly demodulate the self signal. The strong user needs to first remove the weak user's signal through the successive interference cancellation (SIC) process and then demodulate its own signal.

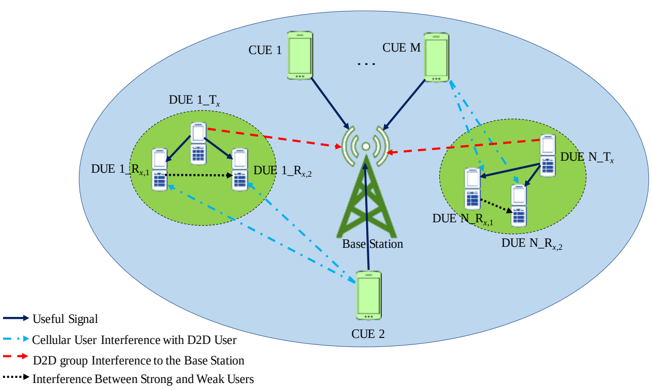

FIGURE 1. Proposed D2D-NOMA system model.

Based on the above conditions, the signal to interference and noise ratio (SINR) of the cellular user i is calculated as

$$SINR_i^C = \frac{P_c g_{i,B}}{\sum_{j\in D} x_{i,j}\, P_d h_{j,B} + \sigma^2}. \tag{1}$$

When D2D group j multiplexes the channel of cellular user i to transmit data, the SINR of the receiving end 1 in the group j is calculated as

$$SINR_{j1}^D = \frac{P_d^1 g_{j,1}}{P_c h_{i,j1} + \sigma^2}. \tag{2}$$

Similarly, the SINR of the receiving end 2 is calculated as

$$SINR_{j2}^D = \frac{P_d^1 g_{j,2}}{P_c h_{i,j2} + P_d^1 g_{j,2} + \sigma^2}. \tag{3}$$

According to the Shannon equation, the total capacity of the D2D group j multiplexing the channel of cellular user i is calculated as

$$C_{sum}^j = log\left(1 + SINR_{j1}^D\right) + log\left(1 + SINR_{j2}^D\right). \tag{4}$$

The energy efficiency of each D2D group can be expressed as the ratio of the total capacity of each group of D2D users to the total power consumed. The power consumed by each group is contributed by the user transmitted power and the average circuit loss power is expressed as P_0. Therefore, the energy efficiency of D2D group j that shares the channel of cellular user i is calculated as

$$e_{sum}^j = \frac{C_{sum}^j}{P_D + P_0}. \tag{5}$$

III. PROPOSED ALGORITHM

A. OPTIMIZATION PROBLEM FORMULATION

The channel allocation of each D2D group and the power allocation of strong and weak users in each group is analyzed using NOMA. To guarantee the QoS of the cellular users and D2D users, an optimization problem to maximize the overall energy efficiency of D2D groups is formulated as follows:

$$\max_{\{P_d^1, P_d^2, x_{i,j}\}} \sum_{j=1}^{N} \sum_{i=1}^{M} e_{sum}^j\, x_{i,j}, \tag{6}$$

Subject to:

$$SINR_i^C \geq \gamma_{th}^c,\ \forall\, i \in C, \tag{7}$$

$$SINR_{j1}^D \geq \gamma_{th}^{d_1},\ \forall\, j \in D, \tag{8}$$

$$SINR_{j2}^D \geq \gamma_{th}^{d_2},\ \forall\, j \in D, \tag{9}$$

$$kP_d^1 < P_d^2,\ k \geq 1, \tag{10}$$

$$P_d^1 > P_d^2 > 0, P_d^1 + P_d^2 = P_D, \tag{11}$$

$$\sum_{i=1}^{M} x_{i,j} \leq 1, x_{i,j} \in \{0,1\}, j \in 1,2,\dots,N, \tag{12}$$

$$\sum_{j=1}^{N} x_{i,j} \leq 1, x_{i,j} \in \{0,1\}, i \in 1,2,\dots,M. \tag{13}$$

Here, γ_{th}^c represents each cellular users' SINR threshold, and $\gamma_{th}^{d_1}$ and $\gamma_{th}^{d_2}$ represent the SINR thresholds of the strong and weak users in each of the D2D group, respectively. Equation (6) is the objective function for maximizing the energy efficiency of the D2D group. Equation (7) ensures that the threshold value of the cellular user is greater compared to its

SINR. Equations (8) and (9) ensure that users in each D2D group satisfy their own QoS requirements. Equation (10) represents the NOMA condition, that is, a strong user with a large channel gain is allocated with less power as compared to a weak user with a small channel gain. Equation (11) ensures that the power allocated to each user is greater than zero and the total power is fixed to the transmit power of D2D. Equations (12) and (13) denote that each D2D group multiplexes up to one cellular user channel and each cellular user channel is multiplexed by one D2D group at most, respectively.

From the analysis of the optimization problem in (6), we can find that the objective function consists of three unknown parameters, namely the powers (P_d^1, P_d^2) and channel selection factor ($x_{i,j}$) of the strong and weak users in each D2D group. The optimization is an NP problem of mixed-integer programming [18], which can be decomposed into two steps. The first step solves the D2D groups' channel allocation problem using the weighted bipartite graph maximum matching technique in graph theory. The second step solves the power allocation problem of the D2D group.

B. CHANNEL ALLOCATION ALGORITHM

Assuming that the power allocation in each D2D group is a fixed value denoted by P_d^{1*} and P_d^{2*}, the sub-problem for channel allocation in the original optimization is formulated as follows:

$$\max_{\{P_d^{1*}, P_d^{2*}, x_{i,j}\}} \sum_{j=1}^{N} \sum_{i=1}^{M} e_{sum}^{j} x_{i,j}, \tag{14}$$

Subject to:

$$\sum_{i=1}^{M} x_{i,j} \leq 1, x_{i,j} \in \{0,1\}, j \in 1,2, \dots, N, \tag{15}$$

$$\sum_{j=1}^{N} x_{i,j} \leq 1, x_{i,j} \in \{0,1\}, i \in 1,2, \dots, M, \tag{16}$$

$$SINR_i^C \geq \gamma_{th}^c, \forall\, i \in C. \tag{17}$$

Figure 2 shows an illustrative example of channel allocation between the D2D users and the cellular users based on (14). This optimization problem can be converted to the maximum matching problem of the weighted bipartite graph. In Figure 2, the set of all D2D users and the set of candidate cellular users represent sets of two non-intersecting vertices in a bipartite graph. Each D2D group selects the most suitable users from cellular users to perform multiplexing. There is a connection if and only if the cellular user i is multiplexed by D2D group j. The weight on the connection is the total energy efficiency gain of the D2D user when the D2D group j multiplexes the channel of user i.

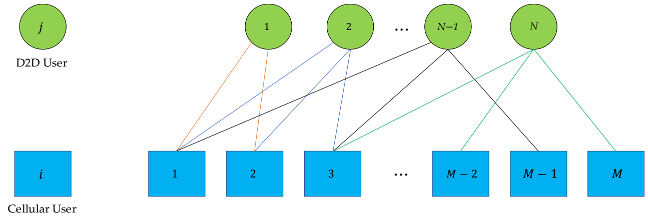

FIGURE 2. Maximum matching D2D groups and cellular-based on weighted Bipartite Graphs.

To solve the problem, we use the Kuhn-Munkres (KM) algorithm, also called the Hungarian algorithm [19]. However, this algorithm cannot be directly applied as it is used to solve the maximum weight matching problem in the bipartite graph. Therefore, we transform the original objective function into the energy efficiency problem of minimizing the total D2D group and set the weight value of each edge to each D2D. The transformed optimization problem is equivalent to the original one. The details of the proposed joint sub-channel power allocation algorithm are presented in Algorithm 1.

Algorithm 1 Subchannel Allocation Algorithm

1: Initialize the cellular user set C in the scenario, D2D user set D, and candidate cellular user set $\boldsymbol{\Omega} = \emptyset$.
2: Calculate the $SINR_i^C$ for user i, $i \in C$, based on (1) after being multiplexed by each D2D group.
3: Determine the magnitude of $SINR_i^C$ and γ_{th}^c.
4: If $SINR_i^C \geq \gamma_{th}^c$
   Add user i to $\boldsymbol{\Omega}$ of the D2D group j.
5: Calculate the energy efficiency corresponding to the centralized multiplexing of different cellular user channels via each D2D group j and its corresponding candidate cellular users according to (5).
6: Compare the maximum energy efficiency values after multiplexing channels in each D2D group.
7: Take the previous energy efficiency value difference as the weight $e_{j,i}$ of the D2D group j and user i.
8: Determine $x_{i,j}$ using the KM algorithm [19].
9: End

C. POWER ALLOCATION ALGORITHM

Channels are assigned to each D2D group in the previous sub-section. As a result of the power allocated by strong and weak users in the D2D group, the P_d^1 and P_d^2 in the original optimization problem can be transformed into variables. Through the introduction of a power allocation factor ε, we could define $P_d^1 = \varepsilon P_D$ and $P_d^2 = (1-\varepsilon) P_D$. From (10) and (11) of the optimization problem (6), we can derive $0 < \varepsilon < \frac{1}{k+1}$. In summary, the power allocation problem of each D2D group in the original optimization problem can be transformed to the following:

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$$\max_{\{\varepsilon\}} \sum_{j=1}^{N} \left\{ \frac{\log_2\left(1+\frac{\varepsilon P_D g_{j,1}}{P_c h_{i,j1}+\sigma^2}\right)+\log_2\left(1+\frac{(1-\varepsilon)P_D g_{j,2}}{P_c h_{i,j2}+\varepsilon P_D g_{j,2}+\sigma^2}\right)}{P_D+P_0} \right\}, \quad (18)$$

Subject to: $SINR_{j1}^{D} \geq \gamma_{th}^{d_1},\ \forall j \in D,$ (19)

$$SINR_{j2}^{D} \geq \gamma_{th}^{d_2},\ \forall j \in D, \quad (20)$$

$$0 < \varepsilon < \frac{1}{k+1}, k \geq 1. \quad (21)$$

To solve the transformed optimization problem (18), the power allocation problem for NOMA users of our system and the work in [15] is solved. Substituting $P_d^1 = \varepsilon P_D$ and $P_d^2 = (1-\varepsilon)P_D$ into the constraints (19) and (20) of the optimization problem, we obtain

$$\frac{\varepsilon P_D g_{j,1}}{P_c h_{i,j1} + \sigma^2} \geq \gamma_{th}^{d_1}, \quad (22)$$

$$\frac{(1-\varepsilon)P_D g_{j,2}}{P_c h_{i,j2} + \varepsilon P_D g_{j,2} + \sigma^2} \geq \gamma_{th}^{d_2}. \quad (23)$$

Equations (22) and (23) are solved to guarantee the QoS of each user in the D2D group and the power allocation factor ε is consequently bounded by

$$\frac{\gamma_{th}^{d_1}(P_c h_{i,j1} + \sigma^2)}{P_D g_{j,1}} \leq \varepsilon \leq \frac{P_D g_{j,2} - \gamma_{th}^{d_2}(P_c h_{i,j2} + \sigma^2)}{P_D g_{j,2}\gamma_{th}^{d_2} + P_D g_{j,2}}. \quad (24)$$

According to (21) in the original optimization problem, the upper and lower bounds of ε in (24) must be less than $\frac{1}{k+1}$ $(k \geq 1)$ to satisfy the NOMA criterion, therefore, the conditions for setting $\gamma_{th}^{d_1}$ and $\gamma_{th}^{d_2}$ can be obtained through

$$\gamma_{th}^{d_1} < \frac{P_D g_{j,1}}{(k+1)(P_c h_{i,j1} + \sigma^2)}, \quad (25)$$

$$\gamma_{th}^{d_2} > \frac{k P_D g_{j,2}}{P_D g_{j,2} + (k+1)(P_c h_{i,j2} + \sigma^2)}. \quad (26)$$

Let

$$\begin{cases} f(\varepsilon) = \dfrac{\log_2\left(1 + \frac{\varepsilon P_D g_{j,1}}{P_c h_{i,j1} + \sigma^2}\right) + \log_2\left(1 + \frac{(1-\varepsilon)P_D g_{j,2}}{P_c h_{i,j2} + \varepsilon P_D g_{j,2} + \sigma^2}\right)}{P_D + P_0}, \\ \mu_1 = \sigma^2 + P_c h_{i,j1}, \\ \psi_1 = P_D g_{j,1}, \\ \mu_2 = \sigma^2 + P_c h_{i,j2}, \\ \psi_2 = P_D g_{j,2}. \end{cases}$$

Taking the derivative of $f(\varepsilon)$ for ε yields

$$\frac{\partial f(\varepsilon)}{\partial \varepsilon} = \frac{1}{\ln 2(P_D + P_0)} \frac{(\psi_1\mu_2 - \mu_1\psi_2)}{(\mu_1 + \varepsilon\psi_1)(\mu_2 + \varepsilon\psi_2)}. \quad (27)$$

To solve the optimization problem (18), the KKT conditions are given as follows:

$$\begin{cases} \dfrac{\partial g(\varepsilon)}{\partial \varepsilon} + \lambda_1 \dfrac{\partial\left(\frac{\gamma_{th}^{d_1}\mu_1}{\psi_1} - \varepsilon\right)}{\partial \varepsilon} + \lambda_2 \dfrac{\partial\left(\varepsilon - \frac{\psi_2 - \gamma_{th}^{d_2}\mu_2}{\psi_2(\gamma_{th}^{d_2}+1)}\right)}{\partial \varepsilon} = 0, \\ \left(\dfrac{\gamma_{th}^{d_1}\mu_1}{\psi_1} - \varepsilon\right)\lambda_1 = 0, \\ \left(\varepsilon - \dfrac{\psi_2 - \gamma_{th}^{d_2}\mu_2}{\psi_2(\gamma_{th}^{d_2}+1)}\right)\lambda_2 = 0, \\ \dfrac{\gamma_{th}^{d_1}\mu_1}{\psi_1} - \varepsilon \leq 0, \\ \varepsilon - \dfrac{\psi_2 - \gamma_{th}^{d_2}\mu_2}{\psi_2(\gamma_{th}^{d_2}+1)} \leq 0, \\ 0 < \varepsilon < \dfrac{1}{k+1}, \\ \lambda_1, \lambda_2 \geq 0, \end{cases} \quad (28)$$

where $g(\varepsilon) = -f(\varepsilon) \leq 0$ and λ_1, λ_2 are the Lagrangian multipliers of the limits (19) and (20), respectively. From the first condition in (28), we obtain

$$\frac{1}{\ln 2(P_D + P_0)} \frac{(\mu_1\psi_2 - \psi_1\mu_2)}{(\mu_1 + \varepsilon\psi_1)(\mu_2 + \varepsilon\psi_2)} - \lambda_1 + \lambda_2 = 0. \quad (29)$$

Both $\lambda_1, \lambda_2 \geq 0$ and the second and third KKT conditions in (28) must be fulfilled when determining the power allocation factor ε. When $\lambda_1 > 0$ and $\lambda_2 = 0$, the power allocation factor ε herein can be obtained through the second condition in equation (28) as

$$\varepsilon_1^{opt} = \frac{\gamma_{th}^{d_1}\mu_1}{\psi_1} = \frac{\gamma_{th}^{d_1}(P_c h_{i,j1} + \sigma^2)}{P_D g_{j,1}}. \quad (30)$$

In this case, when the SINR of the strong user in the D2D group attains the threshold, then allocate the remaining power to the weak user. Therefore, the capacity of the weak user could reach the maximum value of the constrained condition. When $\lambda_1 = 0$ and $\lambda_2 > 0$, the power allocation factor ε can be obtained from the third KKT condition in (28) as

$$\varepsilon_2^{opt} = \frac{\psi_2 - \gamma_{th}^{d_2}\mu_2}{\psi_2(\gamma_{th}^{d_2}+1)} = \frac{P_D g_{j,2} - \gamma_{th}^{d_2}(P_c h_{i,j2} + \sigma^2)}{P_D g_{j,2}\gamma_{th}^{d_2} + P_D g_{j,2}}. \quad (31)$$

In this case, when the SINR of the weak user attains the threshold, the remaining power is then allocated to the strong user. Therefore, the capacity of the strong user can obtain the maximum value under the constraint condition.

Since the objective of the optimization problem is to maximize the total energy efficiency of the D2D groups, the energy efficiency obtained through the two power allocation schemes is compared for each D2D group and the larger one is applied as the final allocation scheme of the re-organization. If the throughput of a single user is required to be the largest, e.g., if the weak user throughput in the D2D group is large, then the allocation scheme of ε_1^{opt} is adopted.

The details of the power allocation algorithm are presented in Algorithm 2.

Algorithm 2 Power Allocation Algorithm

1: Substitute the channel allocation results in Section 3.*B* into each D2D group.

2: Define $P_d^1 = \varepsilon P_D$ and $P_d^2 = (1-\varepsilon)P_D$.

3: If $g_{j,1} > g_{j,2}$

$g_{j,1}$ = Strong user, allocate $P_d^2 \rightarrow$ Strong user.

4: Else

$g_{j,1}$ = Weak user, allocate $P_d^1 \rightarrow$ Weak user.

5: Calculate $P_d^1 = \varepsilon_1^{opt} P_D$ and $P_d^2 = \left(1-\varepsilon_2^{opt}\right)P_D$ in and allocate P_d^1 and $P_d^2$to the strong and weak users, respectively in D2D group j.

6: Calculate the energy efficiency of the D2D group j as follows:

$$e_1^{opt} = \frac{log_2\left(1+\frac{\varepsilon_1^{opt}P_D g_{j,1}}{P_c h_{i,j1}+\sigma^2}\right)+log_2\left(1+\frac{(1-\varepsilon_1^{opt})P_D g_{j,2}}{P_c h_{i,j2}+\varepsilon_1^{opt}P_D g_{j,2}+\sigma^2}\right)}{P_D+P_0},$$

$$e_2^{opt} = \frac{log_2\left(1+\frac{\varepsilon_2^{opt}P_D g_{j,1}}{P_c h_{i,j1}+\sigma^2}\right)+log_2\left(1+\frac{(1-\varepsilon_2^{opt})P_D g_{j,2}}{P_c h_{i,j2}+\varepsilon_2^{opt}P_D g_{j,2}+\sigma^2}\right)}{P_D+P_0}.$$

7: Adopt the larger of the two as the energy efficiency value of the group, i.e., $e_j = max\left(e_1^{opt}, e_2^{opt}\right)$.

8: To obtain the overall energy efficiency of the system, sum up the maximum efficiency values from each group.

$$\frac{\frac{1}{2}log_2\left(1+\frac{\frac{1}{2}P_D g_{j,1}}{P_c h_{i,j1}+\sigma^2}\right)+\frac{1}{2}log_2\left(1+\frac{\frac{1}{2}P_D g_{j,2}}{P_c h_{i,j2}+\sigma^2}\right)}{P_D+P_0}$$

9: End

IV. SIMULATION RESULTS AND ANALYSIS

In this section, the energy efficiency and throughput of the proposed algorithm are compared to the current state-of-the-art D2D-based algorithms [2], [17], [21] under different system settings (i.e., path loss factor, transmit power, and D2D group size). For the simulation, the cellular user and the D2D user sender are randomly generated in the cell using the radius *R*. The D2D user receiving end are then randomly scattered within a circle with the D2D transmitting end as the circle center and d_{max} as the radius. We assume that the channel gain consists of large-scale fading based on path loss and small-scale fading based on Rayleigh fading [20]. Among them, the large-scale fading model adopts the single-slope path loss model, i.e. $P_R = \kappa P_T d^{-\alpha}$, where κ and α represent the path loss constant and the path loss index (large scale fading factor), respectively, and the Rayleigh fading follows the exponential distribution with a mean of 1. The power ratio of the strong and weak users is set to 1 so as to facilitate the analysis. Simulation parameters are shown in Table I.

TABLE I
SIMULATION PARAMETERS

Cell Radius (R)	500 m
D2D group radius (d_{max})	50 m
Number of cellular users (M)	15
Number of D2D groups (N)	10
Transmit power of cellular users	24 dBm
Max. transmit power of D2D users	21 dBm
Circuit power loss	17 dBm
Noise power	-114 dBm
Cellular user SINR threshold	3 η/dB
SINR threshold of strong users	3 $\gamma_{th}^{d_1}$/dB
SINR threshold of weak users	1 $\gamma_{th}^{d_2}$/dB
Path loss constant (κ)	0.01
Path loss factor (α)	4

A. IMPACT OF LARGE-SCALE FADING FACTOR

Figure 3 illustrates the impact of the number of D2D groups and large-scale fading factor on the total energy efficiency of the D2D group. It can be observed from Figure 3 that the number of D2D groups increases, as the total energy efficiency increases. This is because as the number of D2D groups increases, more D2D users can communicate by multiplexing the channels of the cellular users, thus increasing the total energy efficiency of the D2D group. Similarly, the proposed algorithm outperforms the traditional D2D-OMA algorithms [2], [17], [21]. Since NOMA is adopted, each receiving end and the transmitting end occupies the entire bandwidth for data transmission. In the traditional OMA, each receiving end and the transmitting end could only occupy half of the bandwidth. Additionally, comparing Figures 3(a) and 3(b), it can be observed that for a large large-scale fading factor, the energy efficiency is greater. This is as a result of the distance between the D2D pairs being much smaller than the distance between the cellular users and the D2D receiving end. Therefore, the attenuation of the interference value of the D2D user by the cellular user is greater than the attenuation of the D2D transmit signal. Hence, the total energy efficiency of the D2D group increases and it proves that the proposed algorithm can adapt well to fast channel fading environments.

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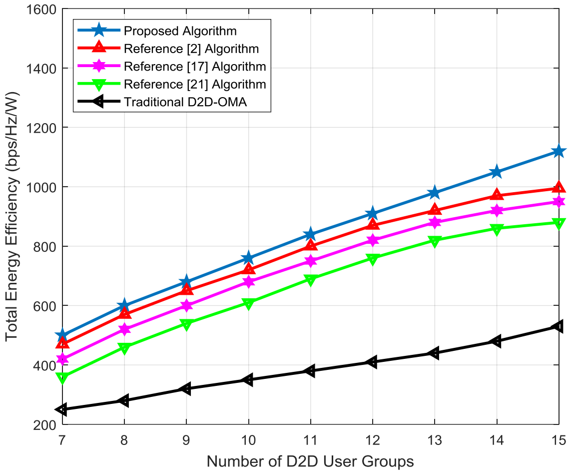
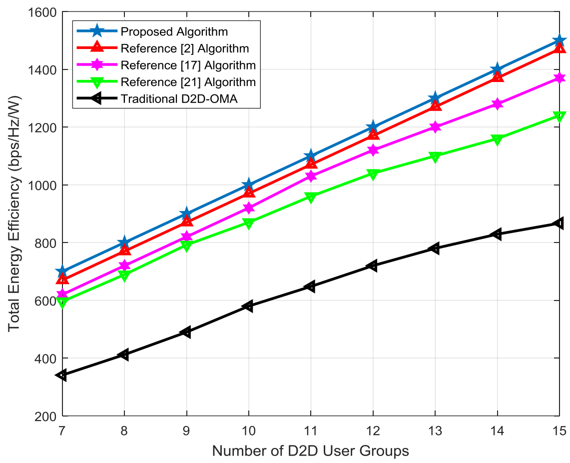


(a)

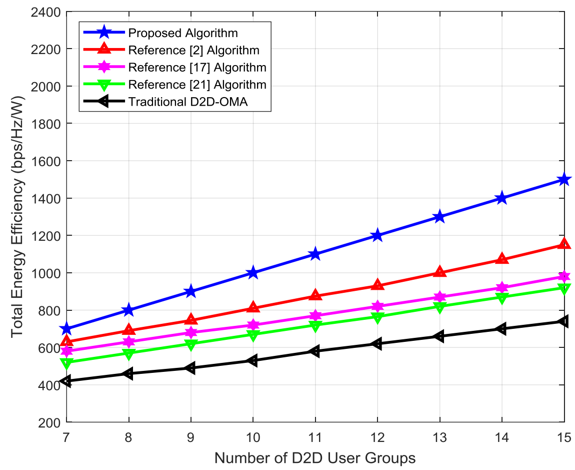


(b)

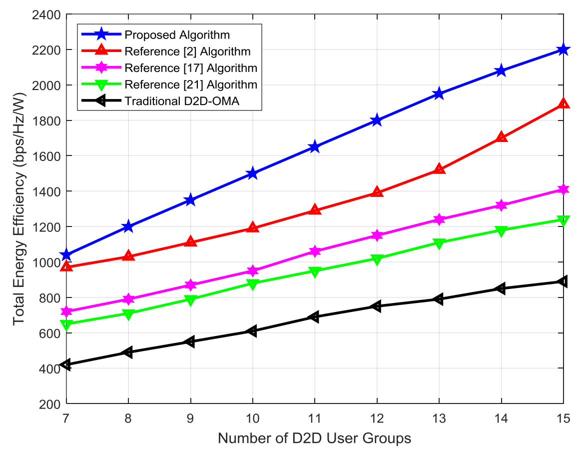
FIGURE 3. The variation of total energy efficiency of D2D users with D2D group under different large-scale fading factors. (a) $\alpha = 2.5$; (b) $\alpha = 4$.

B. IMPACT OF TRANSMIT POWER

Figure 4 shows the impact the number of D2D groups and transmit power has on the total energy efficiency of the D2D group. It can be observed from Figure 4 that as the number of D2D groups increases, the total energy efficiency of the D2D group also increases. This points out that NOMA has a greater advantage for large groups, achieving a greater user throughput for the same power loss. In addition, comparing Figures 4(a) and 4(b), it can be observed that the energy efficiency is greater for a lower transmit power. This is because the increase in the throughput as a result of the increase in the transmit power is smaller than the power loss. Therefore, when the transmit power is large, the energy efficiency becomes lower. Moreover, the proposed algorithm exhibits better total energy efficiency compared to the current algorithms under the same operating conditions.



(a)



(b)

FIGURE 4. The variation of the total energy efficiency of D2D users with different transmit powers with the number of D2D groups. (a) $P_d = 23$ dBm; (b) $P_d = 21$ dBm.

C. IMPACT OF D2D GROUP SIZE

Figure 5 shows the impact of transmit power for different D2D group sizes. It can be observed that the total energy efficiency of the D2D group decreases with an increase in the transmit power irrespective of the number of D2D groups of 7 or 10. This is because the total throughput of the D2D group increases gradually but more energy is consumed as the transmit power increases. In addition, comparing Figure 5 (a) and 5(b), it can be observed that as the D2D transmit power continues to increase, the advantages of increasing the number of D2D groups so as to increase the total energy efficiency of the D2D group gradually reduces. Therefore, the D2D group size has a significant impact on overall energy efficiency.

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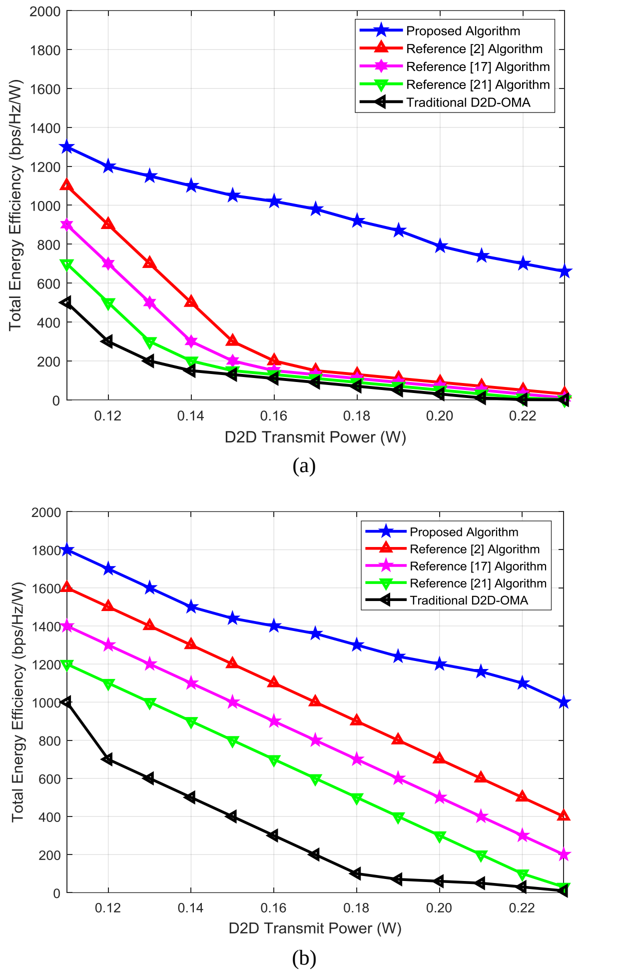

FIGURE 5. **Relationship between the total energy efficiency of D2D users and D2D transmit power under different D2D groups. (a) N = 7; (b) N = 10.**

D. COMPARISON OF THROUGHPUT

Figure 6 shows the cumulative distribution function (CDF) of the systems' throughput for different algorithms when $N = 5$, the maximum transmit power of D2D users is 21 dBm, and the minimum rate requirement of cellular users is 1.08 Mbps. It is noteworthy that the throughput of the proposed algorithms is greatly improved compared to other traditional D2D-OMA algorithms. The throughput of the proposed algorithm is 75%, 41%, and 55% higher compared to algorithms proposed in [21], [17], and [2], respectively. Figure 7 shows the system throughput as a function of D2D users when the maximum transmit power of the D2D user is 21 dBm and the minimum rate requirement of the cellular user is 1.08 Mbps. The throughput of all algorithms generally increases with an increase in the number of D2D users. For any number of D2D users, the proposed algorithm attains significantly better throughput compared to others.

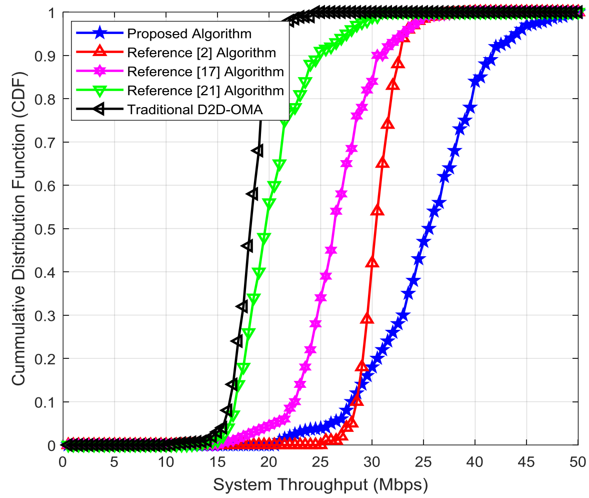

FIGURE 6. **Comparison of CDF of throughput.**

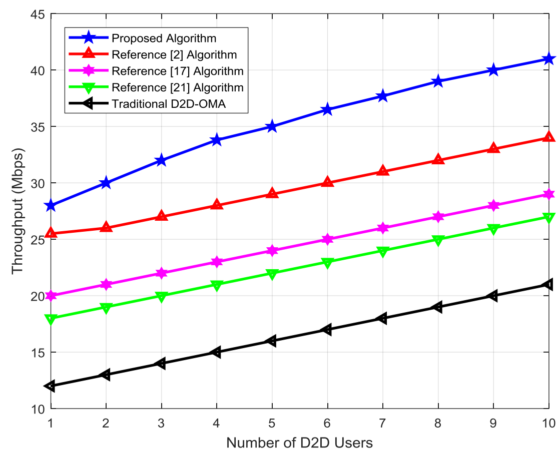

FIGURE 7. **Comparison of the throughput of the proposed algorithm with other state-of-the-art algorithms under different number of D2D users.**

V. DISCUSSION

In this section, we discuss the performance outcome of the proposed algorithm with other works and give a comparative analysis.

The energy efficiency of the proposed algorithm and the current state-of-the-art algorithms is compared under different large-scale fading factor values as shown in Figure 3. As a result, it can be observed that the energy efficiency of the proposed algorithm is clearly better at any value of large-scale fading factor as compared to the algorithms proposed in [2], [17], and [21]. Therefore, the proposed algorithm could significantly reduce energy wastage in D2D-NOMA systems. This also implies that the proposed algorithm would result in energy-efficient hardware implementations.

The energy efficiency is compared under different transmit power levels as shown in Figure 4. The proposed algorithm gives better efficiency and consumes less power than the algorithms for the different transmit power levels. This means that the proposed algorithm requires less power to produce a better outcome than the other works and as a result makes it an attractive candidate for the 5G networks.

The energy efficiency is also tested for an increasing number of D2D user groups as shown in Figure 4. The results clearly indicate that the performance outcome of the proposed algorithm is still better for an increasing number of D2D user groups as compared to the existing algorithms. Therefore, the proposed algorithm can accommodate numerous numbers of D2D user groups more efficiently and improve the handling capacity.

The result of the throughput when using CDF is shown in Figure 6 in order to provide more detailed statistical features of the throughput in comparison with the existing algorithms.

Finally, the throughput analysis under different numbers of D2D users is performed as shown in Figure 7. The result indicates an enhanced performance while using the proposed algorithm over the existing algorithms.

VI. CONCLUSION

In this paper, an efficient joint resource allocation algorithm is proposed for D2D-NOMA systems. According to the interference between the D2D users and the cellular users, the algorithm applies the KM criterion to allocate the channels of the cellular users to each D2D group and then obtains the power values of the strong and weak users in each D2D group according to NOMA using the KKT conditions. The algorithm is designed to maximize the energy efficiency of the system while guaranteeing the QoS of all users and maximum transmit power of the D2D users. The simulation results under various network conditions indicate that the proposed algorithm outperforms the existing algorithms in terms of energy efficiency and throughput. For future work, the influence of the different number of D2D receivers will be investigated.

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