Performance analysis of Cooperative underlay CRN in NOMA aided Energy harvesting for multiple secondary users

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Abstract: This paper proposes a relaying scheme in an underlay cognitive radio network (CRN), where a source node desires to transmit the information simultaneously to more than two desired destinations. The power required for the relay operation is based on applying energy harvesting from the base station (BS). The proposed paper also includes Non-orthogonal multiple access (NOMA) with fixed power allocation to the different users to perform the decoding process irrespective of the channel condition. We have proposed a mathematical expression for the analysis of outage probability for the different users. In this respect, the linear model is discussed for perfect successive interference cancellation (SIC) at the receiver. Using the fixed power allocation process, we have simulated different output parameters such as Bit Error Rate (BER), NOMA capability, and the outage probability.

Keywords: Cognitive radio network, relaying scheme, NOMA, power allocation.

1. Introduction
The wireless powered application in NOMA has been evolved as a new paradigm in the 5G cellular system. Incorporating NOMA to cognitive radio networks aims to solve some of the 5G issues, including spectrum quality and massive connectivity, while consistently preserving primary (PU) and secondary user (SU) transmission [5]. Depending upon the location of PU, cognitive radio network approaches are classified as underlay, overlay, and interweave. PUs and SUs same channels are used in the underlying system provided the primary network interference is below the predefined threshold. An overlay system, SU and PU transmit simultaneously in the same channel. However, PU interference can be compensated using a portion of the SU power to transmit the PU message. The SU uses the spectrum holes in interweave system to transmit without interfering with the PU [15]. The CRNs are generally implemented in mesh, ad hoc, and distributed architectures and work with licensed and unlicensed applications. IEEE 802.22 states that a BS network and several users are part of the system. The BS is a centralized distributor for users’ use of spectrum. Such high overhead contact between users and the BS would positively adversely affect the overall network efficiency. Cooperative Communication with CRN improves the efficiency that links the information to the destination [6]. Power allocation techniques are essential both for cooperative and non-orthogonal multiple access (NOMA) communications.

The proposed work is based on NOMA, where various power levels are assigned to three users. In particular, weak users with poor channel conditions received a higher percentage of power than strong users with better conditions. The NOMA with a fixed power allocation has under some conditions been analyzed to prove that a user with low channel status can strictly guarantee a channel...
Performance in the CR-NOMA. The power allocation for multiple secondary users is also presented to improve spectrum efficiency in underlay CR-NOMA [12] using the interference cancellation method. This paper's primary purpose is to evaluate the system output under energy harvested (EH) with relay-assisted NOMA to select partial relays within a CRN underlay.

2. Motivation and Contribution
In Green broadband communication, the NOMA technique has significantly improved its efficiency by power allocation scheme. NOMA’s primary objective is to analyze the power domain, where users with various levels of power at different locations. The improved spectral efficiency in CR-assisted NOMA is due to fixed power allocation even in the channel condition's poor quality [1]. Moreover, the two different users or secondary users’ power allocation scheme was examined to improve the secondary network’s energy efficiency. [4]. Thus, the spectrum utilization is enhanced through the deployment of NOMA in the secondary network or CRN.

The closed-form expression in terms of outage probability is presented in for two destinations using CR-NOMA. To support the secondary user's achievable capacity, the author in proposed a relaying protocol to forward the superimposed signal to the destination. The authors in discussed that the user, who is close to the base station, acts as relay-aided with EH; further, the outage performance was analyzed between the relay and the destination.

The key contribution of the proposed work,

- We propose EH relays in NOMA, where the best relays are selected using the hybrid partial relay selection process.
- We obtain a closed-form expression for estimating the probability of outage of three secondary users with different power levels in a slow Rayleigh fading channel environment. We also address the efficiency of the network using the EH protocol splitting time.
- The simulation results show that the NOMA device network output analysis is based on the outage probability. The error rate for the three users is better than the two users in the existing work.

The paper is structured as follows: Section 3 defines the NOMA system's system model over fading channel and derives the SNR/SINR expression using fixed power allocation. Section 4 discusses the performance of the network in terms of outage probability under perfect SIC. Section 5 discusses the results of the proposed work. The conclusion of this paper is then seen in section 6.

3. System model
In our proposed work, we considered the downlink NOMA system [8] in the relay-assisted [1] underlay EH-CRN model as shown in Figure 1. The model's function is based on a half-duplex transmission mode with perfect channel state information using primary (both transmitter and receiver) and secondary network. The secondary network consists of the base station or source, relay node, secondary users/nodes (D₁, D₂, and D₃) located at a distance of d₁, d₂, and d₃ from the base station (B). The power is allocated to the user depending on the distance. The nearest node to the base station is considered a weak user due to less power allocation, and the far user is a strong user with high power allocation. For all terminals, zero-mean additive Gaussian noise with unit variance (σ₀) was taken into account. In this paper, the choice of best relay node for the cooperative strategy with the CR network based on high channel gain between B, S and Rk can be represented as (h_{B,S}, h_{B,R_k}), where k ∈ {R₁, R₂, ..., R_N}.

The source selects the relay based on the hybrid partial relay selection method [11] [13] and transmits it to the destination. The hybrid partial relay selection method is expressed as

\[ R_2 : \min(y_{S,R_k}, y_{R_k,D}) = \max_{k=1,2,...R} \min(y_{1r}, y_{2r}) \]  (1)
Figure 1: Proposed model of downlink NOMA system in relay assisted underlay EH-CRN model

Let us consider the harvested power from S used by the selected relay to transmit data signals to (D₁, D₂, and D₃). We assume X₁, X₂ and X₃ denote the modulated message signal that the source needs to transmit to the destination. Then, the superimposed signal transmitting from the base station to the relay and relay to destination [4] can be written as

\[ X = \sqrt{P_S}(\sqrt{a_1 X_1} + \sqrt{a_2 X_2} + \sqrt{a_3 X_3}) , \]  

(2)

where \( a_1, a_2 \) and \( a_3 \) represent fixed power allocation to the destination, satisfying \( a_1 > a_2 + a_3 P_S \) and defined as transmit power from the equation (2). The signal received at both relay (R₂) and to the destination is given by

\[ Y_i = Xh_i + n_i \]  

(3)

\( h_i \) This represents Rayleigh’s channel link between the nodes and \( n_i \) the AWGN between the source and relay.

3.1 Time switching energy harvesting (EH-TS)
In this proposed work, we assume time switching energy harvesting (EH-TS)[2], the time taken by the relay for energy harvested \( \alpha T \). On the other hand, after the energy harvested period, the remaining period for the transmission and reception by the relay is given as \( (1 - \alpha)T / 2 \) then the harvested signal [9] can be written as

\[ E_{source} = \eta P_{source} H_i^2 \alpha T \]  

(4)

The relay node transmission power is measured by using equation (4) as

\[ P_{TS relay} = \frac{E_{source}}{(1 - \alpha)T / 2} = \frac{2\eta P_{source} H_i^2 \alpha}{(1 - \alpha)} \]  

(5)

Where \( \eta \) denote the energy efficiency \( 0 < \eta < 1 \).
The received signal at the relay concerning superimposed signal can be expressed as

\[ y_R^{TS} = h_1 \sqrt{P_R} (\sqrt{d_1} X_1 + \sqrt{d_2} X_2 + \sqrt{d_3} X_3) + w_R \tag{6} \]

When the signal is received at the relay, the successive interference cancellation technique is operated at the chosen relay \( R_2 \). Initially, the receiver decodes the symbol \( X_1 \) by considering other symbols as noise. Then, it decodes \( X_2 \) and discards \( X_1 \) data by using the SIC decoding procedure \[3\]. Finally, the same process is performed by decoding the \( X_3 \) signal and treats the other two signals as noise. Therefore, for different users, the signal-to-noise ratio (SNR) and signal to interference plus noise ratio (SINR) are given as a unit variance at the relay, respectively as

\[ \gamma_{R-X_1} = \frac{a_1 P_S |h_1|^2}{(a_1 + a_2) P_S |h_1|^2 + \sigma^2} \tag{7} \]

\[ \gamma_{R-X_2} = \frac{a_2 P_S |h_1|^2}{a_2 P_R |h_1|^2 + \sigma^2} \tag{8} \]

\[ \gamma_{R-X_3} = \frac{a_2 P_S |h_1|^2}{\sigma^2} \tag{9} \]

In the next time slot, the optimal relay or selected relay \[16\] transmit the message to different secondary users, the received signal obtained can be written as

\[ y_D^{TS} = h_i \sqrt{P_R} (\sqrt{d_1} X_1 + \sqrt{d_2} X_2 + \sqrt{d_3} X_3) + w_D \tag{10} \]

Where \( h_i \) denotes the link between chosen relay and destinations.

Similarly, the same SIC decoding procedure is performed at the destination \( D_1, D_2, \) and \( D_3 \). The signal from the relay undergoes the SIC process at the destination, where the receiver decodes symbol \( D_1 \) by considering other symbols as noise, the signal-to-interference noise at the destination \( D_1 \) using equation (7) written as

\[ \gamma_{D_1} = \frac{a_1 P_R |h_2|^2}{(a_1 + a_2) P_R |h_2|^2 + \sigma^2}. \tag{11} \]

Then, it decodes \( D_2 \) and discards \( D_1 \) data by using the same SIC decoding procedure. Thus, the same process is performed by decoding the \( D_3 \) signal and treats the other two signals as noise, then the ratio of signal-to-noise interference can be expressed as equation (8) & (19)

\[ \gamma_{D_2} = \frac{a_2 P_R |h_3|^2}{a_2 P_R |h_3|^2 + \sigma^2} \tag{12} \]
4. Performance analysis

This section estimates the probability of undecodable at the destination in terms of outage probability if the threshold value is greater than the received SNR or SINR\(^7\). Let \( a_3 \) denote the different power allocation \(^10\) to the different destinations. According to NOMA, the near user has less power allocation than the far user based on the principle; the assumptions are taken \( a_2 > a_1 \) and \( h_2, h_3, h_4 \) modeled identically. Assuming perfect SIC, the analysis has been explained in different cases as follows:

Case (i) probability of undecodable at \( D_1 \)

We denote outage probability at the destination as \( OP_{D_1} \), due to SNR or SINR less than the threshold, the received signal at the destination was unable to decode the information of \( D_1 \) as weak user, using equation (7), (12), and (13) as,

\[
OP_{D_1} = \Pr \left\{ \begin{array}{l}
\frac{a_1 P_S |h_1|^2}{\sigma^2} < \gamma_{\theta_1} \\
\text{or} \quad \frac{a_2 P_R |h_3|^2}{\sigma^2} < \gamma_{\theta_1} \\
\text{or} \quad \frac{a_2 P_R |h_4|^2}{\sigma^2} < \gamma_{\theta_1}
\end{array} \right. \quad (14)
\]

\[
OP_{D_1} = 1 - \Pr \left\{ \begin{array}{l}
\frac{a_1 P_S |h_1|^2}{\sigma^2} > \gamma_{\theta_1} \\
\text{or} \quad \frac{a_2 P_R |h_3|^2}{\sigma^2} > \gamma_{\theta_1} \\
\text{or} \quad \frac{a_2 P_R |h_4|^2}{\sigma^2} > \gamma_{\theta_1}
\end{array} \right. \quad (15)
\]

Where \( \gamma_{\theta_1} = 2^{R_1} - 1 \), the target rate of \( D_1 \).

The achievable rate of \( D_1 \) can be written in terms of power allocation coefficient as

\[
R_1 = \log_2 \left( 1 + \frac{a_1 P_S |h_1|^2}{(a_1 + a_2) P_R |h_3|^2 + \sigma^2} \right) \quad (16)
\]

Case (ii) probability of undecodable at \( D_2 \)
Similar to the case (i), the outage probability at the destination expressed as \( OP_{D_2} \) considering
and \( X_2 \) as interference signal at the destination \( D_2 \). Using case (ii), equations (17) and (18)
framed from the SNR/SINR signal.

\[
OP_{D_2} = \Pr \left\{ \begin{array}{l}
a_2 P_R |h_3|^2 < \gamma \theta_2 \\
(a_1 + a_2) P_s |h_1|^2 + \sigma^2 \theta_2
\end{array} \right. \tag{17}
\]

\[
OP_{D_2} = 1 - \Pr \left\{ \begin{array}{l}
a_2 P_R |h_3|^2 > \gamma \theta_2 \\
(a_1 + a_2) P_s |h_1|^2 + \sigma^2 \theta_2
\end{array} \right. \tag{18}
\]

Where, \( \gamma \theta_2 = 2^{R_2} - 1 \) the target rate of \( D_2 \). The power coefficient at the destination considered as
\( a_2 > a_1 \) and \( a_3 < a_2 \), therefore, the rate equation for the destination \( D_2 \) can be formulated as

\[
R_2 = \log_2 \left( 1 + \frac{a_2 P_s |h_3|^2}{a P_s |h_3|^2 + \sigma^2} \right) \tag{19}
\]

Case (iii) probability of undecodable at \( D_3 \)
In this case, destination \( D_3 \) is considered as a strong user, then the outage probability can be
calculated using equations (12) and (13),

\[
OP_{D_3} = \Pr \left\{ \begin{array}{l}
a_1 P_S |h_1|^2 < \gamma \theta_3 \\
(a_1 + a_2) P_s |h_1|^2 + \sigma^2 \theta_3
\end{array} \right. \tag{20}
\]
Similarly, the target rate for the third destination can be expressed as \( \gamma_{th_3} = 2^{R_3} - 1 \). The power is constant in the third user considered as both \( a_1 \) and \( a_2 \) taken as a higher value than \( a_3 \). The achievable capacity for the strong user or \( D_3 \) can be written as

\[
R_3 = \log_2 \left( 1 + \frac{a_3 P_S |h_4|^2}{\sigma^2} \right) \quad (22)
\]

Let A, B, C, and D be considered channel coefficients from the base station to the selected relay and from the selected relay to the three different destinations [11]. The cumulative density \((f)\) and probability density function \((F)\) applied in the equation (15), (18), and (21), we get

\[
f_A(a) = \sum_{n=1}^{N} (-1)^{n-1} \binom{N}{n} \frac{n}{\lambda_1} \exp \left( -\frac{na}{\lambda_1} \right) \quad (23)
\]

\[
f_B(b) = \frac{1}{\lambda_2} \exp \left( -\frac{b}{\lambda_2} \right), \quad F_B(b) = 1 - \exp \left( -\frac{b}{\lambda_2} \right),
\]

\[
f_C(c) = \frac{1}{\lambda_3} \exp \left( -\frac{c}{\lambda_3} \right) \quad \text{and} \quad f_D(d) = \frac{1}{\lambda_4} \exp \left( -\frac{d}{\lambda_4} \right)
\]

Using the Taylor series, the exponential function using channel gains can be expanded as

\[
\exp \left( -\frac{c}{\lambda_3} \right) = \sum_{k=0}^{\infty} \frac{(-1)^k c^k}{k! \lambda_3^k}. \quad \text{The outage probability is expressed as}
\]

\[
OP = 1 - \Pr \left( B > t_2, C > t_2 \right) f(a)da \quad (23)
\]

Consider \( t_1 = \frac{\gamma_{th_1}}{P_S(a_1 - (a_2 + a_3)\gamma_{th_1})} \) and \( t_2 = \frac{\gamma_{th_1}}{P_S \theta(a_1 - (a_2 + a_3)\gamma_{th_1})} \)
Then \( \theta = \frac{2an}{1-a} \), from equation (23), the expression can be manipulated as

\[
OP_{D_1} = 1 - \sum_{n=1}^{N} (-1)^{n-1} \left( \frac{N}{n} \right) \frac{n^\infty}{\lambda_1} \int_{-\infty}^{\infty} \exp \left( \frac{-\beta}{a} - \frac{na}{\lambda_1} \right) da (24)
\]

Where, \( \beta = \frac{t_2}{\lambda_2} + \frac{t_2}{\lambda_3} + \frac{t_2}{\lambda_4} \).

From equation (14), we get the modified expression as

\[
OP = 1 - \frac{(-1)^{n-1} \left( \frac{N}{n} \right) \sum_{k=0}^{N_t} (-1)^k \beta^k}{\lambda_1} \left( \frac{1}{t_1} \right) \int_{-\infty}^{\infty} \exp \left( \frac{-na}{\lambda_1} \right) da (25)
\]

The exponential integral function applied in the equation (25) [21], we obtained as

\[
OP_{D_1} = 1 - \sum_{k=0}^{N_t} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}(-1)^k \beta^k}{k!} \left( \frac{N}{n} \right) \frac{1}{\lambda_1} \left( \frac{1}{t_1} \right) E_k \left( \frac{nt_1}{\lambda_1} \right) (26)
\]

Therefore, the final expression can be written as

\[
OP = 1 - \sum_{n=1}^{N} \left( 1 \right)^{n-1} \left( \frac{N}{n} \right) \frac{1}{\lambda_1} \left( \frac{1}{t_1} \right) \sqrt{\frac{4n\beta}{K}} (27)
\]

Where, \( K_1(\cdot) \) represented as Bessel functions for the first order in the second kind.

The same probability density and cumulative density function will be applied for the other two destinations and then extended with the Taylor series.

5. Simulation results

In this section, the mathematical expression is simulated and analyzed for the proposed linear EH system, a fading channel model. Moreover, we set the value for the power allocation coefficient as \( a_1 = 0.75, a_2 = 0.15 \text{ and } a_3 = 0.05 \), the distance of secondary user or destination from the base station is set as \( d_1 = 500 \text{m}, d_2 = 200 \text{m}, \text{and } d_3 = 70 \text{m} \), the channel gains are taken as the value of one, the target rates \( \gamma_{th_1} = 1 \text{bps/Hz}, \gamma_{th_2} = 2 \text{bps/Hz} \text{ and } \gamma_{th_3} = 3 \text{bps/Hz} \) for 1MHz bandwidth system. The superimposed signal from the base station is a QPSK modulated signal to the selected relay.

Using equation (27), the outage probability with respective SNR for different power values assigned to each user is plotted, as shown in Figure 2. The performance of user 1 is not good compared to user 2 and user 3 due to high interference at user 1. Thus, depending upon the interference and power allocation, the outage behavior has been improved for higher SNR with the underlay CRN. Moreover, SNR increases will lead to decreased outage performance and then reach a fixed value. Users 2 and 3 have nearly the same outage performance compared to user 1. Figure 3 shows the highest bit error rate for user 1 compared to other users, and user 3 has the lowest value due to the least interference. The BER is determined using the signal obtained at the destination. Figure 4 worked explained about Achievable capacity versus transmitting power.
Figure 2: The outage probability versus transmit power with path loss=3
And energy conversion $\eta=1$ 

Figure 3: The BER versus transmit power 

Figure 4: Achievable capacity versus transmitting power
6. Conclusion
In this paper, we have analyzed NOMA under perfect SIC aided with EH relaying system. The hybrid partial selection scheme has been implemented in the proposed work for the relay selection. The closed-form expression has been derived from analyzing the performance of the NOMA system in multiple secondary users. Moreover, the simulation results prove that fixed power allocation to different users and relay performance can increase users' performance. As a future scope, the network model with multiple users can be analyzed under imperfect SIC and different fading channels.

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