IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Date of publication xxxx 00, 0000, date of current version xxxx 00, 0000.

Digital Object Identifier 10.1109/ACCESS.2017.Doi Number

Sum-rate Optimization for IRS-Aided D2D Communication Underlay Cellular Networks

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ABSTRACT The intelligent reflective surface (IRS)-assisted communication is recognized as a promising technology to enhance capacity and coverage of the network by controlling propagation. However, in IRS-aided device-to-device (D2D) communication underlaying cellular networks, co-channel interference is more complicated and challenging than traditional D2D communication networks due to the addition of extra reflection paths. To alleviate interference and improve sum-rate, we establish a multivariable resource optimization function based on IRS-assisted D2D communication in this paper. Then, a hybrid sub-optimal algorithm is proposed, which includes channel allocation based on game theory, power allocation and phase shift optimization. Specifically, a sub-channel allocation algorithm is introduced to maximize system sum-rate, where the problem of sub-channel allocation is formulated as a two-stage combinatorial auction model, and the approximate optimal solution is obtained by bidding and adjustment. Then, a sub-optimal solution for transmission power and phase shifts is obtained through local search and iterative optimization. Simulation results show that the proposed hybrid sub-optimal algorithm is feasible and effective. Compared to the other 5 schemes, it has best sum-rate performance and lowest power consumption.

INDEX TERMS D2D communication, IRS, system sum-rate, optimization, combinatorial auction.

I. INTRODUCTION

A. MOTIVATION

The popularity of mobile devices, terminals and multimedia services leads to a sharp increase in the demand for high data rates service in wireless communication systems [1]. In order to meet this demand and handle the escalating amount of communication traffic, many novel techniques have been proposed. Among them, D2D communication is considered one of the most promising solutions, where D2D users (*DUEs*) can communicate directly without BS by reusing spectrum resources of cellular users (*CUE*s) [2-4]. Although D2D communication has the potential ability to improve spectrum efficiency (SE) and reduce the load burden of base station (BS), it also brings aggravated interference due to the spectrum sharing with *CUE*s.

On the other hand, a recent and revolutionary approach called the intelligent reflective surface (IRS) has attracted extensive attention because of its capacity to improve the communication environment and weaken interference [5-8]. Equipped with lots of reflection elements that are integrated on a planar surface, the IRS could control the direction of the signals to bypass the blocks and enhance the signal strength at the receiver with very little energy. In detail, for each reflection element, its phase shift and amplitude can be controlled by positive-intrinsic-negative (PIN) diode. By adjusting the phase shift and amplitude, IRS achieves a precise beamforming to enhance or cancel signals. As a consequence, IRS can be used to maximize the coverage and the capacity in a low-cost and energy-efficient manner [9-11]. Motivated by the above mentioned potential benefits, recent studies have attempted to integrate IRSs into D2D communications [12-13]. Since the interference model depends on the radio propagation environment, the interference mitigation and throughput optimization algorithm are closely coupled with the propagation environment. Thus, interference mitigation and throughput optimization schemes based on traditional D2D communications are no longer applicable for IRS-aided D2D communications where the propagation environment is reconfigured by IRS. To solve this problem, some works have attempted to explore resource optimization algorithms and achieved good performance. However, effective resource allocation and performance optimization with low complexity are still lacking. This motivates us to investigate a novel algorithm to mitigate interference and optimize the throughput for IRS-aided D2D communications. Different from the existing work, we comprehensively consider decentralized sub-channel allocation based on game theory, power control and phase shift optimization to upgrade system performance.

B. RELATED WORKS

1) RESOURCE ALLOCATION IN D2D COMMUNICATION

A rich body of literature is studied to manage the wireless resources and mitigate the co-channel interference for D2D communication underlaying cellular networks [14-18].

Dominic in [14] models resource allocation problem as a pricing game based on the non-coupled random learning algorithm, and minimize the weighted interference and payment price. Mach *et al.* in [15] introduce Hungarian algorithm to match all available channels to *DUEs*. [16] proposes a hybrid frequency reuse and power allocation scheme. Liu *et al.* in [17] use the gradient algorithm to increase the quality of communication links and optimize the system capacity. In [18], a sum rate maximization problem with power control and greedy solution are proposed. Although these resource allocation algorithms mitigate co-channel interference and improve system performance, they are mainly designed for the uncontrollable propagation environment. Therefore, it is not directly applicable to IRS-aided systems with the ability to change the propagation environment actively.

2) IRS-AIDED COMMUNICATION SYSTEM

Motivated by the advantages of the IRS, researchers introduce IRS into all kinds of settings [9, 19-21]. Authors in [9] integrate the IRS into unmanned aerial vehicle (UAV) communication and improve the sum-rate of the single antenna UAV system. In addition to applications in single antenna systems, IRS can be used to enhance the performance of multi-antenna systems such as MIMO [20]. What's more, IRS can be designed to improve the capacity in short-range scenarios, such as D2D and cell-free massive MIMO systems [21]. It is unnecessary to introduce reflected equipment to forward useful signals for a D2D pair when the direct path between a D2D transmitter and a D2D receiver is available. However, the interference caused by co-channel D2D pairs and CUEs needs to be suppressed especially in high frequency-reuse-factor scenarios. Therefore, researchers introduce IRS into the D2D communication underlay cellular networks to mitigate co-channel interference [22-27]. In [22], authors optimize the power and phase shift matrix by using the block coordinate descent algorithm and semi-relaxation technology. As expected, D2D communication with IRS aided achieves higher throughput than traditional D2D systems. In [23], authors maximize the sum-rate for IRS-assisted D2D systems by transforming the configuration of the IRSs into a quadratically constrained quadratic program while satisfying certain constraint. In [24], the secrecy performance and outage probability for D2D with IRS empowered communication are analyzed when the direct path between DUEs is blocked by obstacles. To minimize the total time delay, a joint optimization algorithm of computational task allocation, sub-channel assignment, power control and phase shift adjustment is proposed in [25]. [26] focuses on maximizing energy efficiency (EE) by jointly optimizing beamforming of IRS and transmission power. [27] maximizes EE and spectrum efficiency (SE) by jointly designing beamforming, transmission power and frequency reuse factor for IRS-assisted D2D communication according to relative channel strength. Although the previous works improve the system performance of IRS-assisted D2D communications significantly, they mainly focus on centralized optimization with high complexity. Therefore, how to effectively optimize the allocation of wireless resource remains a problem to be solved for the IRS-aided D2D communication systems, especially when multiple DUEs share a channel.

C. CONTRIBUTIONS

In this paper, we consider the uplink communication scenario and focus on sum-rate optimization for IRS-assisted D2D communication underlaying cellular systems. The main contributions of this paper are summarized as follows:

- We introduce a multivariable joint optimization model to improve system sum-rate for an uplink heterogeneous cellular network with IRS assisted D2D communication, where multiple DUEs are allowed to share a CUE's sub-channel.
- We split the optimization problem into three sub-problems. For the sub-problem of channel allocation, we formulate it as a two-stage combinatorial auction game to maximize the system sum-rate under the constraints of the maximum transmission power and the minimum SINR of CUEs.
- We design an iterative optimization scheme for phase shift adjustment and power control. Specifically, the transmission power is optimized with phase shift fixed, and then phase shift is optimized with transmission power fixed. The sub-optimal solution is obtained by iterative optimization of the two sub-problems. Furthermore, in order to reduce the complexity, optimization of the sub-problem is handled by local search algorithm.
- We prove the existence and uniqueness of the Nash equilibrium. In addition, we analyze the computational complexity and signaling overhead of the proposed algorithm.

The rest of this paper is summarized as follows: In section II, we introduce system model and problem description of the paper. The problem function for optimization of sum-rate is divided into three sub-problems, including channel assignment, power control and phase shift in section III. In section IV, we analyze performance of the proposed algorithm by simulation. The work of this paper is summarized in section V. The proofs are given in Appendixes.

II. SYSTEM DESCRIPTION

A. SYSTEM MODEL

As shown in Fig. 1, an IRS is assembled in the uplink heterogeneous network with D2D communication underlaying cellular systems. When the incident signal strikes the surface, it will be reflected. The controller can change the phase shifts of the reflection element by adjusting the PIN diode, so that more effective signals can be reflected to the target receiver. Therefore, for the cellular communications, the signals received by BS conclude two parts: one is the direct signals from *CUE*; another one is the reflected signals through

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the IRS. Similarly, for D2D communications, the D2D receiver can receive both direct signals and reflected ones. For simplicity, we omit the interference signals received by the left D2D pair in Fig. 1.

The set of IRS array elements is defined as $\mathbf{S}=\{(S_1, S_1),\ldots,(S_z, S_y),\ldots,(S_A, S_A)\}$, $1\le z\le A$, $1\le y\le A$. For simplicity, we assume that phase shift of each element only has finite discrete values between [0, 2π] with equal quantization intervals. There are 2^a different phase shift values with a quantization bits, and the response coefficient caused by the element (S_z, S_y) is $q_{S_z,S_y}=a^{j\theta_{S_z,S_y}}$, where $\theta_{S_z,S_y}=2b_{S_z,S_y}\pi/(2^a-1)$, $b_{S_z,S_y}=\{1,2,\ldots 2^a-1\}$, $j=\sqrt{-1}$.

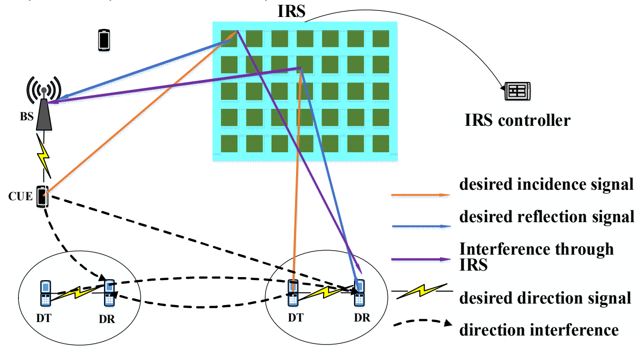

FIGURE 1. System model of uplink IRS assisted heterogeneous networks

According to [28] - [33], we introduce a classical model to describe the system in Fig.1 which is mainly composed of the direct channel and reflection one. That is, the direct channel can be expressed as

$$h_{t,r}=h_m\sqrt{(D_t^r)^{-\alpha_0}}\ , \tag{1}$$

where, h_m is a Nakagami- φ_i small scale fading with parameter $\{\varphi_i, \omega_i\}$. The fading depth coefficient φ_i=3, and the average fading signal power ω_i=1/3. $(D_t^r)^{-\alpha_0}$ represents large-scale fading, D_t^r denotes the distance between transmitter t and receiver r, α_0 is the path loss exponent.

The reflection channel is composed of two parts: line-of-sight (LoS) part and non-line-of-sight (NLoS) part, specifically,

$$h_{t,r}^{S_z,S_y}=\sqrt{\rho/(1+\rho)}\tilde{h}_{t,r}^{S_z,S_y}+\sqrt{1/(1+\rho)}\hat{h}_{t,r}^{S_z,S_y}, \tag{2}$$

where ρ is the Rician factor, $\tilde{h}_{t,r}^{S_z,S_y}$ is the LoS component, $\hat{h}_{t,r}^{S_z,S_y}$ is the NLoS component of the reflection channel. $\tilde{h}_{t,r}^{S_z,S_y}$ and $\hat{h}_{t,r}^{S_z,S_y}$ can be respectively written as

$$\tilde{h}_{t,r}^{S_z,S_y}=\sqrt{(D_t^{S_z,S_y}\cdot D_{S_z,S_y}^r)^{-\alpha_0}}\,a^{-j\frac{2\pi}{\lambda}(D_t^{S_z,S_y}+D_{S_z,S_y}^r)}, \tag{3}$$

and

$$\hat{h}_{t,r}^{S_z,S_y}=\sqrt{(D_t^{S_z,S_y}\cdot D_{S_z,S_y}^r)^{-\alpha_0'}}\,\hat{h}_{t,r}^{NLoS,S_z,S_y}, \tag{4}$$

where λ is the wavelength, α_0' is the path loss exponent of NLoS, $\hat{h}_{t,r}^{NLoS,S_z,S_y}$ is the small-scale fading obeying CN(0, 1) distribution.

B. SINR ANALYSIS

In the system, there are I sub-channels, I *CUEs* and M *DUEs*, and the i-th sub-channel is assigned to the i-th *CUE*. The M *DUEs* reuse the spectrum resources with *CUEs* in the cellular network. We denote packet group ψ_i as the set of *DUEs* who share the sub-channel with the cellular user CUE_i. Then, for the uplink transmission, BS receives desired signal from CUE_i and also receives the co-channel interference from *DUEs* in the packet group ψ_i. Similarly, a *DR* (D2D receiver) in packet group ψ_i receives interference from the CUE_i and other *DUEs* of packet group ψ_i. Therefore, we can express the signal received by BS from CUE_i as

$$\xi_{r_i}=\left(h_{t_i,\mathrm{BS}}+\sum_{S_z,S_y}h_{t_i,BS}^{S_z,S_y}q_{S_z,S_y}\right)\sqrt{p_i^I}\xi_{t_i}+ \sum_{m\in\psi_i}\left(h_{t_m,\mathrm{BS}}+\sum_{S_z,S_y}h_{t_m,BS}^{S_z,S_y}q_{S_z,S_y}\right)\sqrt{p_m^M}\xi_{t_m}+\varpi\ , \tag{5}$$

where, ξ_{t_i} and ξ_{r_i} denote the signal sent by CUE_i and the signal received by BS, respectively. ξ_{t_m} denotes the signal transmitted by the m-th D2D pairs DT_m. p_i^I and p_m^M denote the transmission power of CUE_i and DUE_m, respectively. $h_{t_i,\mathrm{BS}}$ denotes the channel gain of the direct path between CUE_i and BS, and $h_{t_i,\mathrm{BS}}^{S_z,S_y}$ is the channel gain of the reflection path reflected by (S_z, S_y). $h_{t_m,\mathrm{BS}}$ denotes the channel gain of the direct path between DUE_m and BS, $h_{t_m,\mathrm{BS}}^{S_z,S_y}$ is the corresponding reflection path reflected by (S_z, S_y). ϖ is the Gaussian white noise subjected to CN (0, 1) distribution.

The signal received by DR_m is written as:

$$\xi_{r_m}=\left(h_{t_m,r_m}+\sum_{S_z,S_y}h_{t_m,r_m}^{S_z,S_y}q_{S_z,S_y}\right)\sqrt{p_m^M}\xi_{t_m}+ \sum_{m'\in\psi_i,m'\neq m}\left(h_{t_{m'},r_m}+\sum_{S_z,S_y}h_{t_{m'},r_m}^{S_z,S_y}q_{S_z,S_y}\right)\sqrt{p_{m'}^M}\xi_{t_{m'}}+ (h_{t_i,r_m}+\sum_{S_z,S_y}h_{t_i,r_m}^{S_z,S_y}q_{S_z,S_y})\sqrt{p_i^I}\xi_{t_i}+\varpi, \tag{6}$$

where ξ_{t_m} and ξ_{r_m} denote signals sent by DT_m and received by DR_m respectively, $\xi_{t_{m'}}$ denotes the signal transmitted by $DT_{m'}$, $p_{m'}^M$ denotes the transmission power of $DUE_{m'}$, h_{t_m,r_m} and $h_{t_m,r_m}^{S_z,S_y}$ denote the channel gain of direct path from DT_m to DR_m and reflection path from (S_z, S_y)

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respectively, $h_{t_{m'},r_m}$ and $h^{S_z,S_y}_{t_{m'},r_m}$ denote the channel gain of direct path from $DT_{m'}$ to DR_m and reflection path from (S_z, S_y) respectively. h_{t_i,r_m} and $h^{S_z,S_y}_{t_i,r_m}$ denote the channel gain of the direct path from CUE_i to DR_m and the reflection path through (S_z, S_y), respectively.

To simplify the expression, we define

$$\mathbf{G}=\sum_{S_z,S_y} q_{S_z,S_y}\mathbf{H}_{S_z,S_y}, \tag{7}$$

where, $\mathbf{H}_{S_z,S_y}$ is a channel vector consisting of the channel gain of all reflection paths reflected by (S_z, S_y). Obviously, $\mathbf{G}$ contains the channel gain of all reflection paths. Specifically, $G_{t_i,\mathrm{BS}}$ denotes the reflection path gain from CUE_i to BS, $G_{t_m,\mathrm{BS}}$ denotes the reflection path gain from DT_m to BS, G_{t_m,r_m} denotes the reflection path gain from DT_m to DR_m, $G_{t_{m'},r_m}$ denotes the reflection path gain from $DT_{m'}$ to DR_m. Then, we rewrite ξ_{r_i} in (5) as

$$\xi_{r_i}=(h_{t_i,\mathrm{BS}}+G_{t_i,\mathrm{BS}})\sqrt{p_i^I}\xi_{t_i}+\sum_{m\in\psi_i}\left(h_{t_m,\mathrm{BS}}+G_{t_m,\mathrm{BS}}\right)\sqrt{p_m^M}\xi_{t_m}+\varpi, \tag{8}$$

and ξ_{r_m} in (6) can be rewritten

$$\xi_{r_m}=(h_{t_m,r_m}+G_{t_m,r_m})\sqrt{p_m^M}\xi_{t_m}+\sum_{m'\in\psi_i,m'\neq m}\left(h_{t_{m'},r_m}+G_{t_{m'},r_m}\right)\sqrt{p_{m'}^M}\xi_{t_n}$$
$$+\left(h_{t_i,r_m}+G_{t_i,r_m}\right)\sqrt{p_i^I}\xi_{t_i}+\varpi. \tag{9}$$

Therefore, SINR of CUE_i and DUE_m can be expressed as follows

$$\gamma_i^I=\frac{\left|h_{t_i,\mathrm{BS}}+G_{t_i,\mathrm{BS}}\right|^2 p_i^I}{\sum_{m\in\psi_i}\left|h_{t_m,\mathrm{BS}}+G_{t_m,\mathrm{BS}}\right|^2 p_m^M+\varpi}, \tag{10}$$

and

$$\gamma_m^M=\frac{\left|h_{t_m,r_m}+G_{t_m,r_m}\right|^2 p_m^M}{\sum_{m'\in\psi_i,m'\neq m}\left|h_{t_{m'},r_m}+G_{t_{m'},r_m}\right|^2 p_m^M+\left|h_{t_i,r_m}+G_{t_i,r_m}\right|^2 p_i^I+\varpi} \tag{11}$$

respectively.

C. PROBLEM DESCRIPTION

According to (10) and (11), the transmission rate of the i-th CUE and the m-th DUE can be written as

$$R_i^I=log_2(1+\gamma_i^I), \tag{12}$$

and

$$R_m^M=log_2(1+\gamma_m^M), \tag{13}$$

respectively.

Combing (12) and (13), we calculate the sum-rate of the system as

$$R=\sum_{i=1}^{I}R_i^I+\sum_{m=1}^{M}R_m^M. \tag{14}$$

Then, the sum-rate optimization problem can be expressed as follows

$$\max_{\{\psi_i,p_i^I,p_m^M,\theta_{S_z,S_y}\}} R$$

$$s.t.\ \text{CR 1: } \psi_i\cap\psi_j=\phi,\ i,j=1,\dots\mathrm{I},\ i\neq j \tag{15a}$$

$$\text{CR 2: } \bigcup_{i=1}^{I}\psi_i=\Omega \tag{15b}$$

$$\text{CR 3: } 0<p_i^I<p_{max},\ \forall\ i=1,2,\dots,I \tag{15c}$$

$$\text{CR 4: } 0<p_m^M<p_{max},\ \forall\ m=1,2,\dots,M \tag{15d}$$

$$\text{CR 5: } \gamma_i^I>\gamma_{min} \tag{15e}$$

$$\text{CR 6: } q_{S_z,S_y=a}^{j\theta_{S_z,S_y}},\ \theta_{S_z,S_y}=2b_{S_z,S_y}\pi/(2^a\text{-}1),$$
$$b_{S_z,S_y}=\{1,2,\dots2^a\text{-}1\},\ \forall(S_z,S_y)\epsilon\mathbf{S}. \tag{15f}$$

where constraint $(15a)$ indicates that the sub-channel of the CUE can be reused by multiple pairs of $DUEs$, and the sub-channel of each pair of DUE is different. Ω in constraint (15b) denotes a set of all $DUEs$ in the cell. Constraint (15b) ensures that each pair of DUE should be assigned to a sub-channel. Constraints (15c) and (15d) are the transmission power constraints of $CUEs$ and $DUEs$ respectively. Because strong transmission always exists among D2D links [34]-[37], we focus on guaranteeing the QoS of CUEs in this paper. Constraint (15e) ensures that SINR of $CUEs$ should be larger than the minimum SINR threshold. Constraint (15f) shows that phase shift is a discrete variable with amplitude 1. As observed, (15) is a mixed integer non-convex optimization problem which is very hard to be solved. Therefore, we split it into three sub-problems to obtain an approximate optimal solution in the following section.

III. OPTIMIZATION OF THE SUM-RATE

In this section, we divide the optimization of the objective function (15) into three parts: channel allocation, power control and phase shift selection. First, a two-stage auction game is used to allocate sub-channels. Then, we optimize the transmission power and phase shift separately. Finally, the transmission power and phase shift are optimized alternately until the algorithm converges.

A. ALLOCATE SUB-CHANNEL

Assuming that orthogonal sub-channels are allocated to CUEs in the cell, we focus on the sub-channel assignment for DUEs by introducing a two-stage combinatorial auction game. Specifically, BS is the seller and DUEs are the bidders. The seller sells channel resources to maximize revenue. Here, the revenue corresponding to the sub-channel refers to the sum utilities of users sharing this sub-channel. In power control stage, players update transmission power, and maximize their own utility.

For user k in the system, we define its utility function μ_k as $\mu_k = R_k - p_k\beta_k$, $\beta_k = (\sum_{k\neq j} g_{kj})/(p_j \sum_{j\neq k} g_{jj} + \varpi)$ [38], where, $k, j = 1, 2, \ldots, K$, g_{kj} denotes the combined channel gain from transmitter k to receiver j, R_k is the rate of user k, p_k is the power level used by user k, β_k is the interference channel quality of user k to other users, $p_k\beta_k$ is the interference generated by the k-th user.

The seller's purpose is to find the maximum benefit, that is, to maximize system sum-rate. We define the seller's income as $U = \sum_{i=1}^{I} U_i$, where U_i is sum of the utility μ_i of CUE_i and the utility μ_m of DUE_m who shares the same channel with CUE_i, namely, $U_i = \mu_i + \sum_{m\in\psi_i} \mu_m$.

Then, we can express the combinatorial auction problem as

$$\max_{\psi_i} \sum_{i=1}^{I} U_i$$

$$s.t.\ \ \text{CR1}: \gamma_i^I > \gamma_{min} \tag{16a}$$

$$\text{CR2}: \psi_i \cap \psi_j = \phi,\ i, j = 1, \ldots \text{I},\ i \neq j \tag{16b}$$

$$\text{CR3}: \bigcup_{i=1}^{I} \psi_i = \Omega. \tag{16c}$$

The above problem is a combinatorial assignment (CAP) problem, also known as winner determination problem [34]. For combinatorial auctions, it is proved that constructing polynomial-time algorithm cannot guarantee the performance in the worst case [39]. Therefore, we propose an approximate solution called two-stage combinatorial auction which is easier to be solved.

The first stage is called bidding stage. At the beginning, every bidder calculates the bidding amount U_m^i and quotes to the seller. U_m^i is the seller's income where the DUE_m shares the channel with CUE_i. The seller in this stage sells link i^* to the bidder m^*, if $(i^*, m^*) = argmax_{(i,m)} U_m^i$, $1 \leq i \leq I$, $1 \leq m \leq M$. After that, the m^*th pair of D2D is added to the package group ψ_{i^*}. Then, bidders who did not win the bid will recalculate the amount and quote until all bidders find their own package group.

The second stage is called adjustment stage. We try to adjust the bidding results to improve system sum-rate in this stage. In a detail, the seller tries to find a bidder m' with the largest gain Δ_1 and removes the bidder m' from the package group, where $\Delta_1 = U_i' - U_i$, U_i and U_i' are respectively the utility with and without m' in the package group ψ_i. Now, the bidder m' bids to obtain a new link i' with $i' = arg\max_j (U_j' - U_j)$ and obtains a gain Δ_2, where $\Delta_2 = U_{i'}' - U_{i'}$, U_i' and $U_{i'}$ are the utility with and without m' in the package group $\psi_{i'}$. If $\Delta_1 + \Delta_2 > 0$, then the adjustment continues. Otherwise, m' will be put back to the original package group. This means the end of the adjustment stage.

Algorithm 1 Sub-channel Combination Auction Allocation Algorithm

Initialization: the best packet $\psi_i^* = \{\}$, power matrix $\mathbf{P}$, phase shift matrix $\boldsymbol{\theta}$, channel state CR , $\Lambda = \{\ \}$;
Output: CR, ψ_i^*

```
for k=1 to M do
  for m=1 to M do
    if m∈Λ, then
      continue;
    end if
    for i=1 to I do
      Calculate the amount U_m^i when the mth D2D
      pair reuses the resource of the ith cellular link;
    end for
  end for
  Select the combination of cellular user CUE_{i*} and
  D2D user m* that maximizes the bid, mark them as
  (i*, m*), setup ψ_i* = {ψ_i*, m*}, Λ = {Λ, m*}, update
  CR;
end for
while true do
    setup Δ1=0, Δ2=0;
  for m=1 to M do
    Select the package group ψ_i corresponding to m,
    try to kick m out, and calculate the gain Δ_m^i;
    if m=1or Δ_m^i>Δ1, then
      Δ1=Δ_m^i, m*=m;
    end if
  end for
  for i=1 to I do
    put m* into the package group ψ_i to calculate the
    benefit Δ_{m*}^i;
    if i=1 or Δ_{m*}^i>Δ2, then
      Δ2=Δ_{m*}^i, i*=i;
    end if
  end for
  if Δ1 + Δ2 > 0, then
    put m* into ψ_i*, update ψ_i* and CR;
  else
    break;
  end if
end while
```

B. FIX θ AND ALLOCATE POWER

When the bidders calculate their own bid amounts, they will update the power to improve their own quotation and obtain greater competitiveness. In this power allocation game, the co-channel users are regarded as non-cooperative players. Each player chooses one power value from the interval $[0, \bar{p}]$, and $\bar{p}$ is user's upper limit of transmission power. We denote the result of the power allocation game as $\mathbf{P} = (p_1, p_2, \ldots p_k, \ldots p_K)$,

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and denote the utility function of player k as $\mu_k(\mathbf{P})$ or $\mu_k(p_k, \mathbf{P}_{-k})$, where $\mathbf{P}_{-k}$ is the power set of other players except player k, K is the number of players. The objective function of the power allocation game can be expressed as

$$max\, \mu_k\left(p_k, \mathbf{P}_{-k}\right), \forall k. \tag{17}$$

From (17), each player selects the power that maximizes his own utility with other players' strategies fixed. Here, we express the best response to the power for the player k as

$$B(p_k)=min\,(\bar{p}, \tilde{p}_k), \tag{18}$$

where, $\tilde{p}_k$ is the corresponding power value point with the maximum utility function in the interval $(0, +\infty)$, namely,

$$\tilde{p}_k=argmax\, \mu_k\left(p_k, \mathbf{P}_{-k}\right),\ p_k\in \mathrm{R}^+. \tag{19}$$

The proof of the existence of the best response $B(p_k)$ is detailed in Appendix A, while the proofs of the existence and uniqueness of the Nash equilibrium are in Appendix B and Appendix C respectively. Through an iterative process based on the fixed point theory, this equilibrium can be achieved. The specific iterative steps are list as follows

1) initialize τ=0, p_k^τ, $\forall k$;

2) Using the optimal response to update transmission power, $p_k^{\tau+1}=B(P_{-k}^\tau), \forall k$;

3) if $p_m^{\tau+1}$-$p_m^\tau<\varepsilon$, then the iteration is terminated, otherwise it returns to 2).

C. FIX P AND SOLVE DISCRETE PHASE SHIFT θ

In this subsection, phase shift is considered as an independent optimization variable, which is optimized by local search in Algorithm 2. Specifically, for the component (S_z, S_y), when other components' phase shifts are fixed, we solve $\theta^*_{S_z,S_y}=arg\max_{\theta_{S_z,S_y}} R$.

Algorithm 2 Local Search For Phase Shift

Initialization: the number of quantization bits a, optimal phase matrix $\boldsymbol{\theta}^*$

Output: $\boldsymbol{\theta}^*$

1: **for** S_z=1 to A **do**
2: **for** S_y=1 to A **do**
3: To traverse all desirable values for θ_{S_z,S_y}, use the function $\theta^*_{S_z,S_y}=arg\max_{\theta_{S_z,S_y}} R$ to select phase shift under threshold conditions, mark it as $\theta^*_{S_z,S_y}$, then, $\theta_{S_z,S_y}=\theta^*_{S_z,S_y}$, update $\boldsymbol{\theta}^*$;
4: **end for**
5: **end for**

D. SUM RATE OPTIMIZATION BASED ON HYBRID ITERATION

In subsection A, we propose sub-channel allocation based on combination auction. After that, we fix $\boldsymbol{\theta}$ and solve $\mathbf{P}$ based on game theory in subsection B. Then, we solve $\boldsymbol{\theta}$ by fixing power in subsection C. To achieve further improvement of sum-rate, we optimize $\mathbf{P}$ and $\boldsymbol{\theta}$ alternately in this subsection, shown as algorithm 3.

Algorithm 3 System Sum Rate Optimization Based on Hybrid Iteration

Initialization: the best packet ψ_i^*={ }, ∀ i, power matrix $\mathbf{P}$, phase shift matrix $\boldsymbol{\theta}$, channel state CR, $\mathbf{P}^*$=$\mathbf{P}$, $\boldsymbol{\theta}^*$ = $\boldsymbol{\theta}$, Λ={ }, ε=0.01, τ=0;

1: update CR using algorithm 1;
2: Calculate the current state system sum rate $R^\tau(\mathbf{P}^*, \boldsymbol{\theta}^*)$;
3: **while true do**
4: update $\mathbf{P}^*$ using local search algorithm;
5: update $\boldsymbol{\theta}^*$ using algorithm 2;
6: Calculate the current state system sum-rate $R^{\tau+1}(\mathbf{P}^*, \boldsymbol{\theta}^*)$;
7: **if** $R^{\tau+1}(\mathbf{P}^*, \boldsymbol{\theta}^*)$-$R^\tau(\mathbf{P}^*, \boldsymbol{\theta}^*)<\varepsilon$, **then**
8: R^*=$R^{\tau+1}(\mathbf{P}^*, \boldsymbol{\theta}^*)$;
9: output R^*, $\mathbf{P}^*$, $\boldsymbol{\theta}^*$;
10: Break;
11: **else**
12: τ=τ+1;
13: **end while**

E. CONVERGENCE ANALYSIS OF ITERATION

In algorithm 3, the iteration contains two sub-problems, power assignment and phase shift selection. Assuming that the current iteration is n+1 and $\boldsymbol{\theta}^{*(n)}$ has been given by the nth iteration. The local search algorithm is designed to maximize sum-rate R. In the Step 4 of algorithm 3, with $\mathbf{P}^*$ given at n+1 th iteration, we have $R(\mathbf{P}^{*(n+1)}, \boldsymbol{\theta}^{*(n)})\geq R(\mathbf{P}^{*(n)}, \boldsymbol{\theta}^{*(n)})$. Similarly, $R(\mathbf{P}^{*(n+1)}, \boldsymbol{\theta}^{*(n+1)})\geq R(\mathbf{P}^{*(n)}, \boldsymbol{\theta}^{*(n)})$ holds when $\boldsymbol{\theta}^{*(n)}$ is updated in Step 5. Thus, sum-rate function of the original optimization problem is a non-decreasing function of $\mathbf{P}^*$ and $\boldsymbol{\theta}^*$ with the increase of the number of iterations. What's more, the number of phase shifts and the value of power are limited, which makes the system sum-rate maximization problem bounded. Therefore, it is proved that the sum-rate optimization algorithm is convergent.

F. COMPLEXITY AND OVERHEAD ANALYSIS

The complexity of the proposed algorithm depends on the complexity of the three sub-problems. In the first stage of algorithm 1, every sub-channel is evaluated for M DUEs, resulting in a computation of $O(IM^2)$. In the second stage, since each DUE can only be adjusted for no more than once, the complexity is $O(IM)$. Thus, the complexity of the proposed bidding algorithm is only $O(IM^2)$. In algorithm 2, according to [40], the complexity of this part is $O(A^2{*}2^a)$. In algorithm 3, the complexity of power control sub-problem is

$O(I+M)$, so the iteratively optimization of $\mathbf{P}$ and $\boldsymbol{\theta}$ results in a computation of $O(A^2 * 2^a + I + M)$. Therefore, the complexity of our proposed algorithm is $O(N_{outer} * (A^2 * 2^a + IM^2))$, where N_{outer} is the number of iterations, as shown in the simulation part, $N_{outer} = 5$.

CSI between DUEs and CUEs, and CSI between D2D transmitters and D2D receivers are needed in this paper, because our sum-rate optimization algorithm depends on the SINRs in (10) and (11) which are related to these values. Different from centralized algorithms, users complete the resource assignment process locally in this paper, which reduces the signaling overhead significantly.

VI. SIMULATION RESULTS AND ANALYSIS

We establish a 3-D Cartesian coordinate system in Fig. 2. BS is located at the origin, IRS is placed near the BS with the bottom left corner located at (-1, 0, 0), and the Y -axis and Z-axis as the alignment edges. The spacing of each element of IRS is 0.05 m, that is, the coordinate of the element (S_z, S_y) is $(0, 0.05y, 0.05z)$. I *CUEs* and M pair of *DUEs* are randomly distributed in the 120m × 120m area, and the maximum distance between *DT* and *DR* is 10 m. For channel parameters, the large-scale fading is based on the urban micro (UMi) scenario in 3GPP model [41]. It should be noted that we use millimeter-wave centered at 28GHz for simulation. The simulation parameters are listed in Table 1.

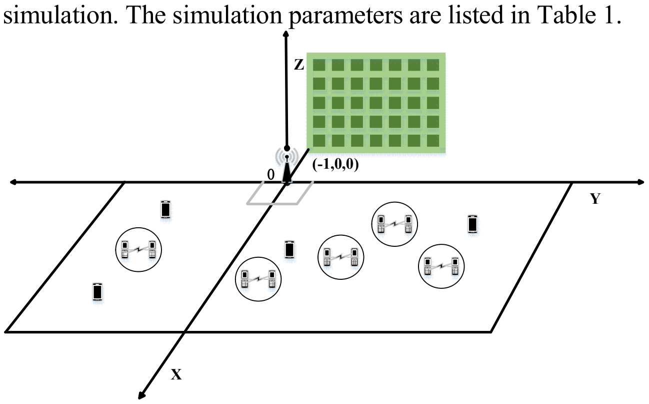

FIGURE 2. Descartes coordinate system of D2D network based on IRS

The six comparison schemes in the simulation are listed as follows:

1) Proposed-algorithm: the proposed joint optimization algorithm in this paper.

2) Greedy algorithm: the greedy channel allocation algorithm [42] combined with the power and phase shift optimization proposed in this paper.

3) RS: the proposed algorithm with random phase shift.

4) RP: the proposed algorithm without power control.

5) RPS: The proposed sub-channel allocation with random transmission power and phase shift.

6) NOIRS: the proposed sub-channel allocation and power optimization without IRS in the system.

TABLE 1. Simulation parameters and values

Parameters	Values
Number of *CUEs* (I)	6
Number of *DUEs* (M)	6:2:14
Users distribution	randomly distribution
Thermal noise power density	-134 dbm/MHz
Channel bandwidth	28 GHz
Maximum transmit power (p_{max})	23 dBm (200 mw)
Minimum required SINR for *CUEs* (γ_{min})	3 dB
Number of reflecting elements ($A \times A$)	8×8
Number of quantization bits (a)	4
Path loss exponent in LoS case (α)	2.5
Path loss exponent in NLoS case (α')	3.6
Maximum distance of *DUEs* (L_{max})	10 m
Iterative threshold (ε)	0.01

Fig. 3 describes system sum-rate v.s. the number of D2D pairs with $A = 8$ and $a = 4$. As shown in Fig. 3, system sum-rate increases with the increasing of the number of *DUEs* because D2D communication improves spectrum efficiency. As observed, sum-rate of the proposed algorithm is superior to other 5 comparison schemes. When the number of *DUEs* is 14, the proposed algorithm achieves 22.6% gain over NOIRS, and 7.8% gain over Greedy algorithm.

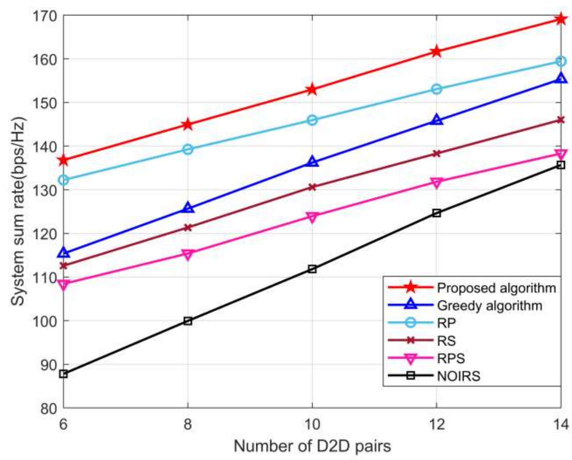

FIGURE 3. Sum-rate versus the number of D2D pairs

Fig. 4 illustrates power consumption of six schemes v.s. the number of D2D pairs. As observed, schemes without power control (RPS and RP) have higher power consumption than those with power control (Proposed algorithm, Greedy algorithm, RS, and NOIRS). Notice that, when the number of *DUEs* is 14, the power consumptions of RPS and RP schemes are 21.73% and 20.79% higher than that of NOIRS, respectively. Our algorithm has a significant advantage in system power consumption, which is 5.38% lower than NOIRS scheme. Combining Fig. 3 and Fig. 4, we come to the conclusion that our algorithm has best sum-rate performance and lowest power consumption compared to other 5 schemes.

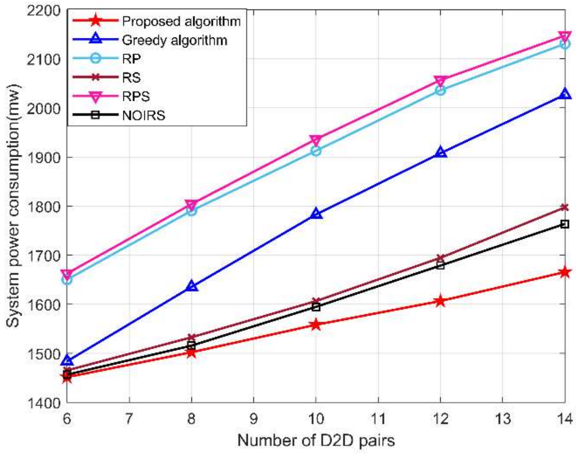

FIGURE 4. **Power consumption v.s. the number of D2D pairs**

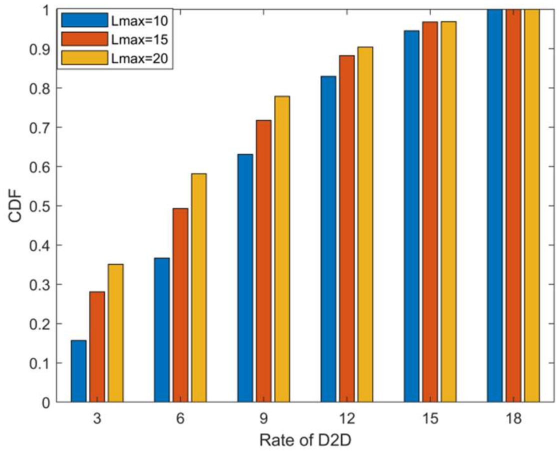

FIGURE 5. **CDF histograms for the rate of DUEs (M=10, A=6, a = 4)**

In Figure 5, we plot cumulative distribution function (CDF) of *DUEs*' sum-rate with different maximum distance L_{max} between *DUEs* of a D2D pair. Fig. 5 shows that the number of low rate users increases with the increasing of L_{max}. This is because larger communication distance leads to more serious path loss between D2D transmitters and D2D receivers.

Next, we analyze how IRS affects the sum-rate in Fig. 6 and Fig. 7. Fig. 6 describes the system sum-rate v.s. a with M=10 and A=6. As shown in Fig. 6, the RPS schemes are almost unaffected by quantization bits (a) due to the random value of phase shift, while system sum-rate of RP, greedy scheme and our proposed scheme increase significantly with the increase of the number of quantization bits because the increase of a contributes to improving precision of beamforming. However, a large value of a will not do contribution to the system sum-rate. This is because for a large a, RISs' improvement in the precision of beamforming is no longer enough to compensate the influence of interference.

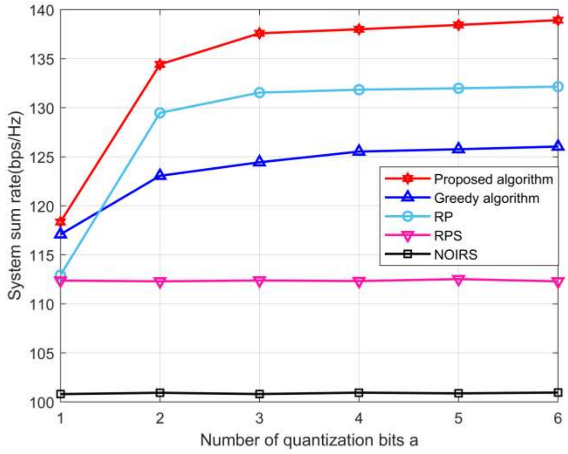

FIGURE 6. **Sum-rate v.s. a (the number of quantization bits)**

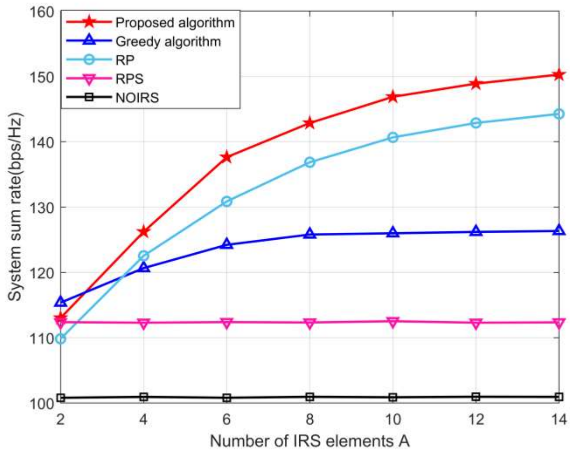

FIGURE 7. **Sum-rate v.s. *A* (the number of IRS elements)**

In Fig. 7, we give the system sum-rate v.s. the number of IRS components (denoted as A) by setting M=8 and a=3. As observed, sum-rates of NOIRS and PRS remain unchanged with the increase of A; while the RP, greedy scheme and our proposed scheme improve sum-rate significantly with the increase of A because the optimization of IRS elements provides beamforming gain for the system. The growth rate of system sum-rate slows down when A exceeds 8. This is because the RIS contributes an increase in the number of interference signal paths. In our proposed scheme, sum-rate gain of A=8 is 33.8 bps/Hz compared to A=2. Whereas, in greedy algorithm, the sum rate gain is 10.05 bps/Hz. In order to reduce the calculation burden of the algorithm, the number of IRS components is supposed to be appropriately small.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2022.3171923, IEEE Access

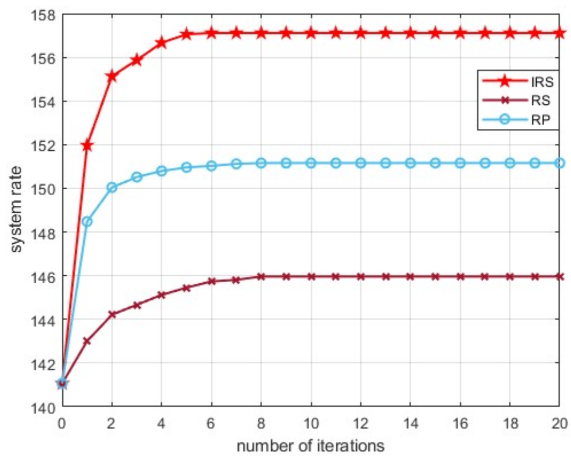

FIGURE 8. Convergence of the algorithms

Fig. 8 describes the convergence performance of the proposed algorithm, RS and RP where M=10, A=6, a=4, and ε=0.01. As shown in Fig. 8, with the increase of iterations, the sum-rate of the proposed algorithm first increases rapidly and then converges to the equilibrium in 5 iterations. It also shows that the proposed algorithm for IRS-aided D2D communication has good convergence performance.

V. CONCLUSION

In this paper, sum-rate optimization of IRS-assisted uplink heterogeneous networks is investigated, subjecting to the constraints of the maximum transmission power and the minimum SINR of *CUEs*. To tackle this mixed-integer non-convex problem, we propose a low-complexity distributed algorithm to acquire a sub-optimal solution. First, we introduce the auction algorithm for the sub-channel allocation to mitigate co-channel interference, and then update the power and phase shift through alternating iteration. Simulation results show that, by joint optimization of sub-channel, user's power and phase shift of IRS components, co-channel interference between users is mitigated effectively, and the sum-rate is improved significantly.

APPENDIX

A. PROOF OF OPTIMAL POWER RESPONSE

We define rate of player k as $R_k=log_2(1+p_k\alpha_k)$, where, p_k is the transmission power of player k, $\alpha_k=g_{kk}/(I_k+\varpi)$ can be regarded as effective channel quality of player k, note that α_k only depends on other players' transmission power $\mathbf{P}_{-k}$. $I_k=\sum_{j\neq k}p_j g_{kj}$ is the interference received by player k. Moreover, denote $\mu_k=log_2(1+p_k\alpha_k)-p_k\beta_k$, where $p_k\beta_k$ is the interference effect of player k on other users, β_k is the channel quality of interference channel with $\beta_k=(\sum_{k\neq j}g_{kj})/(p_j\sum_{j\neq k}g_{jj}+\varpi)$. When p_k>0, μ_k is always greater than zero, and $\alpha_k>\beta_k$. Taking the partial derivative of μ_k with respect to p_k, we have

$$f(p_k)=\frac{\partial\mu_k}{\partial p_k}=\frac{\alpha_k}{(1+p_k\alpha_k)\ln 2}-\beta_k. \tag{20}$$

Then we take the partial derivative of $f(p_k)$ on p_k and drive

$$\frac{\partial f(p_k)}{\partial p_k}=-\frac{\alpha_k^2}{(1+p_k\alpha_k)^2\ln 2}<0,\forall p_k. \tag{21}$$

Notice that, $f(p_k)$ monotonically decreases with the increase of p_k, and there exists $\tilde{p}_k>0$, such that $f(p_k)=0$, which is the global maximum point. Considering the boundary of the feasible set, we obtain the optimal response as $B(p_k)=min(\bar{p},\tilde{p}_k)$.

B. PROOF OF THE EXISTENCE OF NASH EQUILIBRIUM

When the following conditions are satisfied, the Nash equilibrium exists

1) The policy set is a nonempty compact convex subset of Euclidean space;

2) The utility function is continuous and concave [43].

Obviously, the policy set $[0, \bar{p}]$ of player k is a nonempty convex subset of R, and the utility function $\mu_k(p_k, \mathbf{P}_{-k})$ is continuous on p_k, so we just need to prove its quasi-concave.

For p_k, $p_k' \in [0,\bar{p}]$, $\lambda \in [0, 1]$, the utility function is quasi-concave if the following conditions are satisfied

$$\mu_k(\lambda p_k+(1-\lambda)p_k', \mathbf{P}_{-k})>min(\mu_k(p_k, \mathbf{P}_{-k}), \mu_k(p_k', \mathbf{P}_{-k})). \tag{22}$$

In general, we set $p_k<p_k'$, when $\bar{p}<\tilde{p}_k$, we have $f(p_k)>0$, that is, μ_k monotonically increases on $[0, \bar{p}]$. Therefore, $\mu_k(\lambda p_k+(1-\lambda)p_k', \mathbf{P}_{-k})\geq\mu_k(p_k, \mathbf{P}_{-k})$. When $\bar{p}>\tilde{p}_k$, the discussion is divided into the following cases:

1) When $p_k'\leq\tilde{p}_k$, for $\forall p_k\in[0,\tilde{p}_k]$, we have $f(p_k)>0$, and μ_k is monotonically increasing in this interval, i.e. $\mu_k(\lambda p_k+(1-\lambda)p_k',\mathbf{P}_{-k})\geq\mu_k(p_k,\mathbf{P}_{-k})$.

2) When $p_k\geq\tilde{p}_k$, similarly, we can also prove that $\mu_k(\lambda p_k+(1-\lambda)p_k', \mathbf{P}_{-k})\geq\mu_k(p_k', \mathbf{P}_{-k})$.

3) When $p_k<\tilde{p}_k<p_k'$, let $\tilde{\lambda}_k=(p_k'-\bar{p})/(p_k'-p_k)$, then we have

if $\lambda<\tilde{\lambda}_k$, $\mu_k(\lambda p_k+(1-\lambda)p_k', \mathbf{P}_{-k})\geq\mu_k(p_k, \mathbf{P}_{-k})$;

if $\lambda\geq\tilde{\lambda}_k$, $\mu_k(\lambda p_k+(1-\lambda)p_k', \mathbf{P}_{-k})\geq\mu_k(p_k', \mathbf{P}_{-k})$.

In summary, $\mu_k(p_k, \mathbf{P}_{-k})$ is quasi-concave, that is, in this game, Nash equilibrium exists.

C. PROOF OF UNIQUENESS OF NASH EQUILIBRIUM

Appendix B proves the existence of Nash equilibrium $\mathbf{P}=\mathbf{B}(\mathbf{P})$, where $\mathbf{B}(\mathbf{P})=(B_1(\mathbf{P}), B_2(\mathbf{P}),\ldots B_K(\mathbf{P}))$. What's more, $\mathbf{P}=\mathbf{B}(\mathbf{P})$ is unique if the following conditions are satisfied[44]:

1) $\mathbf{B}(\mathbf{P})>0$;

2) if $\mathbf{P} > \mathbf{P}'$, then $\mathbf{B}(\mathbf{P})>\mathbf{B}(\mathbf{P}')$;

3) for $\forall \upsilon>1$, $\upsilon\mathbf{B}(\mathbf{P})>\mathbf{B}(\upsilon\mathbf{P})$.

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According to the definition, we have $\mathbf{B}(\mathbf{P}_{-k})>\mathbf{0}, \forall k$. This obviously meets the condition 1). To prove 2), we first rewrite β_k as

$$\beta_k=\alpha_k \cdot \frac{(\sum_{k\neq j} g_{kj})(\sum_{k\neq j} g_{kj})}{g_{kk}\sum_{j\neq k} g_{jj}}. \tag{23}$$

That is, $\beta_k=\omega\alpha_k$, $0<\omega<1$, so we have $f(p_k)=\frac{\alpha_k}{(1+p_k\alpha_k)\ln 2}-\omega\alpha_k$. Taking the partial derivative of $f(p_k)$ to α_k at $p_k=\tilde{p}_k$, then we have $\frac{\partial f(\tilde{p}_k)}{\partial \alpha_k}=\frac{1}{(1+\tilde{p}_k\alpha_k)^2\ln 2}-\omega$, and $\partial f(\tilde{p}_k)=0$, that is, $\frac{1}{(1+\tilde{p}_k\alpha_k)\ln 2}=\omega$, so $\frac{\partial f(\tilde{p}_k)}{\partial \alpha_k}=\omega(\frac{1}{1+\tilde{p}_k\alpha_k}-1)$, where $\tilde{p}_k\alpha_k>0$, obviously $\frac{\partial f(\tilde{p}_k)}{\partial \alpha_k}<0$. Then, we take the partial derivative of $\tilde{p}_k$ to p_j and get $\frac{\partial \tilde{p}_k}{\partial p_j}=-(\frac{\partial f(\tilde{p}_k)}{\partial \alpha_j}\frac{\partial \alpha_k}{\partial p_j})/(\frac{\partial f(\tilde{p}_k)}{\partial \tilde{p}_k})$. From equation (21), we have $\frac{\partial f(\tilde{p}_k)}{\partial \tilde{p}_k}<0$, and $\frac{\partial \alpha_k}{\partial p_j}=-\frac{\alpha_k^2 g_{kj}}{g_{kk}}<0$. It shows that $\forall k\neq j$, $\tilde{p}_k$ monotonically increases with the increase of p_j. Therefore, for $\forall k$, the optimal response $B(p_k)=min(\bar{p},\tilde{p}_k)$ increases monotonically with the increase of $\mathbf{P}_{-k}$, which proves that when transmission power of other players increases, in order to mitigate interference, the optimal power of player k increases. Similarly, it can be proved that, when the channel quality α_k is better, the optimal response is lower.

For condition 3), let $\alpha_k'=\frac{g_{kk}}{\upsilon I_k+\varpi}$, then $f'(p_k)=f(p_k)|_{\alpha_k=\alpha_k'}$. Substituting $f'(p_k)$ into $\upsilon\mathbf{B}(\mathbf{P})>\mathbf{B}(\upsilon\mathbf{P})$, we get $f'(\upsilon\tilde{p}_k)<0$. In other words, proving 3) is equivalent to prove $f'(\upsilon\tilde{p}_k)<0$. Combining $f'(\upsilon\tilde{p}_k)=\frac{\alpha_k'}{(1+\upsilon\tilde{p}_k\alpha_k')\ln 2}-\omega\alpha_k'$ and $f(\tilde{p}_k)=0$, we have $f'(\upsilon\tilde{p}_k)=\frac{\alpha_k'}{(1+\upsilon\tilde{p}_k\alpha_k')\ln 2}-\frac{\alpha_k'}{(1+\tilde{p}_k\alpha_k)\mathrm{lln}2}$. Since $\alpha_k<\upsilon\alpha_k'$, it is obvious that the denominator in the second item is smaller than that in the first item, that is, the gap is negative, so $f'(\upsilon\tilde{p}_k)<0$.

In summary, condition 1), 2) and 3) are satisfied. This proves the unique of the Nash equilibrium.

REFERENCES

[1] R.- M. Radaydeh, F.- S. Al-Qahtani, A. Celik, K. A. Qaraqe and M.-S. Alouini, "Generalized imperfect D2D associations in spectrum-shared cellular networks under transmit power and interference constraints," *IEEE Access.*, vol. 8, pp. 182517-182536, Oct. 2020.

[2] S. Sharma, N. Gupta, and V. A. Bohara, "OFDMA-Based Device-to-Device Communication Frameworks: Testbed Deployment and Measurement Results," *IEEE Access.*, vol. 6, pp. 12019-12030, Mar. 2018.

[3] M. F. Kader *et al.*, "Device-to-Device Aided Cooperative NOMA Transmission Exploiting Overheard Signal," *IEEE Transactions on Wireless Communications.*, vol. 21, no. 2, pp. 1304-1318, Feb. 2022.

[4] T. Liu, J. C. S. Lui, X. Ma, and H. Jiang, "Enabling relay-assisted D2D communication for cellular networks: Algorithm and protocols," *IEEE Internet Things J.*, vol. 5, no. 4, pp. 3136–3150, Aug. 2018.

[5] Q. Wu, S. Zhang, B. Zheng, C. You and R. Zhang, "Intelligent Reflecting Surface-Aided Wireless Communications: A Tutorial," *IEEE Transactions on Communications.*, vol. 69, no. 5, pp. 3313-3351, May 2021.

[6] L. Dai et al., "Reconfigurable intelligent surface-based wireless communications: Antenna design, prototyping, and experimental results," *IEEE Access*., vol. 8, pp. 45913–45923, 2020.

[7] E. Basar, M. Di Renzo, J. De Rosny, M. Debbah, M. Alouini, and R. Zhang, "Wireless communications through reconfigurable intelligent surfaces," *IEEE Access.*, vol. 7, pp. 116753–116773, 2019.

[8] M. M. Zhao, Q. Wu, M. J. Zhao, and R. Zhang, "Intelligent reflecting surface enhanced wireless networks: Two-timescale beamforming optimization," *IEEE Trans. Wireless Commun.*, vol. 20, no. 1, pp. 2–17, Jan. 2021.

[9] S. Li, B. Duo, X. Yuan, Y. Liang, and M. Di Renzo, "Reconfigurable intelligent surface assisted UAV communication: Joint trajectory design and passive beamforming," *IEEE Wireless Commun. Lett.*, vol. 9, no. 5, pp. 716–720, May. 2020.

[10] Y. Yang, B. Zheng, S. Zhang, and R. Zhang, "Intelligent reflflecting surface meets OFDM: Protocol design and rate maximization," *IEEE Trans. Commun.*, vol. 68, no. 7, pp. 4522–4535, Jul. 2020.

[11] G. Zhou, C. Pan, H. Ren, K. Wang, and A. Nallanathan, "Intelligent reflflecting surface aided multigroup multicast miso communication systems," *IEEE Trans. Signal Process*., vol. 68, pp. 3236–3251, Apr. 2020.

[12] Z. Ji, Z. Qin and C. G. Parini, "Reconfigurable Intelligent Surface Aided Cellular Networks with Device-to-Device Users," IEEE Transactions on Communications, 2022, vol. 70, no. 3, pp. 1808-1819.

[13] Z. Ji and Z. Qin, "Reconfigurable Intelligent Surface Enhanced Device-to-Device Communications," *2020 IEEE Global Communications Conference.*, 2020.

[14] S. Dominic and L. Jacob, "Distributed resource allocation for D2D communications underlaying cellular networks in time-varying environment," *IEEE Communications Letters.*, vol. 22, no. 2, pp. 388-391, Feb. 2018.

[15] P. Mach, Z. Becvar and M. Najla, "Resource allocation for D2D communication with multiple D2D pairs reusing multiple channels," *IEEE Wireless Communications Letters.*, vol. 8, no. 4, pp. 1008-1011, Aug. 2019.

[16] R. Yin, G. Yu and C. Zhong, "Distributed resource allocation for D2D communication underlaying cellular networks," *2013 IEEE International Conference on Communications Workshops.*, pp. 138-143, 2013.

[17] P. Liu, C. Hu, T. Peng and W. Wang, "Distributed cooperative admission and power control for device-to-device links with QoS protection in cognitive heterogeneous network," *7th International Conference on Communications and Networking in China*, pp. 712–716, 2012.

[18] Y. Li, M. Sheng, Y. Zhu, T. Jiang and J. Li, "Sum rate maximization in underlay SCMA device-to-device networks," *2016 IEEE Global Communications Conference.*, pp. 1–6, 2016.

[19] W. Tang *et al.*, "MIMO transmission through reconfigurable intelligent surface: System design, analysis, and implementation," *IEEE J. Sel. Areas Commun.*, vol. 38, no. 11, pp. 2683–2699, Nov. 2020.

[20] Z. Zhang, L. Dai, "A Joint Precoding Framework for Wideband Reconfigurable Intelligent Surface-Aided Cell-Free Network. *IEEE Transactions on Signal Processing.*, vol. 69, pp. 4085-4101, 2021.

[21] W. Khalid *et al*., "RIS-Aided Physical Layer Security with Full-Duplex Jamming in Underlay D2D Networks," *IEEE Access*., vol. 9, pp. 99667-99679, Jul. 2021.

[22] C. Zhang, W. Chen, C. He and X. Li, "Throughput maximization for intelligent reflecting surface-aided device-to-device communications system," *Journal of Communications and Information Networks*., vol.5, no. 4, pp. 403-410, Dec. 2020.

[23] Y. Cao, T. Lv, W. Ni and Z. Lin, "Sum-Rate Maximization for Multi-Reconfigurable Intelligent Surface-Assisted Device-to-Device Communications," *IEEE Trans. Commun.*, vol. 69, no. 11, pp. 7283-7296, Nov. 2021.

[24] M. H. Khoshafa *et al.*, "Reconfigurable Intelligent Surfaces-Aided Physical Layer Security Enhancement in D2D Underlay Communications," *IEEE Communications Letters.*, vol. 25, no. 5, pp. 1443-1447, May.2021.

[25] S. Mao, X. Chu, Q. Wu, L. Liu and J. Feng, "Intelligent reflecting surface enhanced D2D cooperative computing," *IEEE Wireless Communications Letters.*, vol.10, no.7, pp. 1419-1423, Jul. 2021.

[26] S. Jia, X. Yuan and Y. Liang, "Reconfigurable intelligent surfaces for energy efficiency in D2D communication network," *IEEE Wireless Communications Letters.*, vol. 10, no. 3, pp. 683-687, Mar. 2021.

[27] G. Yang, Y. Liao, Y. Liang, O. Tirkkonen, G. Wang and X. Zhu, "Reconfigurable intelligent surface empowered device-to-device communication underlaying cellular networks," *IEEE Transactions on Communications*., vol. 69, no. 11, pp. 7790-7805, Nov. 2021.

[28] H. Guo, Y.-C. Liang, J. Chen, and E. G. Larsson, "Weighted sum-rate maximization for reconfigurable intelligent surface aided wireless networks," *IEEE Tran. Wireless Commun.*, vol. 19, no. 5, pp. 3064–3076, 2020.

[29] S. Abeywickrama, R. Zhang, Q. Wu, and C. Yuen, "Intelligent reflecting surface: Practical phase shift model and beamforming optimization," *IEEE Trans. Commun*., vol. 68, no. 9, pp. 5849–5863, 2020.

[30] J. Chen, Y.-C. Liang, Y. Pei, and H. Guo, "Intelligent reflecting surface: A programmable wireless environment for physical layer security," *IEEE Access*., vol. 7, pp. 82 599–82 612, 2019.

[31] M. Nemati et al., "RIS-Assisted Coverage Enhancement in Millimeter-Wave Cellular Networks," *IEEE Access.*, vol. 8, pp. 188171-188185, Oct. 2020.

[32] H. Zhang, B. Di, L. Song and Z. Han, "Reconfigurable intelligent surfaces assisted communications with limited phase shifts: How many phase shifts are enough?," *IEEE Transactions on Vehicular Technology*., vol. 69, no. 4, pp. 4498-4502, Apr. 2021.

[33] Y. Chen *et al.*, "Reconfigurable Intelligent Surface Assisted D2D Networks: Power and Discrete Phase Shift Design," *GLOBECOM 2020 - 2020 IEEE Global Communications Conference.*, 2020.

[34] T. D. Hoang, L. B. Le, and T. Le-Ngoc, "Energy-effificient resource allocation for D2D communications in cellular networks," *IEEE Trans. Veh. Technol.*, vol. 65, no. 9, pp. 6972–6986, Sep. 2016.

[35] A. Pyattaev, K. Johnsson, A. Surak, R. Florea, S. Andreev, and Y. Koucheryavy, "Network-assisted D2D communications: Implementing a technology prototype for cellular traffic offloading," *in Proc. IEEE Wireless Commun. Netw. Conf.* (WCNC), Istanbul, Turkey, Apr. 2014,pp. 3266–3271.

[36] T. D. Hoang, L. B. Le, and T. Le-Ngoc, "Dual decomposition method for energy-efficient resource allocation in D2D communications underlying cellular networks," *in Proc. IEEE GLOBECOM, San Diego, CA, USA, Dec*. 2015, pp. 1–6.

[37] R. Yin, C. Zhong, G. Yu, Z. Zhang, K. K. Wong and X. Chen, "Joint spectrum and power allocation for D2D communications underlaying cellular networks," *IEEE Transactions on Vehicular Technology.*, vol. 65, no. 4, pp. 2182-2195, Apr. 2016.

[38] A. Pikovsky, "Pricing and Bidding Strategies in Iterative Combinatorial Auctions," Ph.D. dissertation, Dept. Informat., Technischen Universitat Munchen, Munchen, Germany, 2008.

[39] T. Sandholm, "Algorithm for optimal winner determination in combinatorial auctions," *Artif. Intell.*, vol. 135, no. 12, pp. 1–54, Feb. 2002.

[40] S. Luo, P. Yang, Y. Chen, K. Yang, K. Wu, K. C. The and S.Li, "Spatial Modulation for RIS-Assisted Uplink Communication: Joint Power Allocation and Passive Beamforming Design," *IEEE Trans. Commun.*, vol. 69, no. 10, pp. 7017-7031, Oct. 2021.

[41] M. Series, ITU 2135-1, "Guidelines for Evaluation of Radio Interface Technologies for IMT-Advanced," Dec. 2009.

[42] M. Zulhasnine, C. Huang and A. Srinivasan, "Efficient resource allocation for device-to-device communication underlaying LTE network," *In Proc. IEEE Int. Wireless Mobile Comput., Netw. Commun. Conf.*, pp. 368-375, 2010.

[43] C. U. Saraydar, N.B. Mandayam and D.J. Goodman, "Efficient power control via pricing in wireless data networks," *IEEE Transactions on Communications.*, vol. 50, no. 2, pp. 291-303, Feb. 2002.

[44] M. J. Osborne and A. Rubinstein, A Course in Game Theory. Cambridge, MA, USA: MIT Press, 1994.