IJICTR
International Journal of Information & Communication Technology Research

Volume 14- Number 4 – 2022 (1 -8)

Resource Management for a Multi-Channel Cognitive-NOMA D2D Network

Javad Zeraatkar Moghaddam*
Department of Electrical and Computer Engineering
University of Birjand
Birjand, Iran
javad.zeraatkar.m@birjand.ac.ir

Mehrdad Ardebilipour
Department of Electrical Engineering
K. N. Toosi University of Technology
Tehran, Iran
mehrdad@eetd.kntu.ac.ir

Received: 5 May 2022 – Revised: 25 August 2022 - Accepted: 27 November 2022

Abstract—**In this paper, we investigate a non-orthogonal multiple access (NOMA)-based underlay multi-channel cognitive device-to-device (D2D) communications and efficiently exploit a resource management scheme for the investigated model. A two-stage solution is used in which sub-channels (SCs) and powers are jointly assigned to the D2Ds and transmitters, respectively, employing a convex optimization method to achieve the optimal parameters. We show that throughput of the D2D users can be maximized by the proposed strategy, subject to controlling total transmission power, interference power, and minimum rate requirements. We study the performance of the network by increasing the number of PUs and SCs. Moreover, minimum rate requirement and maximum allowed interference at the PUs versus sum rate of the SU transceivers is investigated. The simulation results present insights about the impact of the optimal power and SC allocations.**

Keywords: Cognitive Radio; NOMA; Device to Device Communications; Power Allocation; Sub-Channel Assignment.

Article type: Research Article

Publisher: ICT Research Institute

I. INTRODUCTION

Cognitive radio (CR) network is a promising technology to achieve high spectral efficiency. It allows the SUs to access idle spectrum allocated to the PUs on the condition of not causing the disruptive interference to the PUs. Thus, SUs sense licensed bands by performing accurate spectrum sensing (SS) to detect the presence of the PU and find the idle spectrum spaces. The performance of SS schemes is evaluated by two probabilities, named probability of detection (Pd) and probability of false alarm (Pf), due to correct and false detections of the presence of a PU when the spectrum is actually idle, respectively. Hence, exploiting the spectrum holes is wasted by the Pf, and the SU can access more spectrum opportunities if the Pf is kept below a certain threshold. So, maximum throughput can be achieved by the network. On the hand, harmful interference at the PU can be decreased by higher Pd [1-4].

Various techniques have been proposed in order to improve the throughput of the SUs. Furthermore,

* Corresponding Author

various parameters such as detection threshold, sensing time, number of cooperative users for sensing, transmission power, and sensing-throughput tradeoff have been investigated [5-7].

Recently, NOMA as a promising multiple access scheme in wireless networks, especially for 5G networks, has gained attention [8-10]. NOMA-based CR networks can use the vacant spectrum resources. Hence, the spectral efficiency of communication system can be improved by exploiting the power domain diversity [11-14]. In NOMA scheme, multiple users are supported to use the same resources, e.g., frequency channel, time, or spreading code. In fact, the same radio resources with different power domains are simultaneously used by the multiple users, so that less transmit power is assigned to the user with better channel condition. Also, the receiver employs a successive interference cancellation (SIC) method to decode the aliasing signal [8].

Resource management in NOMA CRNs is a serious problem to avoid harmful interference to PUs [11]. In [15], a NOMA-based CRN was presented where a two-tier power assignment method was investigated so that the best utilization of the inherited characteristics of its power-domain was achieved. In [16], a two-step power allocation approach was presented where the number of acceptable SUs was maximized and minimum throughput of them was gotten while decreasing the received interference at PUs. In [17], a power assignment problem was investigated. Therefore, the number of acceptable SUs was maximized considering some constraints, such as maximum transmit power of SUs, received interference at PU, and received SINR at SUs. Authors in [18] have investigated a two-phase power allocation approach to maximize the number of admitted SUs and the minimum throughput of admitted SUs was achieved meanwhile reducing the harmful interference to PUs. In [19], a cooperative NOMA CRN with imperfect-CSI was presented and the outage probability was studied where the power allocation was not considered. In [20], the secure performance of a NOMA system was studied.

On the other hand, D2D communications have been presented as an effective technique to alleviate the explosive traffic growth in wireless communications and increase the spectral efficiency [21]. In D2D communications, nearby wireless devices can communicate together, directly, bypassing their corresponding BS. Most of the work on D2D focus on how to employ D2D communication in cellular network with limited interference. By integrating D2D with CR, the spectrum efficiency and throughput can significantly be enhanced. The authors in [22] present a D2D cooperative scheme where a group of idle D2D acts as potential relays and cooperates with the PU communications to improve the performance. In [23], a joint D2D spectrum sharing and mode selection method has been studied under a hybrid network model. In [24], a two-stage subcarrier allocation approach has been illustrated. A power assignment method has also been proposed to optimize the transmission rate of the D2D users while simultaneously satisfying some constraints. In [25], the maximization of the sum rate of D2D pairs was provided under the constraints on the minimum rate requirements of NOMA-based cellular users and SIC decoding by solving a power allocation and channel assignment problem considering underlay NOMA-based cellular network with D2D pairs. Then, the authors proposed a dual-based iterative algorithm in order to solve the optimization problem by using the auxiliary variables and relaxing the binary constraints.

To the best knowledge of the authors, none of the mentioned related works considers the cooperation between D2D communication and NOMA technique in CR systems to jointly maximize the spectrum efficiency and throughput of secondary network. In this paper, we investigate the application of NOMA and D2D in multi-channel CRN. More specifically, we propose a NOMA-based CR network with D2D communications between SUs in order to maximize the SUs sum rate. Thus, we optimize the sub-channel and power allocations. A novel solution is used that jointly assigns sub-channels to SU users where they can opportunistically access the spectrum and allocate the power to SU transmitters and PUs, so that the quality of service (QoS) of PUs can also be guaranteed. We consider the work done in [25], with the difference that the cellular network is replaced by a CR network including PUs and SUs. Also, the maximum interference constraint caused to PUs must be applied to guarantee the PU's signal.

The rest of this paper is organized as follows. Section 2 describes the system model and formulates the problem for the investigated network. The proposed resource management scheme is also presented in this section. Section 3 presents numerical results. Finally, the paper is concluded in section 4.

II. SYSTEM MODEL

As shown in Fig. 1, we investigate a downlink NOMA-based CRN, where BS serves multiple PUs through *N* SCs and multiple D2D users (SUs). The SU transmitters are allowed for opportunistically utilizing those unoccupied SCs left by the PUs.

Let, $K=\{1,\ldots,k\}$, $N=\{1,\ldots,n\}$, and $M=\{1,\ldots,m\}$ be sets for SU transceivers, sub-channels, and PUs, respectively. The channel gain between the *k*th SU transmitter and receiver on the *n*th SC is expressed by g_k^n , and between the receiver of *k*th SU transceivers and BS is g_{kB}. On the other hand, the channel gain between *i*th PU and BS on the *n*th SC is denoted by h_i^n and between *i*th PU and transmitter of *k*th SU transceiver on nth SC is considered as h_{ki}^n.

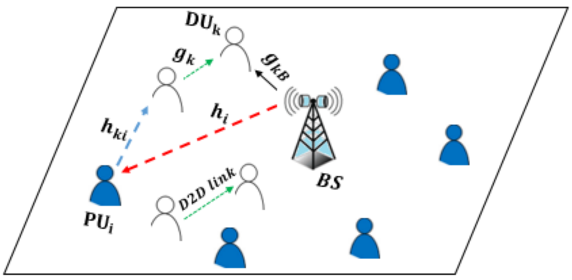

Figure 1. Investigated NOMA-based CR network model with D2D communication.

The SU transceivers transmit information via an underlay mode. We consider a Rayleigh fading channel with path gain $h_{k.i}^n$ between the ith PU and kth SU transceiver defined as follows [26].

$$h_{k,i}=10^{\frac{-L_{k,i}}{20}}\,g_{k,i} \tag{1}$$

where $g_{k.i}$ is a zero-mean and unit-variance complex Gaussian random process. $L_{k.i}$ has two components described as (2) which the first is the path loss according to free-space path loss model and the second is a zero-mean real Gaussian random variable with standard deviation of 3 based on large scale log-normal shadowing [26].

$$L_{k,i}=20\log\left(\frac{d_{k,i}4\pi f_c}{c}\right)+n_j \tag{2}$$

where $d_{k,i}$ expresses the distance of ith PU and kth SU transceiver, f_c denotes the carrier frequency, and C is the speed of light. The total symbol transmitted by BS via nth SC to PUs is

$$S^n=\sum_{i=1}^{M}\sqrt{P_i^n}\,x_i^n(t) \tag{3}$$

where p_i^n and $x_i^n(t)$ denote the transmit power and signal for ith PU on the nth SC, respectively.

According to NOMA, by performing successive interference cancellation (SIC), we assume that the channel gains satisfy the following order $|h_1^n| \leq |h_2^n| \leq \cdots \leq |h_M^n|$. Using SIC, the received SINR of the ith PU to decode the signal s_j $(j < i)$, over nth SC, is defined as

$$\gamma_{i\to j}^n=\frac{p_j^n\left|h_i^n\right|^2}{\left|h_i^n\right|^2\sum_{l=j+1}^{M}p_l^n+\sum_{k=1}^{K}\mu_k^n q_k^n\left|h_{k,i}^n\right|^2+\sigma^2} \tag{4}$$

where p_j^n and q_k^n represent the transmit power of jth PU and kth SU on ith sub-channel, respectively. $\mu_k^n \in \{0.1\}$ is '1' when nth SC is assigned to kth SU transceiver, and is '0' when it is not assigned.

Based on [25], the SIC is successful if the received SINR at the ith PU is no smaller than that of the jth PU, which can be expressed as

$$\frac{\sum_{k=1}^{K}\mu_k^n q_k^n\left|h_{k,j}^n\right|^2+\sigma_u^2}{\left|h_j^n\right|^2}\geq\frac{\sum_{k=1}^{K}\mu_k^n q_k^n\left|h_{k,i}^n\right|^2+\sigma_u^2}{\left|h_i^n\right|^2} \tag{5}$$

where, can be simplified as follows.

$$\frac{\sum_{k=1}^{K}\mu_k^n q_k^n\left|h_{k,i}^n\right|^2+\sigma_u^2}{\left|h_i^n\right|^2}\geq\frac{\sum_{k=1}^{K}\mu_k^n q_k^n\left|h_{k,i+1}^n\right|^2+\sigma_u^2}{\left|h_{i+1}^n\right|^2} \tag{6}$$

According to Shannon formula, the maximum achievable rate per bandwidth of the ith PU on nth SC is

$$C_i^n=\log_2\left(1+\gamma_{i\to j}^n\right) \tag{7}$$

The rate requirements for PUs must satisfy

$$C_i^n\geq C_{\text{th}}^n \quad , \quad \forall n\in N \quad , \quad k\in K \tag{8}$$

where C_{th}^n is the minimum required rate for PUs on nth SC. It is assumed that each SU transceiver can only use one SC. Therefore,

$$\begin{aligned}&\sum_{k=1}^{K}\mu_k^n\leq 1\\&\mu_k^n\in\{0,1\} \quad , \quad \forall n\in N \quad , \quad k\in K\end{aligned} \tag{9}$$

The received SINR at kth SU transceiver on nth SC is expressed as

$$\Gamma_k^n=\frac{q_k^n\left|g_k^n\right|^2}{\left|g_{k,B}^n\right|^2\sum_{i=1}^{M}p_i^n+\sigma_u^2} \tag{10}$$

The rate of the kth SU transceiver on nth SC can be computed as

$$\tilde{R}_i^n=\log_2\left(1+\Gamma_k^n\right) \tag{11}$$

Therefore, the achievable average throughput of the K SU transceivers on all N SCs is given by

$$R_{\text{total}}^D=\sum_{k=1}^{K}\sum_{n=1}^{N}\mu_k^n\tilde{R}_k^n \tag{12}$$

The transmit power constraints for PUs and SU transceivers are considered as

$$\sum_{n=1}^{N}\mu_k^n q_k^n\leq P_{\max}^D \quad , \quad \forall k\in K \tag{13}$$

$$\sum_{i=1}^{M}p_i^n\leq P_{\max}^P \quad , \quad \forall n\in N \tag{14}$$

The interference constraint for expressing the maximum interference caused by all SU transceivers is defined as follows.

$$\begin{aligned}&\sum_{k=1}^{K}\mu_k^n q_k^n\leq I_{\max}\\&\mu_k^n\in\{0,1\} \quad , \quad \forall n\in N \quad , \quad k\in K\end{aligned} \tag{15}$$

We want to maximize the throughput of SU transceivers by jointly power control of SU transceivers and PUs and optimum assignment of SCs to users under constraints of the total transmission power, Interference power, and minimum rate requirements of the users. So, the optimization problem can be written as follows.

$$\max_{\{\mu_k^n,q_k^n,p_i^n\}} R_{\text{total}}^D=\sum_{k=1}^{K}\sum_{n=1}^{N}\mu_k^n\tilde{R}_k^n \tag{16}$$

subject to

$$\sum_{k=1}^{K}\mu_k^n \le 1 \quad \mu_k^n \in \{0,1\} \quad , \quad \forall n\in N \quad , \quad k\in K \qquad (16\text{-}1)$$

$$\frac{\sum_{k=1}^{K}\mu_k^n q_k^n \left|h_{k,i}^n\right|^2 + \sigma_u^2}{\left|h_i^n\right|^2} \ge \frac{\sum_{k=1}^{K}\mu_k^n q_k^n \left|h_{k,i+1}^n\right|^2 + \sigma_u^2}{\left|h_{i+1}^n\right|^2} \qquad (16\text{-}2)$$

$$C_i^n \ge C_{\text{th}}^n \quad , \quad \forall i\in M \quad , \quad n\in N \qquad (16\text{-}3)$$

$$\sum_{n=1}^{N}\mu_k^n q_k^n \le P_{\max}^D \quad , \quad \forall k\in K \qquad (16\text{-}4)$$

$$\sum_{i=1}^{M} p_i^n \le P_{\max}^p \quad , \quad \forall n\in N \qquad (16\text{-}5)$$

$$\sum_{k=1}^{K}\mu_k^n q_k^n \le I_{\max} \quad \mu_k^n \in \{0,1\} \quad , \quad \forall n\in N \quad , \quad k\in K \qquad (16\text{-}6)$$

The optimization problem is non convex with respect to q_k^n due to (16-1). We use the solution investigated in [25] in order to maximize the throughput of the SU transceivers by optimizing the power allocation for PUs and guaranteeing the QoS of the PUs. The optimization problem is non convex. After some mathematical manipulation and temporarily relaxing the integer constraints, it is changed to a convex problem. Finally, it is solved using the Lagrangian multiplier based the convex method.

For notation simplicity, the superscript n can be omitted. we define

$$\xi_{k,i} = \frac{\left|h_{k,i}\right|^2}{\left|h_i\right|^2} \qquad \Delta_i = \frac{\sigma^2}{\left|h_i\right|^2} \qquad (17)$$

Note that the sum rate of D2D pairs can be further enhanced by decreasing p_i, therefore, the constraint (16-3) should be considered as equality to achieve the optimal transmit power of the ith PU denoted as $\forall i \epsilon \mathcal{M}\ p_i^*$. We assume $S_i = \sum_{t=i}^{M} p_t^*$ and obtain a recursive relation of S_i. Then, by using $p_i^* = S_i - S_{i+1}$ and after some manipulations the optimal power of the ith PU can be obtained as:

$$p_i^* = \left(2^{C_{\text{th},i}} - 1\right)\times \sum_{j=1}^{M-i}\left(G_{i,j}\left(q_k\zeta_{k(i+j)} + \Delta_{i+j}\right)\right) + \left(2^{C_{th,i}} - 1\right)\left(q_k\zeta_{k,i} + \Delta_i\right) \qquad (18)$$

where

$$G_{i,j} = 2^{\sum_{l=1}^{j-1} C_{th,i+l}\left(2^{C_{th,i+j}} - 1\right)} \quad , \quad i\in M \qquad (19)$$

Now, we employ an approach in order to control the power of D2D pairs and assign the SCs to users. We define

$$\Gamma_j = 2^{\sum_{l=1}^{j}\gamma_l\left(2^{\gamma_{l+j}} - 1\right)} \qquad (20)$$

The constraint (16-5) can be expressed as

$$q_k^n \le \frac{P_{\max}^p - \sum_{j=0}^{M-1}\Gamma_j \Delta_{1+j}^n}{\sum_{j=0}^{M-1}\Gamma_j \xi_{k,(j+1)}^n} \qquad (21)$$

From (18), the constraint (6) can be rewritten as

$$q_k^n \xi_{k,i}^n + \Delta_i^n \ge q_k^n \xi_{k,(i+1)}^n + \Delta_{i+1}^n \qquad (22)$$

On the other hand, it should be noted that since $|h_i^n| \le |h_i^{n+1}|$, therefore, $\Delta_{i+1}^n \le \Delta_i^n$. If $\xi_{k(i+1)}^n \le \xi_{ki}^n$, (22) is feasible for any non-negative q_k^n. In result,

$$q_k^n \le \min_{\forall i\in M|\xi_{k,(i+1)}^n > \xi_{k,i}^n}\left\{\frac{\Delta_{i+1}^n - \Delta_i^n}{\xi_{k,i}^n - \xi_{k,(i+1)}^n}\right\} \qquad (23)$$

Therefore, if $\xi_{k(i+1)}^n > \xi_{ki}^n$, one additional transmit power constraint should be considered on the D2D pair to protect the SIC decoding order of the PUs. The rate of kth D2D pair on nth SC can be given by:

$$\tilde{R}_k^n\left(q_k^n\right) = \log_2\left(1 + \frac{d_k^n q_k^n}{q_k^n + e_k^n}\right) \qquad (24)$$

where

$$d_k^n = \frac{\left|g_k^n\right|^2}{\left|g_{k,B}^n\right|^2 \sum_{j=0}^{M-1} r_j \xi_{j+1}} \qquad e_k^n = \frac{\left|g_{k,B}^n\right|^2 \sum_{j=0}^{M-1} r_j \Delta_{j+1} + \sigma_u^2}{\left|g_{k,B}^n\right|^2 \sum_{j=0}^{M-1} r_j \xi_{j+1}} \qquad (25)$$

In result, the optimization problem is expressed as follows:

$$\max_{\{p_k^n,\mu_k^n,q_k^n\}} R_{total}^D = \sum_{k=1}^{K}\sum_{n=1}^{N}\mu_k^n \tilde{R}_k^n \quad (26)$$

subject to

$$\sum_{k=1}^{K}\mu_k^n \le 1, \quad \mu_k^n \in \{0,1\} \;,\; \forall n \in N \;,\; k \in K \quad (26\text{-}1)$$

$$\sum_{n=1}^{N}\mu_k^n q_k^n \le P_{max}^D \;,\; \forall k \in K \quad (26\text{-}2)$$

$$\sum_{k=1}^{K}\mu_k^n q_k^n \le I_{max}, \quad \mu_k^n \in \{0,1\} \;,\; \forall n \in N \;,\; k \in K \quad (26\text{-}3)$$

$$0 \le q_k^n \le Q_k^n \quad (26\text{-}4)$$

where

$$Q_k^n = \min\left\{ \max\left\{0, \frac{P_{max}^p - \sum_{j=0}^{M-1}\Gamma_j \Delta_{1+j}^n}{\sum_{j=0}^{M-1}\Gamma_j \xi_{k,(j+1)}^n}\right\}, \min_{\forall i\in M|\xi_{k,i}^n<\xi_{k,(i+1)}^n}\left\{\frac{\Delta_{i+1}^n-\Delta_i^n}{\xi_{k,i}^n-\xi_{k,(i+1)}^n}\right\}\right\} \quad (27)$$

By defining $z_k^n = \mu_k^n q_k^n$, and temporarily relaxing the integer constraints and after some mathematical manipulations, the optimization problem can be rewritten as

$$\max_{\substack{\mu_k^n\in[0,1]\\ z_k^n\in[0,\mu_k^n Q_k^n]}} R_{total}^D(\mu_k^n, z_k^n) = \sum_{k=1}^{K}\sum_{n=1}^{N}\mu_k^n \tilde{R}_k^n\left(\frac{z_k^n}{\mu_k^n}\right) \quad (28)$$

subject to

$$\sum_{n=1}^{N} z_k^n \le P_{max}^D \;,\; \forall k \in K \quad (28\text{-}1)$$

$$\sum_{k=1}^{K}\mu_k^n \le 1, \quad \mu_k^n \in \{0,1\} \;,\; \forall n \in N \;,\; k \in K \quad (28\text{-}2)$$

$$\sum_{k=1}^{K} z_k^n \le I_{max}, \quad \mu_k^n \in \{0,1\} \;,\; \forall n \in N \;,\; k \in K \quad (28\text{-}3)$$

According to [25], the problem (28) is convex with respect to μ_k^n and z_k^n. Therefore, we can use the convex optimization approach to achieve the optimal solution. In result, we use Lagrangian multiplier based convex method to solve the problem. The Lagrangian function is expressed as

$$L = \sum_{k=1}^{K}\sum_{n=1}^{N}\mu_k^n \tilde{R}_k^n\left(\frac{z_k^n}{\mu_k^n}\right) + \sum_{k=1}^{K}\alpha_k\left(P_{max}^D - \sum_{n=1}^{N} z_k^n\right) + \sum_{n=1}^{N}\beta_n\left(1-\sum_{k=1}^{K}\mu_k^n\right) + \sum_{n=1}^{N}\psi_n\left(I_{max} - \sum_{k=1}^{K} z_k^n\right) \quad (29)$$

where α_k, β_n, and ψ_n are the Lagrange multipliers. By taking the derivative of L with respect to μ_k^n , z_k^n, and ψ_n , we have

$$\frac{\partial L}{\partial z_k^n} = \tilde{R}_k'^n\left(\frac{z_k^n}{\mu_k^n}\right) - \alpha_k - \psi_n \quad (30)$$

$$\frac{\partial L}{\partial \mu_k^n} = \tilde{R}_k^n\left(\frac{z_k^n}{\mu_k^n}\right) - \frac{z_k^n}{\mu_k^n}\tilde{R}'^n_k\left(\frac{z_k^n}{\mu_k^n}\right) - \beta_n \quad (31)$$

By considering the KKT condition as (32) and (33), we can obtain the optimal z^{*n}_k as (34):

$$\frac{\partial L}{\partial z_k^n} \begin{cases} <0 \;,\; \text{if } z_k^{*n} \\ =0 \;,\; \text{if } z_k^{*n} \in (0, Q_k^n) \\ >0 \;,\; \text{if } z_k^{*n} \in (0, Q_k^n) \end{cases} \quad (32)$$

$$\frac{\partial L}{\partial \mu_k^n} \begin{cases} =0 \;,\; \text{if } \mu_k^{*n} \in (0, Q_k^n) \\ >0 \;,\; \text{if } \mu_k^{*n} = 1 \end{cases} \quad (33)$$

$$z_k^{*n} = \mu_k^{*n}\left[V_k^n(\alpha_k)\right]_0^{Q_k^n} \quad (34)$$

where

$$V_k^n(\alpha_k) = \frac{-(d_k^n+2)e_k^n + \sqrt{\Delta}}{2(d_k^n+1)} \quad (35)$$

$$\Delta = e_k^n d_k^{n^2} + \frac{4d_k^{n^2}}{\alpha_k \ln 2} + \frac{e_k^n d_k^n}{\alpha_k \ln 2} \quad (36)$$

$$[x]_b^a = \min\{\max(x,b), a\} \quad (37)$$

Then, we define

$$W_k^n = \tilde{R}_k^n(F_k^{*n}) - F_k^{*n}\tilde{R}_k'^n(F_k^{*n}) \quad (38)$$

If W_k^n is different for each $k\epsilon K$, according to constraint (28-2), we have:

$$\mu_{k'}^{*n} = 1 \;,\; \mu_k^{*n} = 0 \;\; \forall \;\; k \ne k' \quad (39)$$

where $k' = arg\max_k W_k^n$. In other words, the SC is assigned to D2D pair with the largest W_k^n.

The sub-gradient method [27] is used to update the optimum Lagrangian multipliers as follows.

$$\alpha_k^{t+1} = \left[\alpha_k^{(t)} - \theta_k^{(t)} \left(P_{\max}^D - \sum_{n=1}^{N} \left(z_k^n \right)^{(t)} \right) \right]^+ \quad (40)$$

$$\psi_n^{t+1} = \left[\psi_n^{(t)} - \phi_n^{(t)} \left(I_{\max} - \sum_{k=1}^{K} \left(z_k^n \right)^{(t)} \right) \right]^+ \quad (41)$$

where $\theta_k^{(t)}$ and $\phi_n^{(t)}$ are the positive step size and $[a]^+ = max(0.a)$. The Algorithm 1 represents a pseudo code to achieve the optimal power allocation and SC assignment to PUs and D2D pairs.

Algorithm 1. Proposed Iterative algorithm for power allocation and SC assignment to PUs and D2D pairs.

Initialize $z_k^{n(0)} = 0. \mu_k^{n(0)} = 0 . \forall k\epsilon K. n\epsilon N$
Initialize $\theta_k^{(0)}. \alpha_k^{(0)}. \phi_n^{(0)} \ \forall k\epsilon K$
ϵ = a small number
WHILE ($|R_{total}^D(t) - R_{total}^D(t-1)| > \epsilon$) do
FOR $k\epsilon K, n\epsilon N$ do
Compute $\mu_k^{n(t)}$ and $z_k^{n(t)}$ according to (29) and (30)
END FOR
UPDATE $\alpha_k^{(t)}$ and $\psi_n^{(t)}$ according to (31) and (32)
UPDATE $R_{total}^D(t)$ according to (23)
END WHILE
Compute p_k^n and $q_k^n . \forall k\epsilon K. n\epsilon N$
OUTPUT: p_k^n , q_k^n, μ_k^n and R_{total}^D

III. SIMULATION RESULTS

The performance of the proposed scheme is obtained through averaging over 10000 independent random experiments. We assume that the channel model from the PUs to the FC as well as every SU transceiver to the FC and PUs is as (1). The 2.4 GHz IEEE 802.15.4/ZigBee is used as the communication technology. The simulation parameters are listed in Table I.

TABLE I. THE PARAMETERS USED IN SIMULATIONS

Parameter	Value
length of area	100 m
The number of SU users (*K*)	8~14
The number of PU (*M*)	2~6
The number of SC (*N*)	12~32
f_s	1 MHz
$P(H_0)$	0.6
$P(H_1)$	0.4
T	10
P_{max}^P	10 dBm
P_{max}^D	10 ~30 dBm
I_{max}	10 ~30 dBm
C	3×10^8 m/s
C_{th}	0.1~1 bps/Hz

Fig.2 indicates the influence of the SC on the sum rate of the SU transceivers for different number of the iteration in the underlay mode. The number of SU transceivers is assumed to be 8 and the number of multiplexed PU on each SC is 12. We can see that the sum rate increases in each iteration and converges to a fixed, and also the maximum point achieves at the 9th iteration. It is also illustrated that the sum rate increases as the number of SC increases, because the more opportunities are provided for SU transceivers in order to use the idle bands.

In Fig.3, the sum rate of the D2D pairs is studied by varying the number of PUs for different number of the iteration in the underlay mode. As shown, the sum rate decreases by increasing the number of multiplexed PUs on each SC.

Fig.4 illustrates the influence of the maximum allowed interference caused by all SU transceivers at the PUs on the sum rate of SU transceivers. It can be seen that the sum rate increases with more interference constraint of the PUs. This is because the SU users will be allowed to send the data with more power because PUs will be able to withstand the higher interference level.

Fig.5 indicates the influence of the minimum rate requirements of PUs on the sum rate of SU transceivers for different number of the iteration in the underlay mode when *K*=12, *M*=2 and *N*=32. From this figure, we see that the sum rate is reduced by increasing the minimum rate requirements of PUs, because higher data rate requires the larger PU transmit power. In result, the co-channel interference caused to the SU transceivers on SC is increased and the sum rate is decreased.

Fig.6 illustrates the joint influence of the minimum rate requirements of PUs and different number of the multiplexed PUs on the sum rate of SU transceivers. From this figure, we see that the sum rate is reduced by increasing the minimum rate requirement of PUs. It can be seen that increasing the minimum rate requirements of PUs and the number of multiplexed PUs on each SC leads to decrement in the sum rate.

In Fig.7, we compare the proposed scheme with two other schemes in order to indicate the superiority of the proposed approach. In the first scheme, the joint power control and channel assignment algorithm presented in [28] is considered. In this scheme, the orthogonal frequency division multiple access (OFDMA) system has been employed and each SC is also shared by M PUs, but each PU is only allowed to access $\frac{1}{M}$ fraction of SC bandwidth. Therefore, each D2D pairs is interfered by M co-channel PUs. In second scheme, none of the power control and channel assignment for users are optimized. We can see that the proposed scheme achieves the more sum rate in comparison to the others.

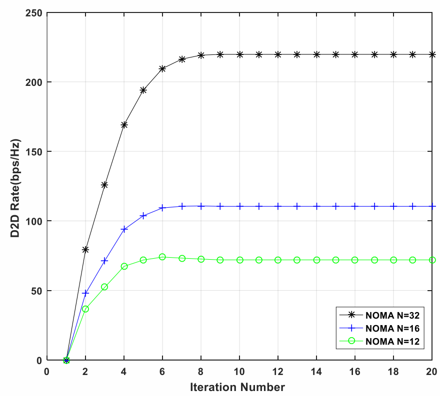

Figure 2. The sum rate versus the number of iteration for different SCs in the underlay mode.

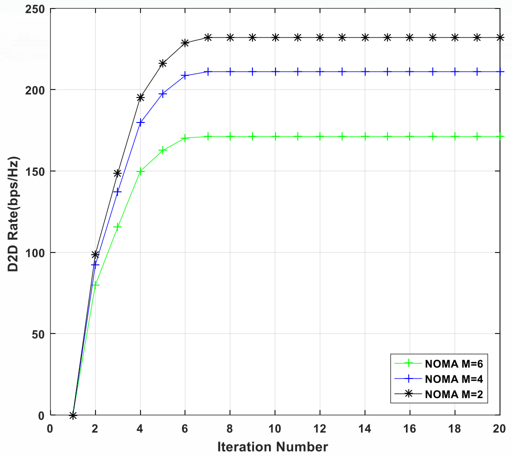

Figure 3. The sum rate versus the number of iteration for different M in the underlay mode.

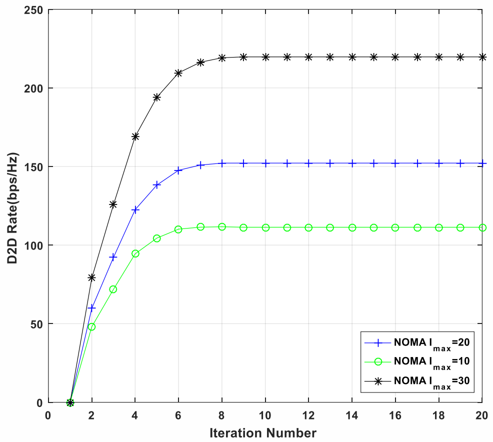

Figure 4. The sum rate versus the the maximum allowed interference for the PUs.

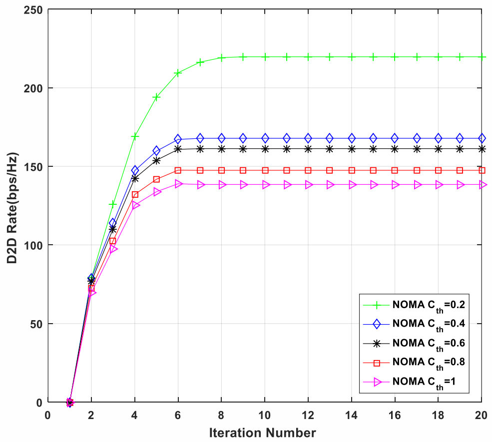

Figure 5. The sum rate of SU transceivers versus the number of iteration for different minimum rate requirements of PUs in the underlay mode

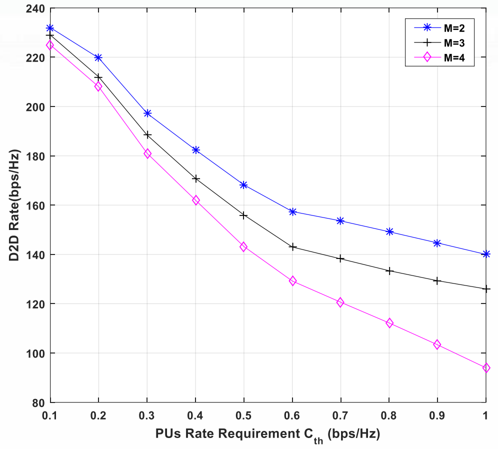

Figure 6. Sum rate of SU transceivers versus minimum rate requirements of PUs for different number of the multiplexed PUs.

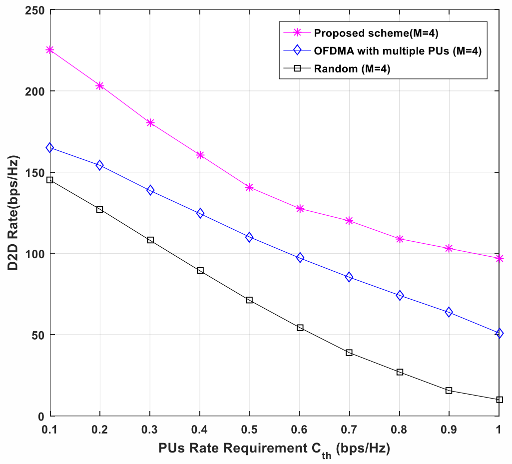

Figure 7. The sum rate of D2D pairs versus minimum rate requirements of PUs for different schemes when M=4.

IV. CONCLUSION

In this paper, we have introduced the SU communications into NOMA-based underlay multi-channel CR networks in order to increase the data rate of the cognitive SU users by optimizing SC and power allocation subject to the target rate requirements of the PU and maximum power constraints, so that the QoS of the PUs has been guaranteed. We used a two-stage scheme to implement power allocation and assignment of SC among SU transceivers and PUs. In addition, the optimization problem was solved by a convex-based iterative optimization algorithm. Simulation results demonstrated that the data rate of the cognitive SU users increases considering different PU target rate requirements with the investigated strategy.

REFERENCES

[1] M. Karimi, S. M. S. Sadough, and M. Torabi, “Optimal cognitive radio spectrum access with joint spectrum sensing and power allocation," IEEE Wireless Communications Letters, vol. 9, no. 1, pp. 8-11, 2019.

[2] A. Nasser, O. Muta, H. Gacanin, and M. Elsabrouty, “Joint user pairing and power allocation with compressive sensing in NOMA systems," IEEE Wireless Communications Letters, vol. 10, no. 1, pp. 151-155, 2020.

[3] L. Xin and M. Jia, “Intelligent spectrum resource allocation based on joint optimization in heterogeneous cognitive radio,"

IEEE Transactions on Emerging Topics in Computational Intelligence, vol. 4, no. 1, pp. 5-12, 2020.

[4] Q. Yang, Y. F. Huang, Y. C. Yen, L. Y. Chen, H. H. Chen, X. M. Hong, J. H. Shi, and L. Wang, "Location based joint spectrum sensing and radio resource allocation in cognitive radio enabled LTE-U systems," IEEE Transactions on Vehicular Technology, vol. 69, no. 3, pp. 2967-2979, 2020.

[5] H. Yang, M. Huang, Y. Li, S. Dey, and L. Shi, "Joint Power Allocation for Remote State Estimation With SWIPT," IEEE Transactions on Signal Processing, vol. 70, pp. 1434-1447, 2022.

[6] L. Qiaoshou, J. Zou, and Y. Gu, "An Analysis of Distributed Joint Spectrum Resource Allocation with Power Control in Ultra-Dense Cellular Networks," IEEE Transactions on Vehicular Technology, vol. 71, no. 10, pp. 11201-112015, 2022.

[7] L. Xin and X. Zhang, "NOMA-based resource allocation for cluster-based cognitive industrial internet of things," IEEE transactions on industrial informatics, vol. 16, no. 8, pp. 5379-5388, 2019.

[8] M. Hassan, M. Singh, and K. Hamid, "Survey on NOMA and Spectrum Sharing Techniques in 5G," IEEE International Conference on Smart Information Systems and Technologies (SIST), Kazakhstan, 2021.

[9] Y. Yin, Y. Peng, M. Liu, J. Yang, and G. Gui, "Dynamic user grouping-based NOMA over Rayleigh fading channels," IEEE Access, vol. 7, pp. 110964-110971, 2019.

[10] C. Soumali and M. Belattar, "Analysis of the Cooperative NOMA performance systems with Energy Harvesting strategies," IEEE 21st International Symposium INFOTEH-JAHORINA (INFOTEH), Bosnia and Herzegovina, 2022.

[11] A. M. Auyo, S. A. Babale, and L. M. Bello, "Effect of Inspired CR-NOMA Power Allocation on Bit Error Rate For Three User NOMA system," IEEE 4th International Conference on Disruptive Technologies for Sustainable Development (NIGERCON), Nigeria, 2022.

[12] G. Wu, W. Zheng, Y. Li, and M. Zhou, "Energy-efficient power allocation for IoT devices in CR-NOMA networks," China Communications, vol. 18, no. 4, pp. 166-181, 2021.

[13] S. Abidrabbu and H. Arslan, "Efficient power allocation for MIMO CR-NOMA networks," IEEE 94th Vehicular Technology Conference (VTC2021-Fall), USA, 2021.

[14] D. T. Do, M. S. V. Nguyen, F. Jameel, R. Jäntti, and I. S. Ansari, "Performance evaluation of relay-aided CR-NOMA for beyond 5G communications," IEEE Access, vol. 8, pp. 134838-134855, 2020.

[15] S. Gamal, M. Rihan, A. Zaghloul, and A. Shaalan, "Two-tier power allocation for non-orthogonal multiple access based cognitive radio networks," IEEE/ACS 15th International Conference on Computer Systems and Applications (AICCSA), pp. 1-5, 2018.

[16] M. Zeng, G. I. Tsiropoulos, A. Yadav, O. A. Dobre, and M. H. Ahmed, "A two-phase power allocation scheme for CRNs employing NOMA," IEEE Global Communications Conference (GLOBECOM), Singapore, pp. 1-6, 2017.

[17] M. Zeng, G. I. Tsiropoulos, O. A. Dobre, and M. H. Ahmed, "Power allocation for cognitive radio networks employing non-orthogonal multiple access," IEEE Global Communications Conference (GLOBECOM), Washington, DC, pp. 1-5, 2016.

[18] M. Zeng, G. I. Tsiropoulos, A. Yadav, O. A. Dobre and M. H. Ahmed, "A two-phase power allocation scheme for CRNs employing NOMA," in Proc. IEEE Global Commun. Conf., Singapore, 2017, pp. 1-6.

[19] G. Im and J. H. Lee, "Outage probability for cooperative NOMA systems with imperfect SIC in cognitive radio networks, "IEEE Commun. Lett., doi: 10.1109/LCOMM.2019.2903040, 2019.

[20] F. Zhou, Y. Wu, R. Q. Hu, Y. Wang, and K. K. Wong, "Energyefficient noma enabled heterogeneous cloud radio access networks," IEEE Network, vol. 32, no. 2, pp. 152–160, 2018.

[21] W. K. Lai, Y. C. Wang, H. C. Lin, and J. W. Li, "Efficient resource allocation and power control for LTE-A D2D communication with pure D2D model," IEEE Transactions on Vehicular Technology, vol. 69, no. 3, pp. 3202-3216, 2020.

[22] Y. Yao, S. Huang, N. C. Beaulieu, and C. Yin, "Cooperative transmission in cognitive and energy harvesting-based D2D networks," IEEE Wireless Communications and Networking Conference (WCNC), pp. 16, 2017.

[23] Hu, J., Heng, W., Li, X., and Wu, J., " Energy-efficient resource reuse scheme for d2d communications underlaying cellular networks," IEEE Communications Letters, vol. 21, no. 9, pp. 2097–2100, 2017.

[24] A. Sultana, L. Zhao, and X. Fernando, "Efficient resource allocation in device-to-device communication using cognitive radio technology," IEEE Transactions on Vehicular Technology, vol. 66, no. 11, pp.10024-10034, 2017.

[25] Y. Pan, C. Pan, Z. Yang, and M. Chen, "Resource allocation for D2D communications underlaying a NOMA-based cellular network." IEEE Wireless Communications Letters, vol. 7, no. 1, pp. 130-133, 2017.

[26] M. S. Kerdabadi, R. Ghazizadeh, H. Farrokhi, and M. Najimi, "Energy consumption minimization and throughput improvement in cognitive radio networks by joint optimization of detection threshold, sensing time and user selection," Wireless Networks, vol. 25, no. 4, pp. 2065-2079, 2018.

[27] D. P. Bertsekas, Nonlinear programming. Athena scientific Belmont, 1999.

Javad Zeraatkar Moghaddam received the B.Sc., M.Sc., and Ph.D. degrees in Electrical Engineering - Telecommunication from the University of Birjand, Birjand, Iran, in 2009, 2011, and 2016, respectively. He was a visiting Ph.D. student with the University of Trento, Trento, Italy. He is currently an Assistant Professor with the University of Birjand. His current research interests include MIMO systems, cooperative communications, cognitive radio networks, D2D communications, cloud computing, cooperative NOMA, and UAV-aided mobile networks.

Mehrdad Ardebilipour received the B.Sc. and M.Sc. degrees in Electrical Engineering from the K. N. Toosi University of Technology, Tehran, Iran, in 1977 and Tarbiat Modarres University, Tehran, Iran, in 1989, respectively. He has also been awarded the degree of Ph.D. by the University of Surrey, Guildford, England, in 2001. He is an Associate Professor with the K. N. Toosi University of Technology and is directing the Spread Spectrum and Wireless Communications research laboratory at the K. N. Toosi University of Technology. His current research interests are cognitive radio, cooperative communication, ad-hoc and sensor networks, MIMO communication, OFDM, game theory, and cross-layer design for wireless communications.