IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received January 17, 2019, accepted January 23, 2019, date of publication January 31, 2019, date of current version February 27, 2019.
Digital Object Identifier 10.1109/ACCESS.2019.2895975

Joint Resource Allocation and Power Control Algorithm for Cooperative D2D Heterogeneous Networks

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This work was supported in part by the National Natural Science Foundation of China under Grant 61571149, in part by the Fundamental Research Funds for the Central Universities under Grant HEUCFP201808, in the part by the Special China Postdoctoral Science Foundation under Grant 2015T80325, in part by the Heilongjiang Postdoctoral Fund under Grant LBH-Z13054, and in part by the China Postdoctoral Science Foundation under Grant 2013M530148.

ABSTRACT The device-to-device (D2D) communication is viewed as an attractive technique to increase the spectrum efficiency and the data transmission rate in the wireless network. In this paper, we investigate the joint resource allocation and power control problem for cooperative D2D users (DUs) which multiplex cellular users (CUs) in downlink cooperative D2D heterogeneous networks. The studied resource allocation problem contains the spectrum resource block allocation and the selection of an idle user which works as a relay to assist the D2D links communication, while the power control aims to reduce the interference between users and improve the communication quality of service (QoS). To efficiently maximize the total throughput of all the DU links and the CU links on the premise of guaranteeing the communication QoS for CUs, we propose a quantum coral reefs optimization algorithm (QCROA) to obtain the optimal joint resource allocation and power control scheme. The simulation results demonstrate that the proposed QCROA achieves an excellent performance for different network communication scenarios.

INDEX TERMS Cooperative D2D communication, resource allocation, power control, multiple relay selection, QCROA.

I. INTRODUCTION

With the increasing demand for higher energy efficiency, better data transmission rates, and local area services, a major paradigm shift is required for the fifth generation (5G) mobile communication technique [1]. Since the current access modes in cellular networks cannot meet above needs, device-to-device (D2D) communication is regarded as an important technique which can reuse cellular resources and enable D2D users (DUs) to communicate directly without handling by the base station (BS) or access point [2], [3]. In this case, D2D communication is able to improve the spectral efficiency for cellular network, reduce BS load, and promote quality of service (QoS) for edge users in the network [4], [5].

A. RELATED WORK

Despite of D2D communication technique merits, it also brings some challenges. On the one hand, DUs cause interference to CUs because of cellular resources reuse [6]. On the other hand, it is difficult to give an efficient strategy to find an optimal scheme for managing interference [7]. Hence, designing interference control strategy between DUs and CUs which is used to guarantee the communication quality of the whole network is regarded as an essential method in D2D communication [8]. Many papers have conducted in-depth research about this direction. Azam *et al.* [9] investigated the network power allocation, admission control and mode selection for maximizing the throughput of cellular network. Then, an outer approximation approach with interference constraint was proposed to solve this problem. Xu *et al.* [10] proposed a channel allocation and power control scheme based on particle swarm optimization (PSO) for maximizing overall network throughput. Radio resource allocation, mode selection, and power coordination needs in D2D network were discussed in [11] for achieving a higher throughput. However, it is difficult to satisfy the QoS of edge users based on traditional methods [9]–[11] because of long-distance fading.

The associate editor coordinating the review of this manuscript and approving it for publication was Dapeng Wu.

TABLE 1. Comparison with related works (√: satisfied, ×: not satisfied).

Reference	PC	RA	CC	DC	DD	MRS
[5]	√	√	×	√	√	×
[11]	√	√	×	√	√	×
[14]	×	√	√	×	×	×
[17]	×	√	√	√	√	×
[18]	√	×	√	×	×	×
[20]	×	√	×	×	√	×
[21]	√	√	×	×	×	×
[22]	√	√	×	×	√	×
[23]	×	√	√	×	√	×
[24]	√	√	×	√	√	×
Our work	√	√	√	√	√	√

(PC: Power control RA: Resource allocation CC: Cooperative communication DC: Dense CUs DD: Dense DUs MRS: Multiple relay selection)

Cooperative communication technology is applied to the case where users require a larger coverage region or a higher throughput demand for edge users [12]–[14]. To exert the advantage of cooperative communication and improve D2D network performance, the recent study works focus on the combination of cooperative communication and D2D communication. Cooperative D2D communication has the ability to improve the system capacity and spectral efficiency [15], [16]. Recently, a two-stages throughput balance scheme was considered in [17]. The authors proposed a relay selection and resource allocation scheme on the basis of bipartite matching theory. In [18], a power allocation and relay selection scheme for underlay D2D network was designed. The idle femtocell base station worked as a relay for D2D transmission pair. However, only small-scale relay selection scenario is investigated in [17] and [18] while the actual scene exists the situation where there are many idle users (IUs) in a dense-scale DUs scenarios [19].

Both resource allocation scheme and power control scheme play a vital role in the performance in D2D network. Various schemes have been developed to find an effective and universal management method. Song *et al.* [20] gave a game-theoretic protocol for the radio resource allocation issue. The aim was to demonstrate the wide application of game-theoretic model to study the D2D radio resource allocation problem. Chen *et al.* [21] investigated the joint spectrum and power allocation issue in the green D2D communication scenery where there was one CU and one D2D pair. An iterative algorithm was proposed to maximize the energy efficiency of the D2D pair. Asheralieva and Miyanaga [22] developed channel and power level selection scheme to maximize the reward of achieved throughput and power consumption cost. In order to meet system demand, the autonomous learning-based method was given. A two-stage auction for D2D relay resource allocation approach was presented in [23]. Simulation results showed good performance in terms of running time and average utility.

B. MOTIVATION AND CONTRIBUTIONS

Although many previous researches have made influential achievements, there are some certain limitations which need to be improved. First, as presented in Table 1, existing literature do not address the case where power control, resource allocation and multiple relay selection should be considered simultaneously for a dense CUs and DUs scenario. This limits the application scope of the actual system. Second, many resource allocation schemes [5], [18], [20], [22]–[24] generally transform resource allocation problem into convex optimization problem or design some incentive schemes to obtain a solution. A lot of complicated mathematical derivations or learning mechanisms are needed for finding a suitable allocation scheme. However, these schemes lack universality because once system requirement changes, especially the case where some other system parameters optimization is needed, assignment schemes need to be redesigned [18], [20], [24]. We aim to design a universal algorithm which can satisfy optimization demand for various system parameters. In addition, previous researches [15], [17], [18] do not consider a dense DUs scenario with multiple relay selection. Only some simple relay selection strategies are proposed due to the difficulty of multi-constraint and the complexity of computation. This causes resource waste and cannot suit a dense DUs network.

In order to break through the limitation of existing models and obtain a better performance for D2D network, it is essential to design a novel cooperative D2D heterogeneous network (CDHN). In our proposed CDHN, DUs share spectrum resource block (SRB) of CUs and select IUs which are located in cellular networks as relays to complete information transmission. Furthermore, to maximize the total throughput of whole network and guarantee the QoS of CUs, we consider power control problem for CUs, DUs and IUs. The main contributions in this paper can be summarized in the following:

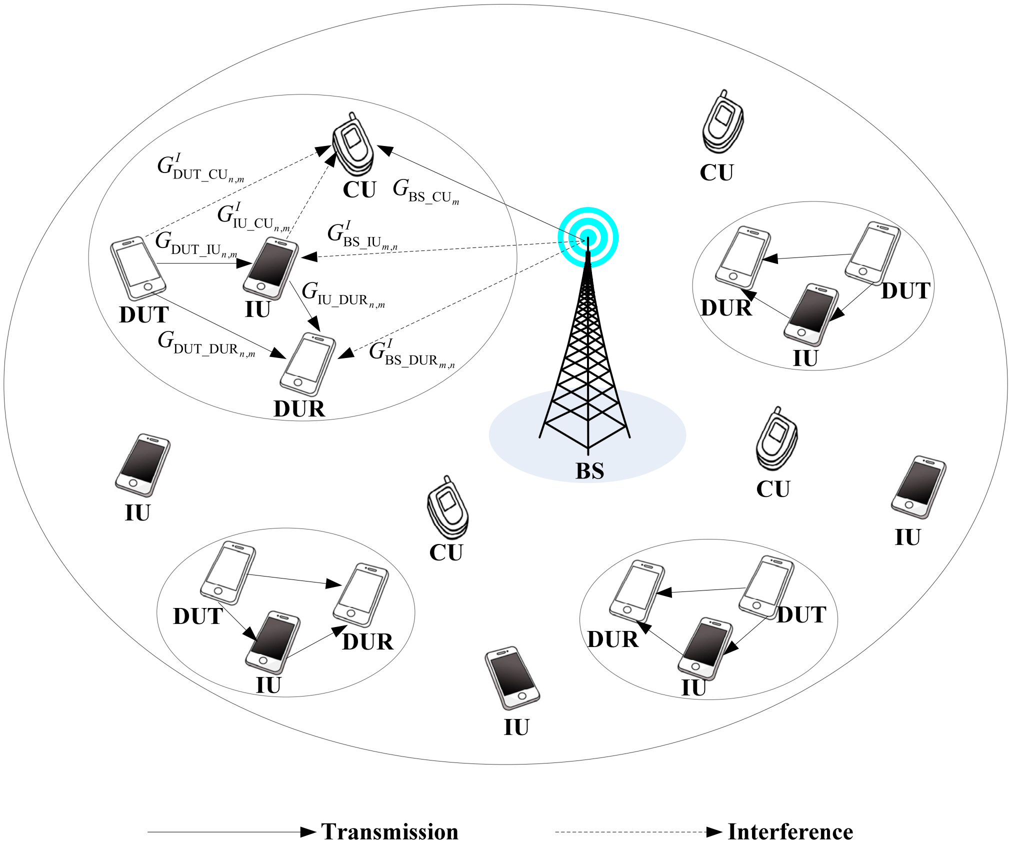

FIGURE 1. System model of CDHN.

- We propose a cooperative D2D communication mechanism-CDHN model then consider the total throughput problem for whole network on the premise of guaranteeing communication quality of CUs.
- We have derived analytical formulas for the total throughput of the proposed model. Analytical expression has proven that selecting a suitable IU as a relay for each DU, allocating SRB and controlling power for each IU, DU and CU are major three aspects which impact the total throughput of CDHN with the CUs throughput requirement constraint.
- We propose QCROA for joint resource allocation and power control problem in D2D heterogeneous networks which aims to maximize the total throughput. Simulation results show that QCROA can obtain a better performance than other algorithms in different communication scenarios. Besides, the total throughput of proposed CDHN based on various system parameters is also investigated.

The other parts for this paper are systemized in the following: In Section II, we propose CDHN model and then derive mathematical expression for the total throughput. A novel QCROA for joint resource allocation and power control is designed in Section III. Simulation results are investigated in Section IV. Finally, conclusion will be provided in Section V.

II. SYSTEM MODEL AND THROUGHPUT ANALYSIS

In this section, CDHN system model is introduced and the total throughput of CDHN is mathematically formulated then we formulate the joint resource allocation and power control problem.

A. CDHN SYSTEM MODEL

In this paper, we consider a downlink CDHN. The CDHN consists of one BS, M CUs which the numerical order can be expressed as $\boldsymbol{\psi} = \{1, 2, \ldots, M\}$, N DU transmission pairs which the numerical order can be expressed as $\boldsymbol{\tau} = \{1, 2, \ldots, N\}$ and D IUs which the numerical order can be expressed as $\boldsymbol{\kappa} = \{1, 2, \ldots, D\}$. Fig. 1 shows CDHN model. BS transmits information to CUs. Each DU transmission pair is composed of one DU transmitter (DUT) and one DU receiver (DUR). Each DUT has its own information to transmit to its corresponding DUR. IUs work as relays to help the information transmission of DUs in CDHN. Each DUT-DUR pair selects one IU to complete transmission and IU recodes information then sends information to its corresponding DUR. For most practical communication scenarios, D is larger than N.

Each transmission channel is a Rayleigh fading channel. Transmission channel gain (TCG) between two nodes remains unchanged in one time slot and TCG is independent from each other in two different time slots. Each CU is allocated a downlink SRB which is orthogonal to each other and we assume that SRB allocation scheme of CUs is determined in advance. $b_{n,m} \in \{0,1\}$ represents whether SRB of the m-th ($m = 1, 2, \ldots, M$) CU is reused by the n-th($n = 1, 2, \ldots, N$) DU and the corresponding IU of the n-th DU. We assume that each downlink SRB of CU only can be shared by one DU at most. Hence, the SRB allocation constraint is represented as

$$\sum_{n=1}^{N} b_{n,m} = 1 \quad b_{n,m} \in \{0,1\} \quad \forall m \in \boldsymbol{\psi}. \tag{1}$$

TCG from BS to the m-th CU is denoted as $G_{\mathrm{BS\_CU}_m}$, TCG from DUT to DUR of the n-th DU transmission pair on the m-th SRB is denoted as $G_{\mathrm{DUT\_DUR}_{n,m}}$, TCG from DUT to its corresponding IU of the n-th DU transmission pair on the m-th SRB is denoted as $G_{\mathrm{DUT\_IU}_{n,m}}$, and TCG from IU to DUR of the n-th DU transmission pair on the m-th SRB is denoted as $G_{\mathrm{IU\_DUR}_{n,m}}$. Let $G^{I}_{\mathrm{BS\_DUR}_{m,n}}$ and $G^{I}_{\mathrm{BS\_IU}_{m,n}}$ denote the interference channel gain (ICG) from BS to the n-th DUR and the n-th IU (the corresponding IU of the n-th DU transmission pair) on the m-th SRB, respectively. Denote $G^{I}_{\mathrm{DUT\_CU}_{n,m}}$ as ICG from the n-th DUT to the m-th CU, and denote $G^{I}_{\mathrm{IU\_CU}_{n,m}}$ as ICG from the n-th IU to the m-th CU.

B. THROUGHPUT ANALYSIS

In the downlink CDHN, BS transmits information to CUs all the time. At the same time, each DU transmits its own information. The information transmission process of DUs contains two steps which are given in the following:

Step 1: Each DUT transmits its signal to DUR and its corresponding IU (the IU is selected from all IUs). IU decodes its received signal.

Step 2: Each IU transmits the decoded signals to DUR and DUR incorporates signals from DUT and IU by maximum ratio combining (MRC) [25].

We assume that the length of time for two steps is equal. For the Step 1, one DUT can only select one IU among all IUs. The selected IU will share the same SRB of its corresponding DU transmission pair to complete communication and the system adopts decode-and-forward (DF) transmission mode. Hence, the signal-to-interference-plus-noise ratio (SINR) of the n-th DUT to DUR link allocated the m-th SRB in Step 1 can be formulated as

$$\gamma_{\mathrm{DUT\_DUR}_{n,m}} = \frac{P_{\mathrm{DUT\_DUR}_{n,m}} G_{\mathrm{DUT\_DUR}_{n,m}}}{\eta_0 + P_{\mathrm{BS\_CU}_m} G^{I}_{\mathrm{BS\_DUR}_{m,n}}} \quad \forall n \in \boldsymbol{\tau}, \quad \forall m \in \boldsymbol{\psi}, \tag{2}$$

where $P_{\mathrm{DUT\_DUR}_{n,m}}$ is transmission power of the n-th DUT on the m-th SRB and $P_{\mathrm{BS\_CU}_m}$ is transmission power from BS to the m-th CU. η_0 is the additive white Gaussian noise (AWGN) power. Similarly, the SINR of the n-th DUT to its corresponding IU link allocated the m-th SRB can be given by

$$\gamma_{\mathrm{DUT\_IU}_{n,m}} = \frac{P_{\mathrm{DUT\_DUR}_{n,m}} G_{\mathrm{DUT\_IU}_{n,m}}}{\eta_0 + P_{\mathrm{BS\_CU}_m} G^{I}_{\mathrm{BS\_IU}_{m,n}}} \quad \forall n \in \boldsymbol{\tau}, \ \forall m \in \boldsymbol{\psi}. \tag{3}$$

For the m-th CU of CDHN, the SINR in Step 1 can be expressed as

$$\gamma^{\mathrm{Step1}}_{\mathrm{BS\_CU}_m} = \frac{P_{\mathrm{BS\_CU}_m} G_{\mathrm{BS\_CU}_m}}{\eta_0 + \sum_{n=1}^{N} b_{n,m} P_{\mathrm{DUT\_DUR}_{n,m}} G^{I}_{\mathrm{DUT\_CU}_{n,m}}} \quad \forall m \in \boldsymbol{\psi}. \tag{4}$$

In Step 2, each IU transmits signal to DUR and the SINR of the n-th IU to DUR link with the m-th SRB is shown as follows

$$\gamma_{\mathrm{IU\_DUR}_{n,m}} = \frac{P_{\mathrm{IU\_DUR}_{n,m}} G_{\mathrm{IU\_DUR}_{n,m}}}{\eta_0 + P_{\mathrm{BS\_CU}_m} G^{I}_{\mathrm{BS\_DUR}_{m,n}}} \quad \forall n \in \boldsymbol{\tau}, \ \forall m \in \boldsymbol{\psi}, \tag{5}$$

where $P_{\mathrm{IU\_DUR}_{n,m}}$ is transmission power of the n-th IU on the m-th SRB. For DF transmission protocol, the throughput for the n-th DU transmission pair allocated the m-th SRB is

$$\begin{aligned} r_{\mathrm{DUT\_DUR}_{n,m}} &= \frac{1}{2}\log_2(1 + \min\{\gamma_{\mathrm{DUT\_IU}_{n,m}}, \gamma_{\mathrm{DUT\_DUR}_{n,m}} + \gamma_{\mathrm{IU\_DUR}_{n,m}}\}) \\ &= \frac{1}{2}\min\{\log_2(1 + \gamma_{\mathrm{DUT\_IU}_{n,m}}), \\ &\quad \log_2(1 + \gamma_{\mathrm{DUT\_DUR}_{n,m}} + \gamma_{\mathrm{IU\_DUR}_{n,m}})\} \\ &\quad \forall n \in \boldsymbol{\tau}, \quad \forall m \in \boldsymbol{\psi}. \end{aligned} \tag{6}$$

Let R_{DU_n} denote the throughput of the n-th DU, which can be derived by

$$\begin{aligned} R_{\mathrm{DU}_n} &= \sum_{m=1}^{M} b_{n,m} r_{\mathrm{DUT\_DUR}_{n,m}} \\ &= \frac{1}{2}\sum_{m=1}^{M} b_{n,m} \min\{\log_2(1 + \gamma_{\mathrm{DUT\_IU}_{n,m}}), \\ &\quad \log_2(1 + \gamma_{\mathrm{DUT\_DUR}_{n,m}} + \gamma_{\mathrm{IU\_DUR}_{n,m}})\} \quad \forall n \in \boldsymbol{\tau}. \end{aligned} \tag{7}$$

Hence, the total throughput of all DUs is

$$R_{\mathrm{DU}} = \sum_{n=1}^{N} R_{\mathrm{DU}_n} = \sum_{n=1}^{N}\sum_{m=1}^{M} b_{n,m} r_{\mathrm{DUT\_DUR}_{n,m}}. \tag{8}$$

Meanwhile, the SINR for the m-th CU in Step 2 can be given by

$$\gamma^{\mathrm{Step2}}_{\mathrm{BS\_CU}_m} = \frac{P_{\mathrm{BS\_CU}_m} G_{\mathrm{BS\_CU}_m}}{\eta_0 + \sum_{n=1}^{N} b_{n,m} P_{\mathrm{IU\_DUR}_{n,m}} G^{I}_{\mathrm{IU\_CU}_{n,m}}} \quad \forall m \in \boldsymbol{\psi}. \tag{9}$$

Denote R_{CU} as the total throughput of all CUs in CDHN, which can be expressed as

$$\begin{aligned} R_{\mathrm{CU}} &= \sum_{m=1}^{M} R_{\mathrm{CU}_m} \\ &= \sum_{m=1}^{M} (\frac{1}{2}\log_2(1+\gamma_{\mathrm{BS\_CU}_m}^{\mathrm{Step1}}) + \frac{1}{2}\log_2(1+\gamma_{\mathrm{BS\_CU}_m}^{\mathrm{Step2}})) \\ &= \frac{1}{2}\sum_{m=1}^{M} (\log_2(1+\gamma_{\mathrm{BS\_CU}_m}^{\mathrm{Step1}})(1+\gamma_{\mathrm{BS\_CU}_m}^{\mathrm{Step2}})). \end{aligned} \tag{10}$$

On the basis of (8) and (10), we can derive the total throughput of CDHN

$$\begin{aligned} R_{\mathrm{total}} &= R_{\mathrm{CU}} + R_{\mathrm{DU}} \\ &= \frac{1}{2}\sum_{m=1}^{M} (\log_2(1+\gamma_{\mathrm{BS\_CU}_m}^{\mathrm{Step1}})(1+\gamma_{\mathrm{BS\_CU}_m}^{\mathrm{Step2}})) \\ &\quad + \sum_{n=1}^{N}\sum_{m=1}^{M} b_{n,m} r_{\mathrm{DUT\_DUR}_{n,m}}. \end{aligned} \tag{11}$$

C. PROBLEM FORMULATION

We investigate the joint optimization problem of SRB allocation, the selection of IUs and the transmission power control on the premise of guaranteeing the QoS of CUs. We aim to maximize the total throughput of all DU links and CU links. The joint optimization problem which maximizes the total throughput is (12a), shown at the bottom of this page.

For (12a), $\mathbf{s} = [s_1, s_2, \ldots, s_N]$ is the IU selection scheme and s_n means that the s_n-th IU is selected as relay by the n-th DU transmission pair. (12b) and (12c), shown at the bottom of this page, are SRB allocation constraints which are stated in (1), i.e., each SRB cannot be used more than one DU. For (12d), shown at the bottom of this page, it is CUs communication QoS constraint, which means that total throughput of CUs must be larger than the required throughput and $R_{\mathrm{CU}}^{\mathrm{require}}$ is threshold value. (12e), shown at the bottom of this page, is relay selection constraint of IU, which states that each DU transmission pair can only select one IU as relay at most. (12f), shown at the bottom of this page, defines power constraints for CUs, DUs and IUs, which is the power range for each user. $P_{\mathrm{BS\_CU}_m}^{\max}$ is maximum transmission power of BS to the m-th CU, $P_{\mathrm{IU\_DUR}_n}^{\max}$ is maximum transmission power of the n-th IU, and $P_{\mathrm{DUT\_DUR}_n}^{\max}$ is maximum transmission power of the n-th DU transmission pairs. From (12a)-(12f), we can see that SRB allocation, selection of IUs and transmission power should be optimized. However, it is a complicated optimization problem and traditional algorithms are difficult to solve effectively. Hence, we propose a novel algorithm which is called as QCROA to solve it.

III. QCROA FOR JOINT RESOURCE ALLOCATION AND POWER CONTROL

A. QCROA FOR OPTIMIZATION PROBLEM

The proposed QCROA combines the merits of traditional coral reefs optimization algorithm (CROA) [26] and quantum evolution [27]. In an I dimensional space, there is a quantum coral reef, which is composed of H quantum corals. Each quantum coral consists of I quantum bits. The h-th ($h = 1, 2, \ldots, H$) quantum coral in the t-th iteration is given by

$$\mathbf{x}_h^t = \begin{bmatrix} \alpha_{h1}^t, \alpha_{h2}^t, \ldots, \alpha_{h(I-1)}^t, \alpha_{hI}^t \\ \beta_{h1}^t, \beta_{h2}^t, \ldots, \beta_{h(I-1)}^t, \beta_{hI}^t \end{bmatrix}, \tag{13}$$

where $|\alpha_{hi}^t|^2 + |\beta_{hi}^t|^2 = 1, i = 1, 2, \ldots, I$. We define $0 \le \alpha_{hi}^t \le 1$ and $0 \le \beta_{hi}^t \le 1$ to improve efficiency of QCROA and $\mathbf{x}_h^t$ can be expressed as

$$\begin{aligned} \mathbf{x}_h^t &= [\alpha_{h1}^t, \alpha_{h2}^t, \ldots, \alpha_{h(I-1)}^t, \alpha_{hI}^t] \\ &= [x_{h1}^t, x_{h2}^t, \ldots, x_{h(I-1)}^t, x_{hI}^t], \end{aligned} \tag{14}$$

$$\begin{aligned} \text{maximize } & R_{\mathrm{total}}(\mathbf{b}, \mathbf{s}, \mathbf{P}_{\mathrm{BS\_CU}}, \mathbf{P}_{\mathrm{DUT\_DUR}}, \mathbf{P}_{\mathrm{IU\_DUR}}) \\ &= \frac{1}{2}\sum_{m=1}^{M} (\log_2(1+\frac{P_{\mathrm{BS\_CU}_m} G_{\mathrm{BS\_CU}_m}}{\eta_0 + \sum_{n=1}^{N} b_{n,m} P_{\mathrm{DUT\_DUR}_{n,m}} G_{\mathrm{DUT\_CU}_{n,m}}^{I}})(1+\frac{P_{\mathrm{BS\_CU}_m} G_{\mathrm{BS\_CU}_m}}{\eta_0 + \sum_{n=1}^{N} b_{n,m} P_{\mathrm{IU\_DUR}_{n,m}} G_{\mathrm{IU\_CU}_{n,m}}^{I}})) \\ &+ \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{M} b_{n,m} \min\{\log_2(1+\frac{P_{\mathrm{DUT\_DUR}_{n,m}} G_{\mathrm{DUT\_IU}_{n,m}}}{\eta_0 + P_{\mathrm{BS\_CU}_m} G_{\mathrm{BS\_IU}_{m,n}}^{I}}), \log_2(1+\frac{P_{\mathrm{DUT\_DUR}_{n,m}} G_{\mathrm{DUT\_DUR}_{n,m}}}{\eta_0 + P_{\mathrm{BS\_CU}_m} G_{\mathrm{BS\_DUR}_{m,n}}^{I}} \\ &+ \frac{P_{\mathrm{IU\_DUR}_{n,m}} G_{\mathrm{IU\_DUR}_{n,m}}}{\eta_0 + P_{\mathrm{BS\_CU}_m} G_{\mathrm{BS\_DUR}_{m,n}}^{I}})\}, \end{aligned} \tag{12a}$$

$$\text{subject to } b_{n,m} \in \{0,1\} \forall n \in \boldsymbol{\tau}, \quad \forall m \in \boldsymbol{\psi}, \tag{12b}$$

$$\sum_{n=1}^{N} b_{n,m} = 1 \quad \forall m \in \boldsymbol{\psi}, \tag{12c}$$

$$\frac{1}{2}\sum_{m=1}^{M} (\log_2(1+\gamma_{\mathrm{BS\_CU}_m}^{\mathrm{Step1}})(1+\gamma_{\mathrm{BS\_CU}_m}^{\mathrm{Step2}})) \ge R_{\mathrm{CU}}^{\mathrm{require}}, \tag{12d}$$

$$s_m \ne s_j \quad \forall m \ne j, \tag{12e}$$

$$\begin{aligned} & 0 \le P_{\mathrm{BS\_CU}_m} \le P_{\mathrm{BS\_CU}_m}^{\max}, \ 0 \le P_{\mathrm{IU\_DUR}_{n,m}} \le P_{\mathrm{IU\_DUR}_n}^{\max}, \ 0 \le P_{\mathrm{DUT\_DUR}_{n,m}} \le P_{\mathrm{DUT\_DUR}_n}^{\max} \\ & \forall n \in \boldsymbol{\tau}, \quad \forall m \in \boldsymbol{\psi}. \end{aligned} \tag{12f}$$

where $0 \leq x_{hi}^t \leq 1$ and $i = 1, 2, \ldots, I$. Each x_{hi}^t is a quantum bit of the h-th quantum coral $\mathbf{x}_h^t$.

Each quantum coral $\mathbf{x}_h^t$should be measured to the measuring state $\overline{\mathbf{x}}_h^t = [\overline{x}_{h1}^t, \overline{x}_{h2}^t, \ldots, \overline{x}_{h(I-1)}^t, \overline{x}_{hI}^t]$,and the measuring rule is given in the following

$$\overline{x}_{hi}^t = \begin{cases} 1, & \xi_{hi}^t \geq x_{hi}^t \\ 0, & \xi_{hi}^t < x_{hi}^t \end{cases} \tag{15}$$

where $\overline{x}_{hi}^t$ is the measuring state of x_{hi}^t. ξ_{hi}^t is a uniform distributed random number ranging from 0 to 1. After measuring each quantum coral, the healthiness of the h-th quantum coral can be calculated by the fitness function. We define the global optimal quantum coral in quantum coral reef until the t-th iteration as $\mathbf{p}_g^t = [p_{g1}^t, p_{g2}^t, \ldots, p_{g(I-1)}^t, p_{gI}^t]$and the corresponding measuring state is $\overline{\mathbf{p}}_g^t = [\overline{p}_{g1}^t, \overline{p}_{g2}^t, \ldots, \overline{p}_{g(I-1)}^t, \overline{p}_{gI}^t]$.

The evolutionary approach for each quantum coral is mainly on the basis of quantum rotation angle and the previous measuring states of quantum corals. A fixed parameter ρ_1 is defined for selecting the reproduction style. For the h-th quantum coral, we generate a random number $\overline{\xi}_h^t$ which is distributed from 0 to 1. If $\overline{\xi}_h^t$ is larger than ρ_1, the quantum coral proceeds external sexual reproduction. At the $(t+1)$th iteration, the i-th $(i = 1, 2, \ldots, I)$ quantum rotation angle and quantum bit for the h-th quantum coral are generated as follows

$$\begin{aligned} \theta_{hi}^{t+1} &= c_1 \cdot \vartheta_1 \cdot (\overline{p}_{gi}^t - \overline{x}_{hi}^t) + c_2 \cdot \mathrm{sign}(f(\overline{\mathbf{x}}_a^t) - f(\overline{\mathbf{x}}_h^t)) \\ &\quad \cdot (\overline{x}_{ai}^t - \overline{x}_{hi}^t), \end{aligned} \tag{16}$$

$$u_{hi}^{t+1} = \mathrm{abs}(x_{hi}^t \cdot \cos\theta_{hi}^{t+1} - \sqrt{1-(x_{hi}^t)^2} \cdot \sin\theta_{hi}^{t+1}), \tag{17}$$

where $\vartheta_1 = 1 - t/K$ and K is the maximal iteration number. c_1 and c_2 are constants. $a \in \{1, 2, \ldots, H\}(a \neq h)$and sign() means sign function. $f(\overline{\mathbf{x}}_h^t)$ is the fitness of the h-th quantum coral. If $\overline{\xi}_h^t$ is not larger than ρ_1, quantum coral proceed internal sexual reproduction. The quantum rotation angle and quantum bit of the h-th quantum coral are generated in the following

$$\theta_{hi}^{t+1} = \vartheta_1 \cdot \hat{\xi}_{hi}^t \cdot (\overline{p}_{gi}^t - \overline{x}_{hi}^t), \tag{18}$$

$$u_{hi}^{t+1} = \mathrm{abs}(x_{hi}^t \cdot \cos\theta_{hi}^{t+1} - \sqrt{1-(x_{hi}^t)^2} \cdot \sin\theta_{hi}^{t+1}), \tag{19}$$

where $\hat{\xi}_{hi}^t$ is a random number which is distributed from 0 to 0.5.

The newly generated quantum coral $\mathbf{u}_h^{t+1} = [u_{h1}^{t+1}, u_{h2}^{t+1}, \ldots, u_{h(I-1)}^{t+1}, u_{hI}^{t+1}]$ will try to set and grow in the quantum coral reef. First, the quantum coral $\mathbf{u}_h^{t+1}$ is measured to $\overline{\mathbf{u}}_h^{t+1} = [\overline{u}_{h1}^{t+1}, \overline{u}_{h2}^{t+1}, \ldots, \overline{u}_{h(I-1)}^{t+1}, \overline{u}_{hI}^{t+1}]$. Then calculate the healthiness of $\overline{\mathbf{u}}_h^{t+1}$. If the healthiness of $\overline{\mathbf{u}}_h^{t+1}$ is better than $\overline{\mathbf{x}}_h^t$, the generated quantum coral takes place of original quantum coral, i.e., $\mathbf{x}_h^{t+1} = \mathbf{u}_h^{t+1}$, $\overline{\mathbf{x}}_h^{t+1} = \overline{\mathbf{u}}_h^{t+1}$, else $\mathbf{x}_h^{t+1} = \mathbf{x}_h^t$, $\overline{\mathbf{x}}_h^{t+1} = \overline{\mathbf{x}}_h^t$.

At the end of the above process, sort the quantum corals according to their healthiness. The top $\rho_2 \times H$ quantum corals with the best healthiness will proceed asexual reproduction and $\rho_2 \times H$ quantum corals are duplicated. ρ_2 is the asexual reproduction ratio. The duplicated quantum corals will depredate the worst healthiness $\rho_2 \times H$ quantum corals in the quantum coral reef. At last, the global optimal quantum coral is generated by the best quantum coral in current iteration.

B. ANALYSIS OF PROPOSED QCROA

For an algorithm, convergence performance is an essential problem that people care about. QCROA we proposed makes use of certain quantum evolution mechanism, i.e., sexual reproduction, asexual reproduction and depredation to make sure that we can obtain the optimal solution. On the one hand, the external sexual reproduction evolution strategy increases convergence speed and convergence accuracy of QCROA. On the other hand, internal sexual reproduction, asexual reproduction and depredation evolution strategy increase population diversity. Now, we will perform the convergence analysis and computational complexity of proposed QCROA.

Proposition 1: $\mathbf{X}_t = \{\overline{\mathbf{x}}_1^t, \overline{\mathbf{x}}_2^t, \ldots, \overline{\mathbf{x}}_H^t\}$is the population measuring state in the t-th iteration. We define the population searching sequence of QCROA as $\{\mathbf{X}_t;t > 0\}$ and $\{\mathbf{X}_t;\, t > 0\}$ is a finite secondary Markov chain.

Proof: The length of each quantum coral is I and the population size of QCROA is H. Since the measuring state for each quantum bit of each quantum coral is $\{0, 1\}$, the size of state space for $\mathbf{X}_t$ is $2^{I \times H}$ and population sequence of QCROA is finite. Besides, sexual reproduction, asexual reproduction and depredation process of QCROA are independent of t. $\mathbf{X}_{t+1}$ is only related to t. Hence, $\{\mathbf{X}_t;t > 0\}$ is a finite secondary Markov chain.

Proposition 2: QCROA converges to global optimum with probability of 1.

Proof: We define the state space for QCROA is $\mathbf{S} = \{\mathbf{S}_1, \mathbf{S}_2, \ldots, \mathbf{S}_{2^{I\times H}}\}$, and the set for state of the optimal solution is $\mathbf{P}$. The probability that quantum coral population is in state $\mathbf{S}_v(v = 1, 2, \ldots, 2^{I\times H})$ at the t-th iteration can be expressed as $P_{\mathbf{S}_v}(t)$ and $\mathbf{S}_v(t)$ is the t-th iteration state of quantum coral population. Define $P_t = \sum_{\mathbf{S}_v(t)\notin\mathbf{P}} P_{\mathbf{S}_v}(t)$ as the probability that quantum coral population does not belong to $\mathbf{P}$ at the t-th iteration. On the one hand, by the nature of Markov chain and *Proposition 1*, we can obtain

$$\begin{aligned} P_{t+1} &= \sum_{\mathbf{S}_v(t)\in\mathbf{S}} \sum_{\mathbf{S}_j\notin\mathbf{P}} P_{\mathbf{S}_v}(t) P_{\mathbf{S}_v\mathbf{S}_j}(t) \\ &= \sum_{\mathbf{S}_v(t)\in\mathbf{P}} \sum_{\mathbf{S}_j\notin\mathbf{P}} P_{\mathbf{S}_v}(t) P_{\mathbf{S}_v\mathbf{S}_j}(t) + \sum_{\mathbf{S}_v(t)\notin\mathbf{P}} \sum_{\mathbf{S}_j\notin\mathbf{P}} P_{\mathbf{S}_v}(t) P_{\mathbf{S}_v\mathbf{S}_j}(t), \end{aligned} \tag{20}$$

where $P_{\mathbf{S}_v\mathbf{S}_j}(t) = P\{\mathbf{X}_{t+1} = \mathbf{S}_j | \mathbf{X}_t = \mathbf{S}_v\}, j \in \{1, 2, \ldots, 2^{I\times H}\}$ is transition probability of quantum coral population at the t-th iteration. On the other hand, we expand on P_t through Markov chain nature as

$$\begin{aligned} P_t &= \sum_{\mathbf{S}_v(t)\notin\mathbf{P}} P_{\mathbf{S}_v}(t) \\ &= \sum_{\mathbf{S}_v(t)\notin\mathbf{P}} \sum_{\mathbf{S}_j\notin\mathbf{P}} P_{\mathbf{S}_v}(t)P_{\mathbf{S}_v\mathbf{S}_j}(t) + \sum_{\mathbf{S}_v(t)\notin\mathbf{P}} \sum_{\mathbf{S}_j\in\mathbf{P}} P_{\mathbf{S}_v}(t)P_{\mathbf{S}_v\mathbf{S}_j}(t). \end{aligned} \tag{21}$$

We move (21) as

$$\sum_{\mathbf{S}_v(t)\notin\mathbf{P}} \sum_{\mathbf{S}_j\notin\mathbf{P}} P_{\mathbf{S}_v}(t)P_{\mathbf{S}_v\mathbf{S}_j}(t) = P_t - \sum_{\mathbf{S}_v(t)\notin\mathbf{P}} \sum_{\mathbf{S}_j\in\mathbf{P}} P_{\mathbf{S}_v}(t)P_{\mathbf{S}_v\mathbf{S}_j}(t). \tag{22}$$

Combine Proposition 1, (20) and (22), we can formulate

$$\begin{aligned} 0 \le P_{t+1} &= \sum_{\mathbf{S}_v(t)\in\mathbf{P}} \sum_{\mathbf{S}_j\notin\mathbf{P}} P_{\mathbf{S}_v}(t)P_{\mathbf{S}_v\mathbf{S}_j}(t) + P_t \\ &\quad - \sum_{\mathbf{S}_v(t)\notin\mathbf{P}} \sum_{\mathbf{S}_j\in\mathbf{P}} P_{\mathbf{S}_v}(t)P_{\mathbf{S}_v\mathbf{S}_j}(t) \\ &< \sum_{\mathbf{S}_v(t)\in\mathbf{P}} \sum_{\mathbf{S}_j\notin\mathbf{P}} P_{\mathbf{S}_v}(t)P_{\mathbf{S}_v\mathbf{S}_j}(t) + P_t. \end{aligned} \tag{23}$$

For $\sum_{\mathbf{S}_v(t)\in\mathbf{P}} \sum_{\mathbf{S}_j\notin\mathbf{P}} P_{\mathbf{S}_v}(t)P_{\mathbf{S}_v\mathbf{S}_j}(t)$, since the global optimal quantum coral are generated by the best quantum coral in current iteration after sexual reproduction, asexual reproduction and depredation process, we can obtain $\sum_{\mathbf{S}_v(t)\in\mathbf{P}} \sum_{\mathbf{S}_j\notin\mathbf{P}} P_{\mathbf{S}_v}(t)P_{\mathbf{S}_v\mathbf{S}_j}(t) = 0$. Hence, according to probability statistics nature and (23), we can have

$$0 \le P_{t+1} < P_t \quad \forall t = 1, 2, 3 \ldots, \tag{24}$$

$$\lim_{t\to\infty} P_t = 0. \tag{25}$$

The quantum coral population could be regarded as a large-scale iteration processing by making use of sexual reproduction, asexual reproduction and depredation evolution method. Hence,

$$\begin{aligned} \lim_{t\to\infty} P\{\mathbf{X}_t = \mathbf{P}\} &= 1 - \lim_{t\to\infty} \sum_{\mathbf{S}_v(t)\notin\mathbf{P}} P_{\mathbf{S}_v}(t) \\ &= 1 - \lim_{t\to\infty} P_t = 1. \end{aligned} \tag{26}$$

Therefore, QCROA converges to global optimum with probability of 1.

Proposition 3: The computational complexity of the QCROA is $O(t \times H \times (3I + \rho_2 + 2))$ after running t iterations.

Proof: As described in Section III-A, for the process of external sexual reproduction external and internal sexual reproduction, QCROA needs to generate the quantum rotation angle and quantum bits of quantum coral in each iteration, which has a computational complexity of $O(2 \times H \times I)$. The quantum coral should be measured by (15) to obtain the corresponding measuring state, with the computational complexity of $O(H \times I)$. The computational complexity is $O(2H)$ when we generate each quantum coral and global optimal quantum coral. For asexual reproduction and depredation process of QCROA, the computational complexity is $O(\rho_2 \times H)$. On the basis of process mentioned above, the computational complexity of the QCROA is $O(t(3 \times H \times I + \rho_2 \times H + 2H)) = O(t \times H \times (3I + \rho_2 + 2))$ after running t iterations.

C. PROCESS OF QCROA FOR JOINT RESOURCE ALLOCATION AND POWER CONTROL

QCROA can optimize the resource allocation and power control problem in CDHN. The fitness function is set as $f(\overline{\mathbf{x}}_h^t) = \begin{cases} R_{\text{total}}(\overline{\mathbf{x}}_h^t), \text{satisfy constraint condition} \\ 0, \text{else} \end{cases}$ and the healthiness of the $h-$ th quantum coral is calculated by this fitness function. The measuring state for each quantum coral $\mathbf{x}_h^t$ in the quantum coral reef is corresponding to the parameter vector which should be optimized. For the proposed resource allocation and power control problem, the parameter vector to be optimized is $[\mathbf{b}, \mathbf{s}, \mathbf{P}_{\text{BS\_CU}}, \mathbf{P}_{\text{DUT\_DUR}}, \mathbf{P}_{\text{IU\_DUR}}]$. The parameter vector can be changed if we need to optimize some other system parameters. For the resource allocation and power control problem in (12), the transmit power of each user and each IU selection numerical order are encoded by binary bits. Hence, the complex engineering problem for finding optimal joint resource allocation and power control scheme is transformed to an optimization problem which is to find the measuring state of global optimal quantum coral. The measuring state of global optimal quantum coral is corresponding to the optimal joint resource allocation and power control scheme. In general, the process of QCROA for joint resource allocation and power control is presented in the next page, **Algorithm 1**.

IV. SIMULATION RESULTS AND ANALYSIS

This part we provide simulation results to examine the performance of our proposed QCROA. During simulations, we assume that DUT-DUR pairs, IUs and CUs are distributed randomly in CDHN and the radius of CDHN is 500 meters. TCG and ICG follow exponentially distribution with parameters $d^{-\ell}$ (d is the distance between any two nodes) and ℓ is path loss exponent. In order not to lose generality, the maximum transmission power from BS to each CU is set as the same, as well as each DU transmission pair. The simulation parameters can be summarized in TABLE 2. All simulation results are the average of 100 trials.

TABLE 2. Simulation parameters.

Parameter	Value
Number of BS	1
Number of CUs	12
Number of DU transmission pairs	10
Number of IUs	20
Path loss exponent	3
Noise power density	−174dBm / Hz
Maximum transmission power from BS to CU	35dBm
Maximum transmission power of DU transmission pairs	30dBm
Maximum transmission power of IUs	30dBm
SRB bandwidth	180kHz
Coverage of the BS	500m
Coverage of each DU transmission pair	30m
CUs communication QoS threshold value	20bit/s/Hz

Algorithm 1 Joint Resource Allocation and Power Control Process Based on QCROA

1 Input TCG, ICG, $P_{\text{BS\_CU}}^{\max}$, $P_{\text{IU\_DUR}}^{\max}$, $P_{\text{DUT\_DUR}}^{\max}$, η_0 and the maximum iteration number

2 Initialize the initial population of H quantum corals in the quantum coral reef;

3 $t = 1$ the first iteration;

4 Calculate the healthiness of each quantum coral according to the fitness function;

5 Find out the global optimal quantum coral $\mathbf{p}_g^t = [p_{g1}^t, p_{g2}^t, \ldots, p_{g(I-1)}^t, p_{gI}^t]$ of the quantum coral reef by comparing the healthiness of each quantum coral ;

6 while $t \leq$ the maximum iteration number

7 if $\bar{\xi}_h^t > \rho_1$

8 Update the quantum coral with external sexual reproduction by (16) and (17)

9 else

10 Update the quantum coral with internal sexual reproduction by (18) and (19)

11 end if

12 Obtain the measuring state of each quantum coral by (15);

13 Calculate the healthiness of each new quantum coral according to the fitness function and update the original quantum corals;

14 The top $\rho_2 \times H$ quantum corals with the best healthiness proceed asexual reproduction.

15 Update the global optimal quantum coral for the current iteration;

16 $t = t + 1$;

17 end while

18 Output: The optimal joint resource allocation and power control scheme.

A. SIMULATION PERFORMANCE COMPARISON OF QCROA

In this part, we give the performance comparison of proposed QCROA with CROA, teaching-learning-based optimization (TLBO) [28], discrete particle swarm optimization (DPSO) [29], sine cosine algorithm (SCA) [30], differential evolutionary algorithm (DEA) [31], max power-random resource selection scheme (MPRRS) and half power-random resource selection scheme (HPRRS). For discrete intelligent algorithms, i.e., QCROA and DPSO, we encode the transmit power of each user and each IU selection numerical order by 10 binary bits and 6 binary bits, respectively. For continuous intelligent algorithms, i.e., CROA, TLBO, SCA and DEA, we will round the continuous variables to integer when optimize SRB allocation. For MPRRS, each node uses maximum transmission power to transmit their information while the scheme for SRB allocation and IU selection adopts the method of random selection. In HPRRS, each node transmits information at half the maximum power while SRB allocation and IU selection adopt random selection. The maximal iteration number is 2000 and the population size is 60 for QCROA, CROA, TLBO, DPSO, SCA, DEA, MPRRS and HPRRS. For proposed QCROA, we make $c_1 = 0.4$, $c_2 = 0.1$, $\rho_1 = 0.9$ and $\rho_2 = 1/12$. Parameter settings for CROA, TLBO, DPSO SCA and DEA refer to [26], [28]–[30], and [31], respectively.

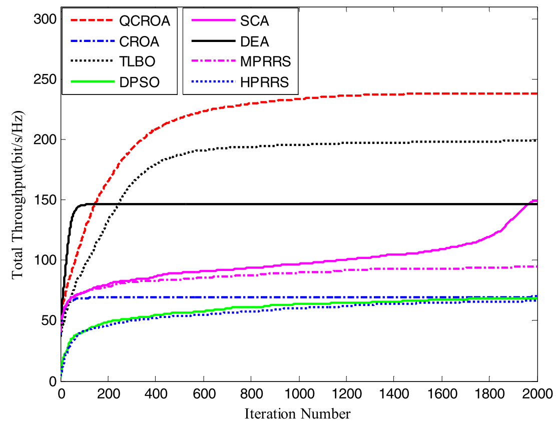

FIGURE 2. Convergent performance comparisons.

Fig. 2 illustrates the convergent performance of total throughput versus iteration number for QCROA, CROA, TLBO, DPSO, SCA, DEA, MPRRS, and HPRRS schemes. It is visible that the proposed QCROA can obtain a higher total throughput than other schemes. On the outset, QCROA owns a fast convergence speed and then converges to the global optimum when the iteration number reaches 1500. It is clear that the convergence speed of proposed QCROA is faster than CROA, TLBO, DPSO, SCA, MPRRS, and HPRRS schemes. In contrast, DEA can also converge very fast to a local optimum when the iteration number reaches 150, while it cannot escape from the local optimum, then DEA falls into local convergence and cannot obtain the global optimum. The reason is that the proposed QCROA combines the merits of quantum evolution theory and CROA. The designed internal sexual reproduction evolutionary mechanism can improve convergence speed of the whole population while the external sexual reproduction evolutionary style increases the population diversity. Besides, asexual reproduction mechanism can quickly remove bad quantum corals. Therefore, the convergence speed and population diversity of QCROA are superior to other schemes based on intelligent optimization algorithms. QCROA has the ability to jump out of the local optimum and obtain the global optimum with highest throughput. Since QCROA can converge when iteration number reaches 1500, to simplify simulation process, we make the maximal iteration number as 1500 for the following simulations.

Fig. 3 compares the total throughput of CDHN for different $P_{\text{BS\_CU}}^{\max}$ with QoS constraint of CUs. For simulation results, at first the total throughput becomes larger and larger when $P_{\text{BS\_CU}}^{\max}$ increases. It is easy to understand that a larger $P_{\text{BS\_CU}}^{\max}$ will permit BS to use more power to transmit information

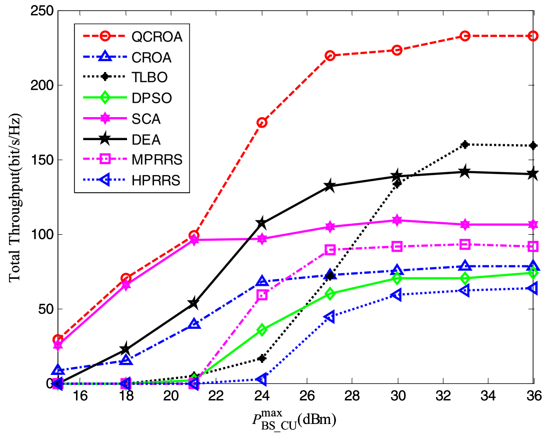

FIGURE 3. **Performance comparison of total throughput with different** $P_{BS\_CU}^{max}$.

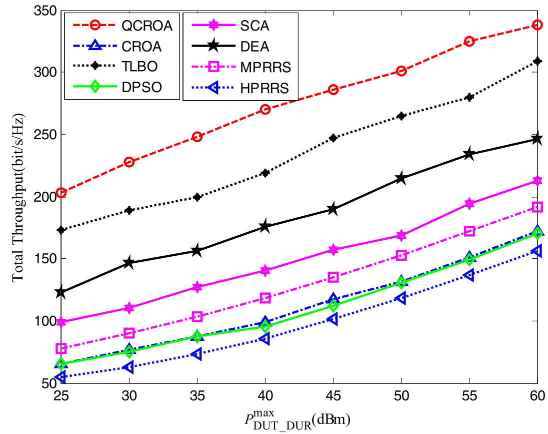

FIGURE 5. **Performance comparison of total throughput with different** $P_{DUT\_DUR}^{max}$.

then the throughput of each CU increases. However, total throughput is no longer significantly increased when $P_{BS\_CU}^{max}$ increases to a certain value. The reason is that a too large transmission power of BS will bring huge interference to DUs and the transmission power of BS no longer changes drastically with $P_{BS\_CU}^{max}$ increases due to the restraint of DUs. From simulation results, we can see that QCROA can obtain the best performance for any $P_{BS\_CU}^{max}$.

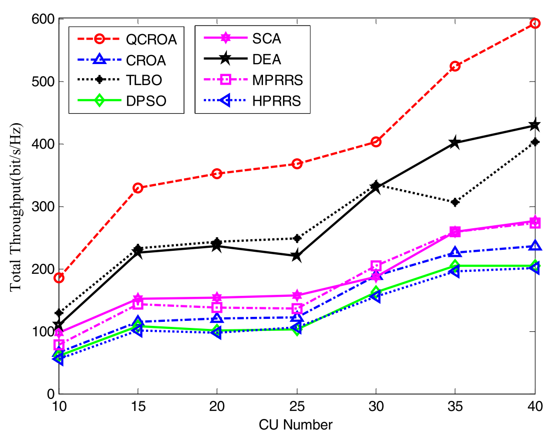

FIGURE 4. **Performance comparison of total throughput with different CU numbers.**

Fig. 4 presents the total throughput for various CU numbers. During the simulation, the number of CU varies from 10 to 40. The total throughputs of CDHN for all algorithms increase with the increasing of CU number. From simulation results, we can see that the merit of proposed QCROA is obvious because it obtains a higher throughput than CROA, TLBO, DPSO, SCA, DEA, MPRRS, and HPRRS on the premise of guaranteeing QoS for CUs.

In Fig. 5, we gives the total throughput while $P_{DUT\_DUR}^{max}$ varies from 25dBm to 60dBm. From simulation results, we may draw a conclusion that the total throughput becomes larger and larger as $P_{DUT\_DUR}^{max}$ increases. It is because a higher $P_{DUT\_DUR}^{max}$ can provide more energy for DUs, so DUs can make use of larger power to transmit their own information. Hence, the total throughput becomes larger. Besides, simulation results also illustrate the QCROA can obtain best performance among all schemes for any certain $P_{DUT\_DUR}^{max}$.

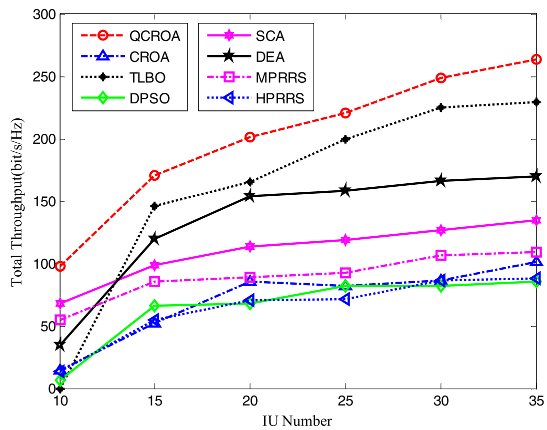

FIGURE 6. **Performance comparison of total throughput with different IU numbers.**

Fig. 6 is the performance comparison for different IU numbers. The number of IUs varies from 10 to 35 and QCROA can obtain a better performance than CROA, TLBO, DPSO, SCA, DEA, MPRRS, and HPRRS for different IU numbers. The total throughput increases as the number of IUs becomes larger and larger. The reason is that more IUs can provide more choices for the information transmission of DUs. Hence, the total throughputs of different schemes will become larger when the IU number increases. From Fig. 2 to Fig. 6, QCROA can get the best performance for different simulation situations and all comparison results show the merits of QCROA.

B. IMPACT OF DIFFERENT PARAMETERS FOR CDHN

This part we investigate the performance of proposed QCROA on the basis of different parameters. Also, the impact on CDHN of different parameters is shown in the following.

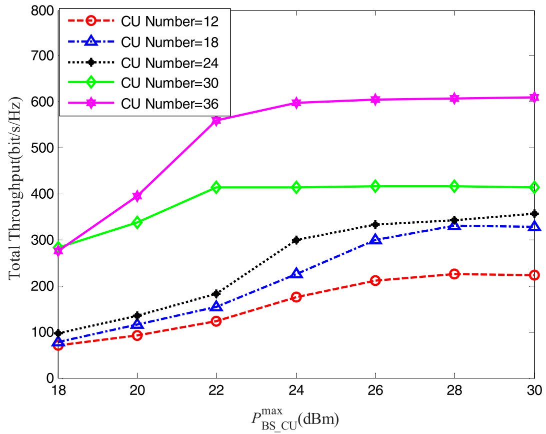

FIGURE 7. Total Throughput of different $P_{BS\_CU}^{max}$ and CU numbers.

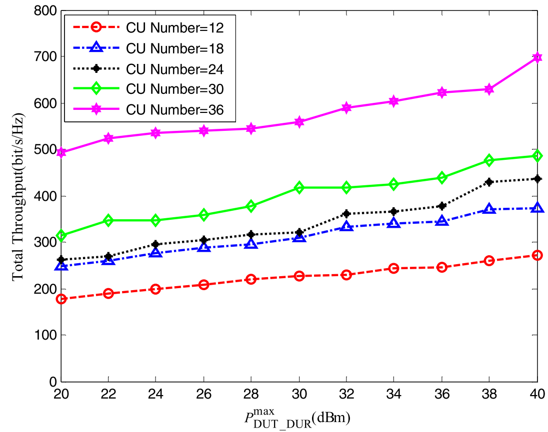

FIGURE 9. Total Throughput of different $P_{DUT\_DUR}^{max}$ and CU numbers.

Fig. 7 is the situation where we consider the impact of different $P_{BS\_CU}^{max}$ and CU numbers on the CDHN. $P_{BS\_CU}^{max}$ varies from 18dBm to 30dBm and the number of CUs is 12, 18, 24, 30 and 36, respectively. From simulation results we can find that the total throughput increases rapidly at the beginning with the increasing of $P_{BS\_CU}^{max}$, and then the increasing rate is no longer significant since a too large transmission power of BS will affect the performance of DUs. Besides, the total throughput of CDHN increases with the increasing of CU number. The reason is that more CUs can bring more SRBs for DUs and then improve the performance of CDHN.

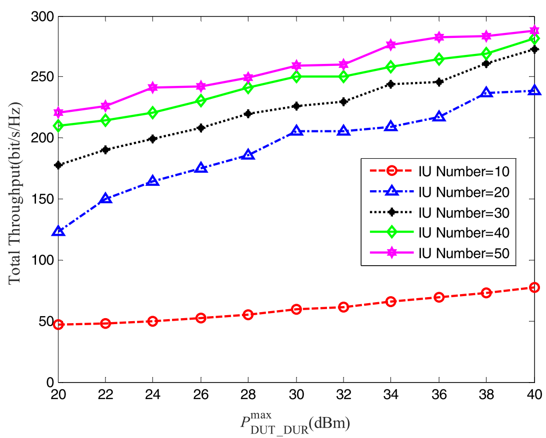

FIGURE 8. Total Throughput of different $P_{DUT\_DUR}^{max}$ and IU numbers.

Fig. 8 illustrates the total throughput when IU numbers is 10, 20, 30, 40 and 50, respectively. $P_{DUT\_DUR}^{max}$ varies from 20dBm to 40dBm. From simulation results, we can find that the total throughput of CDHN increases as $P_{DUT\_DUR}^{max}$ becomes higher and higher due to the fact that a larger $P_{DUT\_DUR}^{max}$ can allow DUs to use more power to transmit information. Besides, more IUs can provide more chances for the cooperative communication of DUs and the total throughput increases gradually when the number of IUs becomes larger.

In Fig. 9, the impact of different $P_{DUT\_DUR}^{max}$ and CU numbers on the CDHN is studied. We increase $P_{DUT\_DUR}^{max}$ from 20dBm to 40dBm, when the number of CU is 12, 18, 24, 30 and 36, respectively. From simulation results, it is illustrated that both higher $P_{DUT\_DUR}^{max}$ and more CUs can boost the performance of CDHN. For a certain value of $P_{DUT\_DUR}^{max}$, a larger number of CUs can provide more SRBs for DUs and greatly increase total throughput. Also, a higher throughput can be obtained when $P_{DUT\_DUR}^{max}$ increases for a certain number of CUs.

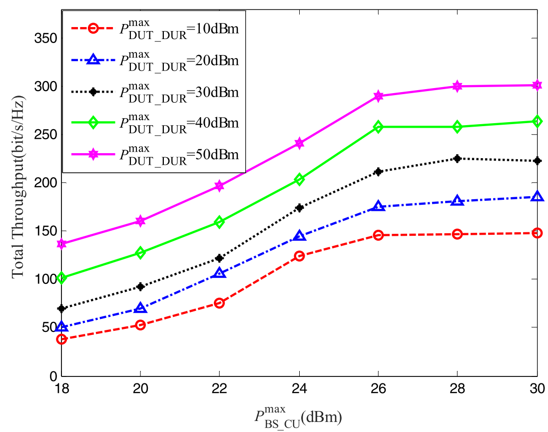

FIGURE 10. Total Throughput of different $P_{BS\_CU}^{max}$ and $P_{DUT\_DUR}^{max}$.

In Fig. 10, we consider the influence of $P_{BS\_CU}^{max}$ and $P_{DUT\_DUR}^{max}$ on the throughput of CDHN. In the simulation, $P_{BS\_CU}^{max}$ varies from 18dBm to 30dBm and $P_{DUT\_DUR}^{max}$ is equal to 10dBm, 20dBm, 30dBm, 40dBm, and 50dBm, respectively. The total throughput achieved by the QCROA gradually increases when $P_{DUT\_DUR}^{max}$ becomes higher because a higher $P_{DUT\_DUR}^{max}$ can permit each DU to use more energy to participate its own information transmission. The trend impact of $P_{BS\_CU}^{max}$ on CDHN is similar to Fig. 8. Hence, we can appropriately increase $P_{BS\_CU}^{max}$ and $P_{DUT\_DUR}^{max}$ to improve the performance of whole network.

V. CONCLUSION

In this paper, we have studied the optimal resource allocation and power control problem in downlink CDHN. To further investigate the performance of CDHN, the expression for total throughput is derived and we formulate a multi-constraints optimization problem which the goal is to maximize the total throughput. To obtain the optimal resource allocation and power control scheme, we have proposed a novel algorithm-QCROA for solving this problem. Simulation results show the excellent performance of QCROA when compared with other algorithms for different system parameters. In the future, this work can be applied to the scenario with ultra-dense node heterogeneity and clustering mechanism. Furthermore, the extension of proposed CDHN can be incorporated with smart grid and big data in the future communication networks.

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