Incremental Relaying with Partial Relay Selection for Enhancing the Performance of Underlay Cognitive NOMA Networks

Archana P., *Student Member, IEEE,* Harigovindan V. P., *Senior Member, IEEE,* Griffith Faustina G., and Babu A. V., *Senior Member, IEEE*

***Abstract*—In this paper, we consider an underlay cognitive non-orthogonal multiple access (CNOMA) network, where incremental relaying with partial relay selection (PRS) scheme (i.e., IRP scheme) is proposed for the secondary network. We derive analytical expressions for the outage probabilities of the secondary users (SUs) and the system throughput of the IRP-CNOMA network. The proposed approach is compared to conventional cooperative relaying-based CNOMA (CR-CNOMA) networks with PRS scheme (i.e., CRP-CNOMA) and random relay selection (RRS) scheme. The results show that the proposed scheme significantly lowers the outage probability of the SUs while improving the system throughput.**

Link to graphical and video abstracts, and to code: https://latamt.ieeer9.org/index.php/transactions/article/view/8795

***Index Terms*—cognitive NOMA, outage probability, system outage probability, system throughput, partial relay selection, incremental relaying.**

I. Introduction

Non - orthogonal multiple access (NOMA) has been identified as an important multiple access strategy in fifth generation (5G) and beyond fifth generation (B5G) wireless networks, for increasing the spectral efficiency (SE) by enabling several users to transmit in the same resource block concurrently [1], [2]. The cooperative relay-based NOMA (i.e., CR-NOMA) has been envisioned to further improve the performance of the far users (i.e., weak or cell edge users) in the NOMA network, where either near users (i.e., strong or cell centric users) or dedicated nodes are used as relays to forward the symbols to the far users [3]–[5]. In the meantime, cognitive radio has been proved as a potential strategy for increasing SE by allowing secondary users (SUs) to access spectrum designated for the primary users (PUs) [6], [7] . This allows multiple wireless communication systems to access the same frequency band at the same time. Cognitive radio employs three spectrum access paradigms: interweave, underlay, and overlay [8], [9]. When interweave mode is adopted, the SUs will detect the spectrum holes by sensing, and then exploit the unoccupied primary frequency bands for their own transmissions. On the other hand, the overlay mode allows the SUs and the PUs to transmit concurrently over the same frequency spectrum. Here, the SUs will act as a relay to forward PUs message so as to enhance the performance of the PUs. In the underlay mode, the SUs are allowed to transmit simultaneously with the PUs in the same frequency band as long as the interference induced on the PUs receiver by the SUs remains below a tolerable interference limit. By incorporating NOMA into cognitive radio systems, system throughput and outage performance can be significantly improved [10], [11]. However, underlay cognitive NOMA (CNOMA) systems are examined in [12], [13]. In these systems, SUs and PUs share the licensed primary spectrum for concurrent transmissions as long as the interference caused by the SUs on the PU receiver remains below the acceptable threshold level. Due to this, the quality of service (QoS) of the SUs cannot be ensured. To improve the coverage, reliability and the QoS performance of the SUs in CNOMA system, cooperative relay based cognitive NOMA (CR-CNOMA) network is proposed. It can provide enhanced SE and throughput [14] compared to the conventional cooperative relay based cognitive OMA networks. In single-cell downlink underlay cognitive NOMA network, if the strong NOMA SU is configured as half-duplex (HD) relay to transmit the message to the far user, then the secondary transmitter (ST) requires two separate time slots for information transmission to SUs [15]. During the first time slot, the ST will broadcast the superimposed signal to the SUs. During the second time slot, the near user will forward the decoded information from the successive interference cancellation (SIC) technique to the far user. This results in the degradation of SE and throughput. The authors in [16], [17] proposed incremental relaying (IR) method in CNOMA network to raise the SE of cooperative NOMA systems. In IR based CNOMA (i.e., IR-CNOMA) network, the near SU will act as a relay for the far SU if and only if the direct path from the ST to far user becomes unreliable. In this transmission, if the direct link to the far SU is successful then the communication from the ST to both the near and far SUs can be accomplished within a single transmission cycle. This ensures higher SE and throughput for the secondary network [18], [19]. However, compared to a fixed relaying strategy, the research work in [20], [21] demonstrated that using multiple relays in NOMA with an appropriate relay selection scheme can result in significant performance gains. Due to inter-network and intra-network interferences present in underlay CR-NOMA systems, the throughput of the secondary network is reduced when a single fixed relay is leveraged to

Archana P, Harigovindan V. P., Griffith F. G., and Babu A. V. are with the Department of ECE, National Institute of Technology Puducherry, Karaikal, India (e-mails: archanavenii@gmail.com, hari@nitpy.ac.in, ggfaustina@gmail.com, and babu@nitc.ac.in).

TABLE I
COMPARISON OF RELATED WORKS

Related Work	Year	Technique	Relay Selection (RS) Method	Mode	Metrics	No. of Relay Nodes	Observations
[25]	2019	Cooperative Underlay CNOMA	Fixed	DF-HD	Outage probability	1	Closed form expressions of the outage probability for SUs is derived. Also, the asymptotic expressions are derived.
[26]	2020	Cooperative Overlay CNOMA	Vickrey auction RS	Hybrid-HD	Sum rate	1	Closed form expressions of sum capacity is derived. Also, simulation results shows that proposed method is more effective than conventional approaches in RS method.
[27]	2021	Underlay CNOMA	PRS	DF-HD	Outage probability & Throughput	2, 3, 4	Closed form expressions of outage probability, asymptotic outage probability and throughput for the SUs is derived. Also compared with RRS.
[28]	2022	Cooperative CNOMA , SWIPT	Two way RS	AF-HD	Sum rate & Energy efficiency	5, 10	In order to reduce system complexity zero-forcing algorithm is proposed. Closed form for the sum rate is derived.
[29]	2024	Interweave CNOMA	Best RS	HD	Outage probability	1,2, 3	Closed form expressions of outage probability, and asymptotic outage probability for the SUs is derived.
Proposed work	–	Incremental relaying Underlay CNOMA	PRS	DF-HD	Outage probability & Throughput	2,3,4 & 5	Closed form expressions of outage probability, system outage probability and throughput for the SUs is derived. Also compared with RRS.

assist the ST-SUs communication. To address such a challenge, multirelay assisted CR-NOMA networks can be proposed in [22], that can provide remarkable performance gains relative to the fixed relaying scheme. Based on that partial relay selection (PRS) scheme in [23], the relay is selected from a group of decode-and-forward (DF) and HD relays. Also authors [24] have analyzed the outage probability and throughput of underlay CNOMA systems using fixed gain for PRS system. Also, Table 1 clearly present the differences and similarities between our proposed work and existing literature, focusing on aspects such as cognitive schemes, relay selection techniques, communication modes, performance metrics, and the number of relay nodes. Differently from the existing papers, we propose incremental relaying with PRS scheme for further improving the performance of underlay CNOMA networks. We obtain closed form analytical equations for the outage probabilities of SUs, system outage probability, and system throughput for the proposed IRP-CNOMA network. The major contributions of this research work are summarized below: (i) we propose a simple yet efficient IR strategy with PRS scheme for enhancing the performance of underlay CNOMA networks; (ii) we investigate the outage probability performance of the SUs and the system throughput through analysis and simulations, considering imperfect SIC (i-SIC) conditions; (iii) we compare the performance of the proposed IRP-CNOMA system against CNOMA system that use conventional cooperative relaying with PRS scheme (i.e., CRP-CNOMA) and random relay selection (RRS) scheme and (iv) we use extensive Monte-Carlo simulations to validate the analytical results.

II. System Model

The considered underlay CNOMA network is shown in Fig. 1, where a primary transmitter (PT) and primary re-

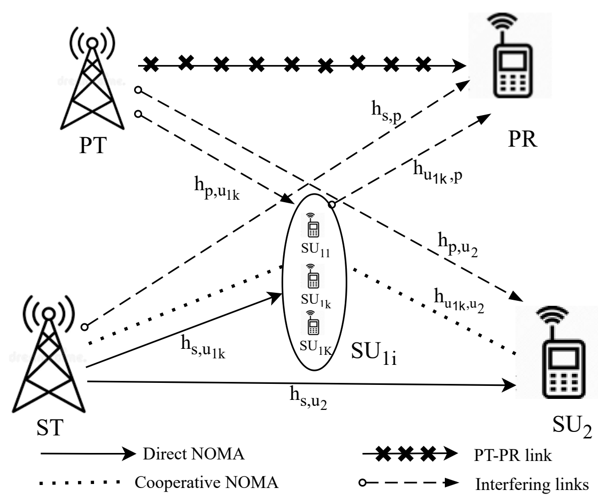

Fig. 1. IRP based underlay cognitive NOMA network with K-near users.

ceiver (PR) pair forms the primary network. The secondary network consists of one ST, K cell-center (i.e., near) SUs ($SU_{1i}; i = 1, 2, ..., K$) and a cell-edge (i.e., far) SU, i.e., SU_2. The channel coefficients $\{h_{ij}\}; i \in (s, u_{1i}, p); j \in (u_{1i}, u_2, p)$ and assumed to follow Rayleigh fading, so that $|h_{ij}|^2$ have exponential probability density function (PDF) with mean values λ_{ij}. All receiver terminals are assumed to suffer additive white Gaussian noise (AWGN) with variance σ^2. When the direct link from ST- SU_2 is unavailable due to heavy shadowing, one of the near SUs, i.e., SU_{1k}, that has highest channel gain over the ST- SU_{1i} ($i = 1, 2, ..., K$) links is selected for assisting communication from ST to SU_2, i.e., $SU_{1k} = arg \ \max_{i=1,..K} |h_{s,u_{1i}}|^2$ [30], which is shown in Algorithm 1. Assuming that the near SUs are positioned relatively closer so that the mean channel gains over the ST-SU_{1i} links are equal (i.e., $\lambda_{s,u_{1i}} = \lambda_o \forall i = 1, 2, ...K$) [31], the PDF of the power gain of the selected best channel from ST- SU_{1i} is given by [30]:

$$f_{|h_{s,u_{1k}}|^2}(x) = \sum_{i=1}^{K} (-1)^{i-1} \binom{K}{i} \frac{i}{\lambda_o} e^{\frac{-ix}{\lambda_o}}, \quad (1)$$

where $\binom{K}{i} = \frac{K!}{i!(K-i)!}$. The various steps involved in the relay selection is clearly described in the Algorithm 1. Let $P_{s,max}$ and $P_{u_{1k},max}$ be the maximum transmit power of ST and SU_{1k}. Due to the underlay mode, $P_s|h_{s,p}|^2 < \theta_I$ and $P_{u_{1k}}|h_{u_{1k},p}|^2 < \theta_I$, where θ_I is the tolerable peak interference threshold of PR; P_s and $P_{u_{1k}}$ are respectively the instantaneous transmit power of ST and SU_{1k}, where are represented as [32]:

$$P_s = \min\left(P_{s,max}, \frac{\theta_I}{|h_{s,p}|^2}\right) \quad (2a)$$

$$P_{u_{1k}} = \min\left(P_{u_{1k},max}, \frac{\theta_I}{|h_{u_{1k},p}|^2}\right) \quad (2b)$$

In the proposed IRP-CNOMA system, ST chooses either direct NOMA (DN) mode or cooperative NOMA (CN) mode to deliver messages to SU_{1k} and SU_2. Let T be the duration of one transmission cycle. Initially, after assessing the quality of the direct ST-SU_2 link through pilot signal transmissions, ST decides as to whether DN or CN mode has to be chosen for message transmissions. If the signal-to-noise ratio (SNR) over the $ST - SU_2$ link is above a predefined threshold, ST decides to opt for DN mode and transmits the NOMA signal $m(t)$:

$$m(t) = \sqrt{\alpha_1 P_s} m_{1k}(t) + \sqrt{\alpha_2 P_s} m_2(t) \quad (3)$$

where m_{1k} and m_2 are the symbols for SU_{1k} and SU_2 respectively; α_1 and α_2 are the power allocation coefficient (PACs) for SU_{1k} and SU_2 respectively with α_1+α_2=1; $\alpha_1 < \alpha_2$. The recieved signal at SU_{1k} and SU_2 are given by:

$$y_{u_{1k}}^{DN}(t) = h_{s,u_{1k}} m(t) + h_{p,u_{1k}} \sqrt{P_p} x_p(t) + n_{1k}(t), \quad (4a)$$

$$y_{u2}^{DN}(t) = h_{s,u_2} m(t) + h_{p,u_2} \sqrt{P_p} x_p(t) + n_2(t), \quad (4b)$$

where $n_{1k}(t)$ and $n_2(t)$ are the AWGN at SU_{1k} and SU_2 respectively; $x_p(t)$ is the signal from PT with power P_p. Now, SU_{1k} will firstly decode m_2 followed by m_{1k} using SIC technique. Then, the corresponding signal to interfernce plus noise ratio (SINR) equations are given by:

$$\Gamma_{1k,m_2}^{DN} = \frac{|h_{s,u_{1k}}|^2 \alpha_2 P_s}{|h_{s,u_{1k}}|^2 \alpha_1 P_s + |h_{p,u_{1k}}|^2 P_p + \sigma^2}, \quad (5a)$$

$$\Gamma_{1k,m_{1k}}^{DN} = \frac{|h_{s,u_{1k}}|^2 \alpha_1 P_s}{|h_{s,u_{1k}}|^2 \alpha_2 P_s \zeta + |h_{p,u_{1k}}|^2 P_p + \sigma^2}, \quad (5b)$$

where ζ ($0 < \zeta < 1$) is the i-SIC coefficient, that introduces residual interference at SU_{1k}. The SINR coresponding to the decoding of m_2 at SU_2 is given by:

$$\Gamma_{2,m_2}^{DN} = \frac{|h_{s,u_2}|^2 \alpha_2 P_s}{|h_{s,u_2}|^2 \alpha_1 P_s + |h_{p,u_2}|^2 P_p + \sigma^2}. \quad (6)$$

Notice that ST will employ CN mode, if the SNR over ST-SU_2 link is found to be lower than the threshold during the pilot signal transmissions. In this case, communication happens in two half cycles. The first half cycle is used for transmission from ST as is the case with DN mode. Therefore, the received signal at SU_{1k} in CN mode, $y_{u_{1k}}^{CN}(t) = y_{u_{1k}}^{DN}(t)$. The SINR at SU_{1k} for decoding m_2 and m_{1k} in CN and DN modes are also equal, i.e., $\Gamma_{1k,m_2}^{CN} = \Gamma_{1k,m_2}^{DN}$ and $\Gamma_{1k,m_{1k}}^{CN} = \Gamma_{1k,m_{1k}}^{DN}$. During the second half cycle, SU_{1k} acts as a DF relay to forward m_2 to SU_2 and the signal received at SU_2 is given by:

$$y_{u2}^{CN}(t) = h_{u_{1k},u_2} \sqrt{P_{u_{1k}}} m_2(t) + h_{p,u_2} \sqrt{P_p} x_p(t) + n_2(t), \quad (7)$$

Now, SU_2 decodes m_2 and the corresponding SINR is given by:

$$\Gamma_{2,m_2}^{CN} = \frac{|h_{u_{1k},u_2}|^2 P_{u_{1k}}}{|h_{p,u_2}|^2 P_p + \sigma^2}. \quad (8)$$

Notice that, the conventional coopeartive relay based CNOMA system only employs CN mode, i.e., message from ST gets delivered to SU_2 via selected relay SU_{1k}.

Algorithm 1 Incremental Relaying based Partial Relay Selection Algorithm

```
Initialize: Threshold SINR (β_{th,1} , β_{th,2}), Predefined Threshold
  (TH), ST − SU2 link SNR (linkSNR), Number of near user
  relays (K), channel coefficients (h_{ij})
ModeSelectionFlag ← None
SU_{1K} ← None
bestChannelGain ← 0
for i = 1 to K do
    if |h_{s,SU_{1i}}|^2 ≥ β_{th,1} and |h_{s,SU_{1i}}|^2 ≥ β_{th,2} then
        if |h_{s,SU_{1k}}|^2 > bestChannelGain then
            bestChannelGain ← |h_{s,SU_{1k}}|^2
            SU_{1k} = arg max_{k=1,..K} |h_{s,SU_{1i}}|^2
        end if
    end if
end for
return SU_{1k} and |h_{s,SU_{1k}}|^2
if linkSNR > TH then
    ModeSelectionFlag ← DN mode
else
    ModeSelectionFlag ← CN mode
end if
```

III. Outage and Throughput Performance Analysis

This section explains analytical equations for the outage probabilities and throughput experienced by SU_{1k} and SU_2 in both IRP-CNOMA and CR-CNOMA networks. Let r_1 and r_2 be the target rates for the m_{1k} and m_2. In the DN mode, let $\beta_{th,1} = 2^{r_1} - 1$ and $\beta_{th,2} = 2^{r_2} - 1$ respectively be the threshold SINR for decoding m_{1k} and m_2. Further the achievable rate is halved and two half cycles are needed to send message symbols to SU_{1k} and SU_2 in CN mode, hence $\beta'_{th,1} = 2^{2r_1} - 1$ and $\beta'_{th,2} = 2^{2r_2} - 1$ respectively are the threshold SINR for the CN mode.

A. Outage Probability (P_o) of Near User SU_{1k} in IRP-CNOMA Network (IRPCN)

Notice that SU_{1k} will experience outage, if it fails to decode m_{1k} in DN or CN mode. Thus, P_o experienced by SU_{1k} in IRPCN is calculated as:

$$\begin{aligned} P_{o,1k}^{IRPCN} =& 1-\Pr(\Gamma_{2,m_2}^{DN} \geq \beta_{th,2}, \Gamma_{1k,m_2}^{DN} \geq \beta_{th,2}, \\ & \Gamma_{1k,m_{1k}}^{DN} \geq \beta_{th,1}) - \Pr(\Gamma_{2,m_2}^{DN} < \beta_{th,2}, \\ & \Gamma_{1k,m_2}^{CN} \geq \beta_{th,2}^{'}, \Gamma_{1k,m_{1k}}^{CN} \geq \beta_{th,1}^{'}) \end{aligned} \tag{9}$$

Proposition 1:Analytical expression for $P_{o,1k}^{IRPCN}$ is given by:

$$P_{o,1k}^{IRPCN} = \begin{cases} 1-\Big(B_0B_1\Big)-\Big(\big(1-B_0\big)B_3\Big); \\ \qquad 0<\alpha_1<\frac{1}{1+\beta_{th,2}^{'}}, \frac{\zeta\beta_{th,1}^{'}}{1+\zeta\beta_{th,1}^{'}}<\alpha_1<1 \\ (1-B_0)B_1; \frac{1}{1+\beta_{th,2}^{'}}<\alpha_1<\frac{1}{1+\beta_{th,2}}, \\ \qquad \frac{\zeta\beta_{th,1}}{1+\zeta\beta_{th,1}}<\alpha_1<\frac{\zeta\beta_{th,1}^{'}}{1+\zeta\beta_{th,1}^{'}} \\ 1 \qquad ; otherwise \end{cases} \tag{10}$$

Note that, here $B_2 = 1-B_0$ and B_0, B_1 , B_3 are given by (14), (15) and (16) respectively, given on next page. where $w_1 = i\phi_1 P_p \lambda_{p,u_{1k}}$ and $w_2 = i\phi_2 P_p \lambda_{p,u_{1k}}$. *Proof*: Assuming that the fading over ST-SU_{1k} and ST-SU_2 links are independent, (9) can be written as follows:

$$\begin{aligned} & P_{o,1k}^{IRPCN} = 1- \\ & \underbrace{\Pr(\Gamma_{2,m_2}^{DN} \geq \beta_{th,2})}_{B_0} \underbrace{\Pr(\Gamma_{1k,m_2}^{DN} \geq \beta_{th,2}, \Gamma_{1k,m_{1k}}^{DN} \geq \beta_{th,1})}_{B_1} \\ & - \underbrace{\Pr(\Gamma_{2,m_2}^{DN} < \beta_{th,2})}_{B_2} \underbrace{\Pr(\Gamma_{1k,m_2}^{CN} \geq \beta_{th,2}^{'}, \Gamma_{1k,m_{1k}}^{CN} \geq \beta_{th,1}^{'})}_{B_3} \end{aligned} \tag{11}$$

Utilizing (6), B_0 becomes:

$$B_0 = \Pr\left(|h_{s,u_2}|^2 P_s \geq \phi_0(|h_{p,u_2}|^2 P_p + \sigma^2)\right) \tag{12a}$$

$$\begin{aligned} &= \underbrace{\Pr\left(|h_{s,u_2}|^2 \geq \frac{\phi_0}{P_{s,max}}(YP_p+\sigma^2); Z < \frac{\theta_I}{P_{s,max}}\right)}_{B_{00}} \\ &+ \underbrace{\Pr\left(|h_{s,u_2}|^2 \geq \frac{\phi_0 Z}{\theta_I}(YP_p+\sigma^2); Z > \frac{\theta_I}{P_{s,max}}\right)}_{B_{01}} \end{aligned} \tag{12b}$$

Here (12b) follows by substituting for P_s given by (2a) in (12a), where $\phi_0 = \frac{\beta_{th,2}}{\alpha_2-\alpha_1\beta_{th,2}}$, $|h_{p,u_2}|^2 = Y$, $|h_{s,p}|^2 = Z$ and notice that, $|h_{ij}|^2$ are exponential with mean values λ_{ij}; then B_{00} and B_{01} are determined as:

$$\begin{aligned} B_{00} =& e^{-\frac{\phi_0\sigma^2}{P_{s,max}\lambda_{s,u_2}}}\left(1-e^{-\frac{\theta_I}{\lambda_{s,p}P_{s,max}}}\right) \\ & \left(\frac{P_{s,max}\lambda_{s,u_2}}{P_{s,max}\lambda_{s,u_2}+w_0}\right) \end{aligned} \tag{13a}$$

$$\begin{aligned} B_{01} =& \frac{-\theta_I\lambda_{s,u_2}}{w_0\lambda_{s,p}}\Bigg[e^{\frac{\theta_I\lambda_{s,u_2}}{w_0}\left(\frac{\phi_0\sigma^2}{\theta_I\lambda_{s,u_2}}+\frac{1}{\lambda_{s,p}}\right)} \times E_i\Bigg[\frac{-\theta_I}{P_{s,max}} \\ & \left(\frac{\phi_0\sigma^2}{\theta_I\lambda_{s,u_2}}+\frac{1}{\lambda_{s,p}}\right) - \left(\frac{\phi_0\sigma^2}{\theta_I\lambda_{s,u_2}}+\frac{1}{\lambda_{s,p}}\right)\frac{\theta_I\lambda_{s,u_2}}{w_0}\Bigg]\Bigg] \end{aligned} \tag{13b}$$

where $w_0 = \phi_0 P_p \lambda_{p,u_2}$ and $E_i()$ is the exponential integral function. Notice that (13b) is obtained by using (3.352.2) of [33]. Substituting (13a) and (13b) in (12b) gives B_0 as in (14), given on next page. Utilizing (1) and (5), further B_1 and B_3 can be determined similar to B_0.

1) Outage Probability of SU_{1k} in CRP-CNOMA Network (CRPCN) : Based on PRS scheme SU_{1k} is chosen and this relay is used for CRP-CNOMA as well. Ensure that both m_2 and m_{1k} are successfully decoded at SU_{1k}, as CRP-NOMA system works in CN mode alone. Thus, P_o experienced by SU_{1k} in CRPCN system is determined as:

$$P_{o,1k}^{CRPCN} = 1-\Pr\left(\Gamma_{1k,m_2}^{CN} \geq \beta_{th,2}^{'}, \Gamma_{1k,m_{1k}}^{CN} \geq \beta_{th,1}^{'}\right) \tag{17}$$

Analytical expression for $P_{o,1k}^{CRPCN}$ is given by:

$$P_{o,1k}^{CRPCN} = \begin{cases} 1-B_3; 0<\alpha_1<\frac{1}{1+\beta_{th,2}^{'}}, \frac{\zeta\beta_{th,1}^{'}}{1+\zeta\beta_{th,1}^{'}}<\alpha_1<1 \\ 1 \qquad ;\text{otherwise} \end{cases} \tag{18}$$

B. Outage Probability of Far User SU_2 in IRPCN

Notice that SU_2 will experience outage, if it fails to decode m_2 in DN and CN mode. Thus, P_o experienced by SU_2 in IRPCN is calculated as:

$$\begin{aligned} P_{o,2}^{IRPCN} =& \Pr(\Gamma_{2,m_2}^{DN} < \beta_{th,2}, \Gamma_{1k,m_2}^{CN} < \beta_{th,2}^{'}) \\ & + \Pr(\Gamma_{2,m_2}^{DN} < \beta_{th,2}, \Gamma_{1k,m_2}^{CN} \geq \beta_{th,2}^{'}, \Gamma_{2,m_2}^{CN} < \beta_{th,2}^{'}) \end{aligned} \tag{19}$$

Analytical expression for $P_{o,2}^{IRPCN}$ is given by:

$$P_{o,2}^{IRPCN} = \begin{cases} \big(1-B_0\big)\big(1-C_0\big) \\ +C_0\big(1-B_0\big)C_1 \ ; 0<\alpha_1<\frac{1}{1+\beta_{th,2}^{'}} \\ 1-B_0 \qquad ; \frac{1}{1+\beta_{th,2}^{'}}<\alpha_1<\frac{1}{1+\beta_{th,2}} \\ 1 \qquad ;\text{otherwise} \end{cases} \tag{20}$$

where C_0 and C_1 can be determined similar to B_0 discussed earlier and are given by (21) and (22), given on next page with $w_3 = i\phi_3 P_p \lambda_{p,u_{1k}}$, $w_4 = P_{u_{1k},max}\lambda_{u_{1k},p}$ and $w_5 = P_{u_{1k},max}\lambda_{u_{1k},u_2}$.

1) Outage Probability of Far User SU_2 in CRPCN : As we know that CRP-CNOMA system works in CN mode alone and then the P_o experienced by SU_2 in CRPCN is determined as:

$$P_{o,2}^{CRPCN} = 1-\Pr\left(\Gamma_{1k,m_2}^{CN} \geq \beta_{th,2}^{'}, \Gamma_{2,m_2}^{CN} \geq \beta_{th,2}^{'}\right) \tag{23}$$

Analytical expression for $P_{o,2}^{CRPCN}$ is given by:

$$P_{o,2}^{CRPCN} = \begin{cases} 1-C_0\big(1-C_1\big); 0<\alpha_1<\frac{1}{1+\beta_{th,2}^{'}} \\ 1 \qquad ;\text{otherwise} \end{cases} \tag{24}$$

C. System Outage Probability ($P_{o,sys}$)

The outage of the system happens when either SU_{1k} or SU_2 or both experience outages in the both the DN mode and the CN mode in IRP-CNOMA. Therefore, the following equation can be used to determine $P_{o,sys}^{IRPCN}$:

$$\begin{aligned}P_{o,sys}^{IRPCN} =& 1-\Pr(\Gamma_{2,m_2}^{DN}\geq\beta_{th,2},\Gamma_{1k,m_2}^{DN}\geq\beta_{th,2},\\ &\Gamma_{1k,m_{1k}}^{DN}\geq\beta_{th,1})-\Pr(\Gamma_{2,m_2}^{DN}<\beta_{th,2},\\ &\Gamma_{1k,m_2}^{CN}\geq\beta_{th,2}^{'},\Gamma_{1k,m_{1k}}^{CN}\geq\beta_{th,1}^{'},\Gamma_{2,m_2}^{CN}\geq\beta_{th,2}^{'})\end{aligned} \tag{25}$$

Knowing B_0, B_1, B_3 and C_1, then $P_{o,sys}^{IRPCN}$ can be determined and the closed form equation is given by:

$$P_{o,sys}^{IRPCN}=\begin{cases}1-\Big(B_0B_1\Big)-\Big(\big(1-B_0\big)B_3\big(1-C_1\big)\Big); & 0<\alpha_1<\frac{1}{1+\beta_{th,2}^{'}},\frac{\zeta\beta_{th,1}^{'}}{1+\zeta\beta_{th,1}^{'}}<\alpha_1<1\\ \big(1-B_0\big)B_1 ; & \frac{1}{1+\beta_{th,2}^{'}}<\alpha_1<\frac{1}{1+\beta_{th,2}},\ \frac{\zeta\beta_{th,1}}{1+\zeta\beta_{th,1}}<\alpha_1<\frac{\zeta\beta_{th,1}^{'}}{1+\zeta\beta_{th,1}^{'}}\\ 1 & ;\text{otherwise}\end{cases} \tag{26}$$

System outage occurs in CRP-CNOMA, when SU_{1k} or SU_2 suffer outage in CN mode. Thus, $P_{o,sys}^{CRPCN}$ is determined as:

$$\begin{aligned}P_{o,sys}^{CRPCN} =& 1-\\ &\Pr\left(\Gamma_{1k,m_2}^{CN}\geq\beta_{th,2}^{'},\Gamma_{1k,m_{1k}}^{CN}\geq\beta_{th,1}^{'},\Gamma_{2,m_2}^{CN}\geq\beta_{th,2}^{'}\right)\end{aligned} \tag{27}$$

The closed form expression for the system outage in CRP-CNOMA is given by:

$$P_{o,sys}^{CRPCN}=\begin{cases}1-B_3\big(1-C_1\big); & 0<\alpha_1<\frac{1}{1+\beta_{th,2}^{'}},\ \frac{\zeta\beta_{th,1}^{'}}{1+\zeta\beta_{th,1}^{'}}<\alpha_1<1\\ 1 & ;\text{otherwise}\end{cases} \tag{28}$$

D. System Throughput

The system throughput depends on P_o experienced by the SUs, since ST serves SU_{1k} and SU_2 with constant target rates. In IRP-CNOMA, let P_1^{DN} and P_1^{CN} be the probabilities of m_{1k} delivered to SU_{1k} in DN and CN modes respectively. Further, let P_2^{DN} and P_2^{CN} be the probabilities which m_2 is delivered to SU_2 in DN and CN modes in CRP-CNOMA. Then, the system throughput for IRPCN and CRPCN is given by:

$$S^{IRPCN}=P_1^{DN}r_1+P_1^{CN}\frac{r_1}{2}+P_2^{DN}r_2+P_2^{CN}\frac{r_2}{2} \tag{29}$$

$$S^{CRPCN}=P_1^{CN}\frac{r_1}{2}+P_2^{CN}\frac{r_2}{2} \tag{30}$$

Now P_1^{DN} and P_2^{DN} are determined as follows:

$$\begin{aligned}P_1^{DN}&=\Pr\left(\Gamma_{1k,m_2}^{DN}\geq\beta_{th,2},\Gamma_{1k,m_{1k}}^{DN}\geq\beta_{th,1}\right)\\ &=B_1;0<\alpha_1<\frac{1}{1+\beta_{th,2}}\frac{\zeta\beta_{th,1}}{1+\zeta\beta_{th,1}}<\alpha_1<1\end{aligned} \tag{31}$$

$$\begin{aligned}P_2^{DN}&=\Pr\left(\Gamma_{2,m_2}^{DN}\geq\beta_{th,2}\right)\\ &=B_0;0<\alpha_1<\frac{1}{1+\beta_{th,2}}\end{aligned} \tag{32}$$

Notice that $P_1^{CN}=1-P_{o,1K}^{CRPCN}$ and $P_2^{CN}=1-P_{o,2}^{CRPCN}$. The throughput can be determined by using (29) and (30).

$$\begin{aligned}B_0=&e^{-\frac{\phi_0\sigma^2}{P_{s,max}\lambda_{s,u_2}}}\left(1-e^{-\frac{\theta_I}{\lambda_{s,p}P_{s,max}}}\right)\left(\frac{P_{s,max}\lambda_{s,u_2}}{P_{s,max}\lambda_{s,u_2}+\phi_0P_p\lambda_{p,u_2}}\right)-\frac{\theta_I\lambda_{s,u_2}}{\phi_0P_p\lambda_{p,u_2}\lambda_{s,p}}\Bigg[e^{\frac{\theta_I\lambda_{s,u_2}}{\phi_0P_p\lambda_{p,u_2}}\left(\frac{\phi_0\sigma^2}{\theta_I\lambda_{s,u_2}}+\frac{1}{\lambda_{s,p}}\right)}\\ &\times E_i\Bigg[-\left(\frac{\phi_0\sigma^2}{\theta_I\lambda_{s,u_2}}+\frac{1}{\lambda_{s,p}}\right)\frac{\theta_I}{P_{s,max}}-\left(\frac{\phi_0\sigma^2}{\theta_I\lambda_{s,u_2}}+\frac{1}{\lambda_{s,p}}\right)\frac{\theta_I\lambda_{s,u_2}}{\phi_0P_p\lambda_{p,u_2}}\Bigg]\Bigg];\quad 0<\alpha_1<\frac{1}{1+\beta_{th,2}}\end{aligned} \tag{14}$$

$$\begin{aligned}B_1=&\sum_{i=1}^{K}(-1)^{i-1}\binom{K}{i}e^{-\frac{i\phi_1\sigma^2}{P_{s,max}\lambda_o}}\left(1-e^{-\frac{\theta_I}{\lambda_{s,p}P_{s,max}}}\right)\left(\frac{P_{s,max}\lambda_o}{P_{s,max}\lambda_o+w_1}\right)-\sum_{i=1}^{K}(-1)^{i-1}\binom{K}{i}\frac{\theta_I\lambda_o}{w_1\lambda_{s,p}}\Bigg[e^{\frac{\theta_I\lambda_o}{w_1}\left(\frac{i\phi_1\sigma^2}{\theta_I\lambda_o}+\frac{1}{\lambda_{s,p}}\right)}\\ &\times E_i\Bigg[-\left(\frac{i\phi_1\sigma^2}{\theta_I\lambda_o}+\frac{1}{\lambda_{s,p}}\right)\frac{\theta_I}{P_{s,max}}-\left(\frac{i\phi_1\sigma^2}{\theta_I\lambda_o}+\frac{1}{\lambda_{s,p}}\right)\frac{\theta_I\lambda_o}{w_1}\Bigg]\Bigg];0<\alpha_1<\frac{1}{1+\beta_{th,2}},\frac{\zeta\beta_{th,1}}{1+\zeta\beta_{th,1}}<\alpha_1<1\end{aligned} \tag{15}$$

$$\begin{aligned}B_3=&\sum_{i=1}^{K}(-1)^{i-1}\binom{K}{i}e^{-\frac{i\phi_2\sigma^2}{P_{s,max}\lambda_o}}\left(1-e^{-\frac{\theta_I}{\lambda_{s,p}P_{s,max}}}\right)\left(\frac{P_{s,max}\lambda_o}{P_{s,max}\lambda_o+w_2}\right)-\sum_{i=1}^{K}(-1)^{i-1}\binom{K}{i}\frac{\theta_I\lambda_o}{w_2\lambda_{s,p}}\Bigg[e^{\frac{\theta_I\lambda_o}{w_2}\left(\frac{i\phi_2\sigma^2}{\theta_I\lambda_o}+\frac{1}{\lambda_{s,p}}\right)}\\ &\times E_i\Bigg[-\left(\frac{i\phi_2\sigma^2}{\theta_I\lambda_o}+\frac{1}{\lambda_{s,p}}\right)\frac{\theta_I}{P_{s,max}}-\left(\frac{i\phi_2\sigma^2}{\theta_I\lambda_o}+\frac{1}{\lambda_{s,p}}\right)\frac{\theta_I\lambda_o}{w_2}\Bigg]\Bigg];0<\alpha_1<\frac{1}{1+\beta_{th,2}^{'}},\frac{\zeta\beta_{th,1}^{'}}{1+\zeta\beta_{th,1}^{'}}<\alpha_1<1\end{aligned} \tag{16}$$

$$C_0 = \sum_{i=1}^{K}(-1)^{i-1}\binom{K}{i}e^{-\frac{i\phi_3\sigma^2}{P_{s,max}\lambda_o}}\left(1-e^{-\frac{\theta_I}{\lambda_{s,p}P_{s,max}}}\right)\left(\frac{P_{s,max}\lambda_o}{P_{s,max}\lambda_o+w_3}\right)-\sum_{i=1}^{K}(-1)^{i-1}\binom{K}{i}\frac{\theta_I\lambda_o}{w_3\lambda_{s,p}}\Bigg[e^{\frac{\theta_I\lambda_o}{w_3}\left(\frac{i\phi_3\sigma^2}{\theta_I\lambda_o}+\frac{1}{\lambda_{s,p}}\right)}$$
$$E_i\Bigg[-\left(\frac{i\phi_3\sigma^2}{\theta_I\lambda_o}+\frac{1}{\lambda_{s,p}}\right)\frac{\theta_I}{P_{s,max}}-\left(\frac{i\phi_3\sigma^2}{\theta_I\lambda_o}+\frac{1}{\lambda_{s,p}}\right)\frac{\theta_I\lambda_o}{w_3}\Bigg]\Bigg]; \quad 0<\alpha_1<\frac{1}{1+\beta'_{th,2}} \tag{21}$$

$$C_1 = \left(1-e^{-\frac{\theta_I}{w_4}}\right)\left(1-\frac{w_5}{\lambda_{p,u_2}\beta'_{th,2}P_p+w_5}e^{-\frac{\beta'_{th,2}\sigma^2}{w_5}}\right)+e^{-\frac{\theta_I}{w_4}}-\frac{\theta_I\lambda_{u_{1k},u_2}}{\lambda_{p,u_2}\lambda_{u_{1k},p}\beta'_{th,2}P_p}\Bigg[e^{\frac{\theta_I\lambda_{u_{1k},u_2}}{\beta'_{th,2}P_p\lambda_{p,u_2}}\left(\frac{\beta'_{th,2}\sigma^2}{\theta_I\lambda_{u_{1k},u_2}}+\frac{1}{\lambda_{u_{1k},p}}\right)}$$
$$\times E_i\Bigg[-\left(\frac{\beta'_{th,2}\sigma^2}{\theta_I\lambda_{u_{1k},u_2}}+\frac{1}{\lambda_{u_{1k},p}}\right)\frac{\theta_I}{P_{u_{1k},max}}-\left(\frac{\sigma^2}{P_p\lambda_{p,u_2}}+\frac{\theta_I\lambda_{u_{1k},u_2}}{\beta'_{th,2}P_p\lambda_{p,u_2}}\right)\Bigg]\Bigg]; 0<\alpha_1<\frac{1}{1+\beta'_{th,2}} \tag{22}$$

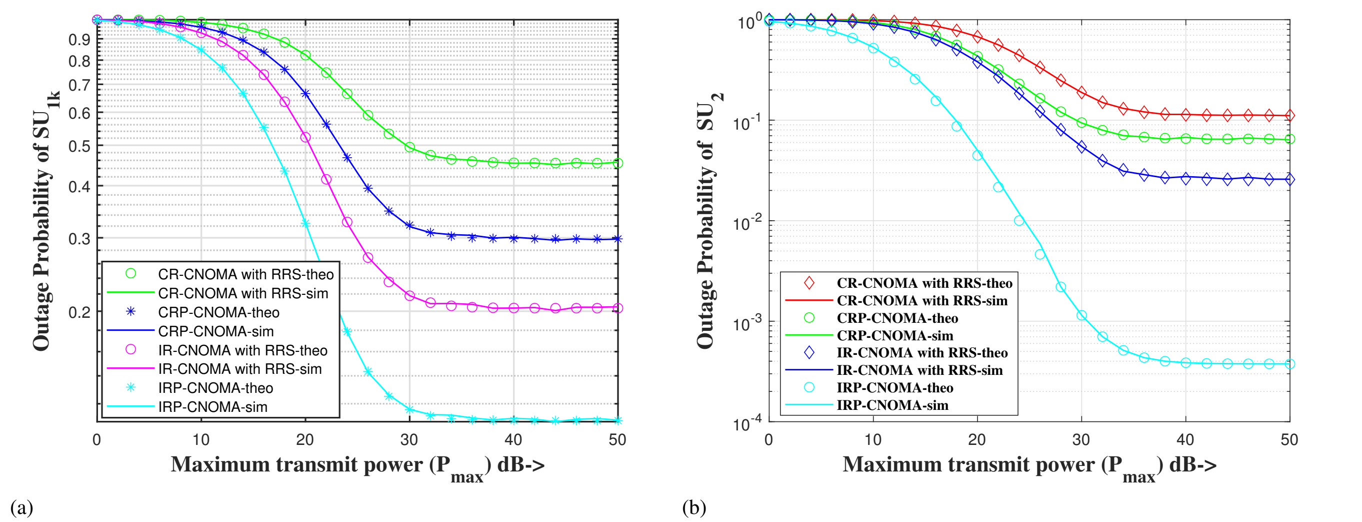

Fig. 2. (a) Outage probability of SU_{1k} vs Maximum transmit power (P_{max}) (b) Outage probability of SU_2 vs Maximum transmit power (P_{max}).

IV. Analytical and Simulation Results

We consider a 2D topology as shown in Fig. 1, whereby the position of ST, SU_{1k}, SU_2, PT and PR are fixed at (0, 0), (5, 5), (10, 0), (2.5, 10) and (7.5, 10) respectively (expressed in meters). The mean channel power gains are assumed to be $\lambda_{i,j} = d_{i,j}^{-n}$, where $d_{i,j}$ is the normalized distance ($d_0 = 10m$ i.e., normalized in relation to the reference distance) between nodes i, j and n (assumed as 3 for all the links) is the path loss exponent [34]. The analysis is carried out by considering various parameters which is shown in Table 2. Also, These analytical findings are validated by Monte-carlo simulations.

In Figs. 2(a)-2(b), the P_o of the SUs is plotted against P_{max} (where P_{max} = $P_{s,max}$ = $P_{u_{1k},max}$) of the ST. The PRS scheme is compared with RRS for IRP/CRP-CNOMA systems. Observed that the P_o of the SUs decrease with the increase in P_{max} of the ST and saturates beyond the threshold. When $P_{max} < \theta_I$, the transmit power depends on P_{max} and when $P_{max} > \theta_I$, the transmit power depends on the threshold power constraint as given in (2). Also, the P_o of SUs with PRS scheme is lower than the RRS scheme. In Fig. 3, the $P_{o,sys}$ of IRP/CRP-CNOMA is plotted against the P_{max}. As P_{max} is increased, the system outage probability is found to decrease as long as $P_{max} < \theta_I$. This happens because, when $P_{max} < \theta_I$, the instantaneous transmit powers of ST and $SU1$ (i.e., P_s and $P_{u_{1k}}$ respectively) depend on P_{max} as is evident from (2). However, when $P_{max} > \theta_I$, the system outage probability saturates and becomes independent of P_{max}, i.e., an outage floor is observed. This happens because, when

TABLE II
SYSTEM PARAMETERS

Parameters	Values
α_1 , α_2	0.2, 0.8
σ^2, imperfect SIC (ζ)	1 , 0.1
K	5
r_1 , r_2	0.6, 0.7
$d_{s,p}$, $d_{s,u_{1k}}$, d_{s,u_2}, d_{u_{1k},u_2}, $d_{p,u_{1k}}$ & $d_{p,u_{1k}}$	3.25 , 0.707, 1, 0.707, 0.55 and 0.559
θ_I, P_p	30 dB, 10 dB

$P_{max} > \theta_I$, both P_s and $P_{u_{1k}}$ no longer depend on P_{max} as is evident from (2). The results demonstrate that PRS scheme reduced $P_{o,sys}$ of the system and the $P_{o,sys}$ of SUs with PRS scheme is lower than the RRS scheme. Increasing the number of relay nodes improves the possibility of choosing the relay with higher channel gain. $|h_{i,j}|^2$. This leads to improvement in the the outage probability and the throughput performances. In Fig. 4, the $P_{o,sys}$ of IRP-CNOMA and IR-CNOMA with RRS is plotted against the P_{max} for distinct K values. Further, the results show that the $P_{o,sys}$ reduced when K is increased. Also, IRP-CNOMA provides lower $P_{o,sys}$ compared to the IR-CNOMA with RRS scheme. Fig. 5, shows the throughput performance of the IRP/CRP-CNOMA considering PRS and RRS schemes against P_{max}, where the interference threshold of the PR (θ_I) is selected as a fixed quantity. As P_{max} is increased, throughput has been observed to increase as long as $P_{max} < \theta_I$. The results show that the IRP-CNOMA provides higher throughput compared to the CRP-CNOMA system and also increased for compared to the RRS scheme. In Fig. 6, the throughput performance of the IRP-CNOMA and IR-CNOMA with RRS is plotted against the P_{max} for distinct K values. Further, the results in Fig. 6 show that the throughput improves when K is increased. Also, IRP-CNOMA provides higher throughput compared to the IR-CNOMA with RRS scheme.

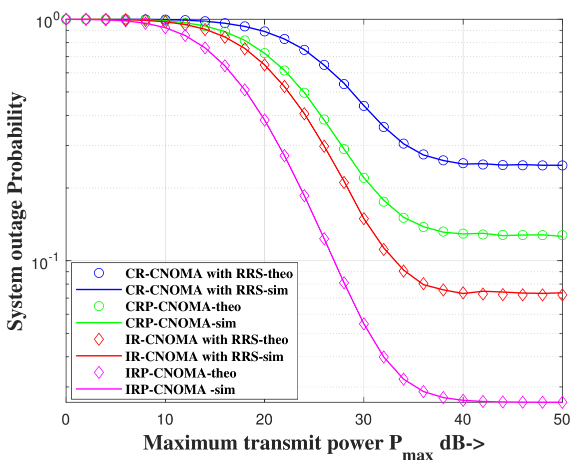

Fig. 3. System outage probability vs Maximum transmit power (P_{max}).

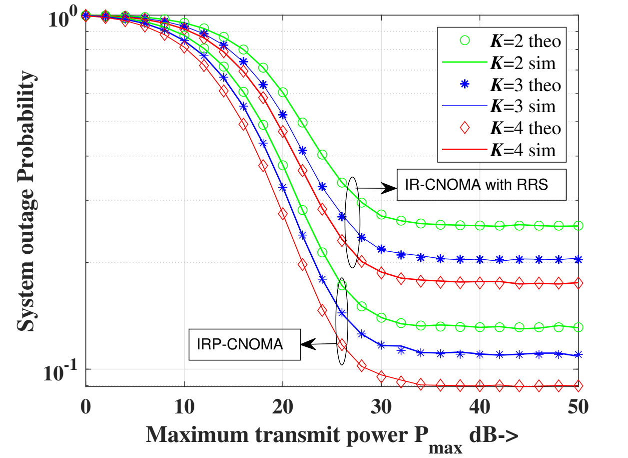

Fig 4: System outage probability vs Maximum transmit power (P_{max}): distinct K

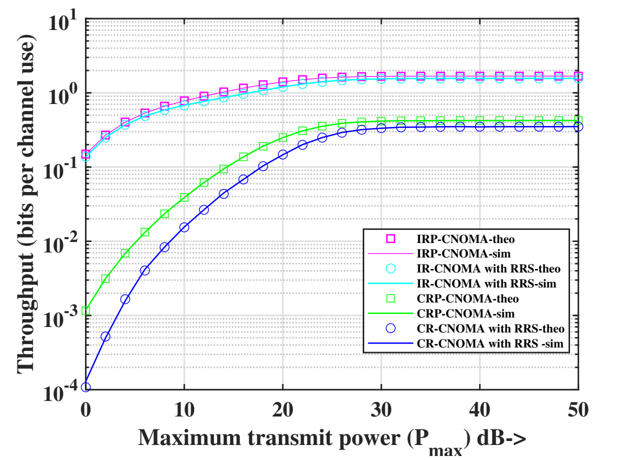

Fig 5: Throughput vs Maximum transmit power (P_{max}).

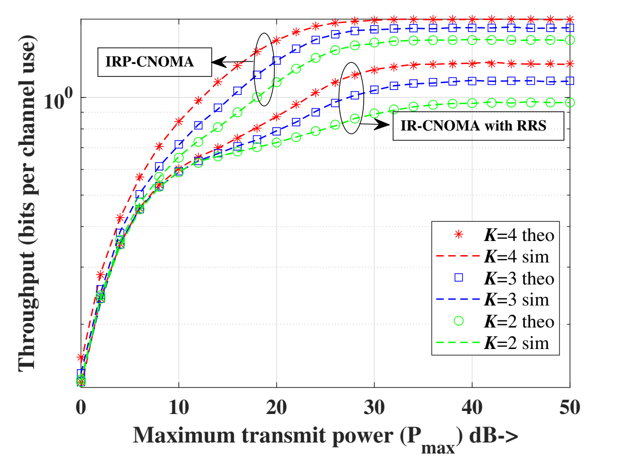

Fig 6: Throughput vs Maximum transmit power (P_{max}) : distinct K.

V. Conclusion

In this research work, we have proposed incremental relaying with partial relay selection scheme for CNOMA system with K-near user relays to forward the message of far user. The throughput performance of the IRP-CNOMA is compared with CRP-CNOMA network and RRS schemes. From the results, it is evident that the proposed scheme reduces the outage probability of the SUs and system outage probability. The proposed scheme is analytically modelled, closed form expression are derived and the results are verified with extensive simulation studies. Simultaneous wireless information and power transfer (SWIPT) - enabled relay-aided CNOMA systems under partial relay selection as well as integration of deep learning (DL) technique to further enhance the performance of IRP-CNOMA are the directions for the future work. But complexity in selecting suitable relays for energy harvesting, limited availability of hardware for SWIPT-enabled relay experimentation and lack of proper data set for the implementation of artificial intelligence (AI) techniques are the major limitations for the proposed future work.

REFERENCES

[1] Y. Liu, Z. Qin, M. Elkashlan, Z. Ding, A. Nallanathan and L. Hanzo, "Nonorthogonal Multiple Access for 5G and Beyond," in Proceedings of the IEEE, vol. 105, no. 12, pp. 2347-2381, Dec. 2017, doi: 10.1109/JPROC.2017.2768666.

[2] S. M. R. Islam, N. Avazov, O. A. Dobre and K. -s. Kwak, "Power-Domain Non-Orthogonal Multiple Access (NOMA) in 5G Systems: Potentials and Challenges," in IEEE Communications Surveys & Tutorials, vol. 19, no. 2, pp. 721-742, Secondquarter 2017, doi: 10.1109/COMST.2016.2621116.

[3] Z. Ding, M. Peng and H. V. Poor, "Cooperative Non-Orthogonal Multiple Access in 5G Systems," in IEEE Communications Letters, vol. 19, no. 8, pp. 1462-1465, Aug. 2015, doi: 10.1109/LCOMM.2015.2441064.

[4] Z. Fang, J. Hu, Y. Lu and W. Ni, "Three-User Cooperative NOMA Transmission," in IEEE Wireless Communications Letters, vol. 9, no. 4, pp. 465-469, April 2020, doi: 10.1109/LWC.2019.2959302.

[5] Goutham, V., and Harigovindan, V.P, “NOMA based Cooperative Relaying Strategy for Underwater Acoustic Sensor Networks under Imperfect SIC and Imperfect CSI: A Comprehensive Analysis,” in IEEE Access vol. 9, pp. 32857-32872, 2021.doi: 10.1109/ACCESS.2021.3060784.

[6] K. Sudha, K. A. Kumari and D. Varunika, "A Critical Survey on Security Issues in Cognitive Radio Networks," 2023 International Conference on Intelligent Systems for Communication, IoT and Security (ICISCoIS), Coimbatore, India, 2023, pp. 292-297, doi: 10.1109/ICISCoIS56541.2023.10100508.

[7] R. Halloush and H. B. Salameh, "A Formula for the Probability of Successful Packet Transmission in Cognitive Radio Networks," in IEEE Systems Journal, vol. 16, no. 4, pp. 6693-6696, Dec. 2022, doi: 10.1109/JSYST.2022.3140680.

[8] S. Haykin, "Cognitive radio: brain-empowered wireless communications," in IEEE Journal on Selected Areas in Communications, vol. 23, no. 2, pp. 201-220, Feb. 2005, doi: 10.1109/JSAC.2004.839380.

[9] B. Wang and K. J. R. Liu, "Advances in cognitive radio networks: A survey," in IEEE Journal of Selected Topics in Signal Processing, vol. 5, no. 1, pp. 5-23, Feb. 2011, doi: 10.1109/JSTSP.2010.2093210.

[10] H. B. Salameh, S. Abdel-Razeq and H. Al-Obiedollah, "Integration of Cognitive Radio Technology in NOMA-Based B5G Networks: State of the Art, Challenges, and Enabling Technologies," in IEEE Access, vol. 11, pp. 12949-12962, 2023, doi: 10.1109/ACCESS.2023.3242645.

[11] F. Zhou, Y. Wu, Y. -C. Liang, Z. Li, Y. Wang and K. -K. Wong, "State of the Art, Taxonomy, and Open Issues on Cognitive Radio Networks with NOMA," in IEEE Wireless Communications, vol. 25, no. 2, pp. 100-108, April 2018, doi: 10.1109/MWC.2018.1700113.

[12] T. -T. Nguyen, T. -H. Vu, T. -V. Nguyen, D. B. d. Costa and C. D. Ho, "Underlay Cognitive NOMA-Based Coordinated Direct and Relay Transmission," in IEEE Wireless Communications Letters, vol. 10, no. 4, pp. 854-858, April 2021, doi: 10.1109/LWC.2020.3046779.

[13] H. Zeng, X. Zhu, Y. Jiang, Z. Wei and L. Chen, "Hierarchical Symbiotic Transmission Strategy With Cooperative-NOMA for Cognitive Radio Networks," in IEEE Wireless Communications Letters, vol. 11, no. 3, pp. 558-562, March 2022, doi: 10.1109/LWC.2021.3136166.

[14] L. Lv, J. Chen, Q. Ni, Z. Ding and H. Jiang, "Cognitive Non-Orthogonal Multiple Access with Cooperative Relaying: A New Wireless Frontier for 5G Spectrum Sharing," in IEEE Communications Magazine, vol. 56, no. 4, pp. 188-195, April 2018, doi: 10.1109/MCOM.2018.1700687.

[15] M. Chitra, S. Yashaswini and S. Dhanasekaran, "Performance Analysis of Cooperative Underlay NOMA-Assisted Cognitive Radio Networks," in IEEE Wireless Communications Letters, vol. 13, no. 1, pp. 203-207, Jan. 2024, doi: 10.1109/LWC.2023.3325240.

[16] G. Li, D. Mishra and H. Jiang, "Cooperative NOMA With Incremental Relaying: Performance Analysis and Optimization," in IEEE Transactions on Vehicular Technology, vol. 67, no. 11, pp. 11291-11295, Nov. 2018, doi: 10.1109/TVT.2018.2869531.

[17] K. Reshma and A. V. Babu, "Throughput Analysis of Energy Harvesting Enabled Incremental Relaying NOMA System," in IEEE Communications Letters, vol. 24, no. 7, pp. 1419-1423, July 2020, doi: 10.1109/LCOMM.2020.2984524.

[18] Alnwaimi, G., Boujemaa, H, "Throughput analysis and optimization of cognitive radio networks using incremental relaying," in Telecommunication System, vol.71, pp. 231–247, 2019, doi.org/10.1007/s11235-018-0527-0.

[19] L. T. TU, P. L. Tung, T. Van Chien, T. T. Duy and N. T. Hoa, "Performance Evaluation of Incremental Relaying in Underlay Cognitive Radio Networks with Imperfect CSI," 2020 IEEE Eighth International Conference on Communications and Electronics (ICCE), Phu Quoc Island, Vietnam, 2021, pp. 472-477, doi: 10.1109/ICCE48956.2021.9352039.

[20] K. S. G. Kiran and S. R, "Performance Analysis of DF-Relaying-based Cooperative NOMA System with Partial Relay Selection," 2022 14th International Conference on COMmunication Systems & NETworkS (COMSNETS), Bangalore, India, 2022, pp. 574-580, doi: 10.1109/COMSNETS53615.2022.9668554.

[21] K. Sultan, "Best Relay Selection Schemes for NOMA Based Cognitive Relay Networks in Underlay Spectrum Sharing," in IEEE Access, vol. 8, pp. 190160-190172, 2020, doi: 10.1109/ACCESS.2020.3031631.

[22] T. Jing et al., "Cooperative Relay Selection in Cognitive Radio Networks," in IEEE Transactions on Vehicular Technology, vol. 64, no. 5, pp. 1872-1881, May 2015, doi: 10.1109/TVT.2014.2338297.

[23] L. Bariah, S. Muhaidat and A. Al-Dweik, "Error Performance of NOMA-Based Cognitive Radio Networks With Partial Relay Selection and Interference Power Constraints," in IEEE Transactions on Communications, vol. 68, no. 2, pp. 765-777, Feb. 2020, doi: 10.1109/TCOMM.2019.2921360.

[24] S. I. Hussain, M. -S. Alouini, M. Hasna and K. Qaraqe, "Partial Relay Selection in Underlay Cognitive Networks with Fixed Gain Relays," 2012 IEEE 75th Vehicular Technology Conference (VTC Spring), Yokohama, Japan, 2012, pp. 1-5, doi: 10.1109/VETECS.2012.6240207.

[25] G. Im and J. H. Lee, "Outage Probability for Cooperative NOMA Systems With Imperfect SIC in Cognitive Radio Networks," in IEEE Communications Letters, vol. 23, no. 4, pp. 692-695, April 2019, doi: 10.1109/LCOMM.2019.2903040.

[26] X. Zhang, K. An, B. Zhang, Z. Chen, Y. Yan and D. Guo, "Vickrey Auction-Based Secondary Relay Selection in Cognitive Hybrid Satellite-Terrestrial Overlay Networks With Non-Orthogonal Multiple Access," in IEEE Wireless Communications Letters, vol. 9, no. 5, pp. 628-632, May 2020, doi: 10.1109/LWC.2019.2963863.

[27] A. V. and B. A. V., "Performance Analysis of NOMA-Based Underlay Cognitive Radio Networks With Partial Relay Selection," in IEEE Transactions on Vehicular Technology, vol. 70, no. 5, pp. 4615-4630, May 2021, doi: 10.1109/TVT.2021.3071338.

[28] C. Hu, Q. Li, Q. Zhang and J. Qin, "Security Optimization for an AF MIMO Two-Way Relay-Assisted Cognitive Radio Nonorthogonal Multiple Access Networks With SWIPT," in IEEE Transactions on Information Forensics and Security, vol. 17, pp. 1481-1496, 2022, doi: 10.1109/TIFS.2022.3163842.

[29] Zhang, M., Wang, X., Li, E. et al. "Secure 5G downlink NOMA cognitive relay network: joint the impact of imperfect spectrum sensing and outdated CSI, "in Wireless Network, 2024, doi: https://doi.org/10.1007/s11276-023-03632-x.

[30] S. Lee, D. B. da Costa, Q. T. Vien, T. Q. Duong, and R. T. de Sousa, “Nonorthogonal multiple access schemes with partial relay selection,“ in IET Communications, vol. 11, no. 6, pp. 846–854, Apr. 2017, doi:10.1049/iet-com.2016.0836.

[31] M. G. Khafagy, M. -S. Alouini and S. Aïssa, "Full-Duplex Relay Selection in Cognitive Underlay Networks," in IEEE Transactions on Communications, vol. 66, no. 10, pp. 4431-4443, Oct. 2018, doi: 10.1109/TCOMM.2018.2840705.

[32] S. Arzykulov, G. Nauryzbayev, T. A. Tsiftsis, B. Maham and M. Abdallah, "On the Outage of Underlay CR-NOMA Networks With Detect-and-Forward Relaying," in IEEE Transactions on Cognitive Communications and Networking, vol. 5, no. 3, pp. 795-804, Sept. 2019, doi: 10.1109/TCCN.2019.2916561.

[33] I. S. Gradshteyn, I. M. Ryzhik, Tables of Integrals, Series and Products, fifth edition, Academic Press: New York, USA, 2007, doi:https://doi.org/10.1016/C2010-0-64839-5.

[34] Goldsmith A, Wireless Communications. Cambridge: Cambridge University Press, 2005, https://doi.org/10.1017/CBO9780511841224.

Archana P. (Graduate Student Member, IEEE) received the B.E. degree in Electronics and Communication Engineering and the M.E. Degree in Embedded Systems Technologies from Anna university, Chennai, India, in 2014 and 2016, respectively. She is currently working towards the Ph.D. degree in Electronics and Communication Department, National Institute of Technology Puducherry, India. Her current research focuses on nonorthogonal multiple access-based 5G and beyond as well as Cognitive radio. (e-mail:archanavenii@gmail.com).

Harigovindan V. P. (Senior Member, IEEE) received the Bachelor of Technology degree in Electronics and Communication Engineering from University of Calicut, the Master of Technology degree in Digital Electronics and Communication Systems from Visvesvaraya Technological University with First Rank, and the Ph.D. degree from the National Institute of Technology Calicut, in 2013. He is currently working as Associate Professor and Head, with the Department of Electronics and Communication Engineering, National Institute of Technology Puducherry (under the Ministry of Education, Government of India). He has more than 50 international publications to his credit. He served as the Principal Investigator for three funded projects, each from the Department of Science and Technology, Government of India, Science and Engineering Research Board and Microsoft AI for Earth. Presently, he is serving as the PI of a project funded by DST - Science for Equity, Empowerment and Development, Govt. of India. He has 4 patents granted to his credit. His research interests include smart aquaculture, wireless networks and wireless communications. (e-mail: hari@nitpy.ac.in).

Griffith Faustina G. holds a Bachelor's degree in Electronics and Communication Engineering from SASTRA deemed to be University. She holds a Master's degree in VLSI Design in the Department of Electronics and Communication Engineering from National Institute of Technology Puducherry. Her research interests include Wireless Communications, NOMA for 5G and beyond and Cognitive Radio. (e-mail: ggfaustina@gmail.com).

Babu A. V. (Senior Member, IEEE) received the Master of Engineering degree in telecommunication from the Department of Electrical Communication Engineering, Indian Institute of Science, Bangalore, India, in 2002 and the Ph.D. degree from the Department of Electronics and Communication Engineering, National Institute of Technology Calicut, Kozhikode, India, in 2008. He is currently a Professor with National Institute of Technology Calicut. He has authored or coauthored more than 75 papers in reputed international journals and conferences. His primary research focuses on wireless networks and the current research focuses on resource allocation for NOMA based 5G wireless networks. (e-mail:babu@nitc.ac.in).