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Joint Spectrum Resource Allocation in NOMA-based Cognitive Radio Network With SWIPT

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ABSTRACT In a conventional cognitive radio (CR) network, only when the primary user's (PU) frequency bands are sensed to be free, secondary users (SUs) can utilize these frequency band resources. Therefore, spectrum sensing (SS) can improve spectrum utilization. Spectrum sharing means that the SUs are allowed to utilize the licensed spectrum bands belonging to the PU to transmit information with PU simultaneously. Spectrum sharing performs well under the conditions that the interference to the PU is assured to be less than a certain threshold. Non-orthogonal multiple access (NOMA) has attracted considerable interests in recent years, which is seen as an important wireless access scheme for the coming 5G wireless communication system. Simultaneous wireless information and power transfer (SWIPT) is proposed as a popular technique to extend the operation duration of power-supply-limited wireless networks. The CR-NOMA is seen as a special form of the power-domain NOMA, wherein the requirements of the SU and PU are strictly met so that excellent system performance can be achieved. In this paper, a joint frame structure is described, wherein SUs first perform SWIPT for spectrum sensing and then transmit information via an overlay and underlay mode. Moreover, the optimization problem to maximize the achievable throughput for the CR network is presented to obtain the optimal sensing slot, while the total transmission power and the minimum rate requirements of the SUs are both constrained. A joint power allocation and sensing time optimizing algorithm based on dichotomy method are proposed to achieve the optimal solution. The simulation results show that there is a maximal throughput via setting an optimal sensing time for the secondary network.

INDEX TERMS Cognitive radio network, NOMA, SWIPT, spectrum sensing, joint optimization.

I. INTRODUCTION

With the development of wireless communication, the demand for spectrum resources is growing. With the arrival of the 5th generation wireless systems (5G) era [1]–[5], the access of large-scale mobile devices can cause shortage of spectrum resources [6]–[8]. However, in traditional radio network system, once the primary user (PU) has occupied the current spectrum and the secondary users (SUs) can not access to the channel. The licensed spectrum always performs low utilization, and existing resources cannot be utilized effectively [9]. Cognitive radio (CR) [10], [11] as an emerging technology is proposed to provide high spectrum utilization, in which SUs are allowed to access the spectrum when PU is absent. Spectrum sensing (SS) [12] can achieve better sensing performance when the probability of detection P_d is higher meanwhile the probability of false alarm P_f is lower. However, SS will consume some system resources and decrease the system performance. Simultaneous wireless information and Power transfer (SWIPT) can harvest the radio frequency (RF) signal energy to supply energy consumption [13]–[15].

Spectrum sharing is proposed as a significant strategy to improve system performance effectively. In [16], two typical models for spectrum sharing are presented. One is normal spectrum sharing, wherein SUs and PU are allowed to transmit information simultaneously. In this model, PU can coexist with SUs, and the interference among SUs is restricted

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to a specific threshold so that the PU's Quality of Service (QoS)requirement is not influenced; the SUs are expected to achieve a high system throughput by developing reasonable power allocation strategy. The other one is opportunistic spectrum access (OSA), wherein SUs sense the channel state and once the spectrum is sensed to be idle, SUs are allowed to access the spectrum licensed to PU. Reference [17] proposed a cooperative spectrum sensing model based on Dempster-Shafer Fusion. Reference [18] have designed a communication system with wireless information and power transfer based on 5G green broadband. CR nodes have the ability to observe, learn and make decisions, and this flexibility presents new challenges to SS technology [19]. Reference [20] proposes a new spectrum sharing algorithm based on game theory to analyze node game strategy. According to information asymmetry, a two-stage dynamic contract incentive model in collaborative system is presented in [21]. To further improve spectrum efficiency and meet 5G communication requirements, a high spectrum efficiency spectrum sharing protocol based on SWIPT is studied in [22]. Spectrum sharing can be divided into static spectrum sharing and dynamic spectrum sharing [23]. Reference [24] investigates a novel Internet of Things (IOT) [25], [26] system based on dynamic spectrum sharing 5G communication. Static spectrum sharing is generally applied to 3G/4G communication system such as Universal Mobile Telecommunications System (UMTS) and Code Division Multiple Access (CDMA) in Long-term Evolution (LTE) standard, where the spectrum utilization efficiency is limited. To further solve this problem, dynamic spectrum sharing has gradually become a hot spot in the industry and the main superiority is to request and release spectrum resources according to network conditions. [27] investigates spectrum shifting problem of multiple pairs of SUs using discrete Markov model considering network environment for licensed channels and unlicensed channels. In addition, when malicious users appear in the CR networks, physical-layer secure transmission has to be used to guarantee the network security [28]–[30].

In CR network, sensing mode, sensing time and some other factors will affect the CR network's performance. In recently years, considerable attentions have been paid to the sensing-throughput tradeoff problem [31]. In [32], the system achieves a maximum throughput by optimizing the sensing time under the constraint of total transmission power. SS can be regarded as an energy detection essentially and it can be applied to many areas such as wireless sensor network (WSN) [33] and traditional CR network. Energy efficiency (EE) is significant in wireless communication system and it can reflect the performance of a system from the side. EE is maximized in CR sensors network in [34]. Reference [35] aims to maximize EE by optimizing sensing time in multi-hops decode-and-forward relay network. In [36], a weight fusion-based periodic SS model has been put forward and the sensing performance is enhanced meanwhile the interference between the PU and SUs is reduced. In multiple subchannels spectrum, there are in general two decoding modes, one is PU first decoding mode (PFDM) and the other is SU first decoding (SFDM) [37]. In the first mode, PU decode firstly perform SWIPT and before SU signals are decoded, successive interference cancellation (SIC) is implemented which is refered to remove PU signal from the received signals. In the second mode, SUs signals are decoded first and then PU decode its own signal after removing SUs' signals from the received signals. For the above two modes, two kinds optimization problems are proposed in [38] and correspondingly joint optimization algorithm is made to solve the problem. The optimal resource allocation method in simultaneous cooperative spectrum sensing and energy harvesting of multichannel CR network is proposed in [39]. Reference [40] proposed a forward backward autoregressive spectrum prediction scheme in CR network. Reference [41] proposed a secure cooperative communications scheme for orthogonal frequency-division multiple-access (OFDMA) CR network, where a primary base station wants to transmit information to some distant primary users in the presence of a set of passive eavesdroppers.

Non-orthogonal multiple access (NOMA) [42] has been an important wireless communication access technique for the coming 5G networks. Related works have obtained many detailed analysis and important conclusions between NOMA and other multiple access techniques. Unlike conventional multiple access techniques, NOMA can meet users' QoS requirements and improve fairness by allocating resource dynamically, in which users with poor channel conditions are allocated more power and considerable total throughput can be achieved. NOMA can also achieve a high gains in capacity and system throughput performance in cellular radio access network [43] so that NOMA is popular in 5G communication to meet demands of enhanced mobile broadband, low latency and massive machine type of communication. Power-splitting which is also called half-duplex operation and time-switching which is also called asynchronous transmission are two typical modes in NOMA. Harvest-then-transmit is a popular power-splitting protocol in NOMA wireless network as it can enhance spectral efficiency. Usually, the frame is divided into two slots and users harvest energy during the time τ then transmit information in the time $1-\tau$. Besides the above works, the throughput optimization of underlay and overlay in NOMA-based CR network, especially for the SWIPT based CR network, has not been well studied. In this paper, NOMA is applied to CR network to improve the performance of CR network. The CR-NOMA meets the users' requirements by the proper power allocation [44]. The power allocation strategy of SUs in underlay cognitive radio is studied in [45]. The SUs simultaneously perform SWIPT and SS during the time τ and then transmit their independent information to the receiver using the shared channel in the duration of $1-\tau$. The power harvested during the period of τ is for SS. The tradeoff between τ and system throughput for CR-NOMA network is analyzed. We focus on finding an optimal τ to achieve the highest throughput for secondary network. Our contributions are summarized as follows:

TABLE 1. System parameters.

Parameters	Variable
Probability of Detection	P_d
Probability of False alarm	P_f
Probability of PU existence	PH_0
Secondary Throughput of Overlay Network	K_0
Secondary Throughput of Underlay Network	K_1
Downlink Transmit Power	P_a
Uplink Transmit Power	P_t
PU Transmit Power	P_p
SUs signal-to-noise ratio	γ
PU channel gain	g_s

- We consider the NOMA based SWIPT scheme in overlay CR network and underlay CR network. We implement NOMA for secondary network due to the non-orthogonality so that the spectrum efficiency can be improved. Furthermore, we implement SWIPT to the process so that the operation time of energy-limited wireless network can be extended which can effectively improve EE.
- We prove the convexity of system total throughput and we derive the concrete expressions of the system throughput for two various network modes under the constrains of transmit power and individual user target rates. We formulate system throughput optimization problem and we optimally allocate the time slot and transmit power such that the system throughput is maximized. In addition, we develop a optimal algorithm to solve the optimization problem.
- Simulation results show the performance of the proposed model using the algorithm for overlay and underlay modes respect to different variable conditions. We mainly focus on the tradeoff between the system throughput and other characteristic parameters such as time slot, total transmit power and PU's channel gain. The results illustrate that the system throughput has a maximum value within a certain range.

The rest of the paper is organized as follows. The system model is proposed in Section 2. In Section 3, we formulate the system throughput optimization problem as a joint power allocation and sensing time optimization under the conditions of overlay and underlay CR network. A joint optimization algorithm is presented. The simulation and conclusion are drawn in Section 4.

II. SYSTEM MODEL

A. OVERLAY CR NETWORK

In general CR network, the system is composed of N SUs, a PU and a base station (BS). Fig.1 shows frame structure of the CR-NOMA overlay network and the frame is divided into two slots. During the first slot τ, the BS performs SWIPT and the SUs sense the channel status simultaneously and the harvested RF energy can supply the transmission consumption. In this part, SWIPT means that the BS receives energy from the wireless channel and information of PU simultaneously. We use the information of PU to detect spectrum status and if the PU is detected to be absent, SUs will transmit information to BS in the next slot $1-\tau$. The network can communicate only when the PU has not been detected in the system. In the traditional CR network, the users can only transmit information using the stored battery energy, which decreases the transmission performance due to great energy consumption. However, CR-NOMA based on harvest-then-transmit protocol has the period of energy harvesting, which can harvest energy of BS for energy consumption of information transmission. Besides, the network structure of underlay and overlay CR is shown in Fig.2.

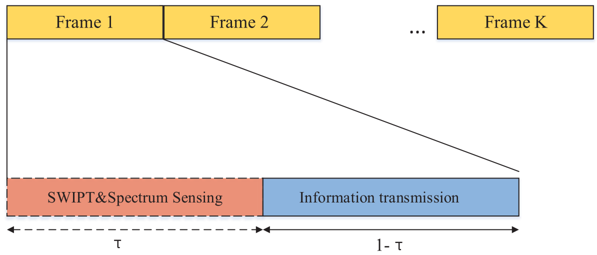

FIGURE 1. Frame structure of overlay CR-NOMA.

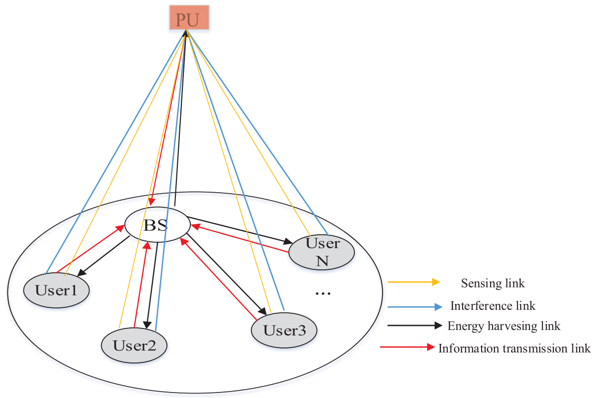

FIGURE 2. Network structure of CR-NOMA.

Suppose that in a CR network with carrier frequency f_c, bandwidth W and sampling frequency f_s. In the spectrum sensing period, the received signal at SU is obtained by using two-fold hypothesis as follows:

H_1: the PU is present and the output is represented as

$$y(n) = s(n) + u(n). \tag{1}$$

H_0: the PU is absent and the received signal is given by

$$y(n) = u(n). \tag{2}$$

The noise $u(n)$ with mean zero and variance σ_u^2 is a Gaussian white noise. The signal $s(n)$ is a random variable with mean zero and variance σ_s^2 and the signal and the noise is independent of each other. $\gamma = \frac{\sigma_s^2}{\sigma_u^2}$ is denoted as signal-to-noise ratio (SNR) of PU under the hypothesis H_1. The probability of detection P_d is the probability that the system will correctly judge the existence of the signal when the signal exists; and probability of false alarm P_f is the probability that the system will declare PU when the signal does not exist.

We utilize an energy detection-based spectrum sensing scheme. Sensing metric using energy detector is given by

$$T(y) = \frac{1}{N}\sum_{n=1}^{N} |y(n)|^2, \tag{3}$$

where $N = \tau f_s$ is the sample quantity. We define $p_i(x)$ $(i = 0, 1)$ as the probability density function (PDF) of $T(y)$. For a given threshold ε, P_f is given by

$$P_f(\varepsilon, \tau) = P_r(T(y) > \varepsilon | H_0) = \int_{\varepsilon}^{\infty} p_0(x)dx. \tag{4}$$

P_d is given by

$$P_d(\varepsilon, \tau) = P_r(T(y) > \varepsilon | H_1) = \int_{\varepsilon}^{\infty} p_1(x)dx. \tag{5}$$

When the complex signal is modulated by phase-shift-keying (PSK) and the noise is circularly symmetric complex Gaussian noise, P_f is approximately given by

$$P_f(\varepsilon, \tau) = Q\left(\left(\frac{\varepsilon}{\sigma_u^2} - 1\right)\sqrt{\tau f_s}\right). \tag{6}$$

P_d is approximately given by

$$P_d(\varepsilon, \tau) = Q\left(\left(\frac{\varepsilon}{\sigma_u^2} - \gamma - 1\right)\sqrt{\frac{\tau f_s}{2\gamma + 1}}\right). \tag{7}$$

When we choose a proper probability of detection $\bar{P}_d$, P_f which related to $\bar{P}_d$ is expressed as follows.

$$P_f = Q\left(\sqrt{2\gamma + 1}Q^{-1}\left(\bar{P}_d\right) + \sqrt{\tau f_s}\gamma\right). \tag{8}$$

P_d which related to $\bar{P}_f$ as follows.

$$P_d = Q\left(\frac{1}{\sqrt{2\gamma + 1}}\left(Q^{-1}\left(\bar{P}_f\right) - \sqrt{\tau f_s}\gamma\right)\right). \tag{9}$$

When the PU is inactive, the throughput of network can be denoted as K_0. Denote P_s be the received power of the secondary user and N_0 is the noise power, thus $K_0 = \log_2(1 + \frac{P_s}{N_0})$. $P(H_1)$ is the probability of the PU when it is active, while $P(H_0)$ is the probability of the PU when it is inactive. In addition, $P(H_1) + P(H_0) = 1$.

In overlay CR network, the main focus is the case in which the PU is absent and the SUs will not generate the false alarm. The probability for the case is $\left(1 - P_f(\varepsilon, \tau)\right)P(H_0)$ and the system throughput is given by

$$R_0(\varepsilon, \tau) = \frac{T - \tau}{T}K_0\left(1 - P_f(\varepsilon, \tau)\right)P(H_0). \tag{10}$$

Then, we substitute (8) into (10) and choose an appropriate $\bar{P}_d$. For convenience, we suppose that $T = 1$, and then the sum rate can be seen as a function of the sensing interval. Thus, we have

$$R(\tau) = K_0 P(H_0)(1 - \tau)\left(1 - Q\left(\alpha + \sqrt{\tau f_s}\gamma\right)\right), \tag{11}$$

where K_0 denotes the throughput of the secondary network when PU is absent, $\alpha = \sqrt{2\gamma + 1}Q^{-1}\left(\bar{P}_d\right)$. The harvested energy at user can be expressed as

$$E_i^{hd} = \tau P_a. \tag{12}$$

where P_a is defined as the transmit power of BS at the transmitter. Then the transmit power for uplink NOMA becomes

$$P_t = \frac{\tau P_a}{1 - \tau}. \tag{13}$$

For uplink NOMA, BS implements successive interference cancellation (SIC) to decode the users' messages. The user who has better channel condition will be decoded first and users who are decoded after it will be acted as interferences. Denote the users' channels by h_i and assume that the users are ordered as $h_1 > h_2 > \cdots > h_n$. The achievable throughput for the N-user NOMA network is

$$K_0 = B\sum_{i=1}^{N}\log_2\left(1 + \frac{P_i\gamma_i}{1 + \sum\limits_{j=i+1}^{N} P_j\gamma_j}\right), \tag{14}$$

where $\gamma_i = \frac{h_i}{N_0 B}$ is the normalized channel gain for UE_i and N_0 denotes power spectral density, B denotes the transmission bandwidth of the subband.

B. UNDERLAY CR NETWORK

In this section, we no longer consider SS in the duration τ and PU and SUs transmit information simultaneously in the time $1 - \tau$. We define a threshold I_{max} expressing the maximum interference caused by all SUs. P_p denotes transmit power of PU and g_s is the channel gain of PU. Thus the total interference is the summation of threshold interference and SUs decoded later. K_1 denotes the throughput of the network when the PU is active in the underlay network. $K_1 = \log_2(1 + \frac{P_s}{P_p + N_0})$. Because the PU can generate the interference power at the receiver, obviously, we have $K_0 > K_1$. The frame structure of underlay CR-NOMA is shown as Fig.3. Similarly, the achievable throughput for the N-user NOMA network is

$$K_1 = B\sum_{i=1}^{N}\log_2\left(1 + \frac{P_i\gamma_i}{P_p g_s + \sum\limits_{j=i+1}^{N} P_j\gamma_j}\right). \tag{15}$$

III. SYSTEM THROUGHPUT OPTIMIZATION

A. OPTIMIZATION IN OVERLAY CR NETWORK

Conventional NOMA scheme allocates more power to users with poor channel conditions. However, conventional NOMA does not fully meet the user's Qos requirements. The key idea of CR-NOMA is to treat NOMA as a special case of CR at the secondary network. And reasonable power allocation policy needs to be formulated to meet the users' Qos requirements.

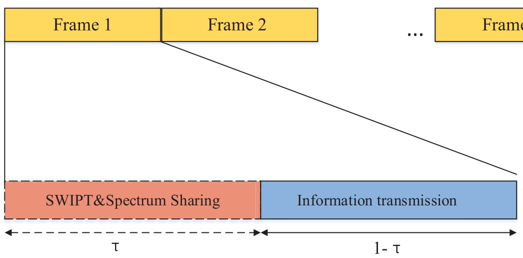

FIGURE 3. Frame structure of underlay CR-NOMA.

As discussed in Section 2, the sum rate of the overlay CR network can be given as (11), where K_0 denotes the throughput of the secondary network when it operates in the absence of PU.

In this part, we aim to maximize the sum-throughput through power control under constraints of the total transmission power and the minimum rate requirements of the users. Then, the optimization problem can be given as

$$max\ R(\tau) = P(H_0)(1-\tau)\left(1-Q\left(\alpha+\sqrt{\tau f_s}\gamma\right)\right)K_0, \tag{16}$$

where K_0 is denoted as (14) and B is set to be 1.

$$subject\ to: \begin{cases} \sum_{i=1}^{N} P_i \le P_t \\ \log_2\left(1+\dfrac{P_i\gamma_i}{1+\sum\limits_{j=i+1}^{N} P_j\gamma_j}\right) \ge R_i, \quad i=1,2,\ldots N \\ P_t = \dfrac{P_a\tau}{1-\tau}. \end{cases} \tag{17}$$

Firstly, we propose a solution to maximize the throughput of the secondary network by optimizing the uplink power allocation. The constructed Lagrangian function can be expressed as

$$\begin{aligned} L(P,\lambda,\mu) &= -\sum_{i=1}^{N}\log_2\left(1+\frac{P_i\gamma_i}{1+\sum\limits_{j=i+1}^{N}P_j\gamma_j}\right)+\lambda\left(\sum_{i=1}^{N}P_i-P_t\right) \\ &\quad+\sum_{i=1}^{N}\mu_i\left[R_i-\log_2\left(1+\frac{P_i\gamma_i}{1+\sum\limits_{j=i+1}^{N}P_j\gamma_j}\right)\right] \\ &= -\sum_{i=1}^{N}(1+\mu_i)\log_2\left(1+\frac{P_i\gamma_i}{1+\sum\limits_{j=i+1}^{N}P_j\gamma_j}\right) \\ &\quad+\lambda\left(\sum_{i=1}^{N}P_i-P_t\right)+\sum_{i=1}^{N}\mu_iR_i. \end{aligned} \tag{18}$$

The corresponding KKT conditions can be given as

$$\begin{aligned} &\lambda^* \ge 0 \\ &\mu_i^* \ge 0, \quad i=1,\ldots,N \\ &\lambda^*\left(\sum_{i=1}^{N}P_i^*-P_t\right)=0 \\ &\mu_i^*\left[R_i-\log_2\left(1+\frac{P_i^*\gamma_i}{1+\sum\limits_{j=i+1}^{N}P_j^*\gamma_j}\right)\right]=0, \\ &\forall i=1,\ldots,N. \end{aligned} \tag{19}$$

According to the property of Langrangian function that the derivative of Langrangian is equal to zero at the optimal solution, we have (20), as shown at the bottom of this page. It is proven that the optimal solution satisfies the following formulas.

$$\begin{aligned} &\sum_{i=1}^{N}P_i^* = P_t \\ &\log_2\left(1+\frac{P_i^*\gamma_i}{1+\sum\limits_{j=i+1}^{N}P_j^*\gamma_j}\right)=R_i, \quad i=2,\ldots,N. \end{aligned} \tag{21}$$

Proof : When i = 1, according to (20), we have

$$\lambda^*=\frac{B\gamma_1\left(1+\mu_1^*\right)}{\sum\limits_{i=1}^{N}P_i^*\gamma_i+1}>0. \tag{22}$$

So, the first equation in (21) can be derived based on (19) and (22). Since

$$\frac{\partial L}{\partial P_2^*}=\frac{\partial L}{\partial P_1^*}=0, \tag{23}$$

the relation between μ_1^* and μ_2^* can be denoted as

$$\begin{aligned} \left(\sum_{i=1}^{N}P_i^*\gamma_i+1\right)\gamma_2\mu_2^* &= \left[P_1^*\gamma_1\gamma_2+\gamma_1\left(\sum_{i=2}^{N}P_i^*\gamma_i+1\right)\right]\mu_1^* \\ &\quad+(\mu_1+\mu_2)\left(\sum_{i=2}^{N}P_i^*\gamma_i+1\right). \end{aligned} \tag{24}$$

$$\frac{\partial L}{\partial P_i^*}=\lambda^*-\gamma_i\left[\frac{1+\mu_i^*}{1+\sum\limits_{j=i}^{N}P_j^*\gamma_j}-\sum_{j=1}^{i-1}\frac{P_j^*\gamma_j\left(1+\mu_j^*\right)}{\left(\sum\limits_{j=1}^{N}P_k^*\gamma_k+1\right)\left(\sum\limits_{k=j+1}^{N}P_k^*\gamma_k+1\right)}\right]=0, \quad \forall i=1,\ldots,N. \tag{20}$$

$$R_{sum} = \log_2\left(1+\frac{\left(\frac{\tau P_a}{1-\tau}-\sum_{i=2}^{N}P_i^*\right)\gamma_1}{P_s g_s+\sum_{i=2}^{N}P_i\gamma_i}\right)+\sum_{i=2}^{N}\log_2\left(1+\frac{P_i\gamma_i}{P_s g_s+\sum_{j=3}^{N}P_j\gamma_j}\right). \quad (28)$$

So we can derive that $\mu_2^* > 0$. Similarly, the relation between μ_1^* and μ_3^* can be expressed as

$$\begin{aligned}&\left(\sum_{i=1}^{N}P_i^*\gamma_i+1\right)\left(\sum_{i=2}^{N}P_i^*\gamma_i+1\right)(\gamma_3\mu_3^*)\\&=\left[P_1^*\gamma_3\left(\sum_{i=3}^{N}P_i^*\gamma_i+1\right)+P_2^*\gamma_3\left(\sum_{i=1}^{N}P_i^*\gamma_i+1\right)\right.\\&\quad\left.+\left(\sum_{i=2}^{N}P_i^*\gamma_i+1\right)\left(\sum_{i=3}^{N}P_i^*\gamma_i+1\right)\right]\gamma_1\mu_1^*\\&\quad+(\gamma_1-\gamma_3)\left(\sum_{i=2}^{N}P_i^*\gamma_i+1\right)\left(\sum_{i=3}^{N}P_i^*\gamma_i+1\right)\\&\quad+P_2^*\gamma_3(\gamma_1+\gamma_2)\left(\sum_{i=2}^{N}P_i^*\gamma_i+1\right). \end{aligned}\quad (25)$$

So we can derive that $\mu_3^* > 0$. Similarly, we can derive the conclusion as

$$\mu_i^* > 0, \quad i = 2, \cdots N. \quad (26)$$

So, the second equation in (21) can be derived according to (19) and (26). As a result, the solution to the optimal power allocation for uplink CR-NOMA based-on SS network can be given by

$$\begin{aligned}P_1^* &= P_t-\sum_{i=2}^{N}P_i^*\\P_i^* &= \frac{1}{\gamma_i}2^{\sum_{j=i+1}^{N}R_j}\left(2^{R_i}-1\right), \quad i=2,\ldots,N.\end{aligned}\quad (27)$$

We replace P_t with (13), and the throughput can be expressed as (28), as shown at the top of this page. Follow the power allocation scheme above, for given R_i, γ_i, P_a, the throughput is only related to the sensing time τ and it will facilitate the solution to our subsequent optimization problems. Substitute (27) into equation (16), the final sum-throughput can be expressed as

$$\begin{aligned}R(\tau) &= P(H_0)(1-\tau)\left(1-Q\left(\alpha+\sqrt{\tau f_s}\gamma\right)\right)\\&\quad\times\left(\log_2\left(1+\frac{\left(\frac{\tau P_a}{1-\tau}-\sum_{i=2}^{N}P_i^*\right)\gamma_1}{1+\sum_{i=2}^{N}P_i\gamma_i}\right)\right.\\&\quad\left.+\sum_{i=2}^{N}\log_2\left(1+\frac{P_i\gamma_i}{1+\sum_{j=3}^{N}P_j\gamma_j}\right)\right).\end{aligned}\quad (29)$$

To prove convexity, we denote (29) as a function which is only dependent on τ.

$$\begin{aligned}R(\tau) &= P(H_0)(1-\tau)\left(1-Q\left(\alpha+\sqrt{\tau f_s}\gamma\right)\right)\\&\qquad\times\log_2\left(1+\frac{\tau\delta}{1-\tau}+\beta\right).\end{aligned}\quad (30)$$

where $\delta=\frac{P_a\gamma_1}{1+\sum_{i=2}^{N}P_i^*\gamma_i}$, $\beta=\sum_{i=2}^{N}\log_2\left(1+\frac{P_i^*\gamma_i}{1+\sum_{j=3}^{N}P_i^*\gamma_j}\right)-\frac{\sum_{i=2}^{N}P_i^*\gamma_1}{1+\sum_{i=2}^{N}P_i^*\gamma_i}$.
Then, apply the derivative criteria to (30), we have (31),as shown at the bottom of this page. Obviously,

$$\begin{aligned}&\lim_{\tau\to 0}R'(\tau)=[1-Q(\alpha)]\frac{\delta}{1+\beta}>0\\&\lim_{\tau\to 1}R'(\tau)\to -\infty.\end{aligned}\quad (32)$$

where $Q(x)$ is a decreasing function and upper bounded by 1. Hence, there is a maximum point of $R(\tau)$ within interval (0, 1) and we use dichotomy to find the maximum value by adjusting the value of target R_i and γ_i.

B. OPTIMIZATION IN UNDERLAY CR NETWORK

According to the discussion above, it is similar to implement throughput optimization problem as overlay CR network and corresponding the solution of optimization problem is also similar. In this section, SUs will not perform SS during the

$$\begin{aligned}\frac{dR(\tau)}{d\tau} &= \left[-\left(1-Q\left(\alpha+\sqrt{\tau f_s}\gamma\right)\right)+(1-\tau)\frac{\gamma\sqrt{f_s}}{2\sqrt{2\pi}}\tau^{-\frac{1}{2}}\exp\left(-\frac{\left(\alpha+\sqrt{\tau f_s}\gamma\right)^2}{2}\right)\right]\\&\quad\times\log_2\left(1+\frac{\tau\delta}{1-\tau}\right)+(1-\tau)\left[1-Q\left(\alpha+\sqrt{\tau f_s}\gamma\right)\right]\frac{\delta}{((\beta+1)(1-\tau)+\delta\tau)(1-\tau)}.\end{aligned}\quad (31)$$

TABLE 2. Algorithm.

Algorithm Sensing time optimization based on the half searching

Initialize $\tau_{min} = 0$, $\tau_{max} = T$ and searching precision δ;
while $|\tau_{max} - \tau_{min}| > \delta$ **do**
  Let $\bar{\tau} = \frac{\tau_{max}+\tau_{min}}{2}$
  if $\nabla R(\bar{\tau}) \equiv \nabla R(\tau_{min})$ **then**
    Let $\tau_{min} = \tau$;
  else
    Let $\tau_{max} = \tau$;
  end if
end while
Output $\tau_0 = \bar{\tau}$.

time τ and we don't need to consider P_d and P_f. In this part, an optimization problem of sum-throughput is formulated subjected to three constraints, total transmission power, minimum rate requirements and the interference among PU and SUs. Then, the optimization problem can be given as

$$maxR(\tau) = (1-\tau)\sum_{i=1}^{N}\log_2\left(1+\frac{P_i\gamma_i}{P_s g_s + \sum_{j=i+1}^{N} P_j\gamma_j}\right). \quad (33)$$

$$subject\ to: \begin{cases} \sum_{i=1}^{N} P_i g_s \le I_{\max} \\ \sum_{i=1}^{N} P_i \le P_t \\ \log_2\left(1+\frac{P_i\gamma_i}{P_s g_s + \sum_{j=i+1}^{N} P_j\gamma_j}\right) \ge R_i, \\ \qquad i = 1\ldots N. \end{cases} \quad (34)$$

We conduct the same power allocation scheme as discussions above, the power can be given as

$$P_1^* = I_{\max} - \sum_{i=2}^{N} P_i^* g_s$$
$$P_i^* = \frac{P_s g_s}{\gamma_i} 2^{\sum_{j=i+1}^{N} R_j}\left(2^{R_i}-1\right), \quad i = 2,\ldots,N. \quad (35)$$

Combining the results in subsection A, we decide P_1 as

$$P_1^* = \min\left\{P_t - \sum_{i=2}^{N} P_i^*, I_{\max} - \sum_{i=2}^{N} P_i^* g_s\right\}. \quad (36)$$

We substitute (35) into (33), the sum throughput of underlay CR-NOMA is derived.

IV. SIMULATION AND CONCLUSION

First, we analyze the complexity of the algorithm. Since this algorithm does not require iteration, the complexity of the algorithm depends mainly on the number of users. The more users, the more complicated the power allocation strategy. For 5G hotspot scenes, the average number of access users per micro BS is 10, therefore the total system throughput is the sum of the rates of 10 individual users. This level of data does not challenge the processing power of modern computers. The complexity of the algorithm is in a completely acceptable range. Since we perform spectrum sensing periodically and the process may increase some sensing power consumption, thus increasing the signal overhead of the system. As we move to 5G networks, the energy consumption of communications should be lower and lower. The user's data rate needs to be increased by at least 100 times, which requires that the energy consumption per bit of information transmitted in 5G needs to be reduced by at least 100 times. A large part of the current energy consumption lies in complex signaling overhead, such as the return signal that the network edge BS transmits back to the BS. For 5G networks, this overhead will be more due to the denser deployment of BS. Therefore, our follow-up research will focus on the optimization of energy efficiency. As we use the dichotomy to iterate the algorithm, so the iterative algorithm is a linear iteration and convergence speed is within the computer's computable range.

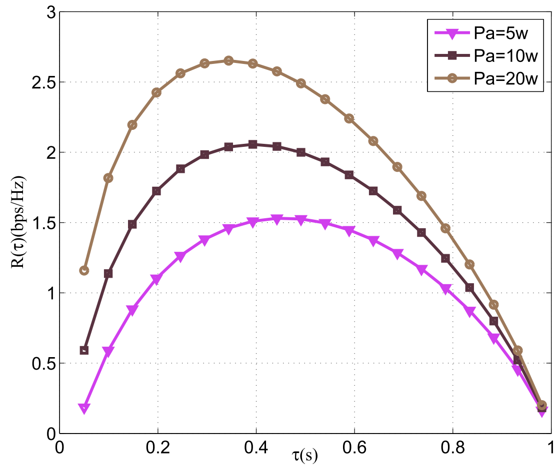

FIGURE 4. Maximum throughput for spectrum sensing with duration τ.

Next, we perform simulation studies on the performance of CR-NOMA system presented before. The simulation parameters are set as follows. The frame time $T = 1s$, the transmission power of PU P_s is ranged among [10, 20, 30], the channel gain g_s is of [1.5, 2.5, 3.5], the received SNR of the PU $\gamma = 0.1$, the sample frequency $f_s = 100$KHz, the number of secondary users $N = 3$, the transmit power of the downlink network $P_a = [5, 10, 20]$. Moreover, the channels obey the Rayleigh distributions. It has been indicated that there is an optimal sensing duration τ that maximizes the throughput of the secondary network. When $\gamma_i = [1, 2, 4]$ and $\mu_i = [40, 40, 40]$.

Fig.4 shows the achievable throughput $R(\tau)$ versus τ in overlay CR-NOMA network. It is seen that $R(\tau)$ firstly improves and then decreases as τ increases, which has proven

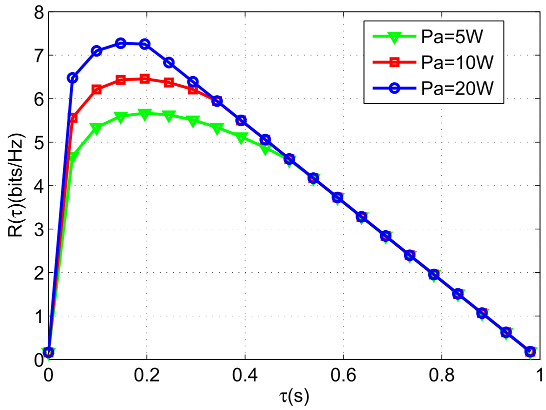

FIGURE 5. Maximum throughput for spectrum sharing with duration τ.

the convex optimization problem. Moreover, there is an optimal τ to maximize $R(\tau)$. The optimal value of τ obtained is 0.3440, and the maximal throughput $R(\tau) = 2.6521$. We also show the different affect between transmission power P_a and the throughput as the value of τ varies in Fig.4. We can see that the situation is different as τ increases and at the small value of sensing time τ, the system throughput is relatively low, which is due to the reason that there is nearly no transmission at the small sensing time. According to the discussions above, we can derive the solution of a convex optimization problem by setting proper R_i and γ_i.

We can see from Fig.5 that in our proposed algorithm, $P_1^* = \min\left\{P_t - \sum_{i=2}^{N} P_i^*, I_{\max} - \sum_{i=2}^{N} P_i^* g_s\right\}$ and $P_t = \frac{\tau P_a}{1-\tau}$. When τ is very small, $P_t - \sum_{i=2}^{N} P_i^* < 0$, there is no power allocation for SU_1 and other users' SINR and target rate is small thus R_1 is very small, in our simulation it's 0.1632. As τ increases, $0 < P_t - \sum_{i=2}^{N} P_i^* < I_{\max} - \sum_{i=2}^{N} P_i^* g_s$, we choose $P_1^* = P_t - \sum_{i=2}^{N} P_i^*$, it's similar with the overlay network and $R(\tau)$ is a convex function of τ and $R(\tau)$ first increases then decreases. As τ increases, $P_t - \sum_{i=2}^{N} P_i^* > I_{\max} - \sum_{i=2}^{N} P_i^* g_s$, we choose $P_1^* = I_{\max} - \sum_{i=2}^{N} P_i^* g_s$, then we substitute P_1^* into the expression of $R(\tau)$ and we will derive that $R(\tau)$ is a function that linearly decreases with τ.

Next we analyze the relationship between transmit power of SUs and the achievable throughput for a given τ as shown in Fig.6. We can see that $R(P_a)$ improves as P_a increases. We derive the conclusion from equation (28) and absolutely $R(P_a)$ is a function that monotonically increases with P_a. Increasing P_a reasonably is important to not only improving the sum throughput but also supplying more power consumption of the process. From Fig.7 we can see that the system throughput decreases as PU's transmission power increases. From the perspective of SUs, the greater P_s is, the greater interference caused by PU to the SUs and

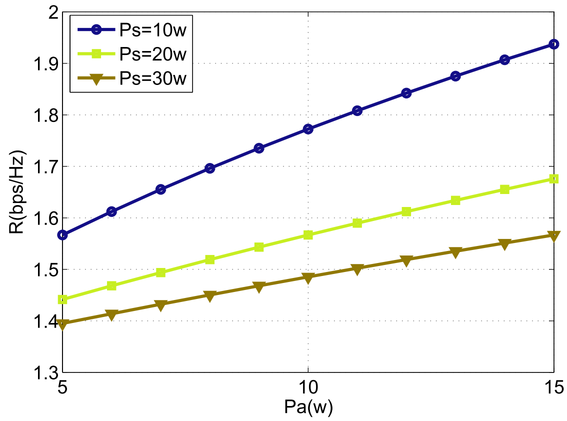

FIGURE 6. System throughput with transmission power P_a of SUs.

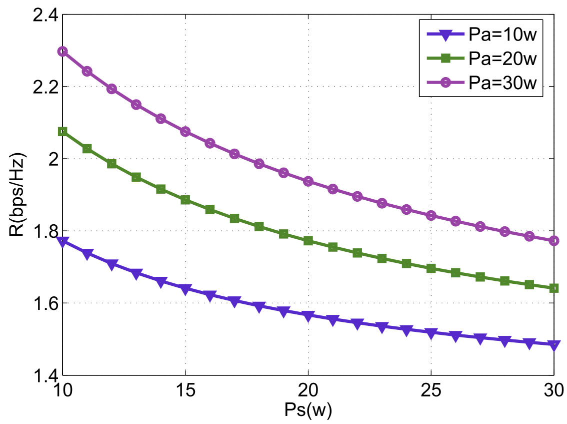

FIGURE 7. System throughput with transmission power P_s of PU.

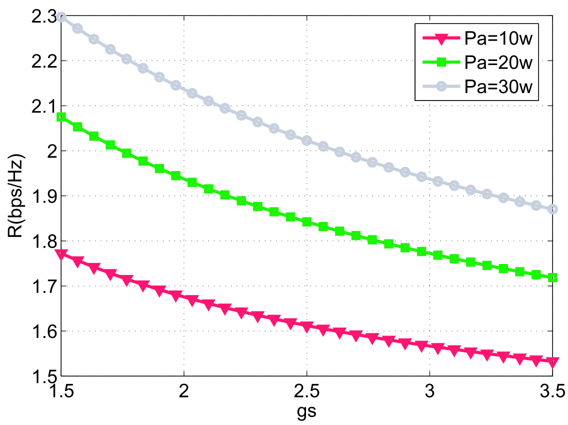

FIGURE 8. System throughput with channel gain g_s of PU.

thus decreasing the system total throughput. Similarly, as g_s increases, the total throughput also decreases. From Fig.7 and Fig.8, we can derive the conclusion that the higher the transmission power of each SU is, the less affected the network may suffer. Fig.9 is the PU's throughput curve with the sensing time τ. We can see that as the transmission power of downlink increases, the PU's throughput decreases. As the greater the transmission power, the greater the interference to PU, thus the throughput decreases. However, higher transmit power may result in outage of the secondary transmission.

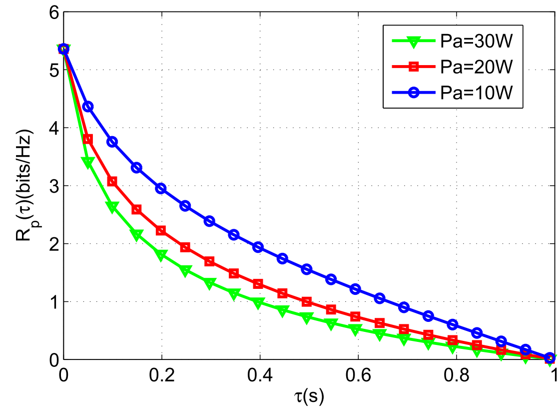

FIGURE 9. PU's throughput for spectrum sharing with τ.

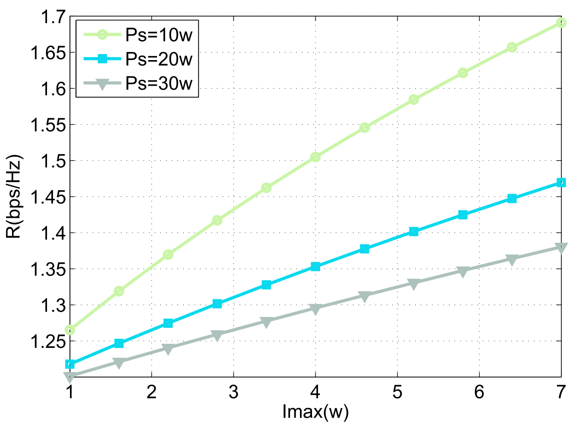

FIGURE 10. System throughput for spectrum sharing with specific threshold I_{max}.

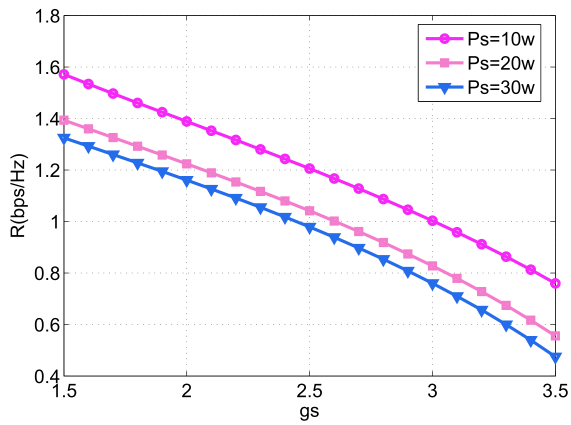

FIGURE 11. System throughput for spectrum sharing with channel gain g_s.

In order to avoid this situation, we must focus on the tradeoff between the SUs' transmit power and the PU's target transmission rate. For example, the PU's target transmission rate is 2bits/Hz when τ is 0.2s, in order to ensure smooth transmission, the downlink transmission power should be no more than 30W.

According to the discussion above, when the P_1 is allocated with $P_1 = I_{max} - \sum_{i=2}^{N} P_i^* g_s$, another power allocation scheme is adopted and the system throughput may be affected by the certain interference threshold and PU's channel gain. The corresponding simulation results are shown as Fig.10 and Fig.11. The bigger fixed threshold I_{max}, the throughput is bigger. The fact is that I_{max} may influence the performance of PU and as the major contributor to the system throughput, increasing I_{max} can cause positive effect on system throughput. Conversely, according to (33) we can see that it is obviously system throughput decreases as g_s increases and R is a monotonically decreasing function with independent variables g_s.

V. CONCLUSION

In this paper, we proposed a NOMA-based CR network with SWIPT scheme for two different modes, overlay and underlay network respectively. In the proposed model, the operation frame is divided into two slots, the users perform spectrum sensing and energy harvesting during the first slot τ and then transmit independent information in the next slot $1 - \tau$.We implement NOMA for CR secondary network to improve spectrum efficiency. Moreover, we analysis the system throughput performance, and derive the concrete expressions of system throughput. In the following, we formulate the optimization problem by optimizing the time slot such that system throughput is maximized. Then, an optimal algorithm based on dichotomy was presented to solve the optimization problem. Numerical results verity the discussions above on system throughput maximization.

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