Reliable and Secrecy Aware Cooperative Framework for Cognitive Radio Non-Orthogonal Multiple Access (NOMA) Networks

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Abstract —Non-Orthogonal Multiple Access (NOMA) aided Cognitive Radio (CR) communication has been investigated as one of the primary candidates to fulfill the huge spectrum requirements of next generation wireless networks. To enhance the reliability and security aspects of CR-NOMA networks, we in this work incorporated cooperative relay-based communication. Cooperative transmission is a promising technology as it can provide reliability, extended coverage, and improved physical layer security. We propose cooperative relaying frameworks for both underlay and overlay cognitive radio frameworks. The primary objective of the work is to enhance the reception reliability of the end users and simultaneously providing the physical layer security against external eavesdropper. Analytical expressions are derived for throughput, secrecy capacity, and intercept probability to depict the performance of cooperative CR-NOMA communication. We have also analyzed the impact of different relaying strategies on the performance of Cooperative CR-NOMA networks. The simulation results prove the effectiveness of proposed frameworks and validates the mathematical modeling derived for various parameters.

Index Terms—Cognitive radio, NOMA, Cooperative communication, outage probability and Physical layer security

I. INTRODUCTION

Non-Orthogonal Multiple Access (NOMA) has been considered as one of the driving forces for next generation networks like Internet of Things (IoT), 5G etc. [1]. NOMA supports the coexistence of multiple transmissions in the single resource block, thus yields the effective utilization of spectrum resources. Cognitive radio is also considered as one of the potential technologies in achieving the higher spectrum efficiency through underlay and overlay sharing approaches [2], [3]. To acquire the multiple benefits, hybrid combination of cognitive radio and NOMA has gathered the attention of various wireless communication researchers. Since NOMA and CR technologies are interference limited, the performance is degraded by internetwork interference of primary and secondary users and also intra network interference caused by power domain NOMA. Thus, to increase the reception reliability and to enhance the capacity of the cell-edge users, cooperative relaying strategies are implemented in CR-NOMA communications. Cooperative transmission [4] enables the nodes to work in collaboration to relay the information successfully from source to destination. Cooperative relaying (Fig. 1) increases the energy efficiency by reducing the transmit power and also provides the coverage extension, enhanced reception reliability and capacity improvement. Due to the broadcast nature of wireless communication, private information can be tapped by external eavesdroppers. Thus, relay selection should be done by considering the Physical Layer Security (PLS). Physical layer security [5], [6] is the alternative way of addressing the security issues without using complicated coding.

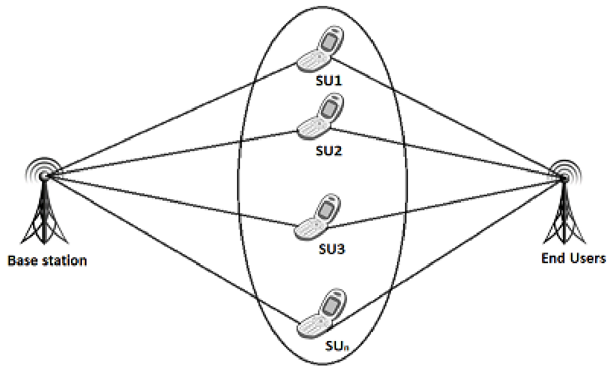

Fig. 1. Cooperative cognitive radio framework

Physical layer security prevents the leakage of private information by exploiting the physical characteristics of the wireless link such as noise, fading, interference etc. PLS essentially boosts the signal level of incumbent users and degrades the reception quality of the eavesdroppers. Optimal relay selection must increase the secrecy capacity by maximizing main channel capacity of the edge/far user. The parameter which defines the difference between the main channel capacity and wiretap channel is considered as secrecy capacity. The effect of intercept event will be significant if the secrecy capacity is less than zero.

II. RELATED WORK

Over the past few years, significant research has been conducted on integrating the two emerging technologies cognitive radio and NOMA. In the particular existing

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work [7], NOMA capabilities are coupled with CR concepts to achieve intelligent spectrum sharing. Three different frameworks such as underlay, overlay and CR-NOMA architectures are well explored and key challenges in providing the reception reliability are addressed. Existing research on hybrid combination of Cognitive radio and NOMA has created the hopes to meet the high expectations of next generation wireless networks [8]-[10]. Author in [11] has studied techniques, advantages, and applications of cooperative wireless communication for LTE advanced system. Previous studies [12], [13] have explored different types of relaying techniques and their effect on BER performance of cooperative communication. It is evident from many experiments that cooperative relaying significantly reduces the outage probability of the cell edge user. In [14], [15] cell centre node is used as relay to assist the cell edge user and this operation is empowered by Simultaneous Wireless Power Transfer (SWIFT). There is a significant improvement in the performance of cell edge user as compared to the conventional communication. Cooperative cognitive radio network model has been proposed in [16], wherein unlicensed secondary users act as relay nodes to high priority primary user. In return, secondary users will get the spectrum opportunities for transmission when primary users are idle. In another study, overlay cooperative-NOMA architecture is proposed [17] -In the first time slot PU-BS transmits signal to its users; signal is also received by SU-BS. In the second slot, SU-BS relays the PU signal by super positioning its own signal using NOMA. This two-slot communication improves the outage performance of the far users; simultaneously providing spectrum opportunities for secondary users. In the particular article [18], impact of cooperative NOMA on reliability and physical layer security against multiple eavesdroppers has been investigated comprehensively. There are few existing works [19]-[21] on optimized relay selection process considering reliability and security aspects. From the available literature and as per our knowledge, cooperative CR-NOMA model is still in the nascent stage; there is lot of scope to explore reliability and PLS aspects cooperative NOMA based cognitive radio networks.

The main contributions of our work are summarized below:

- We have proposed cooperative NOMA framework for both underlay and overlay cognitive radio networks (Section III).
- We have identified and explored different relaying strategies and relay selection schemes best suited for cooperative CR-NOMA frameworks (Section IV).
- The closed form expressions for system throughput and secrecy capacity are derived and validated by numerical results obtained by simulation (Section IV and V).
- Comprehensive investigation of physical layer security has been done for cooperative CR-NOMA frameworks against external eavesdroppers (Section V).
- Simulation results are presented to justify the analytical expressions derived for various parameters (Section VI).

III. System Architecture

A. Underlay CCR-NOMA Framework

In underlay CR-NOMA scenario, both primary and secondary transmissions can happen simultaneously (Fig. 2) without degrading the quality of primary user communication. Consider the scenario of large coverage area, where there are multiple PU Transmitters and PU users operating in different spectrum bands, multiple secondary transmitters and users expecting the spectrum opportunities. In such cases, based on geographical areas primary and secondary networks can be coupled together to effectively utilize the spectrum resources. Since NOMA supports multiple transmissions simultaneously, we can allow PU-BS and SU-BS to transmit in the same orthogonal spectrum band. But this configuration demands coordination PU and SU base stations in producing the superimposed signal. Common transmitter sends the superimposed symbols of both PU and SU using NOMA technique. In return to the benefit of getting free spectrum opportunities, secondary nodes have to cooperate by relaying the PU-BS information to the cell-edge/far primary user. This leads to win-win situation for both the networks. Similar model can be adopted to entire coverage area, and it is more suitable for highly dense heterogeneous networks where there is scarcity of spectrum resources. Due to the participation of multiple primary and secondary networks, selection of optimal relay nodes is the major challenge.

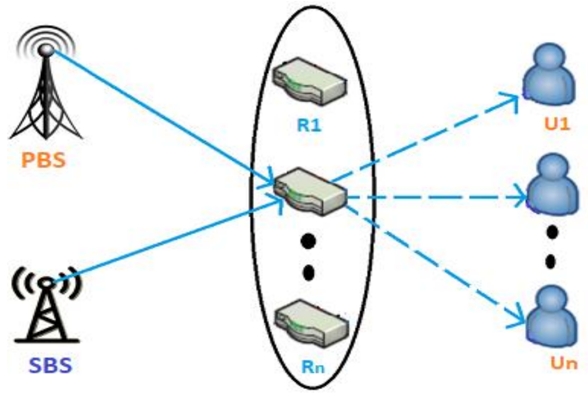

Fig. 2. Underlay cooperative framework

B. Overlay/Interweave CCR-NOMA Framework

Interweave cognitive radio model allows unlicensed users to occupy the spectrum whitespaces whenever the primary user is inactive. The simple interweave approach is secondary network can access the spectrum band opportunistically when primary transmitter is inactive. During primary transmission, the selected secondary node or SU base station can act as relay to support the legitimate network; this creates the win-win cooperation between primary and secondary networks. This interweave model (Fig. 3) can also be modified for fixed time slots to guarantee spectrum opportunity for secondary transmission. In the first slot, primary base station broadcasts its message which will be received by primary users and associated secondary base station.

These time slots can be either fixed or free slots (whitespaces) can be identified using spectrum sensing techniques [22]. Depending upon the scenario, modified version of this framework can be adopted wherein strong secondary users can be used as relay node instead of SU-BS for relaying the primary information. This type of CCR framework is more suitable where secondary network is located close to the edge of primary network. The same design with multiple secondary BS's for one Primary BS can be adopted to improve the energy efficiency simultaneously extending the coverage area.

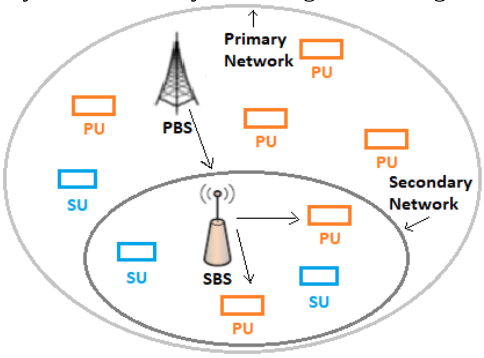

Fig. 3. Overlay cooperative framework

IV. Relaying Strategies for CR-NOMA

We consider a cooperative CR-NOMA network (Fig. 4) with a primary base station (BS), attempts to transmit its data to destination nodes with the support of N secondary relay nodes in the presence of M eavesdroppers who tries to overhear the information. It is assumed that all channels are Rayleigh fading type channels and h_{sr}, h_{rd}, h_{re} are the channel gains of BS to relay, relay to destination user and relay to eavesdropper links. It is also presumed that no direct link available between BS and destination; communication is performed with the help of relay nodes. Data transmission occurs in two orthogonal time slots: In the first time slot, BS sends its data to selected relay and relay forwards the data to the user node in the second time slot. In cooperative relaying system, first source transmits to relay nodes (RN's) and then each relay node process and forwards the information to the end users. There are many existing relaying protocols: we have explored few of them that are suitable for Cognitive radio-NOMA based applications.

A. DF Relaying in CR-NOMA

In DF protocol, each RN decodes the received signal, re-encodes, and forwards it to respective destination. It is very useful for NOMA based communications, where relay nodes must superimpose symbols from multiple transmitters. Selective DF is the variant of DF that checks for errors in the received signal. RN forwards the signal only if it can correctly decode the information, otherwise it remains silent. PU-BS superimposes the symbols and transmits the NOMA signal y_t, where S_i is the user i symbol, ρ is the transmit power density and α is the power allocation coefficient determined based on QoS requirements and channel condition of the participation networks.

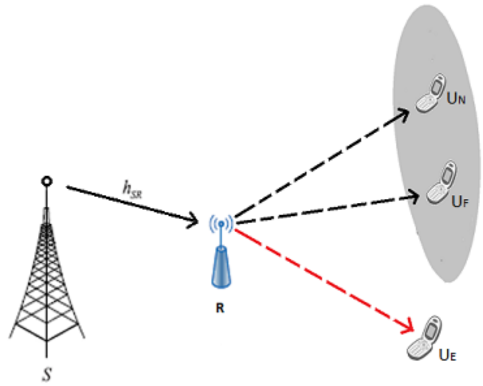

Fig. 4. System model having base station, selected relay, end users and eavesdropper

$$y_t = \sqrt{\alpha\rho}s_1 + \sqrt{\bar{\alpha}\rho}s_2 \tag{1}$$

The signal received by the relay nodes can be modelled as,

$$y_r = h_{br}\left(\sqrt{\alpha\rho}s_1 + \sqrt{\bar{\alpha}\rho}s_2\right) + w_n^r \tag{2}$$

w_n^r is the gaussian noise with mean zero and variance N_0.

In the DF relaying protocol, selected relay first decodes S_2 by treating S_1 as noise and extract S_1 by subtracting S_2 from the superimposed signal.

SNR for the relay to extract S_2 is,

$$\gamma_{sr}{}^2 = \frac{\bar{\alpha}\rho|h_{sr}|^2}{1 + \alpha\rho|h_{sr}|^2} \tag{3}$$

SNR for relay to extract S_1 is,

$$\gamma_{sr}{}^1 = \alpha\rho|h_{sr}|^2 \tag{4}$$

The condition for successfully decoding the symbol Si is given by,

$1/2 * \log_2(1 + \gamma_i) \geq R_T$ Where R_T is the targeted data rate for user i.

During the second slot, decoded signals are superimposed again and forwarded to destination users. At the user end these message signals are decoded by adopting SIC.

The received signal at the end users will be,

$$y_i = h_{ri}\left(\sqrt{\alpha\rho}s_1 + \sqrt{\bar{\alpha}\rho}s_2\right) + w_n^i \tag{5}$$

As per NOMA communication, user1 first decodes the S_2 symbol and then decodes its own signal S_1.

Thus, SNR for decoding S_1 by user1 is,

$$\gamma_{rd}{}^{1} = \alpha\rho|h_{rd1}|^2 \tag{6}$$

User2 decodes its signal by treating S_1 as interference, thus SNR is given by,

$$\gamma_{rd}{}^{2} = \frac{\bar{\alpha}\rho|h_{rd2}|^2}{1+\alpha\rho|h_{rd2}|^2} \tag{7}$$

Considering user1 as PU and user2 as SU, selected relay should offer maximum overall throughput providing at least minimum required data rate for SU.

B. AF Relaying in CR-NOMA

AF protocol is the simple, fast, and low-cost relaying, in which received signal strength is simply boosted up and forwarded by relay nodes. One drawback of AF protocol is that it amplifies the embedded noise along with the information.

In the first time slot of AF relaying, PU-BS superimposes the multiple symbols and transmits the NOMA signal as expressed in (1). The received signal at the relay is same as in case of DF relaying (2). In the second slot, selected relay node amplifies the signal by a factor G and forwards the signal to the end users; relay does not decode the received signal. At the end users, order of decoding depends upon the channel condition and power allocation factor.

The received signal at the end user will be,

$$\mathrm{y_r} = \mathrm{Gh_{ri}}\left(\sqrt{\alpha\rho}\mathrm{s_1} + \sqrt{\bar{\alpha}\rho}\mathrm{s_2}\right) + \mathrm{w_n^i} \tag{8}$$

Thus, SNR for decoding S_1 at user1 is,

$$\gamma_{rd}{}^{1} = \frac{\alpha\rho^2|h_{sr}|^2|h_{rd1}|^2}{1+\rho|h_{sr}|^2+\rho|h_{rd1}|^2} \tag{9}$$

SNR for decoding S_2 at user2 is,

$$\gamma_{rd}{}^{2} = \frac{\bar{\alpha}\rho^2|h_{sr}|^2|h_{rd2}|^2}{1+\rho|h_{sr}|^2+\rho|h_{rd2}|^2+\alpha\rho^2|h_{sr}|^2|h_{rd2}|^2} \tag{10}$$

It must be noted that, order of decoding depends upon the channel coefficients and power allocation factor.

V. Proposed Relay Selection Scheme

The relay selection will be done in two or three stages; Group of secondary nodes are selected as relays and then one of the best relays is selected for forwarding the information to destination. Firstly, the channel gains of BS and relay communication links will be ordered as: $\gamma_{R1}>\gamma_{R2}>\gamma_{R3}\ldots.>\gamma_{RN}$. Among the available secondary nodes, a set of potential relays are selected: S= {R_1, R_2, R_3,….R_k}which can provide minimum targeted rate for far/cell edge users, where R_1 is the relay with highest BS-relay channel gain. Then selection of best possible relay from the set S is done as follows:

Case 1: *If the CSI of the eavesdropping channels are not available*

The optimal relay is selected from the subset S by,

$$R_{OPT} = argmax\ (min(\gamma_{sr_i}{}^{1}, \gamma_{r_id}{}^{1})) \quad \mathrm{i} = 1, 2\ldots.\mathrm{K} \tag{11}$$

The above condition shows that optimum relay is the one which provides highest channel net throughput and at least minimum required rate for far user in the given coverage area. Since BS- relay and relay-destination are within the coverage area of each other, perfect CSI of BS-R_N and R_N to destination can be obtained. Based on BS-R_N CSI information, set of potential relays will be selected and by knowing R_N to destination CSI, optimal relay node is selected.

Case 2: *If the CSI of the eavesdropping channels are available*

The proposed RS schemes invokes the concept of physical layer security which is being evaluated by the parameter secrecy capacity. Secrecy capacity C_{sec}= C_m - C_e, where C_m and C_e are the channel capacities of main link and eavesdroppers link, respectively. If C_m>C_s, then desired positive secrecy capacity can be achieved. Relay selection for case2 is as follows: Firstly, secrecy capacities of BS- R_N are arranged in the descending order as: $C_{BS\text{-}R1}$, $C_{BS\text{-}R2}$, $C_{BS\text{-}R3}$, ..…. $C_{BS\text{-}RN}$, then the subset of relays are selected S={R_1, R_2, ..R_N} which can guarantee successful transmission. Since the CSI of the eavesdropping is assumed to be available, the optimal relay is the one which maximizes the secrecy capacity.

$$R_{0pt}: C = argmax\ (C_{e2e}) \quad \mathrm{i} = 1, 2\ldots.\mathrm{K} \tag{12}$$

This selection is the secrecy aware method wherein wiretaps are active and instantaneous CSI of eavesdropper links can be estimated by source and relay nodes.

A. Performance Metrics

1) Secrecy capacity

Secrecy capacity is the difference between the channel capacities of the main link and wiretap link. Since the cooperative communication happens in two hops, secrecy capacity can be calculated as shown below:

$$C_{S1} = C_{BS-R} - C_{BS-E} \tag{13}$$

C_{S1} is the secrecy capacity for the first hop (time slot).

$$C_{S1} = \left\{ \begin{matrix} \frac{1}{2}\log_2\left(1+\gamma_{sr_i}{}^{1}\right) \\ -\frac{1}{2}\log_2\left(1+\gamma_{SE_n}{}^{1}\right) \end{matrix} \right\} \tag{14}$$

where, $C_{BS\text{-}R}$, $C_{BS\text{-}E}$ are the channel capacities of base station- relay and base station to Eavesdropper channel, respectively. Secrecy capacity of the 2nd hop can be calculated as,

$$C_{S2} = C_{R-D} - C_{R-E_n} \tag{15}$$

$$C_{S2} = \left\{\frac{1}{2} log_2\left(1+\gamma_{r_i d}{}^1\right) - \frac{1}{2} log_2\left(1+\gamma_{r_i E_n}{}^1\right)\right\} \quad (16)$$

where, $C_{R\text{-}D}$, $C_{R\text{-}En}$ are the channel capacities of relay-destination and destination to Eavesdropper channel, respectively. The base station to destination (end users) secrecy capacity can be calculated as,

$$C_{e2e} = min\,(C_{s1}, C_{s2}) \quad (17)$$

The optimal relay should be selected to maximize the end -end secrecy capacity,

$$R_{OPT} = argmax(C_{e2e})$$
$$\mathrm{i} = 1, 2.\ldots \mathrm{K}\ \text{Relays} \quad (18)$$

The above equations represent the FRS method, requires the CSI of all the links which is practically a complex task. To reduce this complexity, partial relay selection can be used as explained in [18]. Partial CSI can be gathered by local control messages which significantly reduces the delay.

2) Intercept probability

Intercept can occur when the secrecy capacity becomes negative. Thus, the intercept probability of non-cooperative communication is obtained by,

$$\mathrm{P}_{\mathrm{Intercept}}^{\mathrm{Non-coop}} = \mathrm{P_r}(\mathrm{C_{sd}} < \mathrm{C_{se}}) \quad (19)$$

$$\mathrm{P}_{\mathrm{Intercept}}^{\mathrm{Non-coop}} = \mathrm{P_r}(|\mathrm{h_{sd}}|^2 < |\mathrm{h_{se}}|^2 \quad (20)$$

Considering the Rayleigh fading model, the closed form expression will be,

$$\mathrm{P}_{\mathrm{Intercept}}^{\mathrm{Non-coop}} = \frac{\sigma_{se}{}^2}{\sigma_{se}{}^2 + \sigma_{sd}{}^2} \quad (21)$$

$$\text{Where } \sigma^2 = E(|h|^2) \quad (22)$$

In this section, intercept probabilities of cooperative communication are presented for DF and AF based schemes. Intercept probabilities for DF based cooperative communication can be expressed as,

$$P_{Intercept}^{Coop-DF} = P(maxCi_{i\in K} < 0) \quad (23)$$

$$P_{Interecept}^{Coop-DF} = P(max(min(Cs1 + Cs2)_i)_{i\in K} < 0) \quad (24)$$

$$P_{Interecept}^{Coop-DF} = \prod_{i=1}^{K} P\left\{min(\left|h_{sr_i}\right|^2, \left|h_{r_i d}\right|^2) < \left|h_{r_i e}\right|^2\right\} \quad (25)$$

Intercept probabilities for AF based cooperative communication can be expressed as,

$$P_{Interecept}^{Coop-AF} = P(maxCi_{i\in K} < 0) \quad (26)$$

Since AF based relaying amplifies and forwards the received signal, the above equation can be approximated as,

$$P_{Interecept}^{Coop-AF} = P(\left|h_{r_i d}\right|^2) < \left|h_{r_i e}\right|^2) \quad (27)$$

$$P_{Interecept}^{Coop-AF} = \prod_{i=1}^{K} \frac{\sigma_{r_i e}{}^2}{\sigma_{r_i d}{}^2 + \sigma_{r_i e}{}^2} \quad (28)$$

B. Algorithm: Reliable and secrecy aware cooperative CR-NOMA

Phase 1: Power allocation

- Users u1 and u2 superimpose their respective symbols S_1 and S_2 at the base station.
- Considering the targeted data rates of the users, the power allocation coefficient is optimized as

$$\alpha = argmax(R)$$
$$s.t\ R_1 \geq \overline{R_1}\ \&\ R_{S2} \geq \overline{R_2} \quad (29)$$

- $\overline{R_1}$, $\overline{R_2}$ are the targeted data rates for symbol 1(Primary user) and symbol 2 (far user/cell edge user) and $R=R_1+R_2$. where $\alpha\rho$ and $\overline{\alpha}\rho$ are the powers allocated to u1 and u2, with $\alpha + \overline{\alpha} = 1$.
- Channel coefficients h_{SR}, h_{RD}, h_{RE} are assumed to be subjected to independent Rayleigh fading.
- The superimposed signal is transmitted to the selected relay for further processing.

Relay selection:

- Group of secondary nodes are selected as potential relays, based on CSI information. It is assumed that potential relays are capable of AF/DF relaying, SC, and SIC.
- In the first stage, subset of relays is selected, which can guarantee successful SIC at the far user/cell edge user; S= {R_1, R_2, R_3, ….R_K}
- In the second stage, Optimized relay is selected based on the following criteria:

  Case 1: If the CSI of the eavesdropping channels are not available

  The optimal relay is selected from the subset S by,

$$R_{OPT} = argmax\ (min(\gamma_{sr_i}{}^1, \gamma_{r_i d}{}^1))$$
$$\mathrm{i} = 1, 2.\ldots \mathrm{K} \quad (30)$$

  Optimum relay is the one which provides highest net throughput and required rate for far user in the given coverage area.

  Case 2: If the CSI of the eavesdropping channels are available

  Since the CSI of the eavesdropping is assumed to be available, the optimal relay is the one which maximizes the secrecy capacity.

$$R_{OPT} = argmax(C_{e2e}) \quad (31)$$
$$\mathrm{i} = 1, 2.\ldots \mathrm{K}\ \text{Relays}$$

Phase 2: Retransmission

- In DF based NOMA, selected optimal relay R_{OPT} decodes the symbols S_1 and S_2 by SIC and decoded symbols are superimposed again and forwarded to destination users. SNR's for DF relaying are calculated using the expressions (3), (4), (6), and (7).

- In AF based NOMA, selected relay Ropt directly amplifies and forwards the signal to the end users. SNR's for AF relaying are calculated using the expressions (9)-(10).
- Subsequently, users u1 and u2 cancel the interference corresponding to their transmitted symbols S_1 and S_2 from their respective received signals.
- Thus, the total achievable rates for u1 and u2 are obtained as

$$R = \mathrm{B}(\log_2(1+\gamma_{rd}{}^1) + \log_2(1+\gamma_{rd}{}^2)) \quad (32)$$

VI. Results and Discussions

In this section, we have evaluated and validated the parameters net throughput, outage probability, secrecy capacity and intercept probabilities for the proposed cooperative CR-NOMA communication. The default values for simulation are assumed by following the standards of NOMA and cognitive radio technology. Fig. 5 depicts the net throughput comparison of DF based cooperative and non-cooperative CR-NOMA communications. It is visible that the cooperative relaying enhances the overall throughput because of small path loss and increased SNR at the relay node. The outage probabilities of Cooperative and non-cooperative communication in Fig. 6, wherein proposed cooperative CR-NOMA framework significantly reduces the outage probabilities of both primary and secondary users compared to the non-cooperative communication.

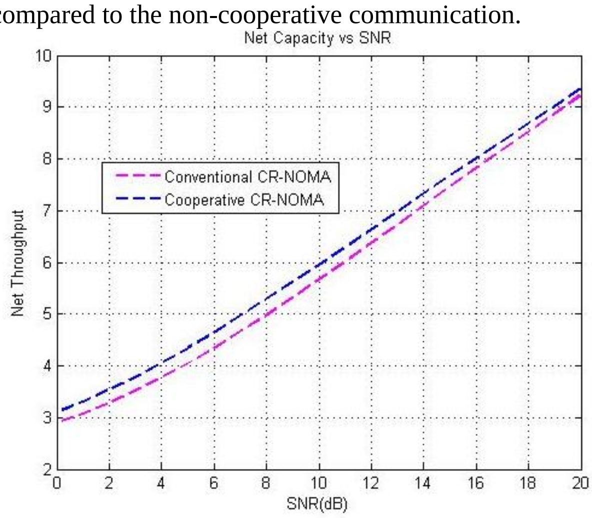

Fig. 5. Throughput comparison of CCR-NOMA with CR-NOMA

The significant improvement in SNR caused by NOMA assisted relaying benefits the SIC processing at the end users, thus proves the reception reliability. The below simulations were carried out by considering all channels are Rayleigh fading, power allocation coefficients for PU and SU 0.8 and 0.2 respectively and target rate of 1.5bps/hz. In cooperative communication, it must be noticed that information signal will be transmitted twice from the source and relay. To make the unbiased comparison, the global (total) transmit power is equally divided for source power and relay power; total transmission power at source and relay will be equal to transmission power of direct communication. From the Eq. (21), it can be interpreted that direct transmission intercept probability is independent (less dependent) of source transmit power. This indicates that reception reliability cannot be improved just by increasing the transmission power at the source. The Fig. 7 shows the variation of secrecy capacity versus global transmit power for cooperative CR-NOMA communication. It is also visible that, this improvement in secrecy capacity motivates the exploitation of cooperative communication to increase the physical layer security. It can also be interpreted from Fig. 6 that, for a particular outage probability, cooperative CR-NOMA requires smaller SNR; mean less transmit power required than non-cooperative method.

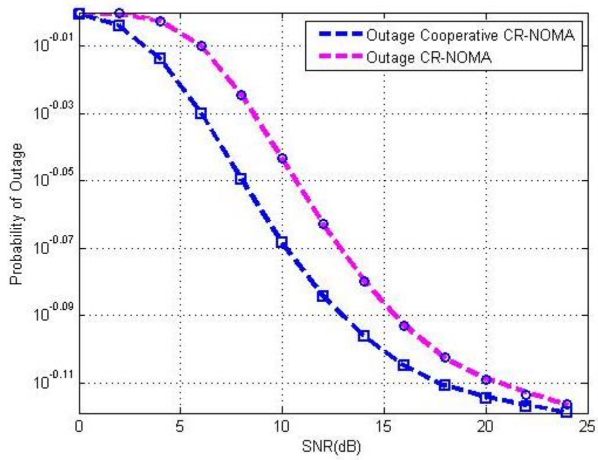

Fig. 6. Outage probability analysis of cooperative CR-NOMA communication.

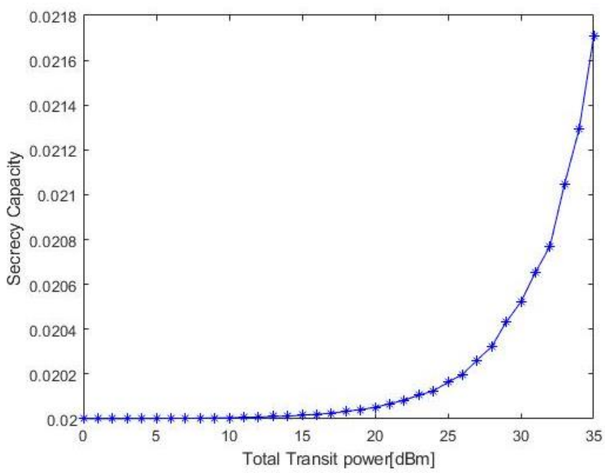

Fig. 7. Secrecy capacity variation for different value of Global transmit power

In this section, numerical results are presented to compare and investigate the performance of AF and DF relaying techniques under various conditions. Fig. 8 shows the fair comparison of AF and DF relaying schemes for different values of path loss exponent (C). It can be seen DF outperforms AF for lower values of C (up to C=3.2), but for C>3.2, AF outperforms DF relaying schemes. Since AF amplifies and forwards both signal and noise, it is not suitable for poor channel conditions.

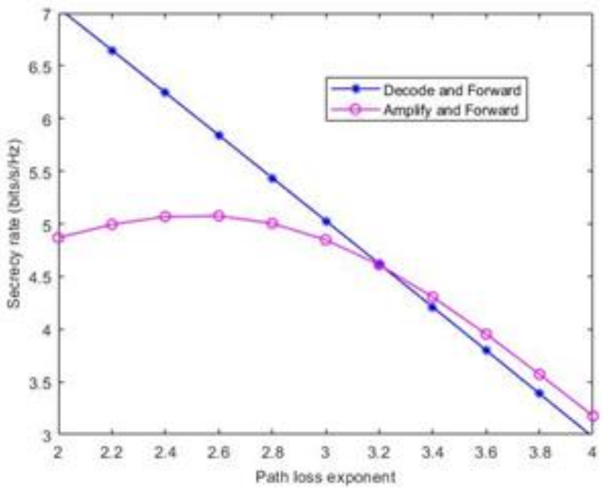

Fig. 8. Plot of secrecy rate versus path loss exponent

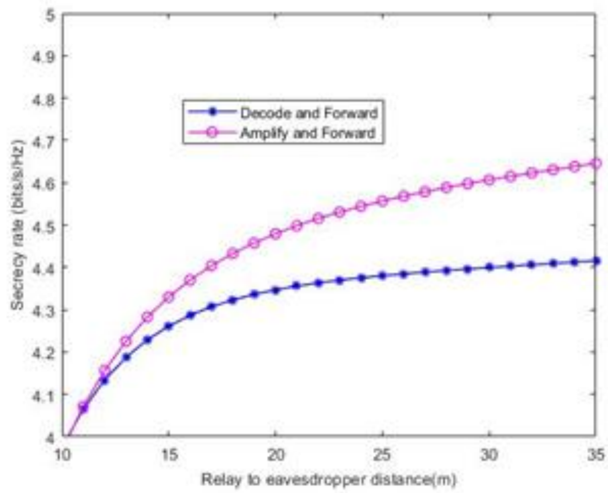

Fig. 9. Plot of secrecy rate versus relay -eavesdropper positions.

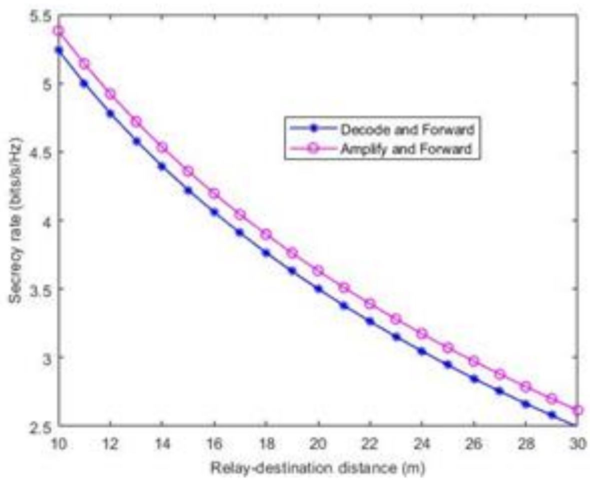

Fig. 10. Plot of secrecy rate versus relay -destination positions.

The plots shown in Fig. 9 and Fig. 10 are obtained for path loss exponent values of 3.2 and for different positions of destination user and the eavesdroppers. Considering source S, relay R, destination D and eavesdropper E, where d_{SR}, d_{RD}, d_{RE} are the distance between S and R, R and D, and R and E respectively. Fig. 9 and Fig. 10 presents the comparison of secrecy rates of two cooperative schemes: Decode and Forward (DF) and Amplify and Forward (AF) for different values of d_{RE} and d_{RD} respectively. Result interpretation shows that secrecy capacity decreases as the distance between R and D decreases and secrecy capacity increases with the increase in distance between R and E. This analysis shows the importance of relay selection and placement to ensure reliability and physical layer security in cooperative communication.

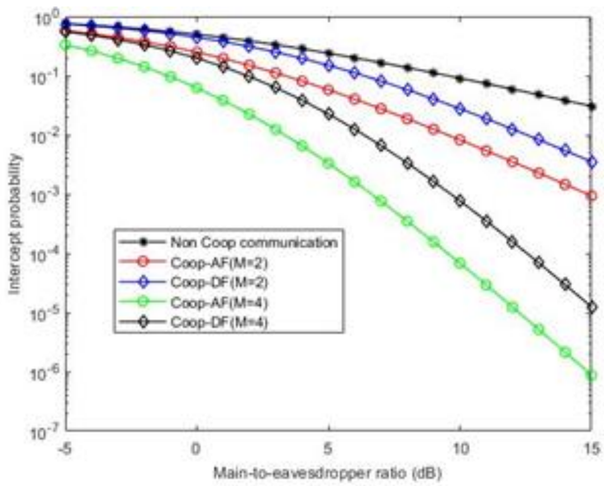

Fig. 11. Plot of intercept probability versus main to eavesdropper ratio.

Intercept probability is the fundamental metric to evaluate the secrecy performance of the relay selection schemes which denotes the intercept probability for a legitimate transmit signal. In Fig. 11, we have presented the numerical intercept probabilities of the proposed AF and DF relaying schemes in comparison with that of direct communication (non-cooperative). It is visible from the Fig. 11 that proposed relay selection method outperforms the conventional relay selection schemes with respect to intercept probability. It is also proven that as the intercept probabilities of the proposed schemes decreases significantly with the increase in number of relays (M). This indicates the physical layer security of cooperative communication compared to direct communication and conventional relay selection algorithms. It is worth mentioning that AF based relay selection algorithm performs better than DF based algorithms for higher values of Main to eavesdropper ratio (MER). As aforementioned, optimal relay selection shows the great potential to enhance the reception reliability in cooperative communication.

VII. Conclusion

In this article, we have presented the cooperative CR-NOMA frameworks for downlink scenario and evaluated the reliability and security aspects in comparison with non-cooperative communication. Relay selection strategies are also presented considering the physical layer security parameters. Mathematical modelling is derived for net throughput, secrecy capacity and intercept probability for cooperative CR-NOMA communication. These derivation expressions are verified and validated by simulation results. Simulation results demonstrates that cooperative CR-NOMA outperforms its non-cooperative counterpart in terms of throughput, outage, and secrecy performance. Major outcomes of the proposed work are superior spectrum utilization by exploiting the simultaneous transmission capabilities of NOMA and enhanced reception reliability of cooperative communication. The proposed cooperative CR-NOMA framework also exhibits coverage extension, reduced transmit power and outage reduction.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Author Madan H T has conducted the research, development and development of the proposed algorithm. Prabhugoud I. Basarkod supervised the work as a supervisor and contributed in writing the article.

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