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RESEARCH ARTICLE

Energy-Efficient Utility Function-Based Channel Resource Allocation and Power Control for D2D Clusters With NOMA Enablement in Cellular Networks

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ABSTRACT Device-to-device(D2D) communication combined with non-orthogonal multiple access(NOMA) can further improve the quality of service for future communications systems and increase spectrum utilization and connection density in cellular networks. In this paper, an effective power allocation scheme is designed to optimize the performance of a D2D communication system based on NOMA for imperfect Successive Interference Cancellation(SIC) decoding. To solve the non-convexity of the problem due to integer constraints and coupling variables, an alternate optimization algorithm was designed to obtain the optimal solution of each subproblem by Lagrange duality analysis and the sub-gradient descent method. Finally, the numerical simulation results demonstrate the performance advantages of the proposed joint optimization algorithm for channel resource allocation and power control in energy efficiency.

INDEX TERMS Non-orthogonal multiple accesses, D2D channel resource allocation, power allocation, Lagrange duality analysis.

I. INTRODUCTION

With the constant emergence of new services and network applications, the rate of network traffic growth is reaching unprecedented levels. The rapid development of wireless communication technology is connecting people and businesses worldwide, creating a tightly integrated global information network [1], [2]. In particular, the explosive growth of the Internet of Things (IoT) business is driving demand for machine-to-machine communication. It is projected that there will be more than 75.4 billion connected devices worldwide by 2025. To cope with the pressure of future data transmission, 5G technology has emerged as a key solution offering higher transmission rates, greater spectrum efficiency, and lower latency [3]. 5G technology is set to revolutionize every aspect of people's lives by establishing an all-encompassing, comprehensive, and intelligent wireless mobile communication ecosystem, with user equipment at its core [4]. However, addressing the challenges posed by this paradigm shift requires the adoption of new architecture and technological solutions for existing networks. To enhance performance, D2D communication is being introduced as a complementary mechanism for traditional networks.

D2D communication offers a direct communication mode between adjacent devices, which can alleviate some of the services from the base station and prevent high flow load congestion at the base station, thereby achieving better throughput and lower latency [5]. Moreover, it helps reduce the return process load and increase the overall system capacity. Since D2D devices are usually located in close proximity, the power requirements for transmitting information are not high, enabling better spectrum reuse and improved energy efficiency. Additionally, D2D communication offers various other advantages, including fairness, congestion control, and Quality of Service (QoS) guarantee [6]. For instance, in the weak coverage area of a cell, D2D communication

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can enhance the cell's coverage, improve communication quality of edge devices, and further increase network throughput. However, the current D2D system employs orthogonal multiple access (OMA) where each cellular user occupies a resource block. This results in D2D users occupying some spectrum resources of the cellular network, leading to underutilization of wireless resources.

NOMA technology, which was proposed by DOCOMO communication operators in Japan at the end of 2014, has gained significant attention from both industry and academia due to its ability to improve spectrum utilization rates. By utilizing non-orthogonal superposition coding to transmit signals from multiple users and employing SIC at the receiver to eliminate interference, NOMA breaks the traditional principle of exclusive resource allocation to a single user in the power domain, proposing a new concept of multi-user power domain sharing [7]. NOMA is particularly suited to address scenarios with user overload and has the potential to solve large-scale connection problems [8]. In this context, this paper proposes a novel approach that combines NOMA technology with D2D communication to enhance radio resource utilization and improve the overall system performance of cellular networks. Specifically, the proposed scheme aims to solve the resource allocation problem of D2D communication in cellular networks based on NOMA.

A. RELATED WORKS

1) STUDIES ON D2D COMMUNICATIONS

The current status of D2D communication resources has been widely studied [9], [10], [11], [12], [13]. In order to reduce the interference caused by D2D communication and maximize the regional spectral efficiency of D2D communication, for the interference problem caused by the coexistence of D2D and cellular communication in the same frequency band, a statistical feature-based power control (SFPC) method is proposed in the literature [9] and applied to a single-cell uplink D2D system model, and it is demonstrated through simulation that SFPC can improve the D2D cellular communication success probability and energy efficiency of D2D communication, and reduce the average D2D transmit power; In the literature [10], in order to break the regional limitation of device deployment and meet the requirement of green communication, energy harvesting (EH) technique is introduced in D2D pairs while maximizing energy efficiency and spectral efficiency on the basis of fairness index, firstly, the multi-objective optimization problem is transformed into a single-objective optimization problem using the power sum method, and then the problem is solved by the Lagrange dual method, and it is proved that D2D pairs can have higher spectral efficiency and energy efficiency in this context; in order to maximize the average energy efficiency of all D2D links, In the literature [11], for the D2D downlink spectrum re-source problem, a non-convex problem about D2D energy efficiency is established based on the power and spectrum RB allocation of the D2D link again considered, and the optimal solution of D2D energy efficiency is solved using Dinkelbach and Lagrange con-strained optimization; With the development of deep reinforcement learning (DRL) for D2D power allocation usually modeled as an NP-hard combinatorial optimization problem with linear constraints, the literature [12] applied the DRL algorithm to optimize the transmit power of uplink cellular networks in D2D communications and demonstrated through simulations that the proposed DRL algorithm achieves near-global optimality while providing the advantage of low computational complexity. In the literature [13], to address the severe co-channel interference degrading the network performance of D2D pairs, the weighted sum rate of maximizing the D2D pair network is modeled as a joint channel selection and power control optimization problem, first using fractional programming (FP) to obtain an approximate optimal solution, while a distributed deep reinforcement learning (DRL) scheme is introduced to centralize the transient global channel state information (CSI) so that D2D pairs can autonomously optimize channel selection and transmit power by using only local information and obsolete non-local information.

2) STUDIES ON NOMA

As one of the key technologies of the fifth-generation mobile communication network, resource allocation under the NOMA system has been extensively studied by related scholars [14], [15], [16], [17], [18]. In the literature [14], the energy efficiency problem of single-cell downlink NOMA under imperfect CSI is studied, and the problem is modeled as a probabilistic mixed nonconvex optimization problem by introducing constraints on the maximum system power, the minimum user data rate, and the maximum number of multiplexed users sharing the same subchannel, leading to the introduction of a low-complexity suboptimal user scheduling algorithm and the derivation of a closed-form power allocation expression for users on each subchannel. In order to promote green communications, a distributed algorithm is proposed in the literature [15] to minimize the total transmit power of all base stations according to the data rate of the users, under a multi-cell downlink NOMA system, proving the uniqueness of the optimal solution; A low-complexity suboptimal solution based on matching theory is proposed in the literature [16] for the orthogonal multiple access (OMA) and NOMA re-source allocation problems; In the literature [17], an optimal power allocation scheme is developed for the joint power allocation and channel assignment problem under perfect SIC with Karush-Kuhn-Tucker (KKT) optimality conditions, combined with different NOMA constraints, to maximize channel and rate and system fairness; In downlink millimeter-wave non-orthogonal multiple access systems, two optimization problems are proposed in the literature [18] to maximize the achievable sum rate (ASR) and energy efficiency (EE), respectively, ensuring the SIC stability conditions, and the ASR maximization-based power allocation (ASRMax PA) and EE maximization-based energy allocation (EEMax PA) algorithms are proposed.

B. MOTIVATION AND CONTRIBUTIONS

D2D communication allows users to communicate by multiplexing cellular spectrum, thus saving channel resources, and NOMA technology is similar in that it allows multiple devices to communicate on the same channel, increasing spectrum utilization. There has been some work on the combination of NOMA and D2D communication. The concept of D2D clusters transmitted using NOMA technology was first proposed in the literature [19], where the D2D transmitters within each cluster communicate through multiple D2D receivers in the NOMA technology domain.Under real system conditions, NOMA-based expressions for the coverage probability and average throughput of millimeter-wave D2D networks are derived in the literature [20]. The asymptotic analysis of the traversal capacity and coverage probability for high and low SNR states is also analyzed and the corresponding closed form expressions are given; In the literature [21], cellular users combining multiple D2D pairs using the NOMA approach to communication are modeled as two subproblems of pow-er control and channel assignment in order to maximize the sum rate of the D2D pairs, which are solved optimally by introducing auxiliary variables and relaxing binary constraints using a pairwise iterative algorithm; The literature [22] extends the coverage by introducing collaborative relaying to improve the performance of cell edge users, and in order to solve the maximum sum rate problem of D2D pairs, a Pareto-improved bilateral stable multi-to-one matching algorithm is proposed to execute the sub-channel assignment algorithm; unlike several others, the literature [23] investigates the joint uplink and downlink resource allocation problem, and in order to maximize the total data rate of NOMA-enabled D2D groups, a sub-carrier assignment algorithm is designed to assign downlink and uplink sub-carriers to D2D groups and simulations demonstrate that the data rate of D2D groups can be significantly improved.The two-stage D2D-assisted NOMA scheme is proposed [24]. The interruption probability and delay tolerance capacity are investigated by analyzing two scenarios with successfully paired users and without successful pairing, and the superiority of its scheme is demonstrated by theoretical analysis and simulation.Literature [25] proposes to introduce NOMA in D2D mobile groups under uplinks, thus exploring interference suppression schemes to maximize network throughput. The authors model the problem as a mixed integer linear programming problem by joint user pairing and resource allocation, and prove the superiority of the proposed scheme using a three-dimensional game, branch definition method, and successive convex approximations.Literature [26] proposes a NOMA and D2D communication scheme to improve the physical layer security of D2D users, and at the same time to obtain higher rates by clustering, using matching theory and sub-optimization algorithms to solve the user clustering and power allocation problems, respectively, and finally the significant advantages of the authors' proposed approach are confirmed by simulations.With the introduction of D2D pairs in the NOMA system, the decoding complexity of the system also increases. Literature [27] addresses the large decoding complexity by mentioning the use of the Lagrangian pairwise method and the cyclic triangular successive elimination scheme to reduce the computational complexity of decoding.

In summary, both NOMA and D2D are hot elements in the research of next-generation mobile communication, and combining them can significantly improve the spectrum utilization and meet the deployment requirements of future communication networks, however, most of the current research on D2D-NOMA communication assumes that the SIC process of NOMA can be successfully decoded, but in the actual scenario, due to the limitation of hardware SIC may occur errors leading to decoding On the other hand, most of the current studies on channel resource allocation and power control algorithms consider improving the spectral efficiency. Therefore, in this paper, by managing the energy efficiency of NOMA-D2D communication, we propose an iterative algorithm for joint channel resource allocation and power control under the comprehensive consideration of energy efficiency and user fairness, and the main contributions of this paper are summarized as follows:

1) A D2D cluster is constructed by introducing NOMA, i.e., a D2D transmitter communicates with two D2D receivers through the NOMA protocol, and a power allocation for D2D communication in cellular networks based on NOMA imperfect SIC is proposed for practical situations where the SIC decoding process may be erroneous, with comprehensive consideration of energy efficiency and user equity.

2) A compromise between user rate and fairness is achieved by introducing a model with a logarithmic utility function, and subsequently, to maximize the energy efficiency of the D2D cluster, the original problem is transformed into an integer problem using a fractional programming approach, and then the transformed problem is decomposed into two subproblems using an alternating optimization approach and solved using a Lagrange pairwise approach, respectively.

3) The simulation verifies that the scheme in this paper outperforms the OMA power allocation scheme and the NOMA-based average power allocation scheme, and also verifies that the D2D cluster reachability rate varies with the imperfect SIC parameters, the number of D2D clusters, and the distance within the D2D clusters.

The rest of this paper is organized as follows. In Section II, we present the system model and problem formulation. Section III is the resource allocation strategy based on the energy efficiency utility function. Section IV proposes the Simulation results and analysis. Section V highlights our conclusions.

II. SYSTEM MODEL AND PROBLEM FORMULATION

A. SYSTEM MODEL

In this paper, we consider the uplink transmission scenario where cellular communication and D2D group communication coexist in a non-perfect SIC scenario, assuming that the base station is located in the center of the cell and has access to all user channel information, while the base station

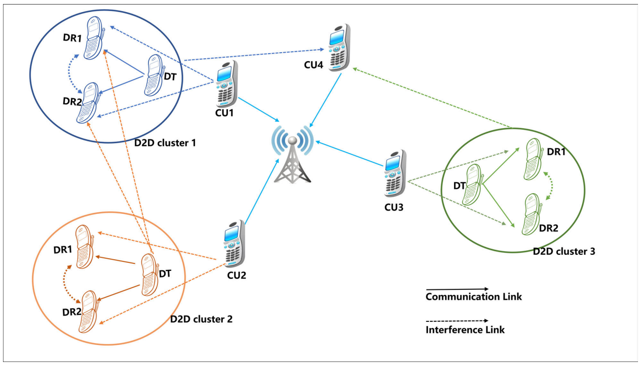

FIGURE 1. Model of a D2D communication system based on NOMA.

pre-assigns an orthogonal sub-channel to each cellular user, and each cellular user only occupies one sub-channel for communication, and each sub-channel is interacting with each other without interference. In the D2D cluster, the transmitting user sends a superimposed signal to the receiving user, as shown in Figure 1. It can be seen that there are three types of interference in the D2D-NOMA communication model in the figure.

1) Interference from D2D transmitters within the same D2D-NOMA cluster.

2) Interference from clusters multiplexing the same cellular user subchannel between different D2D-NOMA clusters.

3) Interference from cellular users multiplexing the same sub-channel.

The system contains a base station, which provides M mutually orthogonal channels, and the set of channels are $\mathbb{SC} = \{SC_1, S\,C_2, \ldots, S\,C_M\}$; M cellular users are represented by the set $\mathbb{C} = \{C_1, C_2, \ldots, C_M\}$; unlike conventional D2D pairs, there are N D2D-NOMA clusters in a small cell, and a D2D-NOMA cluster consists of one D2D transmitter and two D2D receivers. $\mathbb{D}$ denotes the set of a D2D-NOMA cluster, denoted as $\mathbb{D} = \{D_1, D_2, \cdots, D_N\}$. In this paper, the NOMA technique is used in the D2D cluster to enable the D2D transmitter to send messages to two D2D receivers simultaneously using serial interference cancellation techniques.

B. PROBLEM FORMULATION

In this paper, we assume that each cellular user occupies a separate channel, a D2D cluster can only reuse the channel of one cellular user, and a channel can be reused by multiple D2D clusters.

During cellular transmission, the cellular user sends a signal to the BS $x = \sqrt{P_c} x$. Thus,the signal received by the base station on the subchannel SC_m can be expressed as:

$$y_c = |G_c|^2 \sqrt{P_c} x + |H_{DT}|^2 \left(\sqrt{p_{n,1}} s_1 + \sqrt{p_{n,2}} s_2\right) + \omega_c \quad (1)$$

where P_c is the transmit power of the cellular, $P_{n,1}$ and $P_{n,2}$ are the transmitted power to DR_1 and DR_2, respectively, and G_c denotes the channel gain from CU to BS, H_DT is the channel gain from DT to BS and w_c is additive Gaussian white noise (AWGN) with a mean of 0 and variance of σ^2.

Therefore, the signal-to-noise ratio and transmission rate of the cellular user C_m on the channel SC_m is defined as:

$$\gamma_c = \frac{|G_c|^2 P_c}{\sigma^2 + |H_{DT}|^2 \left(p_{n,1} + p_{n,2}\right)} \quad (2)$$

$$R_c = \log_2 (1 + \gamma_c) \quad (3)$$

For the transmission model of D2D users, assume that D2D group n multiplexes subchannels SC_m for data transmission, NOMA access is used in the D2D group, where DT sends signal $s = \sqrt{p_{n,1}} s_1 + \sqrt{p_{n,2}} s_2$ to DR_1 and DR_2, Thus the signals received by DR_1 and DR_2 from DT can be expressed as:

$$y_1 = H_1^{DT} \sqrt{p_{n,1}} s_1 + H_1^{DT} \sqrt{p_{n,2}} s_2 + \sqrt{P_c} G_1^c x + \omega_1 \quad (4)$$

and,

$$y_2 = H_2^{DT} \sqrt{p_{n,2}} s_2 + H_2^{DT} \sqrt{p_{n,1}} s_1 + \sqrt{P_c} G_2^C x + \omega_2 \quad (5)$$

where G_1^c and G_2^c are the channel gains from CU to DR_1 and to DR_2, respectively. H_1^{DT} and H_2^{DT} are the radio channel gains from DT to DR_1 and to DR_2, respectively. In addition, ω_1 and ω_2 are Gaussian white noise with mean 0 and variance σ^2.

Assume that DR_1 has a better channel state condition and DR_2 has a worse channel state with $\left|H_1^{DT}\right|^2 \geq \left|H_2^{DT}\right|^2$. Since the D2D intra-cluster communication follows the NOMA protocol, DR_2 treats the signal from DR_1 as noise to decode the signal, and DR_1 will apply SIC to decode the signal directly. However, considering the limited decoding capability, DR_1 cannot always decode the signal correctly by performing SIC. Therefore, the signal-to-noise ratio and transmission rate of DR_1 are defined as:

$$R_1 = \log_2 (1 + \gamma_1) \quad (6)$$

$$\gamma_1 = \frac{\left|H_1^{DT}\right|^2 p_{n,1}}{\sigma^2 + p_{n,2} \left|H_1^{DT}\right|^2 \beta + \left|G_1^c\right|^2 P_c} \quad (7)$$

where β denotes the imperfect SIC parameter [28] and the expression is $\beta = \mathbb{E}\left[\left|S_1 - \tilde{S_1}\right|^2\right]$, where $S_1 - \tilde{S_1}$ is the difference between the actual signal and the estimated signal.

The signal-to-noise ratio and transmission rate of DR_2 are defined as:

$$R_2 = \log_2 (1 + \gamma_2) \quad (8)$$

$$\gamma_2 = \frac{\left|H_2^{DT}\right|^2 p_{n,2}}{\sigma^2 + p_{n,1} \left|H_2^{DT}\right|^2 + \left|G_2^c\right|^2 P_c} \quad (9)$$

In this scenario, the channel resources of each cellular user can be occupied by different D2D clusters, and a binary variable $\{x_{m,n}\}$ is used to indicate whether D2D cluster n occupies the channel resources of cellular user m. If the D2D cluster n multiplexes the cellular user m, then $x_{m,n} = 1$, otherwise $x_{m,n} = 0$. In a collaborative network like this paper, if it is assumed that a D2D cluster can be served by multiple cellular users at the same time, i.e., a D2D cluster will occupy multiple subchannels at the same time, it is more difficult to configure a collaborative user connection, and issues such as synchronization and control signaling need to be considered, and most of the actual networks still use a non-collaborative configuration. Therefore, in this paper, it is assumed that each D2D cluster multiplexes the channel resources of at most one cellular user at the same time. That is, the following conditions must be satisfied:

$$\sum_{m\in\mathbb{C}} x_{m,n} = 1, \quad \forall n \in \mathbb{D} \tag{10}$$

The variable k_m to denote all D2D clusters that occupy the m-channel of a cellular user, satisfying the following equation relationship:

$$k_m = \sum_{n\in\mathbb{D}} x_{m,n} \tag{11}$$

Assuming that the total system bandwidth is W and all subchannels share these frequency resources, the D2D cluster accessing cellular user m shares the resources of $W/k_m M$, so that the throughput of the n-th D2D cluster is:

$$R_n = \frac{W}{k_m M}\left[\log_2(1+R_1) + \log_2(1+R_2)\right], \quad \forall m \in \mathbb{C}, \quad \forall n \in \mathbb{D} \tag{12}$$

In this paper, a logarithmic utility function [29] is used to achieve a compromise between network throughput and user fairness, to reasonably allocate resources to D2D clusters under the premise of guaranteeing the maximum transmit power constraint, to find the optimal D2D cluster optimal channel reuse X and transmit power p to maximize the energy efficiency of D2D clusters, and based on the above system model, the resource optimization problem can be expressed as P_1:

$$\mathrm{P}_1: \max_{X,k,p} \frac{\sum_{m\in\mathbb{C}}\sum_{n\in\mathbb{D}} x_{m,n}\log R_n}{\sum_{n\in\mathbb{D}}\left(p_{n,1}+p_{n,2}\right)+P_0} \tag{13}$$

$$\text{s.t. } 0 \le \left(p_{n,1}+p_{n,2}\right) \le P_c \quad \forall n \in \mathbb{D} \tag{14}$$

$$\sum_{m\in\mathbb{C}} x_{m,n} = 1, \quad \forall n \in \mathbb{D} \tag{15}$$

$$k_m = \sum_{n\in\mathbb{D}} x_{m,n}, \quad D_N = \sum_{m\in\mathbb{C}} k_m \tag{16}$$

$$x_{m,n} \in \{0,1\} \quad \forall m \in \mathbb{C}, \ \forall n \in \mathbb{D} \tag{17}$$

where, X denotes the matrix of the D2D clusters accessing the channels of the cellular users, k denotes all the D2D clusters occupying the sub-channels, and P_0 denotes the average circuit loss power. (14) represents the power constraint; (15) represents the single connection limit, i.e., each D2D cluster multiplexes at most one cellular user's channel; (17) is a binary constraint, indicating that A takes a value of 1 or 0, representing whether the channel is multiplexed or not.

III. RESOURCE ALLOCATION STRATEGY BASED ON ENERGY EFFICIENCY UTILITY FUNCTION

This paper solves the problem of maximizing the energy efficiency utility function. P_1 is a classical nonlinear planning problem, and the original problem in fractional form can be transformed into an equivalent parametric subtractive form and then solved by using fractional planning methods, and the subtractive function after the transformation is:

$$F(\lambda) = \max_{X,k,p} \sum_{m\in\mathbb{C} n\in\mathbb{D}} x_{m,n}\log R_n - \lambda\left(\sum_{n\in\mathbb{D}}\left(p_{n,1}+p_{n,2}\right)+P_0\right) \tag{18}$$

Suppose $f(X,k,p) = \sum_{m\in\mathbb{C}}\sum_{n\in\mathbb{D}} x_{m,n}\log R_n - \lambda\left(\sum_{n\in\mathbb{D}}\left(p_{n,1}+p_{n,2}\right)+P_0\right)$, The optimal objective function value of P_1 is the solution λ^* satisfying equation $F(\lambda^*) = 0$ and for any given λ, there is $F(\lambda) = f(X^*, k^*, p^*)$. Therefore, it is only necessary to first solve for the optimal value of $f(X,k,p)$ corresponding to each fixed λ, and then derive the optimal λ^* according to the monotonicity of $F(\lambda)$.

For a fixed λ, the P_1 can be converted to:

$$\mathrm{P}_2: \max_{X,k,p} \sum_{m\in\mathbb{C}}\sum_{n\in\mathbb{D}} x_{m,n}\log R_n - \lambda\sum_{n\in\mathbb{D}}\left(p_{n,1}+p_{n,2}\right) \quad \text{s.t. (14)-(17)} \tag{19}$$

Now, the objective function of the original problem has been transformed into an integer form, however, P_2 is a non-convex mixed-integer optimization problem and it is difficult to obtain an optimal solution. Therefore, P_2 is further decomposed into two subproblems, first considering the channel resource allocation problem under fixed transmission power, and then the power control problem under fixed channel allocation. Finally, the joint optimization of channel allocation and power will be performed alternately and iteratively.

A. CHANNEL RESOURCE ALLOCATION SCHEME FOR A GIVEN POWER

First, consider the channel resource allocation optimization problem at a fixed transmission power. To simplify the expression, $m_{m,n} \triangleq \log_2(1+R_n)$ is introduced,and the channel resource allocation problem at a given power can be expressed as:

$$\mathrm{P}_3: \max_{\mathbf{X},k} \sum_{m\in\mathbb{C}}\sum_{n\in\mathbb{D}} x_{m,n}m_{m,n} - \sum_{n\in\mathbb{D}} k_n\log k_n \quad \text{s.t. (15)-(17)} \tag{20}$$

Since X is a two-valued type and can only be 0 or 1, the integer constraint (17) is deflated.

$$0 \le x_{m,n} \le 1, \quad \forall m \in \mathbb{C}, \ \forall n \in \mathbb{D} \tag{21}$$

Introducing the dyadic variables $\boldsymbol{\mu} = \{\mu_n\}_{n\in\mathbb{D}}$ and v, the Lagrange function of (20) is:

$$L(\mathbf{X}, \mathbf{k}, \boldsymbol{\mu}, v) = \sum_{m\in\mathbb{C}}\sum_{n\in\mathbb{D}} x_{m,n}\left(m_{m,n} - \mu_m\right) + \sum_{m\in\mathbb{C}} k_m\left(\mu_m - v - \log k_m\right) + vD_N \tag{22}$$

Since (20) is a convex problem [30] that satisfies strong duality and can be solved equivalently by solving the dual problem, the problem P_3 can be transformed into:

$$\begin{aligned} &\min_{\boldsymbol{\mu},v}\ \max_{\mathbf{X},\mathbf{k}} L(\mathbf{X}, \mathbf{k}, \boldsymbol{\mu}, v) \\ &\text{s.t. } (15)(21) \end{aligned} \tag{23}$$

The method of solving the pairwise problem is to obtain the optimal solution of the original variables by first fixing the pairwise variables to solve the original variables, and then updating the pairwise variables with the given optimized variables, alternating iterations. In each iteration, the optimal X and k are first obtained by maximizing the Lagrange function $L(\mathbf{X}, \mathbf{k}, \boldsymbol{\mu}, v)$ under the given pairwise variables $\boldsymbol{\mu}$ and v.

Assuming $\frac{\partial L(\cdot)}{\partial k_m} = 0$, we have $k_m^* = e^{\mu_m - v - 1}$. The optimization problem for X is:

$$\begin{aligned} &\max_{\mathbf{X}} \sum_{m\in\mathbb{C}}\sum_{n\in\mathbb{D}} x_{m,n}\left(m_{m,n} - \mu_m\right) \\ &\text{s.t. } (14)(20) \end{aligned} \tag{24}$$

From (15) and (21), the upper bound of the objective function is $\sum_{m\in\mathbb{C}}\sum_{n\in\mathbb{D}} x_{m,n}\left(m_{m,n} - \mu_m\right) \leq \sum_{n\in\mathbb{D}} \max_{m\in\mathbb{C}} \left(m_{m,n} - \mu_m\right)$. There exists a feasible solution $x_{m,n}^*$ such that the objective function reaches the upper bound.

$$\begin{aligned} x_{m,n}^* &= \begin{cases} 1, & \text{if } m = m^{(n)} \\ 0, & \text{if } m \neq m^{(n)} \end{cases} \\ \text{where } m^{(n)} &= \arg\max_{q\in\mathbb{C}} \left(m_{nq} - \mu_q\right) \end{aligned} \tag{25}$$

After obtaining the optimal original variable, let $\delta^{(t)}$ be the update step value, then the even variables are updated according to the following rules.

$$\mu_m^{(t+1)} = \mu_m^{(t)} - \delta^{(t)}\left(e^{\mu_m^{(t)} - v^{(t)} - 1} - \sum_{n\in\mathbb{D}} x_{m,n}^{(t)}\right) \tag{26}$$

$$v^{(t)} = \frac{\log \sum_{m\in\mathbb{C}} e^{\mu_m^{(t)} - 1}}{D_N} \tag{27}$$

B. POWER CONTROL SCHEME

The previous section discussed how to obtain the optimal channel resource allocation for a given transmission power, and this section focuses on how to optimize the base station power when the channel resource allocation is given. The power control problem under a fixed channel resource allocation is as follows:

$$\begin{aligned} \mathrm{P}_4:\ \max_{p}\ &\sum_{m\in\mathbb{C}}\sum_{n\in\mathbb{D}} x_{m,n}\frac{W}{k_m M} \\ &\log\left(\log_2\left(1 + R_1\right) + \log_2\left(1 + R_2\right)\right) \\ &- \lambda \sum_{n\in\mathbb{D}} \left(p_{n,1} + p_{n,2}\right) \\ \text{s.t. } &(14) \end{aligned} \tag{28}$$

Since P_4 is a non-convex problem, the auxiliary variable $\theta = \{\theta_n\}_{n\in\mathbb{D}}$ is introduced in this section. Also let α be the power distribution coefficient of DR_1 such that $p_{n,1} = \alpha p_n$. Neglecting the constant term independent of the power, P_4 can be rewritten as:

$$\mathrm{P}_5:\ \max_{p,\theta} \sum_{m\in\mathbb{C}}\sum_{n\in\mathbb{D}} \log\left(\log\left(1 + \theta_{m,n}\right)\right) - \lambda \sum_{n\in\mathbb{D}} p_n \tag{29}$$

$$\text{s.t. } 0 \leq p_n \leq P_c \quad \forall n \in \mathbb{D} \tag{30}$$

$$\frac{\left|H_{DT}\right|^2 p_n}{\sigma^2 + \left|G_c\right|^2 P_c} \geq \theta_{m,n} \tag{31}$$

For constraint (31), introduce auxiliary variables $p_n \triangleq e^{\rho_n}$ and $\theta_n \triangleq e^{\delta_n}$, rewritten in exponential sum form as:

$$e^{\delta_n - \rho_n + \beta_n} + e^{\delta_n - \rho_n + P_C + \gamma_n} \leq 1 \tag{32}$$

where $\beta_n \triangleq 2\log\left(\frac{\sigma}{H_{DT}}\right)$, $\gamma_n \triangleq \log\left(\frac{G_c}{H_{DT}}\right)$, it is easy to know that β_n and γ_n are constants. Let $\omega_n \triangleq \delta_n - \rho_n + \beta_n$, $s_n \triangleq \delta_n - \rho_n + P_C + \gamma_n$, the problem P_5 is transformed into:

$$\mathrm{P}_6:\ \max_{\rho,\theta,\omega,s} \sum_{m\in\mathbb{C}}\sum_{n\in\mathbb{D}} \log\left(\log\left(1 + e^{\delta_n}\right)\right) - \lambda \sum_{n\in\mathbb{D}} e^{\rho_n} \tag{33}$$

$$\text{s.t. } \rho_n \leq \log\left(P_C\right), \quad n \in \mathbb{D} \tag{34}$$

$$e^{\omega_n} + e^{s_n} \leq 1, \quad n \in \mathbb{D} \tag{35}$$

$$\omega_n \triangleq \delta_n - \rho_n + \beta_n, \quad n \in \mathbb{D} \tag{36}$$

$$s_n \triangleq \delta_n - \rho_n + P_C + \gamma_n, \quad n \in \mathbb{D} \tag{37}$$

Since the objective function of P_6 has a negative second derivative, the objective function is concave and the constraint (34)-(37) is non-linear which is convex, so the problem is a convex optimization problem. Introducing a, b, ζ, χ by the Lagrange dual method yields the Lagrange function as:

$$\begin{aligned} &L\left(\boldsymbol{\rho}\delta, \boldsymbol{\omega}_3, , \mathbf{a}, \mathbf{b}, \zeta, \zeta_n \chi\right) \\ &= \sum_{m\in Cn\in\mathbb{D}} \log\left(\log\left(1 + e^{\delta_n}\right)\right) - \lambda \sum_{n\in\mathbb{D}} e^{\rho_n} \\ &\quad - \sum_{n\in\mathbb{D}} a_n\left(e^{\omega_n} + e^{\delta_x} - 1\right) - \sum_{n\in\mathbb{D}} b_n\left(\rho_n - \log P_C\right) \\ &\quad - \sum_{n\in\mathbb{D}} \zeta_n\left(\omega_n - \delta_n + \rho_n - \beta_n\right) \\ &\quad - \sum_{n\in\mathbb{D}} \chi_n\left(s_n - \delta_n + \rho_n - \gamma_n\right) \end{aligned} \tag{38}$$

From the KKT condition, the optimal solution of P_6 satisfies:

$$\frac{\partial L}{\partial \rho_n} = -\lambda \mathrm{e}^{\rho_n} - b_n - \zeta_n - \chi_n = 0 \tag{39}$$

$$\frac{\partial L}{\partial \delta_n} = \frac{\mathrm{e}^{\delta_n}}{\left(1+\mathrm{e}^{\delta_n}\right)\log\left(1+\mathrm{e}^{\delta_n}\right)} + \zeta_n + \chi_n = 0 \tag{40}$$

$$\frac{\partial L}{\partial \omega_n} = -a_n \mathrm{e}^{\omega_b} - \zeta_n = 0 \tag{41}$$

$$\frac{\partial L}{\partial s_n} = -a_n \mathrm{e}^{s_n} - \chi_n = 0 \tag{42}$$

From the above optimal solution we can obtain the update formula for $\boldsymbol{\rho}$, $\boldsymbol{\omega}$, S.

$$\rho_n(t+1) = -\log\lambda + \log\left(-b_n(t) - \zeta_n(t) - \chi_n(t)\right) \tag{43}$$

$$\omega_n(t+1) = \log\left(-\frac{\zeta_n(t)}{a_n(t)}\right) \tag{44}$$

$$s_n(t+1) = \log\left(-\frac{\chi_n(t)}{a_n(t)}\right) \tag{45}$$

According to the sub-gradient descent method, the update formula for the dyadic variables can be obtained as follows:

$$a_n(t+1) = a_n(t) + \sigma^{(t)}\left(\mathrm{e}^{\omega_n(t)} + \mathrm{e}^{s_n(t)} - 1\right) \tag{46}$$

$$b_n(t+1) = b_n(t) + \sigma^{(t)}\left(\rho_n(t) - \log P_C\right) \tag{47}$$

$$\zeta_n(t+1) = \zeta_n(t) + \sigma^{(t)}\left(\omega_n(t) - \theta_n(t) + \rho_n(t) - \beta_n(t)\right) \tag{48}$$

$$\chi_n(t+1) = \chi_n(t) + \sigma^{(t)}\left(s_n(t) - \theta_n(t) + \rho_n(t) - \gamma_n(t)\right) \tag{49}$$

where $\sigma^{(t)}$ is the updated step value.

C. JOINT RESOURCE ALLOCATION PROGRAM

The resource allocation algorithm in this paper is the process of allocating channel resources and power for D2D users within a cluster under the condition of D2D cluster formation, and the channel resource allocation and power control results are continuously iterated and finally converge to a stable solution. According to the previous section, the flow of the whole algorithm is shown in Algorithm 1.

For the above algorithm, the computational complexity lies in the solution of the channel resource allocation problem and the power control problem in each iteration. First, according to literature [31], the Lagrangian pairwise decomposition method has a complexity $\mathcal{O}(M(M+N))$ when solving the problem. For problem A in III, the complexity depends mainly on the computation of each iteration, and the inverse function value complexity can be obtained using the dichotomy method, Let Δ be the precision of the dichotomy with complexity $\mathcal{O}\left(\log_2 \frac{1}{\Delta}\right)$.Since problem B in III is also solved by the pairwise method, similarly the complexity of problem B can be obtained as $\mathcal{O}\left(M(M+N)\log_2\frac{1}{\Delta} + M(M+N)^2\right)$, so the overall complexity of the above iterative algorithm is $\mathcal{O}\left(M(M+N)\left(\log_2\frac{1}{\Delta} + M + N\right)\right)$.

Algorithm 1 Iterative Optimization Algorithm for Channel Resource Allocation and Power Control

```
Initialize $\Psi = 0$ and a small threshold $\Upsilon > 0$;
repeat;
Initialize the power $p$ to any feasible value;
repeat;
According to III-A solve the channel resource allocation problem under fixed power;
The power allocation problem under fixed channel resources is solved according to III-B;
Calculatio $\Upsilon^* = \sum_{m\in\mathbb{C}\in\mathbb{D}}\sum_{m,n} x_n \log R_n - \lambda\sum_{n\in\mathbb{D}}\left(p_{n,1}+p_{n,2}\right)$;
Update $\Psi = \frac{\sum_{m\in\mathbb{C}}\sum_{n\in\mathbb{D}} x_{m,n}\log R_n}{\sum_{n\in\mathbb{D}}(p_{n,1}+p_{n,2})+P_0}$;
until $\Upsilon^* \leq \Upsilon$;
Output the optimal $X^*$ and $p^*$.
```

TABLE 1. Simulation parameter setting.

Parameter	Parameter Value
Base Station Coverage	500m
CU maximum transmitting power	30dBM
DT maximum transmitting power	30dBM
Imperfect SIC parameters	0.1∼0.5
Number of D2D clusters	20∼60
D2D intra-cluster spacing	10∼50
Gaussian white noise	-10dBM

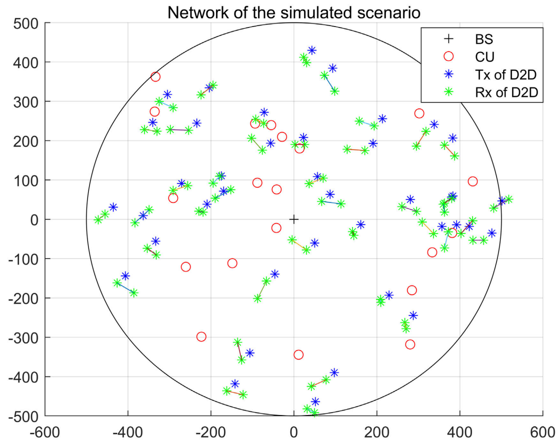

FIGURE 2. D2D-NOMA Network of the simulated scenario.

IV. SIMULATION RESULTS AND ANALYSIS

In this section, simulations are used to evaluate the performance of the proposed channel resource allocation and power control algorithms. The main parameters used in the simulation and the simulation experimental diagram are shown in TABLE 1 and Figure 2, respectively.

Figure 3 shows the schematic diagram of the variation of D2D cluster rate with transmit power DT for different algorithms with 20 fixed cellular users, 40 D2D-NOMA clusters, 20m inter-cluster distance, and imperfect SIC parameter set to 0.1. From the simulation plots,the reachable rates of the D2D clusters of the optimized power allocation scheme and the

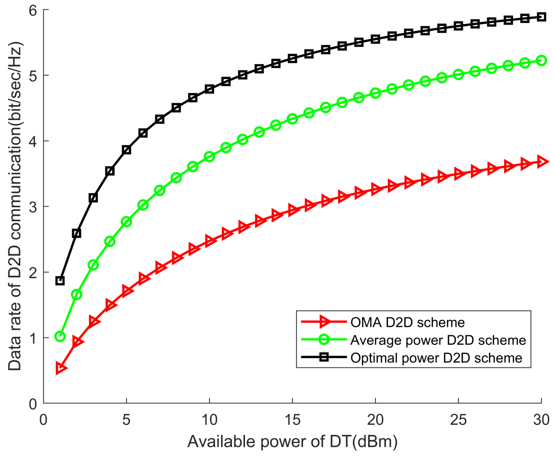

FIGURE 3. D2D cluster rate versus transmit power for the three schemes.

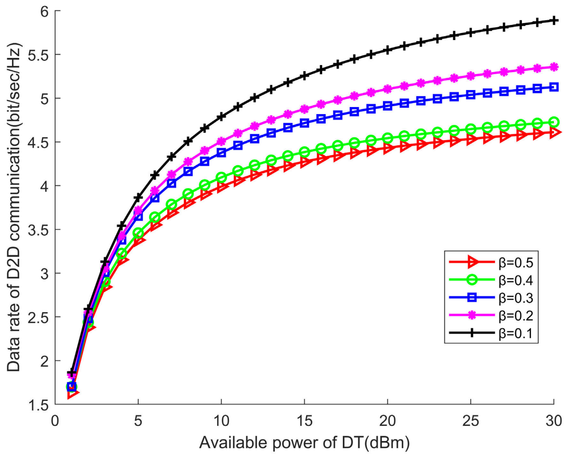

FIGURE 4. Relationship between imperfect SIC parameters on D2D cluster rate.

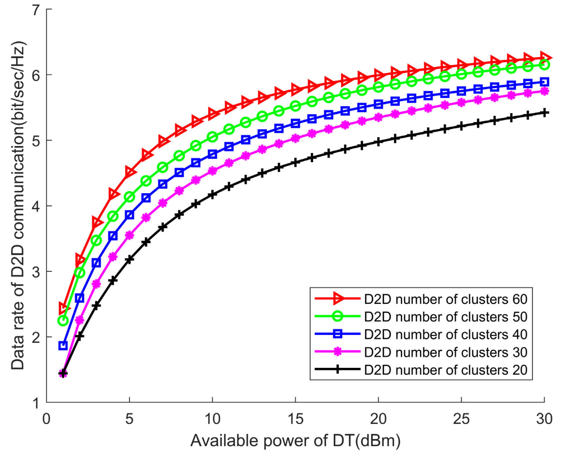

FIGURE 5. Transmitted power versus D2D cluster rate for different number of D2D clusters.

average power allocation scheme as well as the conventional OMA scheme proposed in this paper all increase with the increase of the transmit power, while the optimized power scheme proposed in this paper is significantly better than the average power scheme and the conventional OMA scheme under the same environmental parameters. The difference in the reachable rate between the NOMA scheme and the OMA scheme increases as the DT transmit power increases because the NOMA with higher transmit power provides higher energy efficiency than the OMA.

To obtain the effect of SIC parameters on the D2D cluster rate when the SIC decoding is not perfect at the NOMA receiver. The performance of the proposed algorithm is compared for different values of β as shown in Figure 4. Simulation results show that although the throughput increases with increasing D2D transmit power for all imperfect SIC decoding conditions, However, as the parameter β takes higher values,the larger the deviation of SIC decoding, the lower the reachable rate of D2D clusters. The deviation of SIC decoding at the NOMA receiver side has a significant impact on the reachable rate of D2D clusters, and the simulation verifies the importance of successful SIC decoding in the actual NOMA-based D2D communication system.

Figure 5 compares the transmit power versus D2D cluster rate for different D2D cluster numbers with 20 fixed cellular users, 20m inter-cluster distance, and imperfect SIC parameter set to 0.1. As the number of D2D-NOMA clusters increases, the proposed scheme increases the D2D-NOMA reachable rate. Also, when the DT transmit power is the same, the reachable rate of D2D clusters increases as the number of D2D-NOMA clusters increases, because the system throughput increases as the number of D2D clusters increases.

Figure 6 shows the relationship between transmit power and D2D cluster rate for different D2D cluster spacing with 20 fixed cellular users, 40 D2D-NOMA clusters, and imperfect SIC parameter set to 0.1, the rate of NOMA-D2D system decreases significantly as the distance between D2D clusters becomes larger,and also when the DT transmit power is the same, the rate of D2D cluster decreases as the D2D-NOMA cluster spacing becomes larger. This is because the larger distance between D2D clusters makes the path loss serious, which directly affects the reachable rate of D2D.

Figure 7 shows the D2D reachable rate variation curve for a fixed number of cellular users of 20, an inter-cluster distance of 20m, and a change in the number of D2D-NOMA clusters from 20 to 60. In this paper, we compare three schemes, and it can be seen that the throughput of all schemes shows an increasing trend as the number of D2D-NOMA clusters increases. The conventional OMA scheme has the worst performance, and the average power algorithm is not as good as the optimized power allocation in this paper,because according to the NOMA transmission protocol, the size of the power allocation should be differentiated for users with channel gain difference, which the average power allocation does not do.

For D2D communication, the communication distance between the transmitter and the receiver has a large impact on

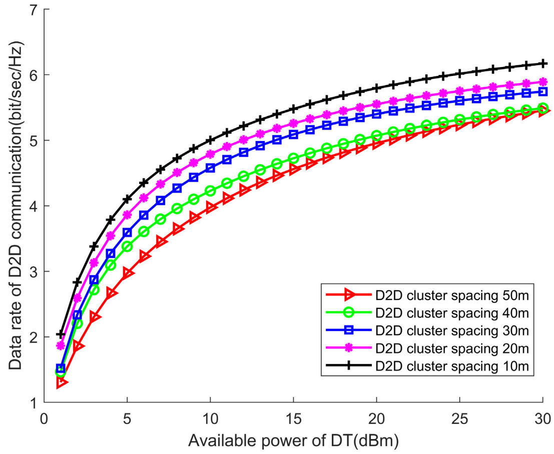

FIGURE 6. **Transmitted power versus D2D cluster rate for different D2D cluster spacing.**

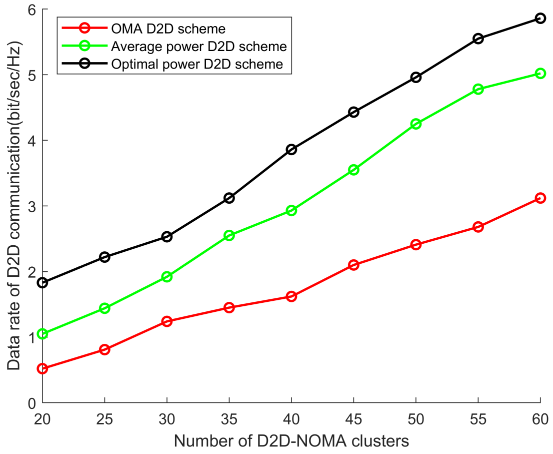

FIGURE 7. **D2D cluster rate versus number of clusters for the three schemes.**

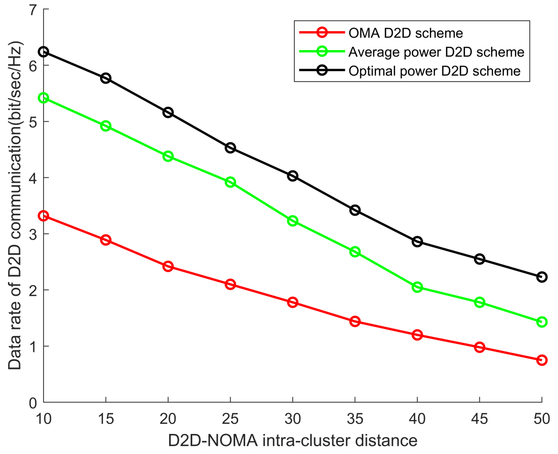

FIGURE 8. **D2D cluster rate versus intra-cluster distance for the three schemes.**

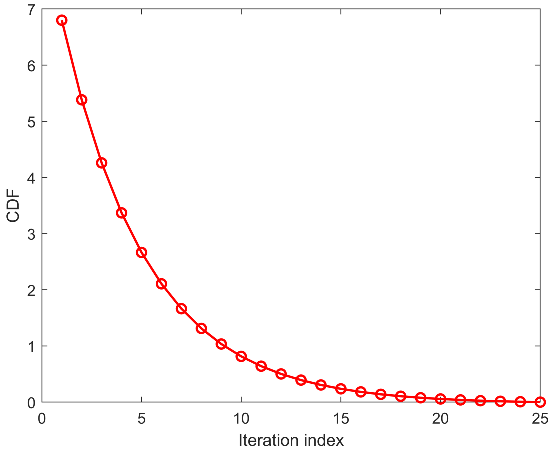

FIGURE 9. **Convergence of the proposed optimization algorithm.**

the system's performance. As shown in Figure 8, the variation curve of the D2D reachable rate is shown when the number of cellular users is set to 20, the number of D2D transmitters is set to 40, the imperfect SIC parameter is set to 0.1, and the intra-cluster spacing is in the interval of 10m-50m. It can be seen that the D2D reachable rate of all three schemes decreases significantly as the intra-cluster distance becomes larger,which is because the larger intra-cluster distance makes the path loss serious and directly affects the system throughput.

Finally, the complexity of the proposed scheme is shown iteratively. The graph represents the convergence curve, and the vertical coordinate is the difference between the current objective function value and the optimal value. From the Figure 9, it can be seen that the algorithm converges quickly, after about 25 iterations, so that the proposed optimization scheme obtains the solution of the power distribution coefficient with the maximum achievable rate of the D2D system at the cost of lower computational complexity.

V. CONCLUSION

In this paper, the joint optimization algorithm of channel resource allocation and power control in D2D-NOMA is studied. Under the comprehensive consideration of energy efficiency and user fairness, the original problem is divided into two sub-problems to solve, and appropriate auxiliary variables are introduced separately to obtain the optimal solution by using Lagrange analysis, and then the solution of the original problem is obtained by alternate optimization, and finally, the performance advantage of the joint optimization algorithm of channel resource allocation and power allocation in energy efficiency is proved by simulation.In addition, this paper adopts the strategy of uniform resource allocation for cellular users, and the next step can consider both the joint optimization of non-uniform channel resource allocation and power control is expected to further improve the system performance. In the future, the authorized frequency bands of B5G and 6G communications are getting higher and higher, and the number of terminal devices is increasing dramatically, it is still worth to further studying and exploring how to effectively develop and expand various application schemes of NOMA-D2D technology while guaranteeing the safety performance. Therefore, future work can consider joint optimization of channel resource allocation and power control strategies under the guarantee of safety performance.

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