An optimized power allocation algorithm for cognitive radio NOMA communication

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Article Info	ABSTRACT
	The primary objective of cognitive radio network is to effectively utilize the unused spectrum bands. In cognitive radio networks, spectrum sharing between primary and secondary users is accomplished using either underlay or interweave cognitive radio approach. Non orthogonal multiple access (NOMA) is the proven technology in the present wireless developments, which allows the coexistence of multiple users in the same orthogonal block. The new paradigm cognitive radio NOMA (CR-NOMA) is one of the potential solutions to fulfill the demands of future wireless communication. This paper emphasizes on practical implementation of NOMA in cognitive radio networks to enhance the spectral efficiency. The goal is to increase the throughput of the secondary users satisfying the quality of service (QOS) requirements of primary users. To achieve this, we have presented the optimized power allocation strategy for underlay downlink scenario to support the simultaneous transmission of primary and secondary users. Furthermore, we have proposed QOS based power allocation scheme for CR-NOMA interweave model to support the coexistence of multiple secondary networks. Also, the changes adopted in implementing superposition coding (SC) and successive interference cancellation (SIC) for CR-NOMA are highlighted. Finally, simulation results validate the mathematical expressions that are derived for power allocation coefficient and outage probability.

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1. INTRODUCTION

Ever increasing demand for wireless mobile communication has resulted in shortage of radio resources. It is predicted that, number of connected devices may reach 50 billion by 2025. On the contrary, most of the licensed spectrum bands are underutilized, sometimes even less than 40%. Considering the above facts, it can be stated that the only way to cater the demand for wireless spectrum is to make the best use of underutilized channels. As a result of this, cognitive radio approach is extensively examined by the researchers. Currently sensing based spectrum sharing is supported by many international standards like IEEE 802.22, 802.11, and 802.15, thus by effectively utilizing the underutilized channels, future spectrum needs can be fulfilled. There are two modes in cognitive radio-based spectrum sharing [1], [2]: underlay and interweave modes. In the former approach, both incumbent and cognitive users permitted to transmit in the same channel at the same time. This mode suffers from the limitations of channel capacity and degradation of

quality of service. In the later, white spaces are identified using spectrum sensing technique such as energy detection, and feature detection. Then, secondary users (SU) can transmit their data in the identified slots. It must be noted that spectrum handoff is required wherever the primary user (PU) becomes reactive. In the recent advancement of wireless research, NOMA has become the enabling technology [3] which supports the transmission of multiple users in the same orthogonal block. Various NOMA techniques are reported in the recent studies, which are categorized as code division multiple access (CDM), pattern division multiple access (PTD-MA), sparse code multiple access (SC-MA), and power domain multiplexing (PDM).

The hybrid combination of cognitive radio and NOMA is very much essential to bear the coexistence of primary and secondary networks and the self-coexistence of multiple secondary networks. The practical implementation of NOMA in cognitive radio networks demands optimal power distribution, outage probability analysis and suitable decoding techniques. Moreover, NOMA can be implemented either in power domain or code domain. Since we are associating NOMA with CR, power division multiple access is explored in the proposed work. Zhanji *et al.* [4] have briefed about various existing NOMA technologies, challenges for future wireless networks. In [5], [6], authors have reviewed potential challenges in power domain NOMA which uses SC at the transmitter end and SIC at the reception end. Reference [7] gives the different power allocation strategies for NOMA applicable to 5G mobile communications. CR-NOMA with simultaneous wireless information and power transfer (SWIPT) is studied in [8] towards the maximization of energy efficiency. In the survey literature [9], Thakur *et al.* have presented the existing challenges and gaps in the integration of NOMA with cognitive radio networks. Vaezi *et al.* [10] has identified and clarified common myths about NOMA pertaining to power allocation and decoding order in successive interference cancellation. In conventional NOMA [11]-[13], highest power allotted to the user with poor channel condition to maintain the fairness. But in CR-NOMA underlay model, power allocation should be done based on quality of service (QOS) requirements of the primary network. In interweave model, we need to consider the QOS rates of all the participating networks. Contributions of our work are listed here:

− We have proposed the possible CR-NOMA frameworks for underlay and interweave approaches.
− Analytical expressions are obtained for power allocation coefficient to maximize the secondary throughput, providing incumbent users with minimum required QOS rates.
− This work analyses the performance NOMA in cognitive radio network with respect to throughput and fairness in comparison with NOMA.

The rest of the paper is presented in a following way: Underlay and interweave CR-NOMA frameworks are shown in the section 2. Superposition coding and interference cancellation for CR-NOMA is also demonstrated in this section. Mathematical modelling is derived for power allocation strategy for both framework 1 and 2, which is presented in the section 3. Moreover, we have derived the optimal values of power allocation coefficients to maximize the throughput of the system, considering the QOS requirements of the participating networks. Simulation and numerical results are plotted in the section 4. Conclusion remarks are given in the section 5.

2. CR-NOMA SYSTEM MODEL

In the proposed model, CR-NOMA is represented as power domain NOMA, through which QOS requirements of primary users can be strictly met and throughput of the secondary users can be increased to best possible extent. We have demonstrated two CR-NOMA frameworks: Underlay CR-NOMA model and interweave CR-NOMA model. In framework 1, power allocation factor is oprimized to maximize the secondary network throughput. In framework 2, power allocation factor is optimized to satisfy the QoS requirements of multiple secondary networks.

2.1. Framework 1: Underlay model

In this framework, secondary users coexist with primary users and protection to primary users is provided by limiting the interference of secondary users to certain level. Presumptions for framework 1 are: i) PU and SU base stations are well coordinated and situated in the nearby places. ii) Transmitter is equipped with SC and SIC capability. iii) Both primary and secondary users are equipped with SIC capability. Figure 1 depicts the coexistence of n primary users and n secondary users where NOMA is employed to support simultaneous transmission.

2.2. Framework 2: Interweave model

Framework 2 is developed to support interweave model wherein spectrum white spaces are identified through cooperative sensing and SU's are allowed to transmit their data in the identified slots. This framework (Figure 2) supports the coexistence of multiple secondary networks. Presumptions for framework 2 are: i) First spectrum holes are identified using cooperative sensing, where fusion center makes the decision and maintains the availability status of spectrum bands; ii) Transmitter must be located at the fusion center

and base stations of the secondary networks are located nearer to fusion center; and iii) SU 1 and SU 2 base stations must be coordinated to produce superposition coded signal at the transmitter located in the fusion center. It must be noted that, spectrum hand-off is managed by fusion center.
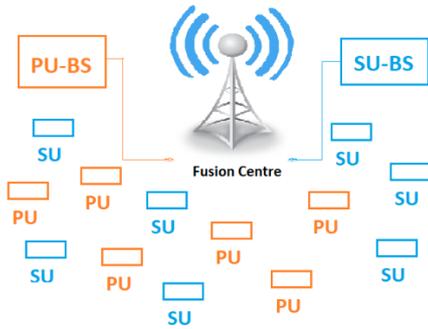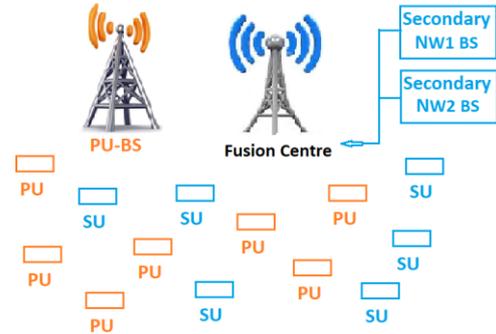

Figure 1. CR-NOMA underlay framework

Figure 2. CR-NOMA interweave framework

2.3. SC and SIC for CR-NOMA
2.3.1. Downlink scenario
The downlink scenario are:
a. Coded information of BS1and BS2 are combined at FC to produce Superposition coded signal.
b. Power allocation is done based on the QOS requirements of network 1 and 2.
c. At user1, user2 signal is decoded first by considering user1's signal as interference and then user1information is extracted by subtracting user2 signal from the received signal.
d. At user2, signal is extracting by considering user1's signal as interference.

2.3.2. Uplink scenario
The uplink scenario are:
a. Multiple primary and secondary users transmit their signal in the same orthogonal block towards the fusion center.
b. Power allocation is done in the controlled way based on their channel gain.
c. The transceiver at FC receives the superimposed (Yu) signal of multiple users.
d. SIC is adopted to recover the individual signals:
− Arrange the users according to their received power in descending order.
− User1 signal is decoded by considering all other signals as interference
− Subtract the decoded signal from the received signal (Y_u), yields (Y_{1u}).
− Decode user2 signal from Y_{1u} as done in the previous step.
− Process is continued until the extraction of all user's signals.

3. POWER ALLOCATION OPTIMIZATION
Our research work emphasis on practical implementation of NOMA in cognitive radio networks to facilitate the simultaneous transmission of primary and secondary users and also self-coexistence of multiple secondary networks. NOMA can be implemented in many ways such as power domain, and code domain. Since we are adopting power domain NOMA, the major challenge lies in the distribution of power among the users. In the proposed work, we have presented mathematical modeling of optimal power allocation for both framework 1 and framework 2.

3.1. Power allocation for framework 1 in downlink scenario
Framework 1 is designed to support simultaneous transmission of PU network and SU network in underlay mode. The objective of this design is to maximize the throughput of the secondary network without denying the QOS requirements of primary network. We have selected the downlink scenario (Figure 3) wherein a primary network and secondary network base stations coordinate with a fusion center (transmitter) to produce the superposition coded signal [14]. The transmitted signal after superposition coding can be represented as (1);

$$x = \sqrt{\alpha\rho}x_p + \sqrt{\bar{\alpha}\rho}x_s \qquad (1)$$

x_p is primary base station signal, x_s is secondary base station signal, ρ is the total transmit SNR and $\alpha+\bar{\alpha}=1$, where α is the power allocation coefficient.
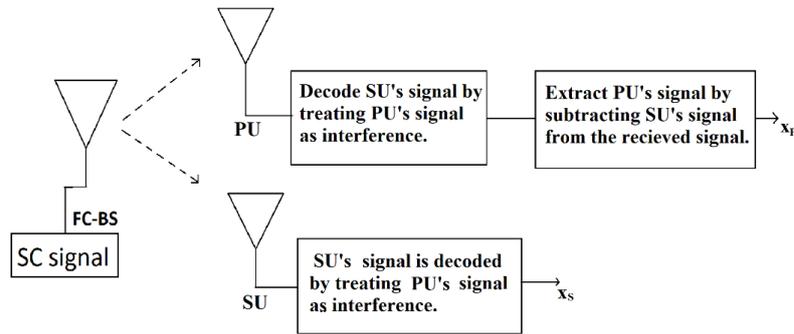

Figure 3. Framework 1 downlink scenario for two users

3.1.1. Decoding at primary users

The received signal at the primary users is the combined signal, which can be expressed as (2);

$$y_p = h_p x + w_p \qquad (2)$$

where, h_p is the channel gain between primary user and transmitter. W_p is the additive white Gaussian noise at the primary user.

$$y_p = h_p\left(\sqrt{\alpha\rho}x_p + \sqrt{\bar{\alpha}\rho}x_s\right) + w_p \qquad (3)$$

Primary user performs decoding of SU's signal first by considering PU's signal as interference and then decodes its own signal by subtracting SU's signal from the received combined signal [15]. Thus, SNR for decoding SU's signal at PU is given by;

$$\gamma = \frac{\bar{\alpha}\rho|h_p|^2}{1+\alpha\rho|h_p|^2} = \frac{\bar{\alpha}\rho\beta_p}{1+\alpha\rho\beta_p} \qquad (4)$$

Signal from SU does not interfere with primary user signal, so the resultant signal y_p after subtracting decoded SU's signal from the received signal is;

$$y_{p=}h_p\left(\sqrt{\alpha\rho}x_p\right) + w_p \qquad (5)$$

At the primary user's side, resultant SNR for decoding PU's signal is;

$$\gamma_p = \alpha\rho|h_p|^2 = \alpha\rho\beta_p \qquad (6)$$

Therefore, the maximum achievable throughput for primary user can be formulated as;

$$R_p = B_D \log_2(1 + \gamma_p) = \log_2(1 + \alpha\rho\beta_p) \qquad (7)$$

3.1.2. Decoding at secondary users

The received superposition coded signal at the secondary user is written as;

$$y_s = h_s\left(\sqrt{\alpha\rho}x_p + \sqrt{\bar{\alpha}\rho}x_s\right) + w_s \qquad (8)$$

It must be noted that, SIC order need not to be dependent on amount of power allocated to user [10]. Secondary users decode their signal by considering PU's signal as interference. Due to this, signal from primary network acts as noise/interference for secondary network signal. Thus, SNR for decoding SU's signal at secondary user side can be expressed as;

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$$\gamma_s = \frac{\bar{\alpha}\rho|h_s|^2}{1+\alpha\rho|h_s|^2} = \frac{\bar{\alpha}\rho\beta_s}{1+\alpha\rho\beta_s} \tag{9}$$

Therefore, the maximum achievable throughput for secondary users in downlink scenario is;

$$R_s = B_D \log_2(1+\gamma_s) = \log_2\left(1 + \frac{\bar{\alpha}\rho\beta_s}{1+\alpha\rho\beta_s}\right) \tag{10}$$

The total capacity of downlink CR-NOMA for framework 1 can be formulated as;

$$R = \log_2(1+\alpha\rho\beta_p) + \log_2\left(1 + \frac{\bar{\alpha}\rho\beta_s}{1+\alpha\rho\beta_s}\right) \tag{11}$$

3.1.3. Optimization of power allocation coefficient (α) for framework 1

Conventionally NOMA allocates more power to the users with poor channel conditions. It should be noted that, power allocation need not to be dependent only on channel gain, it depends the targeted objective. In framework 1, the goal is to increase the throughput of the secondary network protecting the QOS requirements of the primary network. Thus, the problem can be defined as:

$$\alpha = argmax(R_s)$$
$$s.t \quad R_p > \overline{R_P} \tag{12}$$

where, $\overline{R_P}$ is the minimum QOS rate required for primary network. To satisfy the above constraint, we must have:

$$\log_2(1+\alpha\rho\beta_p) \geq \overline{R_P} \tag{13}$$

The power allocation coefficient **α** must be;

$$\alpha \geq \frac{2^{\overline{R_P}}-1}{\rho\beta_p} \geq \frac{\bar{\bar{R}}_P}{\rho\beta_p} \text{ ,where } \bar{\bar{R}}_P = 2^{\overline{R_P}} - 1 \tag{14}$$

$\alpha_{min} = \frac{\bar{\bar{R}}_P}{\rho\beta_p}$ (14) is the minimum power that must be allocated to primary signal to maintain its QOS requirements. To satisfy the total power constraint (1), we must write;

$$\bar{\alpha} = 1 - \alpha = 1 - \frac{\bar{\bar{R}}_P}{\rho\beta_p} \tag{15}$$

$\bar{\alpha}_{max} = 1 - \frac{\bar{\bar{R}}_P}{\rho\beta_p}$ (15) is the maximum power that can be allocated to secondary network and it is the optimal value of power at which secondary network gets maximum throughput meeting the QOS requirements of primary user network. Generally secondary users require less data rate compared to the primary users, it is practical to operate primary and secondary users in the same orthogonal block.

3.2. Power allocation for framework 2 in downlink scenario

Framework 2 depicts the coexistence of two secondary multicast networks, where in primary network can transmit information without any interference and secondary networks must transmit in the free slots. Figure 4 shows the time frame where slot1 indicates the PU busy state and slot3 can be used for secondary communication. Spectrum whitespaces are identified using cooperative sensing [16], [17] and fusion center maintains the database on available spectrum bands. Same fusion center used for cooperative sensing can be used to transmit the superposition coded signal of secondary networks.

slot1	slot2	slot3

slot1-Primary user busy state

slot2-Cooperative sensing duration
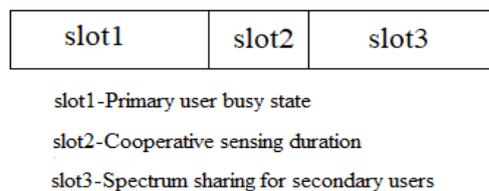
slot3-Spectrum sharing for secondary users

Figure 4. Time Frame-interweave spectrum sharing in cognitive radio networks

The coded information of two secondary base stations are added up to produce SC signal at the transmitter located in the fusion center (Figure 5). The superposition coded signal at the transmitter can be modelled as;

$$x = \sqrt{\alpha\rho}x_{s1} + \sqrt{\bar{\alpha}\rho}x_{s2} \tag{16}$$

where, x_{s1} is secondary network1 (SN1) base station signal, x_{s2} is secondary network2 (SN2) base station signal and power constraint $\alpha+\bar{\alpha}=1$.

The received signal at the users of secondary network1 can be written as;

$$y_{s1} = h_{s1}\left(\sqrt{\alpha\rho}x_{s1} + \sqrt{\bar{\alpha}\rho}x_{s2}\right) + w_{s1} \tag{17}$$

where, h_{s1} is the channel gain between SN1 user and transmitter. W_{s1} is the additive white Gaussian noise at the SN1 user. At SN1 user, first SN2 signal is decoded and then SN1 signal is extracted by subtracting SN2 signal from the received signal. Thus, decoding of SN1 signal does not face the interference from SN2 signal. Corresponding SNR is given by;

$$\gamma_{s1} = \alpha\rho|h_{s1}|^2 = \alpha\rho\beta_{s1} \tag{18}$$

The achievable data rate for SN1 can be calculated by;

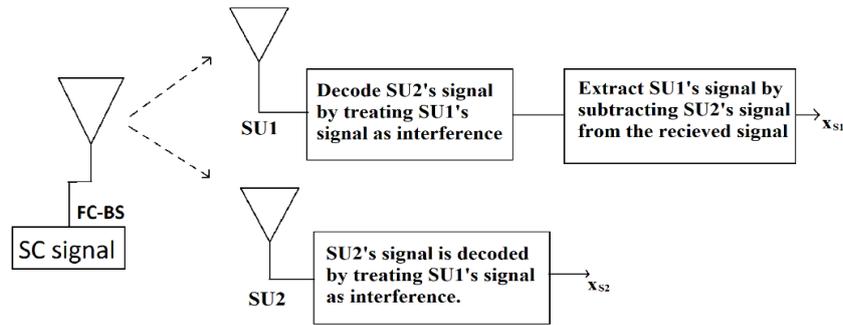$$R_{s1} = B_D \log_2(1 + \alpha\rho\beta_{s1}) \tag{19}$$

Figure 5. Framework 2 downlink scenario for two users

The received signal at the users of secondary network2 can be written as;

$$Y_{s2} = h_{s2}\left(\sqrt{\alpha\rho}x_{s1} + \sqrt{\bar{\alpha}\rho}x_{s2}\right) + w_{s2} \tag{20}$$

where, h_{s2} is the channel gain between SN2 user and transmitter. W_{s2} is the additive white Gaussian noise at the SN2 user. At the SN2 user, information is decoded directly from SC signal by considering SN1 signal as interference. Thus, corresponding SNR can be written as;

$$\gamma_{s2} = \frac{\bar{\alpha}\rho|h_{s2}|^2}{1+\alpha\rho|h_{s2}|^2} = \frac{\bar{\alpha}\rho\beta_{s2}}{1+\alpha\rho\beta_{s2}} \tag{21}$$

The achievable data rate for SN2 can be determined by;

$$R_{s2} = B_D \log_2\left(1 + \frac{\bar{\alpha}\rho\beta_{s2}}{1+\alpha\rho\beta_{s2}}\right) \tag{22}$$

The total capacity of downlink CR-NOMA for framework 2 can be formulated as;

$$R = \log_2(1 + \alpha\rho\beta_{s1}) + \log_2\left(1 + \frac{\bar{\alpha}\rho\beta_{s2}}{1+\alpha\rho\beta_{s2}}\right) \tag{23}$$

3.2.1. Optimization of power allocation coefficient (α) for framework 2

In the coexistence of two secondary networks, it is important to meet the QOS requirements of both the networks. Say, $\overline{R_{S1}}$, $\overline{R_{S2}}$ are the minimum QOS rates required for SN1 and SN2 respectively. We must find the optimal value of power allocation coefficient to meet the requirements of the participating networks [18].

$$\alpha = argmax(R)$$

$$s.t \quad R_{S1} \geq \overline{R_{S1}} \quad \& \, R_{S2} \geq \overline{R_{S2}} \tag{24}$$

To satisfy the above conditions, we must have;

$$\log_2(1 + \alpha\rho\beta_{s1}) \geq \overline{R_{S1}} \tag{25}$$

$$\log_2\left(1 + \frac{\bar{\alpha}\rho\beta_{s2}}{1+\alpha\rho\beta_{s2}}\right) \geq \overline{R_{S2}} \tag{26}$$

The simplification of the above the (25) and (26), yields to

$$\alpha \geq \frac{2^{\overline{R_{S1}}}-1}{\rho\beta_{S1}} \geq \frac{\bar{\bar{R}}_{S1}}{\rho\beta_{S1}} \tag{27}$$

where, $\bar{\bar{R}}_{S1} = 2^{\overline{R_{S1}}} - 1$ and (27) gives the minimum value of α required to satisfy the QOS of secondary network1.

$$\alpha \leq \frac{\rho\beta_{S2}-\bar{\bar{R}}_{S2}}{\rho\beta_{S2}(1+\bar{\bar{R}}_{S2})} \tag{28}$$

here, $\bar{\bar{R}}_{S2} = 2^{\overline{R_{S2}}} - 1$ and (28) gives the maximum value of α required to satisfy the QOS of secondary network2. From (27) and (28), optimal value of α required to meet the QOS rates $\overline{R_{S1}}$ and $\overline{R_{S2}}$ lies in the interval (29).

$$\frac{\bar{\bar{R}}_{S1}}{\rho\beta_{S1}} \leq \alpha \leq \frac{\rho\beta_{S2}-\bar{\bar{R}}_{S2}}{\rho\beta_{S2}(1+\bar{\bar{R}}_{S2})} \tag{29}$$

By examining expression (23) and (29) in case of $|h_{s1}| \geq |h_{s2}|$, it can be concluded that the maximum throughput occurs at maximum value of α (28).

$$\alpha_{opt} = \frac{\rho\beta_{S2}-\bar{\bar{R}}_{S2}}{\rho\beta_{S2}(1+\bar{\bar{R}}_{S2})} \tag{30}$$

Algorithm 1: Power allocation algorithm to maximize overall throughput

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Inputs:  |h_p|,|h_s|,|h_s1|,|h_s2|, and R̄_P, R̄_s, R̄_s1, R̄_s2
Initialization:
Framework1 R1 = R̄_P; R2 = R̄_s
Framework2 R1 = R̄_s1; R2 = R̄_s2
Constraint: (R1 + R2) < R_Total
Calculation of power allocation coefficient:
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Framework1 $\quad \alpha_{opt} = 1 - \frac{\bar{R}_P}{\rho|h_p|^2}$

Framework2

- Find $\alpha_1 = \frac{2^{\overline{R_1}}-1}{\rho|h_{s1}|^2}$
- Find $\alpha_2 = \frac{\rho|h_{s2}|^2-\bar{R}_2}{\rho|h_{s2}|^2(1+\bar{R}_2)}$ where $\bar{\bar{R}}_2 = 2^{R_2} - 1$
- $\alpha_{max} = max(\alpha_1, \alpha_2)$
- $\alpha_{min} = min(\alpha_1, \alpha_2)$

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if (|h_s1| > |h_s2|)
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     $\alpha_{opt} = \alpha_{max}$
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else
```
        $\alpha_{opt} = \alpha_{min}$
```
Maximum overall throughput satisfying the QOS constraint:
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$R = \log_2(1 + \alpha_{opt}\rho\beta_1) + \log_2\left(1 + \frac{\overline{\alpha_{opt}}\rho\beta_{s2}}{1+\alpha_{opt}\rho\beta_{s2}}\right)$
```
where β_1 = |h_s1|²,  β_2 = |h_s2|²
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3.3. Channel modelling and outage probability analysis

If channel condition of the user is not able to support the desired rate, then there will be outage. It is not always possible to support the desired QoS because of fading channel. We have taken underlay cognitive radio communication for downlink outage probability analysis. $\overline{R_P}$ and $\overline{R_s}$ are the minimum rates required for primary and secondary networks, respectively.

Probability of outage corresponding to primary network user is:

$$P_{outage} = P\left(C_p^{x_s} < \overline{R_s} \ \cup \ C_p^{x_p} < \overline{R_p}\right) \tag{31}$$

where C_p^x is achievable capacity of the PU for decoding the signal x. This first condition says, outage occurs when:

$$C_p^{x_s} = \log_2\left(1 + \frac{\overline{\alpha}\rho\beta_p}{1+\alpha\rho\beta_p}\right) < \overline{R_s} \tag{32}$$

The second condition that may lead to primary user outage is:

$$C_p^{x_p} = \log_2(1 + \alpha\rho\beta_P) < \overline{R_p} \tag{33}$$

We assume channel gain |h| as Rayleigh fading coefficient, then $\beta = |h_p|^2$ will be exponentially distributed. For Rayleigh fading Model: $\beta = |h|^2$, $\delta^2 = E\{\beta\}$. Primary user outage occurs when the channel coefficient:

$$\beta_p < max\left\{\frac{\overline{\overline{R}}_P}{\rho\alpha}, \frac{\overline{\overline{R}}_S}{\rho(\overline{\alpha}-\alpha\overline{\overline{R}}_S)}\right\} \tag{34}$$

$$P_{outage} = 1 - \exp\left(-\frac{1}{\delta^2} max\left\{\frac{\overline{\overline{R}}_P}{\rho\alpha}, \frac{\overline{\overline{R}}_S}{\rho(\overline{\alpha}-\alpha\overline{\overline{R}}_S)}\right\}\right) \tag{35}$$

3.4. Practical challenges in the CR-NOMA implementation

The energy efficiency of CR-NOMA technique relies on the optimal power allocation, which requires exact information on the downlink channel coefficients. Handling imperfect CSI is the biggest challenge in the implementation of CR-NOMA. Future wireless networks must support heterogeneous devices with different levels of QOS requirements. Thus, meeting the QOS requirements of secondary networks without causing harmful interference to the primary users is another major challenge [19]. CR-NOMA technology demands for SC and SIC capabilities for base station and SIC capability for users, providing these prerequisites is the primary challenge in the implementation. Generation of superposition coded signal at the transmitter requires proper synchronization of primary and secondary base stations.

In CR-NOMA interweave model, users of secondary networks must cooperate with FC to identify the spectrum whitespaces. Spectrum handoff is also crucial in overlay model-shifting the channel dynamically and adjusting the power allocation accordingly. Thus, dynamic power allocation considering the spectrum handoff is a potential challenge. Another challenge is to identify the suitable coding and decoding techniques to implement SC and SIC considering the privacy and security aspects. The regulatory policies for CR-NOMA needs to be standardized to support CR standards and NOMA conventions. When there are larger number of secondary networks /users participate, then we have to adopt dynamic user grouping and power allocation for NOMA with successive interference cancellation (SIC) in down link systems. It is a two-step methodology that comprises of user grouping followed by optimized power allocation for each group considering transmitted power, expected data rate. In NOMA, multiple access is performed in power domain, a small variation in the channel gain or sudden increase in the number of users affects the throughput performance. To overcome these inherent problems, hybrid combination (Figure 6) of NOMA and OMA [20], [21] can be used to determine the best pattern based on the system capacity. In CR-NOMA Paradigm, hybrid combination of underlay and interweave sharing is also possible.
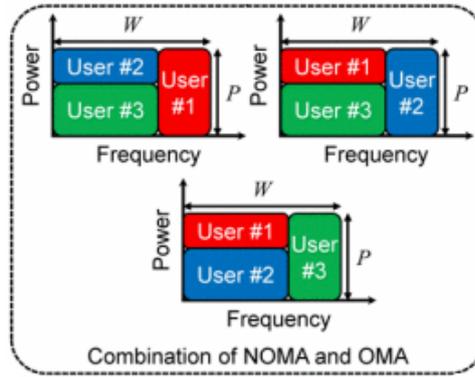
Figure 6. Hybrid Multiple access: combination of NOMA and OMA

4.   SIMULATION RESULTS

To validate the proposed mathematical models, we have conducted simulation experiments on CR-NOMA in downlink scenario for both framework 1 and 2. Simulation environment is setup by assuming necessary values according to IEEE 802.22 standards [22], [23] and 5G conventions [24], [25]. First, we calculated the achievable data rates R_p and R_s for continuous values of α (power allocation coefficient) and same is plotted in Figure 7 (a). $α = 0$ indicates no power is allocated to primary user, hence secondary user date rate is at its maximum. As α increases, power allocation will be distributed among primary and secondary users, correspondingly data rates also vary as shown in Figure 7. At particular value of α, both primary and secondary user possesses the same throughput. Framework 1 depicts the simultaneous transmission of primary and secondary network users, constraint is to maintain the minimum QOS requirements of the primary network user. Figure 7 shows the minimum value of α at which secondary network user gets maximum throughput by providing the required QOS rate ($\overline{R_P}$) for primary network users. Framework 2 comprises the coexistence of multiple secondary networks, it is necessary to provide the minimum QOS rates both the secondary networks (SN1and SN2).

Figure 7 (b) shows that, any value of α in the interval (α$_{min}$, α$_{max}$) satisfy the minimum QOS rates $\overline{R_{S1}}$ and $\overline{R_{S2}}$ given by the secondary networks. From expression (23) and Figure 7 (b), it can be stated that maximum overall capacity (R$_{max}$) is achievable at α= α$_{max.}$ The simulation results are perfectly matching with the proposed mathematical models and calculations. In orthogonal multiple access techniques (CR-OMA), total available bandwidth is divided among the users, however in CR-NOMA, complete bandwidth is assigned to both the user (Figure 8 (a)). Due to this, it can be apparently mentioned that there is a huge improvement in the throughput of user2 in comparison with CR-OMA. It can also be interpreted from Figure 8 (b) that, CR-NOMA performs even much better when the deference h$_{d1}$-h$_{d2}$ is more.
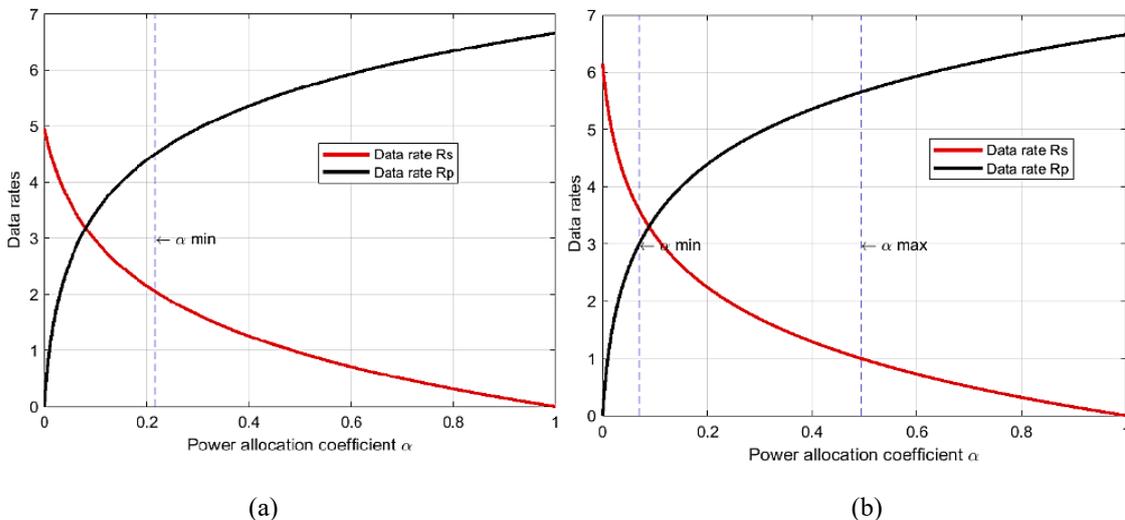

| (a) | (b) |

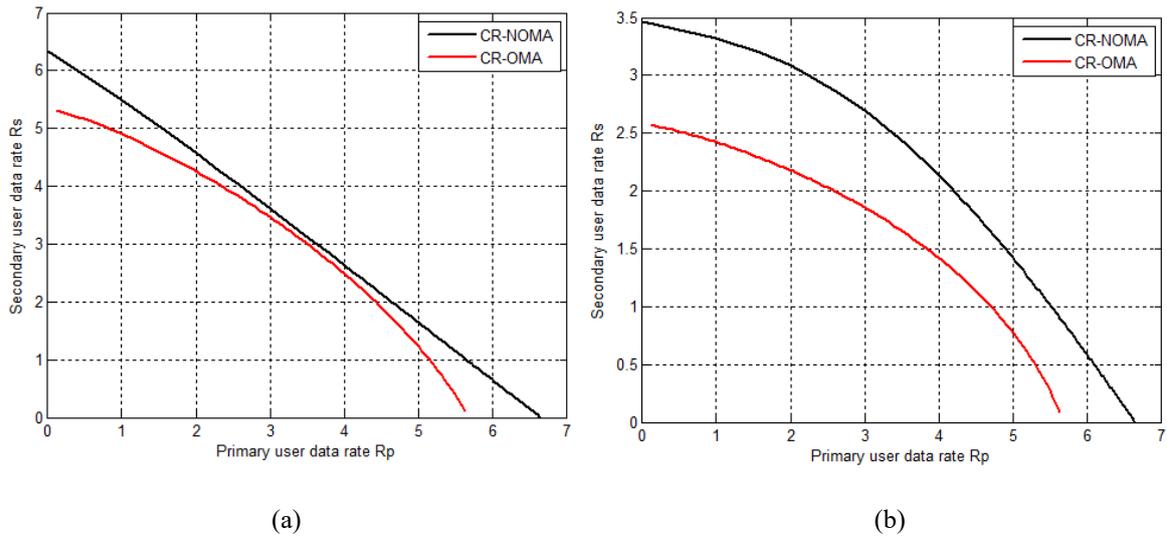Figure 7. Downlink data rates distribution among the users; (a) underlay, (b) interweave sharing

(a) (b)

Figure 8. Overall throughput comparison of CR-NOMA vs CR-OMA; (a) $|h_{d1}|=|h_{d2}|$, (b) $|h_{d1}|>>|h_{d2}|$

The CR-NOMA sum capacity is very high compared to the sum data rates of CR-OMA due to the above-mentioned reasons. The plot of total capacity (23) versus power allocation coefficient α is shown in Figure 9. It is observed that total capacity is maximized when more power is allocated to the channel with more gain (Algorithm1). Hence it is more significant to find the optimal value of α to meet the targeted objectives. Figure 10 shows the outage probabilities of PU and SU for optimized CR-NOMA, wherein power is allocated based on the required QoS rate and channel conditions. The above simulations were carried out by keeping fixed QoS rates and changing only power allocation coefficients. On comparison (Figures 10 (a) and (b)), it can be clearly seen that outage probability of PU has been greatly reduced by adopting QoS based power allocation technique without affecting the secondary user performance. From the obtained results and observations made, it can be concluded that the combination of cognitive radio (CR) and Non orthogonal multiple access (NOMA) brings good impact on spectrum efficiency and ensures that secondary user is served with fairness.
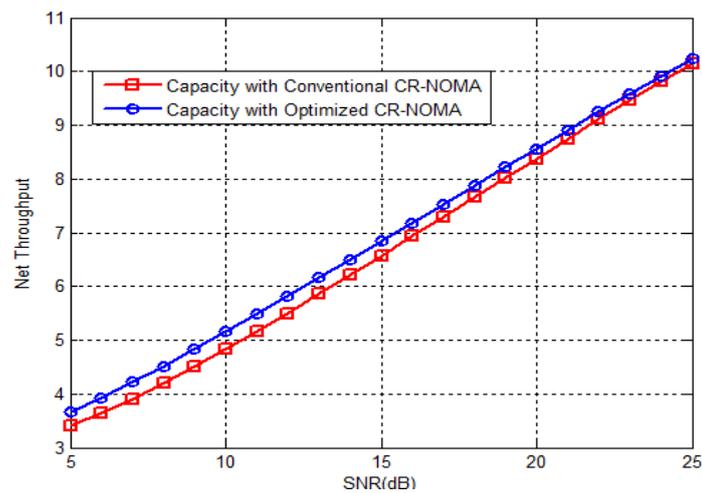

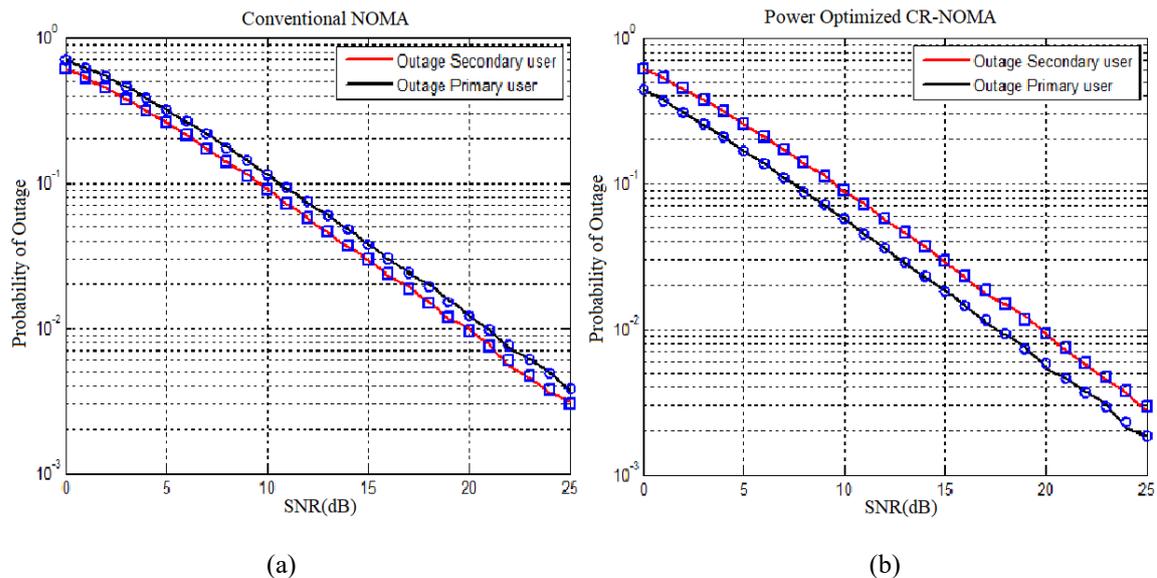Figure 9. Net throughput of optimized CR-NOMA for different SNR values

Figure 10. Downlink outage probability analysis; (a) conventional CR-NOMA (b) optimized CR-NOMA

5.   CONCLUSIONS

Cognitive radio technology is one of the potential solutions to fulfill the spectrum demands by effectively utilizing the underused licensed spectrum. In this work, we have simultaneously exploited cognitive radio and NOMA techniques to achieve the higher spectral efficiency. In this context, we have examined power domain NOMA for two frameworks: underlay and interweave CR models. In framework 1, power allocation coefficient (α) is optimized to maximize the secondary user throughput providing minimum QOS rates demanded by the primary network. In framework 2, we have calculated the range of α (α_{min}, α_{max}) within which QOS rates of multiple (two) secondary networks can be met. Presented results shows that CR-NOMA outperforms CR-OMA in heterogeneous scenario when there are users with different channel coefficients and different QoS requirements. It can be visualized that; our proposed optimization algorithm outperforms conventional NOMA in terms of overall system throughput even satisfying the QOS requirements of users of individual network. Outage probability analysis depicts the effectiveness of the optimization algorithm for different values of SNR.

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