Scientific Research Publishing

Journal of Computer and Communications, 2023, 11, 32-46
https://www.scirp.org/journal/jcc
ISSN Online: 2327-5227
ISSN Print: 2327-5219

Research on Physical Layer Security in Cognitive Wireless Networks with Multiple Eavesdroppers Based on Resource Allocation Algorithm

Yuxin Du, Xiaoli He, Yongming Huang

School of Computer Science, Sichuan University of Science and Engineering, Zigong, China
Email: 454746038@qq.com

How to cite this paper: Du, Y.X., He, X.L. and Huang, Y.M. (2023) Research on Physical Layer Security in Cognitive Wireless Networks with Multiple Eavesdroppers Based on Resource Allocation Algorithm. *Journal of Computer and Communications*, **11**, 32-46.
https://doi.org/10.4236/jcc.2023.113004

Received: February 19, 2023
Accepted: March 26, 2023
Published: March 29, 2023

Abstract

With the rapid development of the Internet of Things (IoT), non-Orthogonal Multiple Access (NOMA) technology and cognitive wireless network are two promising technologies to improve the spectral efficiency of the system, which have been widely concerned in the field of wireless communication. However, due to the importance of ownership and privacy protection, the IoT system must provide corresponding security mechanisms. From the perspective of improving the transmission security of CR-NOMA system based on cognitive wireless network, and considering the short-comings of traditional relay cooperative NOMA system, this paper mainly analyzes the eavesdropping channel model of multi-user CR-NOMA system and derives the expressions of system security and rate to improve the security performance of CR-NOMA system. The basic idea of DC planning algorithm and the scheme of sub-carrier power allocation to improve the transmission security of the system were introduced. An algorithm for DC-CR-NOMA was proposed to maximize the SSR of the system and minimize the energy loss. The simulation results show that under the same complexity, the security and speed of the system can be greatly improved compared with the traditional scheme.

Keywords

Cognitive Radio Networks, Non-Orthogonal Multiple Access, Physical Layer Security, Sum of Safety Rates

1. Introduction

At present, with the development of technology, the Internet of Things and the

Internet of Vehicles are becoming more and more applications. Studies have shown that wireless communication network data services will increase by about 1,000 times in the next ten years. Non-orthogonal Multiple Access (NOMA) and Cognitive Radio (CR) are recognized as two important technologies in 5G wireless networks due to their ability to realize massive connections and provide higher transmission rate and spectrum utilization [1] [2]. At the receiving end, the signals superimposed and transmitted by multiple users are decoded and received through the serial interference cancellation (Successive Interference Cancellation, SIC) technology [3], which greatly improves the utilization of spectrum resources. Information security issues in wireless communication systems have always attracted attention, and the technical advantages of the NOMA system have also made the system's information security issues more prominent. Once the eavesdropping user successfully intercepts and decodes the superimposed signal, it will cause huge security risks to the entire system. Physical Layer Security (PLS) technology is based on the basic principles of information theory, using the physical characteristics of wireless channel such as multipath fading and propagation delay to achieve secure communication [4] [5], to ensure that eavesdroppers cannot eavesdrop legitimate information on the physical layer, it is an existing promising wireless security technology [6]. Nowadays, there are many solutions for the physical layer security of cognitive radio networks, but there are few researches on the physical layer security of based on CR-NOMA system. This is one of the key points of this paper, and the in-depth physical layer security technology research can further guarantee the high-quality and reliable transmission of communication networks in people's lives.

And, NOMA has been deeply studied and discussed by many researchers. Paper [7] analysis shows that the MIMO-OMA system is superior to the MIMO-OMA system in sum rate and traversal sum rate for the simple scenario of two users. When applied to multiple user scenarios, the conclusion is still valid. The author of the study [8] proposed a joint subcarrier and power allocation scheme to maximize the weighted sum rate of the NOMA system. The paper [9] considers the scheme of allocating two users on a subcarrier at the same time. The paper [10] analyzes the security performance of the NOMA network based on two-way relay transmission. The relay node not only forwards information to the legitimate user node, but also always transmits interference signals to confuse any potential eavesdroppers, and derives the closed expression of ergodic secure sum rate (ESSR) and proves the advantages of the proposed network. On the premise of considering the reliability outage probability constraints, the safety performance of the downlink NOMA system is studied in [11]. The paper [12] studies the physical layer security performance of CR-NOMA system. The paper [13] proposes a cooperative NOMA system in which the near user acts as a relay node to assist the transmission. Literature [14] first proposed the NOMA cooperative eavesdropping system model without additional relay, and proved that the optimal system security performance can be achieved through appropriate power control. Literature [15] discusses the maximum and minimum rate optimization of NOMA cooperation scheme in full duplex mode, and derives the expression of the optimal power. We considering the shortcomings of traditional relay cooperative NOMA system, this paper mainly analyzes the eavesdropping channel model of multi-user CR-NOMA system and derived the expressions of system security and rate to improve the security performance of CR-NOMA system.

2. System and Network Model

2.1. System Model

Let us now present our system model in **Figure 1**. All nodes in this model are single antenna users, and the transmission of the network follows the transmission principle of non-orthogonal multiple access. Assume that both the secondary base station SBS and users transmitting end can estimate the CSI in the network through some calculations, and all CSI are accurate. In addition, in this network, the Eve may pretend to be a user to eavesdrop and decode all legal information in the network. In this case, the base station can obtain the relevant CSI of the eavesdropper.

In this system model, it is assumed that all channel parameters obey a quasi-static Rayleigh distribution that is the channel coefficients are constant for each transmission slot, but vary independently between different slots.

Among them, the base station broadcasts information S to each user. The information broadcast by the base station is definite. At the transmitting end, the central base station can simultaneously transmit signals through multiple legal links composed of multiple sub-carriers through frequency-domain multiplexing. On each sub-carrier, SC technology is used, multiplexing in the power domain, and simultaneously sending signals of multiple users. Then, the user signal x_n multiplexed on the nth subcarrier can be expressed as:

$$x_n = \sum_{m=1}^{M}\left(\sqrt{p_{n,m}}s_m * x_{n,m}\right),\quad m = 1,2,\cdots,M \tag{1}$$

where s_m represents the signal sent by the base station to the k^{th} user node. And $x_{n,m}$ is a parameter, it is defined as 1 or 0, which respectively means that

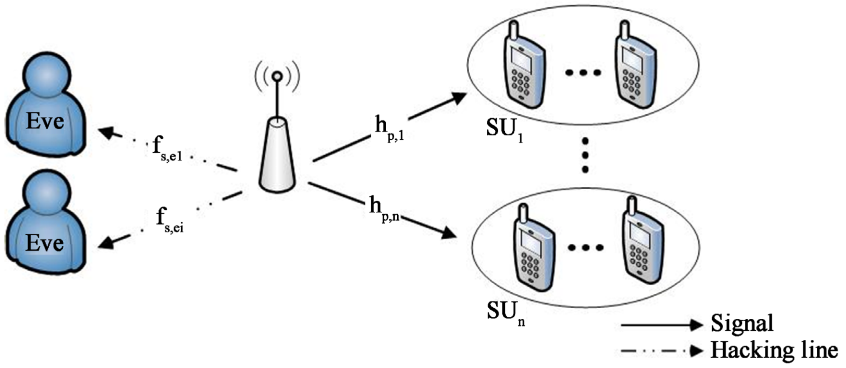

Figure 1. NOMA-based cognitive radio network eavesdropping system model with multiple eavesdroppers.

user m is assigned to sub-carrier n, and user m is not assigned to sub-carrier.

At the same time, Eve can eavesdrop on all relevant information in the network. Multiple eavesdroppers in this model can eavesdrop on all signals and information in the main network. Therefore, the signal $Y_{n,e}$ intercepted by the eavesdropper Eve is:

$$Y_{n,e} = h_{n,e}x_n + \eta_e^2 = h_{n,e}\left(\sqrt{p_{n,1}}s_{n,1} + \sqrt{p_{n,2}}s_{n,2}\right) + \eta_e^2 \tag{2}$$

where η_e is the additive white Gaussian noise signal received by the eavesdropper Eve, with an average value of 0 and a variance of σ^2. Similarly, at the receiving end, the received signal of the k^{th} user receiving the signal on the nth sub-carrier can be expressed as the formula (3):

$$Y_{n,m} = h_{n,m}x_n + \gamma_m^2 = h_{n,m}\left(\sum_{m=1}^{M}\sqrt{p_{n,m}}s_m * x_{n,m}\right) + \eta_k^2,\quad m = 1,2,\cdots,M \tag{3}$$

where η_k is the additive white Gaussian noise signal received by the m-$^{\text{th}}$ user, with an average value of 0 and a variance of σ^2.

The system allocates multiple users to each subcarrier $SC_n\left(n = 1,2,\cdots,N\right)$ and the base station transmit power is $P_{t'}$, $P_n\left(n = 1,2,\cdots,N\right)$ represents the base station transmit power allocated to the n-$^{\text{th}}$ subcarrier, represents the transmission power required by the system to transmit signals to the m-$^{\text{th}}$ user node on the n-$^{\text{th}}$ sub-carrier. And SIC technology is adopted on the nth sub-carrier SC_n, assuming that the channel conditions meet the following conditions: $\left|h_{n,1}\right|^2 \ge \left|h_{n,2}\right|^2 \ge \cdots \ge \left|h_{n,m}\right|^2 \ge \cdots \ge \left|h_{n,m_n}\right|^2$, where m is the total number of users on sub-carrier SC_n. Then the power allocated by its system meets the following conditions: $P_{n,1} \le P_{n,2} \le \cdots \le P_{n,m} \le \cdots \le P_{n,m_n}$.

Then the SINR of the k^{th} user node on subcarrier SC_n can be expressed as:

$$\eta_{n,m} = \frac{P_{n,m}\left|h_{n,m}\right|^2}{\sum_{m'=1}^{m-1} P_{n,m'}\left|h_{n,m}\right|^2 + \sigma_0^2} \tag{4}$$

Then, according to Shannon's formula, its signal rate can be expressed as:

$$R_{n,m} = \log_2\left(1 + \eta_{n,m}\right) = \log_2\left(1 + \frac{P_{n,m}\left|h_{n,m}\right|^2}{\sum_{m'=1}^{m\text{-}1} P_{n,m'}\left|h_{n,m}\right|^2 + \sigma_0^2}\right) \tag{5}$$

In the eavesdropping link, the eavesdropper can obtain the signal sent by the central base station to the legitimate user. A worst-case scenario is assumed here, that is, an eavesdropper can correctly decode each user's signal through SIC technology. Similarly, on the subcarrier SC_n, the signal rate that an eavesdropper can eavesdrop on the signal of the k^{th} user node can be expressed as the formula (6):

$$R_{n,m,e} = \log_2\left(1 + \eta_{n,m,e}\right) = \log_2\left(1 + \frac{P_{n,m}\left|h_{n,e}\right|^2}{\sum_{m=1}^{m-1} P_{n,m}\left|h_{n,e}\right|^2 + \sigma_e^2}\right) \tag{6}$$

2.2. Security Evaluation

We describe the subchannel allocation and power allocation of the downlink CR-NOMA network as a channel security optimization problem. In order to obtain a power allocation scheme with high security, we decouple subchannel allocation and subchannel power allocation. Suppose we can provide the maximum transmission power of the base station. For subchannel allocation, we first assume that the power distribution between subchannels is equal, and then transform the subchannel allocation formula into a bilateral matching problem between subchannels and users.

According to formulas (5) and (6), the safety signal rate of the m-th user node can be expressed as:

$$R_{n,m,s} = \left[R_{n,m} - R_{n,m,e} \right]^{+} \tag{7}$$

Then the sum of security rate (SSR) on subcarrier n can be expressed as:

$$R_{n,s} = \sum_{m=1}^{N} R_{n,m,s}, \quad m = 1, 2, \cdots, N_n \tag{8}$$

The sum of safety rates R_s^{Sum} of the system can be expressed as:

$$R_s^{Sum} = \sum_{n=1}^{N} R_{n,s}, \quad n = 1, 2, \cdots, N \tag{9}$$

2.3. Power Allocation

In order to further improve the sum of safety rate and energy efficiency of NOMA system, we consider the sub-channel power allocation of CR-NOMA system. In this section, we will use the DC programming method to solve the algorithm problem, and discuss the application of its power scaling factor and power distribution between sub-channels to improve the system security. In power-limited systems, how to achieve an optimal power allocation scheme and achieve the best system performance is a key issue. Here we mainly use the Fractional Transmit Power Allocation (FTPA) method. FTPA balances the complexity of decoding at the receiving end and system performance. In FTPA, the transmit power allocated to user m in candidate user group U_n can be expressed as:

$$P_{n,m} = P_n \frac{\left(H_{n,m}\right)^{-\alpha}}{\sum_{m=1}^{M_n} \left(H_{n,m}\right)^{-\alpha}} = \frac{P_n}{\sum_{m=1}^{M} \left(\frac{h_{n,m}^2}{N_0(m)} \right)^{-\alpha}} \left(\frac{h_{n,m}^2}{N_0(m)} \right)^{-\alpha} \tag{10}$$

where P_n is the U_n power of the user group allocated by the system, $h_{n,m}$ and $N_0(m)$ represent the channel coefficient and noise power at user m. As increases, more power is available to users with low channel gain $\alpha\left(0 \le \alpha \le 1\right)$ is the power allocation factor of the FTPA algorithm. In particular, it is equal power distribution when $\alpha = 0$. The same α will be applied to all user groups and transmission times, and the power difference between users caused by different α will be large. Therefore, α is the optimization parameter of FTPA.

How to choose the appropriate power attenuation factor α will have a great influence on the system performance. The best power attenuation factor can be found through computer simulation.

Then for each subchannel in the NOMA system, given assigned power p_n on SC_n and additional circuit power consumption p_0, the energy efficiency over SC_n is defined as:

$$E_n = \frac{R_n}{p_n + p_0} = \frac{p_n \log_2\left(1+\eta_n\right)}{\sum_{n=1}^{N-1}\left(\frac{h_n^2}{N_0\left(n\right)}\right)^{-\alpha}} + \frac{1}{p_0} \tag{11}$$

To obtain the resource allocation scheme for this system, we formulate the optimization problem as:

$$\max_{p_n>0} \sum_{n=1}^{N} \frac{R_n\left(p_n\right)}{p_n + p_0} \tag{12}$$

$$\text{Subject to} \quad \left.\begin{aligned} &\mathrm{L1}: R_{l,n}\left(p_n\right) \geq R_{\min} \geq R_{n,e} \\ &\mathrm{L2}: P_S = \sum_{n=1}^{N} p_n \end{aligned}\right\} \tag{13}$$

where L1 guarantees user minimum transfer rate constraint and $R_{\min}$ is denoted as minimum data rate determined by quality of service (QoS) requirement. The constraint L2 ensures the maximum BS power constraint. Since this optimization problem is non-convex and NP-hard. Assuming equal power is allocated to the subchannels, we first match subchannels to multiple users to maximize the energy efficiency and find proportional factor for multiplexed users on each subchannel. Based on the efficient subchannel assignment, then focus on the energy-efficient power allocation across subchannels within the constraint of total transmit power of BS.

3. Optimization

DC programming approach has been studied recently to solve non-convex optimization problems [16]. It is shown that DC programming can be applied if the objective function can be written as a minimization of a difference of two convex functions, which is represented as:

$$\min_{x\in\chi} q\left(x\right) = f\left(x\right) - g\left(x\right) \tag{14}$$

where $x = \left[x_1, x_2, \cdots, x_l\right]^{\mathrm{T}}$ and χ is the convex set; $f\left(x\right)$ and $g\left(x\right)$ are continuous, convex or quasi-convex. In general, the problem defined (14) is non-convex. It can be solved sub-optimally by using Algorithm 1 [17] [18] [19] [20] (**Table 1**). The key idea of Algorithm 1 is to convert a non-convex problem to convex sub problems by using successive convex approximations.

In the algorithm 1, ε is the difference tolerance. The term $-g\left(x\right)$ in the objective function (14) is replaced by $-g\left(x^{(k)}\right) - \nabla g^{\mathrm{T}}\left(x^{(k)}\right)\left(x - x^{(k)}\right)$ in (15). The convex optimization problem in (16) can be solved by using standard algorithms from convex optimization theory [17] [18] [19], *i.e.*, interior point method and

Table 1. Suboptimal Solution for DC Problems.

```
Algorithm 1        Suboptimal Solution for DC Problems

Initialize $x^{(0)}$, set iteration number $k=0$.
do { define convex approximation of $q^{(k)}(x)$ as
        $\hat{q}^{(k)}(x) = f(x) - g\left(x^{(k)}\right) - \nabla g^{\mathrm{T}}\left(x^{(k)}\right)\left(x - x^{(k)}\right)$        (15)
        solve the convex problem
        $x^{(k+1)} = \arg\min_{x\in\chi} \hat{q}^{(k)}(x)$        (16)
        $k++$
    } while ( $\left|q\left(x^{(k+1)}\right) - q\left(x^{(k)}\right)\right| \ge \varepsilon$ );
end
```

sequential quadratic programming. Now in this paper, sequential quadratic programming is used in the simulations.

3.1. DC Programming to Obtain Power Proportional Factor λ_n

Firstly, we considered two users SU_1 and SU_2 that are to be multiplexed over SU_n with CRNNs $h_{1,n} \ge h_{2,n}$ and weighted bandwidths $W_{1,n}$, $W_{2,n}$. According to the principle of SIC decoding sequences, SU_1 can cancel the interfering power term of SU_2, whereas SU_2 treats the symbol power SU_1 as noise. The problem of finding λ_n to maximize resource utilization efficiency of SU_n can be formulated as:

$$\begin{aligned} &\max_{\lambda_n\in(0,1)} \frac{W_{1,n}\log_2\left(1+\lambda_n p_n h_{1,n}\right)}{p_c+p_n} + \frac{W_{2,n}\log_2\left(1+\dfrac{\left(1-\lambda_n\right)p_n h_{2,n}}{1+\lambda_n p_n h_{2,n}}\right)}{p_c+p_n} \\ &= \max_{\lambda_n\in(0,1)} \frac{W_{1,n}\log_2\left(1+\lambda_n p_n h_{1,n}\right)+W_{2,n}\log_2\left(\dfrac{1+p_n h_{2,n}}{1+\lambda_n p_n h_{2,n}}\right)}{p_c+p_n} \end{aligned} \tag{17}$$

Then, we can convert (14) to DC representation:

$$\min_{\lambda_n\in(0,1)} -\frac{W_{1,n}\log_2\left(1+\lambda_n p_n h_{1,n}\right)}{p_c+p_n} - \frac{W_{2,n}\log_2\left(\dfrac{1+p_n h_{2,n}}{1+\lambda_n p_n h_{2,n}}\right)}{p_c+p_n} \tag{18}$$

which can be rewritten as:

$$\min_{\lambda_n\in(0,1)} \left[f\left(\lambda_n\right)-g\left(\lambda_n\right)\right] \tag{19}$$

Both terms are convex functions with respect to λ_n because $\nabla^2 f\left(\lambda_n\right)>0$ and $\nabla^2 g\left(\lambda_n\right)>0$. Therefore, the DC programming approach can be used to find λ_n by replacing x with λ_n in Algorithm 1.

3.2. Subchannel Power Allocation by DC Programming

According to the sub-channel user matching scheme and power scaling factor on different sub-channels, the optimization problem in (12) can be rewritten as:

$$\max_{p_n>0}\sum_{n=1}^{N}\left[\frac{W_{1,n}\log_2\left(1+\lambda_n p_n h_{1,n}\right)}{p_c+p_n}+\frac{W_{2,n}\log_2\left(\frac{1+p_n h_{2,n}}{1+\lambda_n p_n h_{2,n}}\right)}{p_c+p_n}\right] \tag{20}$$

$$\text{Subject to}\quad \left.\begin{aligned} &\mathrm{L1}: R_{n,m}\left(p_n\right)\ge R_{\min}\ge R_{n,e}\\ &\mathrm{L2}: \sum_{n=1}^{N} p_n = P_S \end{aligned}\right\} \tag{21}$$

where $R_{n,m}\left(p_n\right)$ is defined in (5) and $p_{n,\min}$ is the minimum assigned power on SU_n determined by $R_{\min}$. Condition L2 in (21) guarantees BS power constraint. But that the optimization problem in (20) is non-convex with respect to p_n. Thus (21) can be rewritten as (22) and (23) at the top of next page. Where $P=\left[p_1,p_2,\cdots,p_n,\cdots,p_N\right]^{\mathrm{T}}$ represents the allocated powers on the subchannels. Problem (21) can be written

$$\begin{aligned} &\min_{p_n>0}-\sum_{n=1}^{N}\left[\frac{W_{1,n}\log_2\left(1+\lambda_n p_n h_{1,n}\right)}{p_c+p_n}+\frac{W_{2,n}\log_2\left(\frac{1+p_n h_{2,n}}{1+\lambda_n p_n h_{2,n}}\right)}{p_c+p_n}\right]\\ &=\min_{p_n>0}\left\{-\sum_{n=1}^{N}\frac{W_{1,n}\log_2\left(1+\lambda_n p_n h_{1,n}\right)}{p_c+p_n}-\sum_{n=1}^{N}\frac{W_{2,n}\log_2\left(1+p_n h_{2,n}\right)}{p_c+p_n}+\sum_{n=1}^{N}\left(\frac{W_{2,n}\log_2\left(1+\lambda_n p_n h_{2,n}\right)}{p_c+p_n}\right)\right\} \end{aligned} \tag{22}$$

Let

$$\left.\begin{aligned} &F\left(P\right)=-\sum_{n=1}^{N}\frac{W_{1,n}\log_2\left(1+\lambda_n p_n h_{1,n}\right)}{p_c+p_n}-\sum_{n=1}^{N}\frac{W_{2,n}\log_2\left(1+p_n h_{2,n}\right)}{p_c+p_n}+\sum_{n=1}^{N}\left(\frac{W_{2,n}\log_2\left(1+\lambda_n p_n h_{2,n}\right)}{p_c+p_n}\right)\\ &G\left(P\right)=-\sum_{n=1}^{N}\left(\frac{W_{2,n}\log_2\left(1+\lambda_n p_n h_{2,n}\right)}{p_c+p_n}\right) \end{aligned}\right\} \tag{23}$$

Then

$$\min_{P\succ 0} Q\left(P\right)=\min_{P\succ 0} F\left(P\right)-G\left(P\right) \tag{24}$$

Subject to

$$\begin{aligned} &\mathrm{L1}: P\succ P_{\min}\\ &\mathrm{L2}: \left\|P\right\|_1 = P_s \end{aligned} \tag{25}$$

where $P=\left[p_1,p_2,\cdots,p_n,\cdots,p_N\right]^{\mathrm{T}}$ and $P\succ P_{\min}$ means all the elements in P are larger than the corresponding elements in $P_{\min}$, $p_n > p_{n,\min}$.

According to the optimization of the algorithm in the paper [21], the DC programming method can be used to increase the power allocation of SSR using algorithm 2 (**Table 2**). Once the power allocation on the sub-channel is obtained, we will replace the equal power allocation with a new power allocation scheme to achieve the sum of higher security rates of the system.

In Algorithm 2, $\nabla G\left(P^{(m)}\right)$ is the gradient of $G(P)$ at the point $P(m)$:

$$\nabla G\left(P^{(m)}\right)=\sum_{n=1}^{N}\frac{W_{1,n}\log_2\left(1+\lambda_n p_n h_{2,n}\right)-\left(p_c+p_n\right)\frac{\lambda_n h_{2,n}}{\ln 2\left(1+\lambda_n h_{2,n} p_n\right)}}{\left(p_c+p_n\right)^2} \tag{26}$$

In order to use the DC programming approach, the quasi-convexity of $F(P)$ and $G(P)$ needs to be established.

4. Simulation Results and Analysis

This section will simulate and verify the performance of the proposed resource allocation scheme based on DC-programming. First of all, compare the sum of the proposed scheme and other traditional schemes for the system security rate, then analyze the impact of the number of users on the system security and rate, and finally verify the effectiveness of the proposed scheme. The simulation parameters in this section are set as follows: in the NOMA downlink system of multi-user grouping, the service distance R of the base station is 500 m; the number of legal users M in the system is 24, which are evenly distributed within the range from the base station (50 - 350 m), and the distance between eavesdropping users. The distance of the base station is 480 m; the path loss coefficient of the flat Rayleigh fading channel is $\alpha=3$; In order to facilitate the analysis of the noise power at the legitimate user and the noise power at the eavesdropper $\sigma_0^2=\sigma_e^2=10^{-8}\ \mathrm{W}$. In our simulations, like **Table 3**, we set BS peak power, P_s, to be 41 dBm and circuit power consumption $p_c=1\ \mathrm{W}$ [20]. The maximum number of users is 60 and $\sigma=2$, where $N_0=-174\ \mathrm{dB}\cdot\mathrm{m/Hz}$. We set the value of α as 0.4.

In **Figure 2**, the performance of total sum rate SSR is evaluated with the

Table 2. DC Programming Algorithm for Power Allocation.

Algorithm 2 DC Programming Algorithm for Power Allocation

```
Initialize $P^{(0)}$, set iteration number $m=0$.
The Objective function $Q(P)$, convex functions $F(P)$ and $G(P)$.
do {    define convex approximation of $G^{(m)}(P)$ at $P^{(m)}$ as
            $G^{(m)}(P)=F(P)-G\left(P^{(m)}\right)-\nabla G^{\mathrm{T}}\left(P^{(m)}\right)\left(P-P^{(m)}\right)$    (27)
        solve the convex problem
            $P^{(m)}=\underset{\|P\|_1=P_s,\,p_n\ge p_{n,\min}}{\arg\min}\ Q^{(m)}(P)$    (28)
            $k++$
}       while ($\left|Q\left(P^{(M+1)}\right)-Q\left(P^{(m)}\right)\right|\ge\varepsilon$);
end
```

number of users *M*. We set the bandwidth is limited to 5 MHz and difference tolerance $\varepsilon = 0.01$. It is shown that the total sum rate increases when the number of the users grows. As expected from the Shannon's formula in calculating the performance of NOMA system with the proposed resource allocation algorithms, it is better than the OFDMA. And as the number of users grows larger, the sum rate continues to increase, but the rate of growth becomes slower. Because of in OFDMA scheme, one subchannel can only be used by one user. As a result, BS cannot fully use the spectrum resources. For different subchannel power allocation schemes, the sum rate of NOMA-DC is higher than that of NOMA.

Figure 3 shows the relationship between the allocatable base station power and SSR. We can see that when the base station allocatable power increases, the SSR also increases accordingly. Due to the power distribution expression, the trend of the curve is similar to that of **Figure 2**. From this figure, the performance of sub-channel and power allocation proposed by us is better than that of OFDMA scheme. The sub-channel power allocation proposed by us through DC programming achieves better performance than equal power allocation. When

Table 3. Simulation parameters.

Simulation Parameters	Simulation Parameters		
	Value	Parameter	Value
R	50 - 500 m	M	24
R_e	450 m	σ_0^2/σ_e^2	10 - 8 W
p_c	1 W	N	10 - 60

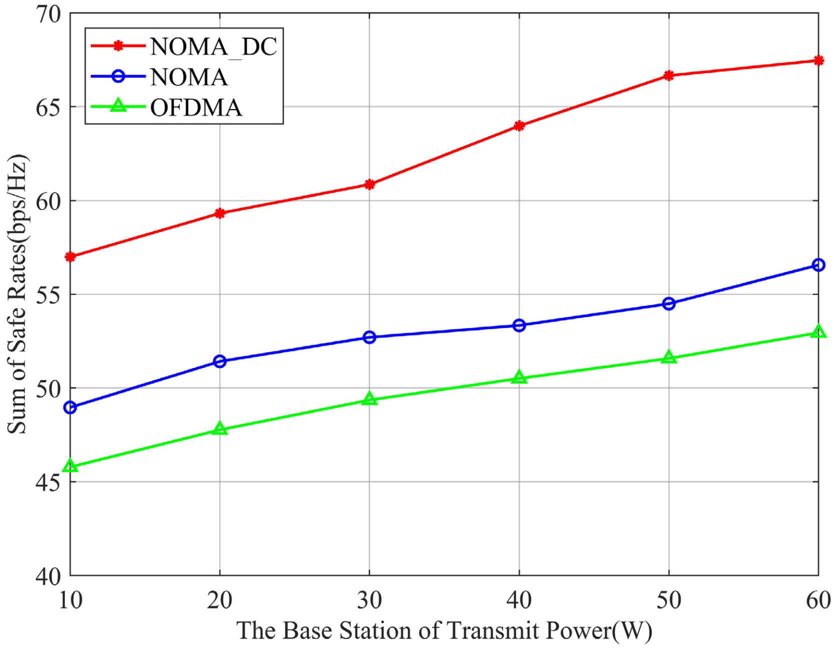

Figure 2. Sum rate of the system versus different number of users.

the base station allocatable power is 40, the energy efficiency of NOMA-DC is 36% higher than that of OFDMA and 14% higher than that of NOMA.

Analysis of the impact of different user grouping schemes on system security and rate. The simulation results are shown in **Figure 4**. Three comparison scenarios are shown in the figure. Among them, the scheme 1 represents the user scheme based on DC-Programming, the scheme 2 represents the fixed user scheme based on NOMA, and the scheme 3 represents the user scheme based on OMA. Secondly, the power allocation scheme between users adopts FTPA. In

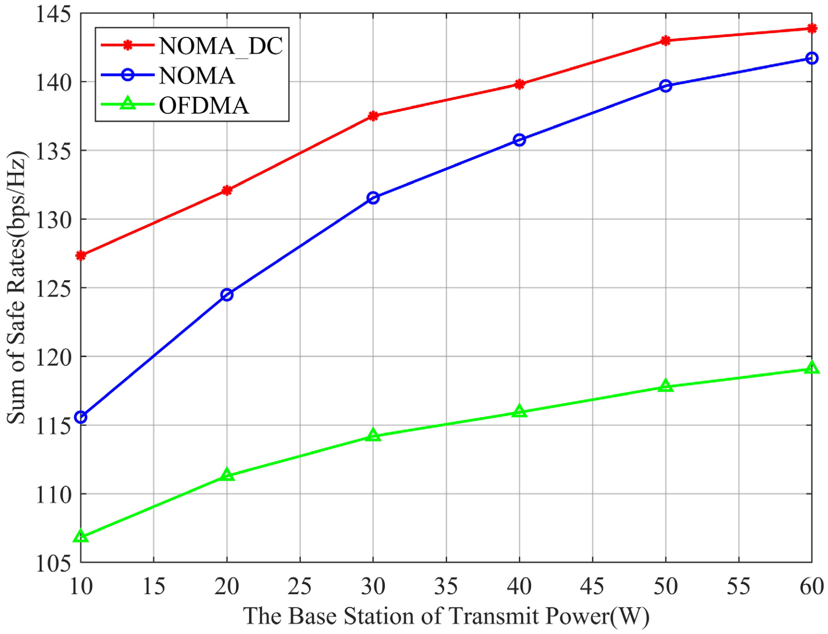

Figure 3. The effect of different power allocation schemes on the sum of security rates.

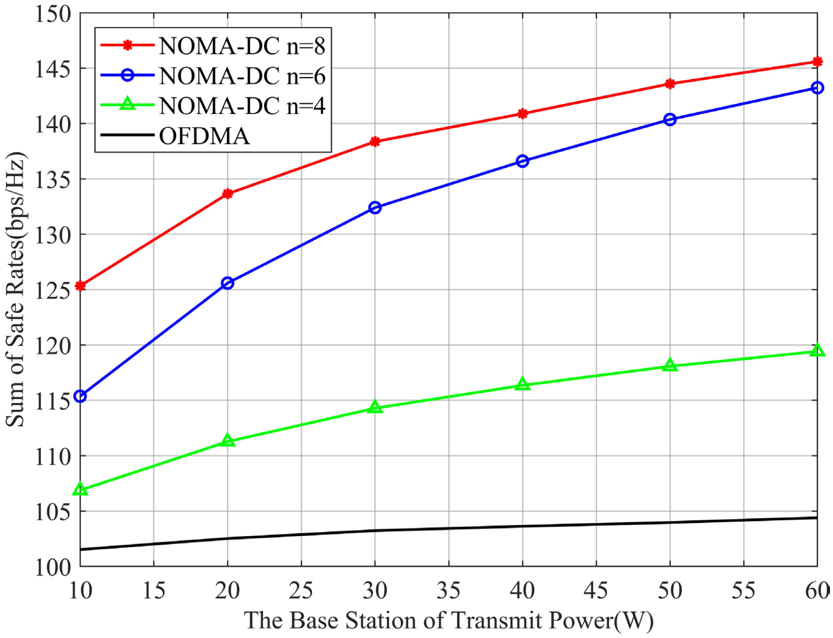

Figure 4. The impact of the number of subcarriers on sum of safe rates.

this simulation, the number of subcarriers N in the system is 6, and the number of users M on each subcarrier is 4.

For all the above assumptions, the simulation analysis is carried out. From the results shown in the figure, it can be seen that the performance of the proposed scheme 1 has different degrees of improvement compared with other schemes. On this basis, the performance of user grouping based on DC-Programming proposed in this paper is better than scheme 2 greatly improved. This verifies that the proposed scheme has good performance.

Figure 5 shows the total energy efficiency versus power to BS power pc/Ps under the same number of subcarriers. The system energy efficiency decreases when the ratio pc/Ps increase. With the fixed BS power of 14 W, the system performs less energy-efficient when the circuit power increases. According to the definition of energy efficiency, its value will become smaller when pc increases. However, the DC-CR-NOMA system equipped with the proposed resource allocation algorithms still outperforms the OFDMA system.

5. Conclusion

In order to improve the security performance of CR-NOMA system, the eavesdropping channel model of multi-user CR-NOMA system is analyzed firstly, and the expressions of system security and rate are derived. Then the basic idea of DC planning algorithm and the scheme of subcarrier power allocation to improve the transmission security of the system are introduced. By describing the subchannel allocation problem as a bilateral matching problem, we propose an algorithm for DC-CR-NOMA to maximize the SSR of the system and minimize

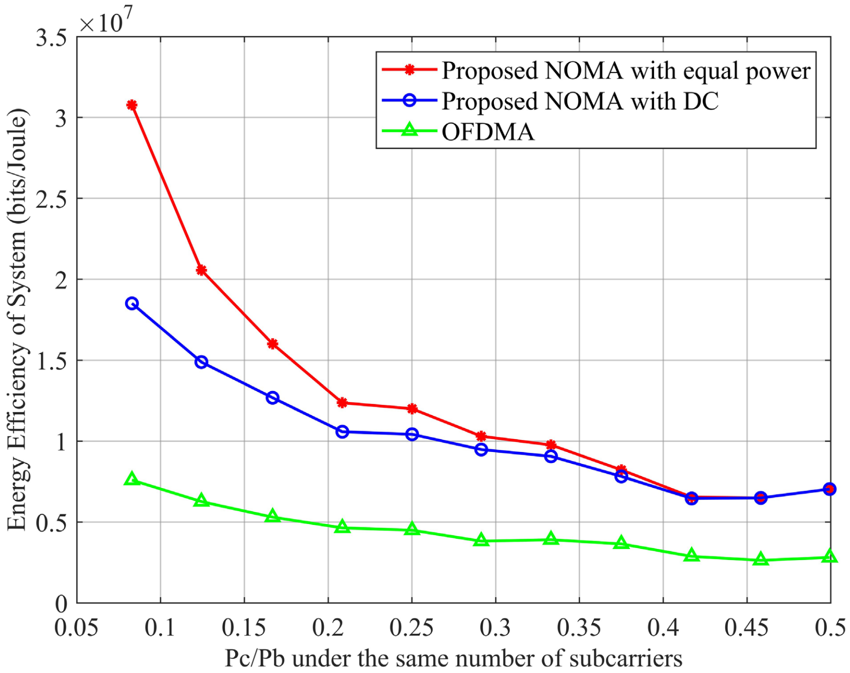

Figure 5. Energy efficiency of the system versus BS power under the same number of subcarriers.

the energy loss. The power scaling factor of multiplexing users on each sub-channel is determined by the power allocation algorithm in this paper. In the power allocation scheme across sub-channels, because the objective function is non-convex, the non-convex optimization problem is approximated to a convex sub-problem by DC programming. Therefore, the sub-optimal power allocation between sub-channels is obtained by iteratively solving the convex sub-problem. Based on the proposed algorithm, the proposed subchannel power allocation scheme further improves the SSR of the system and minimizes the energy loss. Through a large number of simulations, the performance of the proposed power allocation algorithm is compared with that of OFDMA system. The results show that the SSR of CR-NOMA system is much higher than that of OFDMA scheme. The proposed power allocation scheme for subchannel users is superior to the FTPA scheme. In addition, the effectiveness of the proposed scheme and the effect of the number of subcarriers on the sum of the system security rates are also verified by simulation.

Acknowledgements

The authors would like to thank the anonymous reviewers for their selfless reviews and valuable comments, which have improved the quality of our original manuscript.

Funding Statement

Research project of online ideological and political education of Sichuan University of Light Industry and Technology (SZ2022-21); the second batch of industry-university collaborative education projects of the Department of Higher Education of the Ministry of Education (202102123021); Key Laboratory of Enterprise Informatization and Internet of Things Measurement and Control Technology of Sichuan University (2022WYY02); Zigong Key Science and Technology Plan Project (Zigong Medical Big Data and Artificial Intelligence Research Institute Collaborative Innovation) (2022ZD16).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Haykin, S. (2015) Cognitive Radio: Brain-Empowered Wireless Communications. *IEEE Journal on Selected Areas in Communications*, **23**, 201-220. https://doi.org/10.1109/JSAC.2004.839380

[2] Feng, Y., Yan, S., Yan, N., Yang, Z. and Yuan, J. (2022) Safe Guarding Non Orthogonal Multiple Access with Physical Layer Techniques. *IEEE Network*, **36**, 145-151. https://doi.org/10.1109/MNET.014.2100091

[3] Lv, L., Jiang, H., Ding, Z., Yang, L. and Chen, J. (2020) Secrecy-Enhancing Design for Cooperative Downlink and Uplink NOMA with an Untrusted Relay. *IEEE*

Transactions on Communications, **68**, 1698-1715. https://doi.org/10.1109/TCOMM.2019.2960345

[4] Bisen, S. and Shaik, P. (2021) On Performance of Energy Harvested Cooperative NOMA under Imperfect CSI and Imperfect SIC. *IEEE Transactions on Vehicular Technology*, **70**, 8993-9005. https://doi.org/10.1109/TVT.2021.3099067

[5] Xiang, Z., Yang, W., Pan, G., Cai, Y. and Song, Y. (2019) Physical Layer Security in Cognitive Radio Inspired NOMA Network. *IEEE Journal of Selected Topics in Signal Processing*, **13**, 700-714. https://doi.org/10.1109/JSTSP.2019.2902103

[6] Hamamreh, J.M., Furqan, H.M. and Arslan, H. (2018) Classifications and Applications of Physical Layer Security Techniques for Confidentiality: A Comprehensive survey. *IEEE Communications Surveys & Tutorials*, **21**, 1773-1828. https://doi.org/10.1109/COMST.2018.2878035

[7] Zeng, M., Yadav, A., Dobre, O.A., Tsiropoulos, G.I. and Poor, H.V. (2017) On the Sum Rate of MIMO-NOMA and MIMO-OMA Systems. *IEEE Wireless Communications Letters*, **6**, 534-537. https://doi.org/10.1109/LWC.2017.2712149

[8] Liu, F., Mhnen, P. and Petrova, M. (2016) Proportional Fairness-Based Power Allocation and User Set Selection for Downlink NOMA Systems. *Proceedings of* 2016 *IEEE International Conference on Communications* (*ICC*), Kuala Lumpur, 22-27 May 2016, 1-6. https://doi.org/10.1109/ICC.2016.7510916

[9] Yang, Z., Ding, Z., Fan, P. and Al-Dhahir, N. (2016) A General Power Allocation Scheme to Guarantee Quality of Service in Downlink and Uplink NOMA Systems. *IEEE Transactions on Wireless Communications*, **15**, 7244-7257. https://doi.org/10.1109/TWC.2016.2599521

[10] Zheng, B., Wen, M., Wang, C.-X., *et al.* (2018) Secure NOMA Based Two-Way Relay Networks Using Artificial Noise and Full Duplex. *IEEE Journal on Selected Areas in Communications*, **36**, 1426-1440. https://doi.org/10.1109/JSAC.2018.2824624

[11] Lei, H., Gao, R., Park, K.H., Ansari, I.S., Kim, K.J. and Alouini, M.-S. (2020) On Secure Downlink NOMA Systems with Outage Constraint. *IEEE Transactions on Communications*, **68**, 7824-7836. https://doi.org/10.1109/TCOMM.2020.3021139

[12] Zheng, X., Zhang, J. and Pan, G. (2022) On Secrecy Analysis of Underlay Cognitive UAV-Aided NOMA Systems with TAS/MRC. *IEEE Internet of Things Journal*, **9**, 22631-22642. https://doi.org/10.1109/JIOT.2022.3181826

[13] Yue, X., Liu, Y., Kang, S., Nallanathan, A. and Ding, Z. (2021) Exploiting Full/Half-Duplex User Relaying in NOMA Systems. *IEEE Transactions on Communications*, **66**, 560-575. https://doi.org/10.1109/TCOMM.2017.2749400

[14] El Halawany, B.M., Ruby, R., Riihonen, T., *et al.* (2018) Performance of Cooperative NOMA Systems under Passive Eavesdropping. *Proceedings of* 2018 *IEEE Global Communications Conference* (*GLOBECOM*), Abu Dhabi, 9-13 December 2018, 1-6. https://doi.org/10.1109/GLOCOM.2018.8647883

[15] Al-Ahmadi, S. (2020) On the Achievable Max-Min Rates of Cooperative Power-Domain NOMA Systems. *IEEE Access*, **8**, 173112-173122. https://doi.org/10.1109/ACCESS.2020.3025734

[16] Ng, D., Lo, E. and Schober, R. (2018) Energy-Efficient Resource Allocation in OFDMA Systems with Large Numbers of Base Station Antennas. *IEEE Transactions on Wireless Communications*, **11**, 3292-3304. https://doi.org/10.1109/TWC.2012.072512.111850

[17] Beretsekas, D.P. (1999) Nonlinear Programming. Athena Scientific, Belmont, MA.

[18] Ben-Tal, A. and Nemirovski, A. (2001) Lectures on Modern Convex Optimization:

Analysis, Algorithms, and Engineering Applications. MPS-SIAM Series on Optimization, Philadelphia. https://doi.org/10.1137/1.9780898718829

[19] Boyd, S. and Vandenberghe, L. (2004) Convex Optimization. Cambridge University Press, New York. https://doi.org/10.1017/CBO9780511804441

[20] Yu, X., Li, D., Xu, Y. and Liang, Y.-C. (2022) Convolutional Autoencoder-Based Phase Shift Feedback Compression for Intelligent Reflecting Surface-Assisted Wireless Systems. *IEEE Communications Letters*, **26**, 89-93. https://doi.org/10.1109/LCOMM.2021.3123941

[21] Vucic, N., Shi, S. and Schubert, M. (2020) DC Programming Approach for Resource Allocation in Wireless Networks. *Proceedings of International Symposium on Modeling and Optimization in Mobile*, *Ad Hoc and Wireless Networks* (*WiOpt* 2020), Avignon, May 2010, 380-386.