Frameworks of Non-Orthogonal Multiple Access Techniques in Cognitive Radio Communication Systems

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Abstract: Recently, the increasing demand of radio spectrum for the next generation communication systems due to the explosive growth of applications appetite for bandwidths has led to the problem of spectrum scarcity. The potential approaches among the proposed solutions to resolve this issue are well explored cognitive radio (CR) technology and recently introduced non-orthogonal multiple access (NOMA) techniques. Both the techniques are employed for efficient spectrum utilization and assure the significant improvement in the spectral efficiency. Further, the significant improvement in spectral efficiency can be achieved by combining both the techniques. Since the CR is well-explored technique as compared to that of the NOMA in the field of communication, therefore it is worth and wise to implement this technique over the CR. In this article, we have presented the frameworks of NOMA implementation over CR as well as the feasibility of proposed frameworks. Further, the differences between proposed CR-NOMA and conventional CR frameworks are discussed. Finally, the potential issues regarding the implementation of CR-NOMA are explored.

Keywords: cognitive radio; channel state information; non-orthogonal multiple access; power division multiple access; superposition-coding; successive-interference-cancellation

I. INTRODUCTION

The next generation communication systems demand huge spectral and energy efficiency, low latency, high-scalability, improved connectivity and reliability, as well as advanced security due to massive growth in the wireless connected devices such as internet-of-things (IoT), wireless sensor networks (WSNs), and wireless body area networks (WBANs) etc. The prominent and effective approaches to fulfill these demands are the cognitive radio (CR), non-orthogonal multiple access (NOMA), multi-antennas or multiple-input-multiple-output (MIMO), cooperative communication (CC), network function virtualization (NFV), millimeter-wave communication (MMC), ultra-classification etc. [1]. The cognitive radio is a well-explored technique in literature to manage the issue of spectrum scarcity by exploiting the unutilized spectrum

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opportunities. However, the NOMA is recently explored technique for spectral efficient communication by creating the new spectrum opportunities. The briefs about these two technologies are given as follows.

1.1 Cognitive radio and non-orthogonal multiple access technology

The cognitive radio (CR) has emerged as a promising candidate for the 5th generation (5G) communication systems to improve the spectral efficiency by allowing the unlicensed/secondary/cognitive users (CU) to utilize the underutilized/unutilized bands of the spectrum which are already allocated to the licensed/primary users (PUs) [1-7]. Conventionally, the CR comprises the spectrum sensing, spectrum analysis and decision, spectrum accessing/sharing and spectrum mobility operational units [8-11]. The spectrum sensing is prime function according to which the CU senses its environment to perceive the spectrum hole/white spaces (the unutilized portion of spectrum) or idle channels, analyze all channels and accesses the most suitable idle channel for communication. It is worth to mention that if the PU resumes its services during the CU data transmission then at that moment the CU needs to switch its communication on other available channels and this process is known as spectrum handoff/mobility. Moreover, the idle channels can be accessed by the CU via the accessing strategies, namely, the interweave, underlay, hybrid and overlay [12-14]. On the other hand, the NOMA is an emerging technique for the 5G communication systems in order to fulfill the demand for ultra-high data rate and low latency. In literature, numerous techniques are reported for the feasibility of the NOMA mechanism which are conventionally categorized as power domain multiplexing (PDM) and code domain multiplexing (CDM) [15-17] which further includes power division multiple access (PDMA), sparse code multiple access (SCMA), low density spreading - code division multiple access (LDS-CDMA), pattern division multiple access (PTDMA). The PDMA is popular technique which is explored more for NOMA as compared to all other techniques [16], therefore we have chosen this for further discussion. The PDMA is a potential multiple access technique which relies on the two prerequisites at transmitter and receiver, namely, the superposition coding (SC) and successive interference cancellation (SIC), respectively. The superposition coding is a technique which allows simultaneous transmission of multiple users' information on the same channel from the transmitter end and the reception at receivers is performed using SIC technique.

1.2 Related work

Various researchers have presented the potential review and tutorial articles to explain the concepts of NOMA over orthogonal multiple access (OMA) and its various possible varieties [16-21]. Islam et. al. in [16] have presented a review which primarily focused on power-domain NOMA that utilizes SC at the transmitter and SIC at the receiver. The authors have presented the recent progresses of NOMA in 5G systems where the key intent is on the state-of-the-art capacity analysis, power allocation strategies, user fairness, and user-pairing schemes in NOMA. Further, the interplay of NOMA with other existing 5G techniques such as CC, MIMO, beam-forming, space-time coding, and network coding among users is illustrated. In addition, several important issues on NOMA implementation and some avenues for future research are highlighted. Ding et. al. [17] have presented a review on NOMA techniques where these techniques are classified as a single carrier (power domain-NOMA (PD-NOMA) and CR-NOMA) and multi-carrier (LDS, SCMA, and PDMA), MIMO-NOMA, cooperative-NOMA, and millimeter wave NOMA. Further, the practical implementation challenges for NOMA such as imperfect channel state information (CSI), cross-layer resource allocation, coding and modulation for NOMA are discussed. In addition, the future research challenges such as simultaneous wireless information and power transfer (SWIPT)-NOMA, CR-NOMA, and security in NOMA are also explored. Liu et. al. [18] have provided a comprehensive survey of the state-of-the-art power domain multiplexing-aided NOMA, with a focus on the theoretical NOMA principles, multiple-antenna-aided NOMA design, on the interplay between NOMA and cooperative transmission, on the resource control of NOMA, on the coexistence of NOMA with other emerging potential 5G techniques. The key intent is on the superiority of the power-domain multiplexing NOMA compared to other NOMA techniques. Further, the research challenges of existing NOMA techniques with their potential solutions are discussed. Yunzheng et. al. [19] have presented the briefs about the various existing NOMA technique including SCMA, multi-user shared access (MUSA), pattern division multiple access (PTDMA) and some key waveforms including filter-bank based multicarrier (FBMC), universal filtered multi-carrier (UFMC), generalized frequency division multiplexing (GFDM). The potential challenges and research directions in the field of NOMA are presented. Wang et. al. [20] have presented the briefs about various NOMA techniques and have highlighted the challenges for the standardization of NOMA techniques by the international telecommunication union (ITU). The cognitive radio is well explored technique in the literature [2-7], however, the practical implementation and reliable communication is still a challenging issue. Wang et. al [21] have presented the most feasible framework for spectrum management in wireless networks using the software-defined networking. The authors have illustrated the design principles and key challenges in realizing the software-defined wireless networking (SDWN) enabled spectrum management architecture. By considering these principle and design challenges, the authors have developed a general architecture with a new baseband virtualization design. Further, a prototype is designed that seamlessly integrates with the IEEE 802.11 protocol stack and commodity RF front-end. It is reported that the proposed architecture increases the spectrum efficiency significantly.

1.3 Motivation

Since the CR and NOMA support the concept of spectral efficiency which is major concern for the next generation communication systems. Therefore, simultaneous exploitation of the CR and NOMA to develop the more spectral efficient systems suitable for next-generation communication systems is the potential demand. The comparison of review articles presented in the literature is tabulated in the Table. 1. From the discussion in section 1.2, it is palpable that the Ding and Liu [17, 18] have discussed the concept of CR-NOMA in brief where the CR is used to select the power allocation strategy in the NOMA. However, the spectral efficient nature of both the techniques i.e. CR and NOMA encourages exploring the simultaneous exploitation of the CR and NOMA to achieve higher spectral efficiency. Therefore, in this technical review, we have proposed the potential CR-NOMA frameworks with the implementation challenges and future research directions.

1.4 Organization

This rest of the paper is structured as follows. In section II, the spectrum accessing strategies in CR are presented. The section III comprises the fundamentals of NOMA and working principles for the uplink and downlink scenarios. In Section IV, we have presented the prominent frameworks of NOMA in CR for uplink and downlink scenarios. The section V comprises the challenging issues in CR-NOMA frameworks and their recommended solutions. Finally, section VI illustrates the conclusion of the paper.

II. COGNITIVE RADIO SPECTRUM ACCESSING STRATEGIES

The spectrum accessing techniques are exploited in the CR communication to avoid the interference at PU receiver due to CU communication.

The spectrum accessing techniques are categorized as follows: 1) Interweave spectrum access, 2) Underlay spectrum access, 3) Hybrid spectrum access, and 4) Overlay spectrum access [22]. In the interweave spectrum access, the CU performs spectrum sensing to detect the idle channels/bands of the spectrum known as spectrum holes/white spaces and starts data transmission with full-power on the suitable idle channel [23]. However, if all the channels are detected as active then CU needs to stop its data transmission which is a major milestone for seamless communication. Therefore, to achieve the seamless communication, the underlay spectrum access technique is proposed by the researchers in which the CU transmits the data parallel to the PU on the same channel, time and space [24]. The interference from CU communication to PU is avoided by constraining the transmitted power so that it does not interfere with the PU receiver. However, the major limitation of the underlay spectrum access technique is the limited channel capacity due to constrained power transmission. As both the techniques have specific inadequacies, therefore, in order to avoid these inadequacies and to enjoy the adequacies of both the techniques, the hybrid spectrum accessing technique is explored by various researchers [25-28]. In this technique, the CU accesses the idle sensed channels using interweave spectrum access technique i.e. data transmission with full-power whereas the active sensed channels are accessed via underlay spectrum access technique i.e. data transmission with the constrained-power trans-

Table I. *Comparison of various spectrum accessing strategies.*

Reference	NOMA Technique	Pre-requisites	Performance Analysis using	Integration of NOMA with other techniques	NOMA+ CR	Partial or imperfect CSI	Remarks
Islam et. al. [17]	PD-NOMA	SC and SIC techniques	capacity analysis, power allocation strategies, user fairness, and user-pairing schemes	COPC, MIMO, beamforming, space–time coding, and network coding among users	No	Yes	Perfect SC at the transmitter and error-free SIC at the receiver, optimum power allocation, QoS-oriented user fairness, appropriate user pairing, and good link adaptation are also required to obtain the maximum benefits offered by NOMA.
Ding et. al. [18]	PDMA, LDS, SCMA	SC and SIC techniques	----------	CC, SWIPT, CR, mellimeter wave,	Yes (Brief)	Yes	NOMA is an enabling technology to achieve high throughput, low latency, and massive connectivity.
Liu et. al. [19]	PDM	SC and SIC techniques	-----------	Multiple antenna, CC, SWIPT, CR, MMC	Yes (Brief)	Yes	Highlights the main advantages of power-domain multiplexing NOMA compared to other existing NOMA techniques.
Yunzheng et. al. [20]	SCMA, MUSA, PTDMA and FBMC, UFMC, GFDM.	SC and SIC techniques	--------------	No	No	No	Have duscussed various non-orthogonal mutilple access and non-orthogonal modulation techniques.
Wang et. al. [21]	PD-NOMA, SCMA, PTDMA, MUSA	SC and SIC techniques	Sum throughput, Target SNR, complexity	No	No	No	Presented the relationship among OMA, PD-NOMA, SCMA, PDMA and MUSA. Illustartes the progresses and challenges on standardization
Proposed	PD-NOMA, CR-PD-NOMA	SC and SIC techniques	Sum throughput of user-1 and user-2	CR	Yes (in detail with proposed frameworks)	Yes	The simultaneous use of CR and NOMA results in the improved spectral efficiency and allows more users to access the same spectrum.

mission. In [25], the authors have presented the capacity analysis of interweave, underlay as well as a combination of both (hybrid) spectrum accessing techniques and reported that the hybrid technique outperforms both the techniques. In addition to this, a simple power allocation scheme for the hybrid strategy is illustrated and claims that its achieved capacity is very close to the maximum achievable capacity of the CU. Jiang et. al. in [26] have proposed a hybrid technique which combines the interweave and underlay spectrum access schemes by exploiting a double-threshold energy detection method. Moreover, a Markov chain model is introduced to derive the performance metrics for the proposed technique. In [27], the authors have proposed a hybrid transmission system that exploits both interweave and underlay using multicarrier code-division multiple accesses due to its interference avoidance capability. To the best-of-authors knowledge, the MAC protocols are not exploited with hybrid spectrum accessing techniques to analyze the performance of CR networks. From the above discussion, it is palpable that the spectrum accessing strategy is an integral part of the cognitive radio communication systems where the power allocation to the CU has a very key role whether the full-power or constrained power. In addition to the interweave, underlay, and hybrid spectrum accessing strategies the recently developed strategy is overlay in which the CU and PU access the channel simultaneously with full-power, however, the interference cancellation with each other is achieved by using the advanced encoding schemes such as dirty-paper coding and Gelfand-Pinsker binning [28].

Due to the requirement of such advance encoding techniques, the overlay technique shows complex nature due to which it is less explored. The comparison of different spectrum accessing strategy is illustrated in Table 2. Since interweave and underlay spectrum accessing strategies seem like the primary spectrum accessing strategies, therefore, it is worth to analyze the effect of NOMA implementation in the CRNs for these two strategies. Therefore, in section 4, we have presented the proposed CR-NOMA frameworks.

III. WORKING OF NOMA SYSTEM FOR UPLINK AND DOWNLINK SCENARIOS

The PDMA is a potential NOMA technique which is explored in the literature [15, 29, 30] and relies on the SC at the transmitter end and SIC at the receiving end. In this section, both the techniques are presented and their implementation in the downlink, as well as uplink

Table II. *Cognitive radio spectrum accessing strategies.*

Spectrum Accessing Strategy	Simultaneous Transmission of CU and PU	Prerequisite	Constraints	Interference Management	NOMA-CR in Literature
Interweave	Not Allowed	Spectrum sensing to perceive the idle chanels.	-----------------	Interference controlling	Proposed
Underlay	Allowed	Interference power tolerable limit of PU	Power at PU receiver due to CU transmission needs to be below the interference limit.	Interference avoiding	[30, 31], Proposed
Hybrid	Allowed	Spectrum sensing, Interference power tolerable limit of PU	Power at PU receiver due to CU transmission needs to be below the interference limit tolerable by the CU.	Interference controlling and Interference avoiding	---------------
Overlay	Allowed	Advance interference cancellation techniques are required at PU and CU.	------------------	Interference mitigating	----------------

scenarios, is illustrated as follows. The superposition coding is a technique which allows simultaneous transmission of information from the transmitter to multiple receivers at the same frequency/code with different power levels. The transmitter transmits a signal S_i with power P_i for i^{th} user (i = 1,2,3...N), where $E\left[\left|S_i\right|^2\right]=1,\ \sum_{i=1}^{N} P_i = P$ and signals are superposition coded to formulate the transmitted signal as:

$$x=\sqrt{P_1}S_1+\sqrt{P_2}S_2+\sqrt{P_3}S_3\ldots\ldots \\ \sqrt{P_i}S_i\ldots\ldots..\sqrt{P_N}S_N \tag{1}$$

The received signal at the i^{th} user is represented as:

$$y_i = h_i x + w_i, \tag{2}$$

where, h_i is the complex channel gain between the i^{th} user and transmitter, and w_i denotes the additive white Gaussian noise (AWGN) including inter-cell interference at the i^{th} user receiver.

Further, the SIC is a technique which is employed at the receiver to decode the superimposed signals at the particular receiver. The key approach exploited in the SIC is that the users are successively decoded which means initially one users' signal decoded and after that, it is subtracted from the combined signal before to decode the next user. In order to execute the process of SIC, initially, the users are sorted in descending order of their signal strengths so that the receiver can decode the high power signal first, subtract it from the combined signal and isolate the weaker signal from the residue [14]. The complete detail of SIC and representation using constellation diagrams are presented in [15, 29]. Further, the downlink and uplink scenarios for cellular-NOMA are discussed as follows.

3.1 Downlink scenario for cellular - NOMA

In the downlink scenario for cellular-NOMA, the base station (BS) serves the number of users (subject to the number of channels) in their cellular boundaries. However, at a particular channel, the BS broadcasts the information to serve the number of users (N) with different information. The channel gains from the base station to the i^{th} users is h_{Di} where $i = 1,2\ldots N$ and $\left|h_{D1}\right|^2 > \left|h_{D2}\right|^2 > \left|h_{D3}\right|^2 > \ldots > \left|h_{Di}\right|^2 \ldots. > \left|h_{DN}\right|^2$. The power allocated to the i^{th} user is P_i such that $P_1 < P_2 \ldots.. < P_i \ldots. < P_N$. The process of the signal detection at the i^{th} user in downlink scenario proceeds as follows.

- Decode the signal for N^{th} user (S_{Nd}) from the received signal y_i by assuming signals from all another user as interference.
- Subtract S_{Nd} from the y_i and yield the resultant signal without S_{Nd} (S_{wN}).
- Decode the signal for $(N\text{-}1)^{the}$ user ($S_{(N-1)d}$) from the signal S_{we} by considering signals from all another user i.e. S_i where $i < N$-1 as interference.
- Subtract $S_{(N-1)d}$ from the S_{wN} and yield the resultant signal without S_{Nd} and $S_{(N-1)d}$ ($S_{w(N-1)}$).
- This process continues till the decoding of i^{th} user.

The phenomenon of downlink scenario is depicted as shown in figure 1 for N = 2 in (1). In the downlink scenario, the BS serves as a transmitter and the information of all users are superposition coded which results in the transmission of that superimposed signal at same time/frequency/code. The assumed bound in the channel power gains due to considered set up is: $\left|h_{D1}\right|^2 > \left|h_{D2}\right|^2$ where subscript D is used for downlink metrics. Moreover, the process of decoding the signal at the receivers is shown in figure 1 and proceeds as follows. The users with poor channel conditions (user-2) decode its information by assuming the signals from other users as interference whereas the users with strong channel conditions (user-1), initially, decode the information signal of the partner user and then yield its own signal by subtracting the partners' signal from the combined received signal.

Since the user-1 performs user-2 detection first, then decode its own signal by subtracting user-2 signal from the combined received signal y_{D1}, and due to this the signal from the user-2 does not interfere with user-1, therefore, the throughput of the user-1 is:

$$R_{DN1} = B_D.log_2\left[1+\left\{P_1|h_{D1}|^2 \middle/ N_{01}\right\}\right]. \quad (3)$$

On the other hand, at the user-2, the SIC is implemented by treating the signal from user-1 as interference, therefore the throughput of the user-2 is:

$$R_{DN2} = B_D.log_2\left[1+\left\{P_2|h_{D2}|^2 \middle/ \left(P_1|h_{D1}|^2 + N_{02}\right)\right\}\right]. \quad (4)$$

where, N_{01} and N_{02} are the noise powers at user-1 and user-2, respectively. B_D denotes the bandwidth of downlink channel. Moreover, in the downlink scenario with orthogonal multiple access (OMA) implementation using frequency division multiple access (FDMA), the bandwidth must be divided into two parts i.e. B_{D1} for user-1 and B_{D2} for user-2 such that $B_{D1} + B_{D2} = B_D$. Since the individual channels are allocated to every user in order to avoid interference to each other. Therefore, the throughput of user-1 and user-2 is derived as:

$$R_{DO1} = B_{D1}.log_2\left[1+\left\{P_1|h_{D1}|^2 \middle/ N_{01}\right\}\right], \quad (5)$$

and

$$R_{DO2} = B_{D2}.log_2\left[1+\left\{P_2|h_{D2}|^2 \middle/ N_{02}\right\}\right]. \quad (6)$$

3.2 Uplink scenario for cellular-NOMA

In the uplink scenario for cellular-NOMA, all the users transmit their information signal S_{Ui} on the same channel/time/code towards the base station through a channel having gain coefficient h_i, however, the power allocated to users in two ways either full power allocation or controlled power. In the controlled power strategy, the total power P_{Ui} is allocated to i^{th} the user in such a way that $\sum_{i=1}^{N} P_{Ui} = P_U$, where, P_U is the maximum power that can be transmitted from the base station to avoid the interference with the adjacent cells and $P_{U1} = P_{U2} \ldots = P_{UN}$. In the uplink scenario, the BS receives the superimposed signal of all different users. Therefore, the complete received signal y_U at the base station is the sum of all received signals due to all the transmitted signals which are represented as:

$$y_U = \sqrt{P_{U1}}h_{U1}S_{U1} + \sqrt{P_{U2}}h_{U2}S_{U2}\ldots\ldots \sqrt{P_{UN}}h_{UN}S_{UN} + W, \quad (7)$$

where, W is the AWGN with noise power N_0 at the BS receiver.

Further, at the receiving end, the BS must have SIC ability to extract information of each user. The process of users' signal detection is performed as follows.

- Arrange the users (U) according to their received signal strengths at the BS i.e. *U1 > U2 > U3..... UN.*
- Decode the signal for 1st user (S_{1d}) from the received signal y_U as given in (7) by assuming signals from all other users as interference.
- Now, subtract the decoded signal S_{1d} from the received signal y_U i.e. $y_{s2} = y_U - S_{1d}$
- Decode the signal S_{2d} for user 2 from the signal y_{s2} by considering signals from the user having signal strength lower than *U2*.
- This process continues till the detection or decoding of the signal for all users at the base station.

Let us assume the similar case as considered for the downlink scenario i.e. $N = 2$, as shown in figure 2 the achieved data rates for

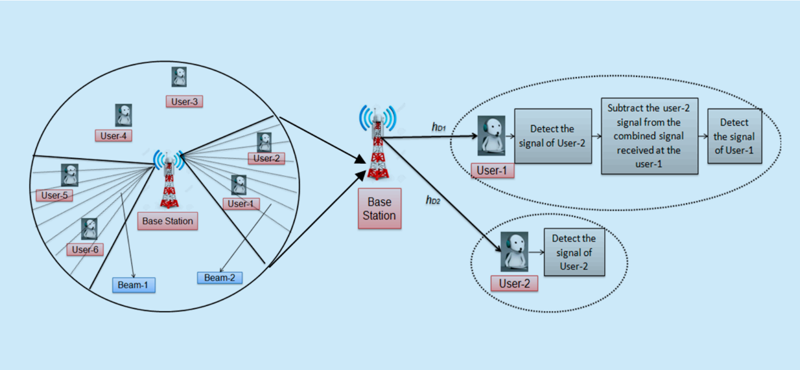

Fig. 1. *The schematic of cellular-NOMA for downlink scenario.*

the user-1 and user-2 are computed as follows. The P_1 and P_2 are assumed to be equal, however, $h_{U1} > h_{U2}$. The received signal from user-1 has high signal strength as compared to that of the user-2. Therefore, at the BS, initially, the signal of user-1 is detected by assuming the signal of user-2 as interference. Further, a resultant signal is yielded by subtracting the user-1s' signal from the combined received signal and the resultant signal is exploited to decode the signal of user-2. Thus it is apparent that the user-1 gets interference due to user-2, however, user-2 enjoys the interference-free communication. Therefore the data rates of user-1 and user-2 are as follows.

$$R_{UN1} = B_U.log_2\left[1+\left\{P_1|h_{U1}|^2 \middle/ (P_2|h_{U2}|^2+N_0)\right\}\right], \tag{8}$$

and

$$R_{UN2} = B_U.log_2\left[1+\left\{P_2|h_{U2}|^2 \middle/ N_0\right\}\right], \tag{9}$$

where B_U is the total bandwidth dedicated to the uplink channel. In the uplink scenario for conventional OMA technique, the bandwidth B_{U1} and B_{U2} are dedicated to the user-1 and user-2 under the constraint $B_{U1} + B_{U2} = B_U$. Therefore the achieved data rates for the user-1 and user-2 are presented as follows.

$$R_{UO1} = B_{U1}.log_2\left[1+\left\{P_{U1}|h_{U1}|^2 \middle/ N_0\right\}\right], \tag{10}$$

and

$$R_{UO2} = B_{U2}.log_2\left[1+\left\{P_{U2}|h_{U2}|^2 \middle/ N_0\right\}\right]. \tag{11}$$

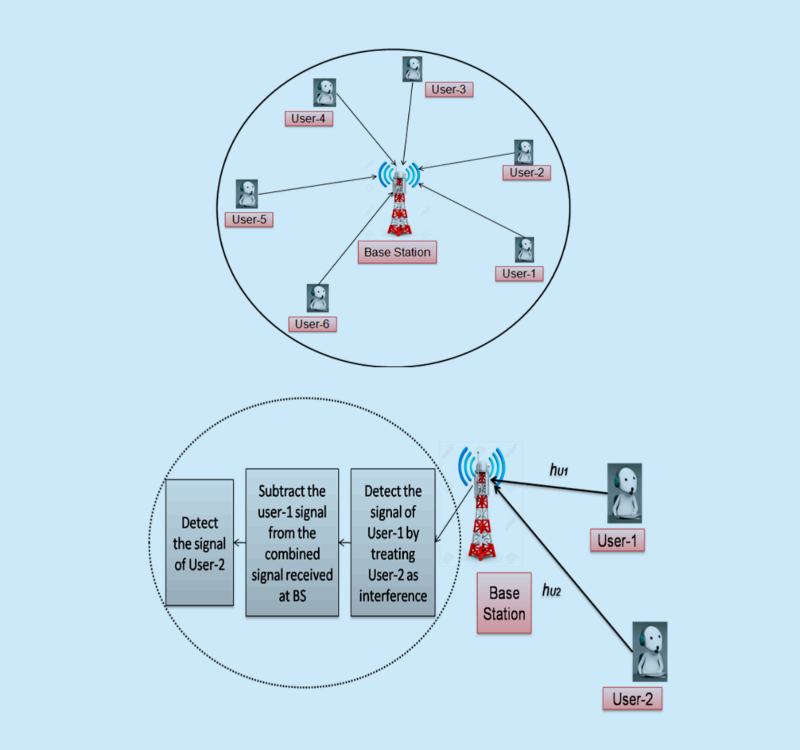

Fig. 2. *The schematic of cellular-NOMA for the uplink scenario.*

IV. PROPOSED FRAMEWORKS OF COGNITIVE RADIO WITH NOMA

It is well known that the CR and NOMA are promising techniques for the next generation communication systems to improve the spectral efficiency. Therefore, recently, researchers have focused on the analysis of simultaneous exploitation of CR and NOMA for the next generation communication systems and known as CR-NOMA [31, 32]. The existence of CR-NOMA is a challenging issue due to the requirement of interference avoidance technique for NOMA and simultaneous accessing of the same channel for the CU and PUs and in this section, we have proposed two potential frameworks for the CR-NOMA systems.

4.1 Framework-1

The framework relies on the underlay spectrum accessing strategy where the CU exploits the spectrum of PU in the presence of PU however, the power controlled transmission is achieved via NOMA technique. In the Framework-1, a network-cell comprises the PUs and a BS is considered where the BS uses three antennas to serve the PUs in three different sectors as shown in figure 3 (a). The CU is allowed to use the spectrum of PUs simultaneously using NOMA techniques as depicts in figure 3(b). In every sector, the PU and CU can share the spectrum by employing the NOMA technique and selection of the user for SIC relies on the channel conditions. If we consider only the path loss for channel condition, the far user gets interference due to the information signal of the near user, therefore, the far user decodes its signal by considering the near user as interference. This framework imposes the prerequisite of SIC supporting nature for the PUs and SC ability at the base station. In addition to this, the CR transmitting unit is assumed to be at the BS where both the transmitter (CR and PU) cooperate with each other to formulate the superimposed transmitted signal having information of both the users. In general, this framework violated the fundamental concept of the cognitive radio which is as follows. The CU must establish its communication using PUs' spectrum in such a way that its structure and communication remains impervious, however for the next generation communication system where the spectral efficiency is the prime objective, the proposed framework is a suitable option. The Framework-1 is suitable for the underlay CR networks where the CU is allowed to access the channel of PU subject to avoid the interference at PU and the power allocation plays an important role for this. The implementation of NOMA in underlay CRN strengthens the power allocation strategies and interference management. In addition to this, the interference management allows the CU to transmit the signal with more power which results in the improvement in throughput of CU. The data rate or capacity computation for each sector is similar as discussed in the downlink and uplink scenarios in section II.

4.2 Framework-2

The Framework-2 relies on the interweave spectrum access strategy where CU perceive the idle spectrum through spectrum sensing and have implemented the NOMA technique to support more than one CUs on that spectrum. In the Framework-2, we have assumed a cell for the CU communication where a BS serves the CUs and it is assumed that within that cell there is no PU receiver, however, some CU may experience interference due to the PU transmission as shown in figure 4 (a). The BS serves CU in the circular cell using three different sectors where the single frequency channel can support only one user at a time in one sector. On the other hand, if the NOMA technique is employed in the CR systems, the number of CU supported in the cell can be increased with their sum rate as depicts in figure 4(b). Moreover, some of CUs lie on the edge of the cell gets interference from the PU signals which affect the signal-to-noise-plus-interference ratio (SINR) at the CUs. Therefore, the data rate of CU-1 and CU-4 in the figure 4(b) is:

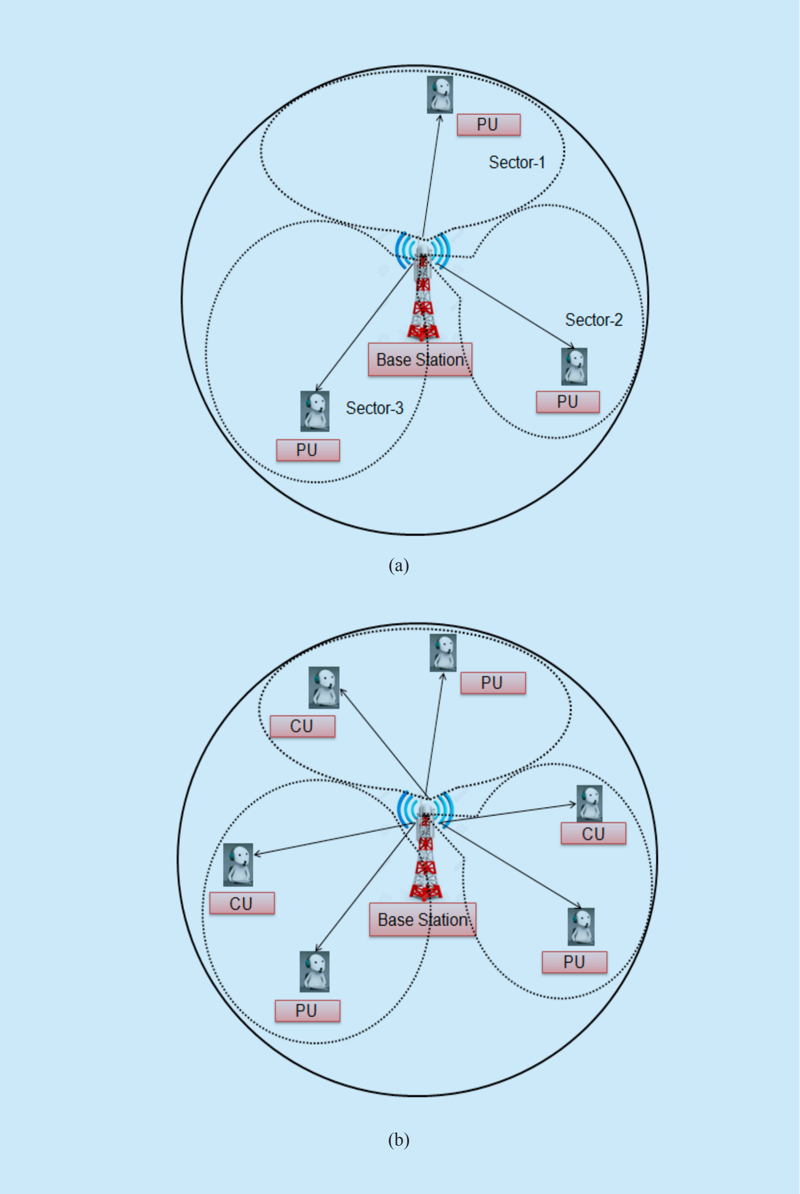

Fig. 3. *Proposed Framework-1 for (a) PU network and (b) CU and PU network with NOMA.*

$$R_{D1N} = B_D.log_2\left(1+\frac{P_1\left|h_{cc1}\right|^2}{N_{01}}\right), \quad (12)$$

and

$$R_{D4N} = B_D.log_2\left(1+\frac{P_2\left|h_{D2}\right|^2}{P_1\left|h_{D1}\right|^2+P_{PU}\left|h_{pc4}\right|^2+N_{02}}\right), \quad (13)$$

where h_{cci} the channel gain coefficient between the CU base station and ith CU in the network, P_1 and P_2 are the powers allocated to CU-1 and CU-4, respectively $h_{cc1} > h_{cc4}$, due to which $P_2 > P_1$. h_{pci} denotes the channel gain coefficient between the PU-base station and i^{th} CU in the network and P_{PU} is the power transmitted by the PU base station.

On the other hand, if two cognitive users need to be served in the same sector without using NOMA, the bandwidth must be divided into two parts i.e. B_{D1} and B_{D2}, where $B_{D1} + B_{D2} = B_D$. Thus the data rates of user-1 and user-4 are:

$$R_{D1O} = B_{D1}.log_2\left(1+\frac{P_1\left|h_{cc1}\right|^2}{N_{01}}\right), \quad (14)$$

and

$$R_{D4O} = B_{D2}.log_2\left(1+\frac{P_2\left|h_{D2}\right|^2}{P_{PU}\left|h_{pc4}\right|^2+N_{02}}\right). \quad (15)$$

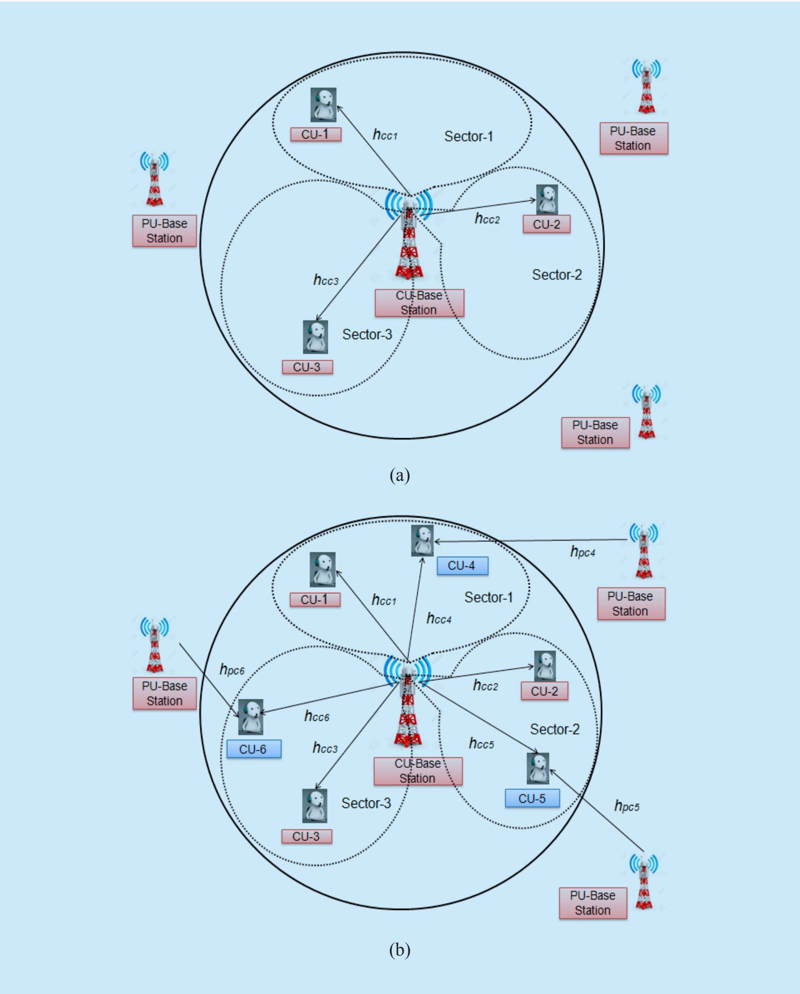

Fig. 4. *Proposed Framework-2 CR Network with (a) OMA and (b) NOMA.*

V. SIMULATION ENVIRONMENT AND RESULTS

We have considered the downlink environment in order to analyze the effect of NOMA, OMA, CR-NOMA (Framework-2), and CR-OMA (Framework-2) techniques on the data rates of the user-1 and user-2. In the simulated environment, the user-1 and user-2 are considered static and mobile, respectively. Therefore due to static nature of the user-1, the channels gain h_{D1}= 0.9 is assumed to be constant, however h_{D2} varies due to mobile nature of user-2.

The total bandwidth of the channel is assumed to be a unity which is divided into two parts in case of OMA however, complete bandwidth is assigned to both the users in case of NOMA. The total power is taken as 10W whereas the power allocated to user-1 and user-2 varies between 0 to 10 and vice-versa, respectively. The noise power at both the users is assumed to be 0.1W. From the presented results in figure 5, it is apparent that there is a significant improvement in the data rate of user-2 for the NOMA technique as compared to that of the OMA technique, however, this improvement decreases with increase in the value of h_{D2} which validates the concept of NOMA. The fundamental concept of NOMA is that the NOMA performs well as compared to that of the OMA if the channel gain difference between two users is high since it improves the performance of the detection using

SIC [7]. Moreover, the data rate achieved in case of CR-OMA and CR-NOMA are less as compared to that of the conventional OMA and NOMA data rates and it is due to additional interference at user-2 due to PU communication in Framework-2. However, it is worth to mention that the effect of cognitive concept on the data rates is not considered here and achieved results are obtained for the Framework-2 in which the spectrum holes are already detected and a user is using that spectrum hole. The proposed CR-framework (Framework-2) supports three users on the same channel in one sector however, the conventional OMA supports only two users.

Conventionally, the CR-NOMA sum-data rates are more as compare to that of the conventional NOMA technique but due to aforementioned reason, its data rates seem less in the figure 5. Moreover, the results of CR-NOMA Framework-1 will be similar to that of the NOMA technique because in this case ,entire framework is similar to NOMA except the user names since user-1 and user-2 are replaced with CU and PU however, Framework-1 supports only two users.

VI. RESEARCH POTENTIALS FOR NOMA AND CR-NOMA IMPLEMENTATIONS

The proposed frameworks are recommended as potential solutions to implement the NOMA techniques in the CR communication systems. However, the implementation of CR-NOMA technique is in the infant stage and still need to explore to achieve feasible systems by exploiting the following challenging issues.

6.1 Imperfect CSI

The NOMA technique relies on the power allocation to the users on the bases of channel conditions which impose a bound on the transmitter side to obtain the channel state information (CSI). However, it is very difficult to obtain the perfect CSI at the transmitter side due to random nature (uncertainty) of the channel. By considering this critical issue, Yang et. al [33] have investigated the performance of the NOMA over OMA for two scenarios of the partial channel states as follows: 1) imperfect CSI and 2) second-order-statistics (SOS). For the first scenario, which is based on imperfect CSI, the authors have present-

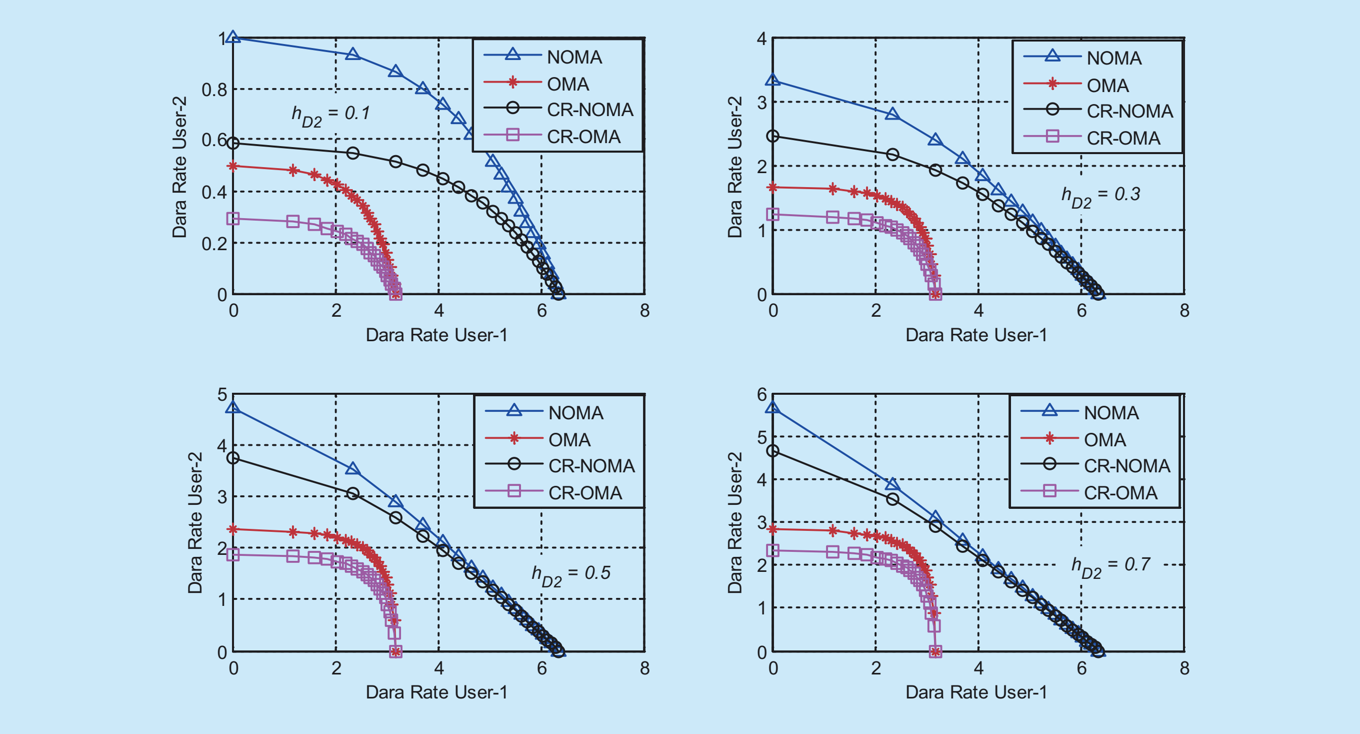

Fig. 5. *The variations of the data rate of user-2 with data rate of user-1in the downlink scenarios.*

ed a simple closed-form approximation for the outage probability and the average sum rate, as well as their high signal-to-noise ratio (SNR) expressions. However, for the 2nd scenario which is based on SOS, the authors have derived a closed-form expression for the outage probability and an approximate expression for the average sum rate. Wei et. al. [34], the authors have proposed a power efficient resource allocation algorithm when the imperfect CSI is available at the transmitter (CSIT). A non-convex optimization problem is formulated in which the optimal SIC decoding policy was determined by the channel-to-noise ratio (CNR) outage threshold. Further, a suboptimal resource allocation scheme was proposed based on the difference of convex (D.C.) programming, which can converge to a close-to-optimal solution rapidly. Through simulation results, it is reported that the proposed resource allocation schemes provide significant transmit power savings and enhanced robustness against channel uncertainty via exploiting the heterogeneity of channel conditions and QoS requirements of users in MC-NOMA systems. Liu. et. al. [35] have investigated a NOMA downlink multiuser system where transmitter perceives the CSI through limited feedback channel and have studied the effects of two traditional beam-forming technologies namely, zero-forcing beam-forming and random beam-forming. Based on the CSI available at the transmitter, the authors have proposed a user selection scheme to reduce the interference between the NOMA users. Moreover, a power allocation scheme is proposed to improve the sum-rate of NOMA system. Through simulation results, it is perceived that the NOMA system with limited feedback channel still gains larger system rate than traditional orthogonal multiple access systems. It is also reported that the random beam-forming is more suitable for the NOMA system with limited CSI feedback.

These research efforts to manage the imperfect CSIT in NOMA are appreciable however simultaneous exploitation of CR and NOMA in the networks demands further exploration of imperfect CSIT in the NOMA-CR frameworks. Therefore, the analysis of CR-NOMA systems with imperfect/partial CSI needs to be investigated.

6.2 Spectrum hand-off management

The spectrum handoff management is a crucial issue in the CR networks, however, the implementation of NOMA in CR networks makes it more challenging since the power allocation relies on the channel gain coefficients. The users need to follow the cellular communication protocols in the cellular region and in addition, have to take care of the power allocation according to the variations of channel gain. Thus, the spectrum hand-off management for CR-NOMA is completely unexplored and potential research area.

6.3 Standardization

The standardization of regulatory policies for the CR-NOMA is a challenging task due to its two different frameworks as discussed. In the Framework-1 the BS must have SC and SIC ability for the downlink and uplink scenarios, respectively which is generally overlooked in the cellular systems. Further, the PU must have the ability of SIC and these prerequisites demand the new standards for the next generation wireless communication systems so that according to that CR-NOMA standards can be suggested. Moreover, in the Framework-2 as the role of PU is not so significant and therefore the standards for this framework can be suggested.

6.4 Less complex and cost effective systems

The simultaneous use of CR and NOMA enhances the spectral efficiency significantly but on the cost of complex and costly systems as well as algorithms such as coding and interference cancelation techniques etc. Thus it opens a door of research for less complex and cost-effective systems and algorithms for implementation of CR-NOMA systems.

6.5 Energy efficient design and frameworks

The energy efficient designs are the most preferable in order to support the green communication which is much desired. In addition, most of the communications devices are battery operated which further requires the energy efficient designs. Therefore, the energy efficient designs are further open research issues which must be investigated. To the best-of-the-authors knowledge, recently in [36, 37] a step ahead in this direction is taken where the authors have investigated a CR-NOMA from the perspective of energy efficiency and have reported that it outperforms the CR-OMA approach. Even though, it is interesting as well as open research problem which needs to be investigated. Yang et. al. [38] have explored an uplink energy minimization problem for machine-to-machine communications (MMC) with NOMA. The formulated problem is of non-convex nature, therefore, it is proved that transmitting with minimum rate and full time is optimal. Further, the original problem is transformed into an equivalent convex problem, which can be effectively solved by the proposed optimal power control and time scheduling scheme. These efforts to achieve energy efficiency frameworks of NOMA are in infantry stage which needs to explore more for NOMA and CR-NOMA frameworks.

6.6 QoE management

The quality of service (QoS) is the major objective for the next generation communication systems to support the concept of reliability. The next generation networks appear to be crowded by multiple and heterogeneous devices/users which have to serve various applications. At every user, the quality needs to be maintained to serve all the user, simultaneously. By considering this, Chen et. al. [39] have proposed a new performance metric known as quality of experience (QoE). The QoE is the perceptual QoS from the users' perspective [40].

In CR networks, the prime objective is to enhance the performance of CU network by satisfying the QoS constraints of the PU network. However, in the CR-NOMA the QoE metrics of both the networks must be improved since both the networks directly affects the performance of each other (Framework-2). To the best-of-authors knowledge, this is completely unexplored and interesting as well as broad research area so far.

6.7 Power allocation strategy for CUs to implement NOMA without interfering to PU

In NOMA, researchers have put some efforts on the power allocations schemes [41-43]. The authors in [41] have proposed two power allocation strategies for NOMA which are based on the CSI experienced by NOMA users and on the pre-defined QoS per NOMA user. Lei et. al. [42] have investigated a problem of jointly optimizing the power and channel allocation for NOMA. The key insights are on the complexity and optimality have been provided, where an algorithm framework based on Lagrangian dual optimization and dynamic programming is proposed. Shahab et. al. [43] have proposed a novel power allocation strategy that can optimize the system ergodic sum capacity constraining the minimum mutual interference between the paired users. It is claimed that the proposed scheme outperforms conventional power allocation in terms of bit error rates at the user ends with negligible effect on the system ergodic sum capacity.

In the NOMA technique, the power is allocated to CUs on the bases of channel conditions. However, in the CR-NOMA techniques such as Framework-2, the transmitted power must be allocated to the CUs in such a way that the PU communication remains unaffected which means the power allocation in CR-NOMA is a more challenging task as compared to that of NOMA technique which is also an open research issue.

6.8 Cooperative CR-NOMA

The cooperative communication is a promising technology for the efficient spectrum utilization and this technology is also eligible for the CR-NOMA (Framework-2). In [31, 32, 44], the authors have presented the concept of co-operative-NOMA to improve the performance of NOMA systems. Therefore, the cooperative CR-NOMA is a completely unexplored area which has to be investigated for the next generation communication systems.

6.9 Interference cancellation techniques

The entire concept of NOMA relies on the superposition coding and interference cancellation techniques which are well explored for wireless communication however later one has scope to get explore therefore researchers are focusing on more efficient interference cancellation techniques [45-47] such as triangular interference cancellation technique. This is also a challenging area of research in order to improve the performance of CR-NOMA and NOMA systems.

6.10 Security aspects in CR-NOMA

From the first view about NOMA, it seems that the security is a major challenge in NOMA due to detection of the other user's information before decoding its own information. However, researchers have worked on this issue and perceived that the security can be provided in NOMA. Ding et. al. [48] have explored the security aspects with reference to the uni-casting and multicasting and it is reported that the use of NOMA in uni-casting always improves the uni-casting security when compared with the OMA. Further, the uni-casting secrecy outage probability is investigated to further enhance the security of NOMA. In [49], the authors have investigated the physical layer security of NOMA in the large-scale networks with invoking stochastic geometry for the single- and multi-antenna transmission scenarios, where the base station (BS) communicates with randomly distributed NOMA users. Moreover, the exact expressions of the security outage probability are derived for both single-antenna and multiple-antenna aided scenarios. In [50], Qin et. al. have studied the aspects of security aspects of NOMA in large-scale networks in which both the NOMA users and eavesdroppers are spatially randomly deployed. To improve the security of the random network, a protected zone around the source node is adopted. The secrecy performance is analyzed through the new deriving asymptotic expression of the security outage probability. Further, it is perceived from simulation results that the secure performance of the NOMA networks can be improved by either enlarging the scope of the protected zone or reducing the scope of the user zone.

These security aspects are presented with reference to the NOMA techniques however, the CR has its own security challenges such as primary user emulation attack (PUEA), falsifying data or denial of service attack (DOS) [51]. Therefore, the CR-NOMA will face the security challenges of both the technique and potential research efforts are required for future communication.

6.11 Role of user clustering and challenges

Since in the downlink NOMA, multiple data flows are superimposed in the power domain and user decoding is based on successive interference cancellation, therefore, its performance highly relies on the power split among the data flows and the associated power allocation (PA) problem. By keeping this in view, the problem of user fairness arises. In order to study this problem, the Timotheou and Krikidis [52] have investigated PA techniques which guarantees the fairness in the downlink for two scenarios of channel state information (CSI) namely, i) instantaneous CSI at the transmitter, and ii) average CSI. The key feature of NOMA is the tradeoff between throughput and user fairness which is studied for the single antenna case in this paper. To consider the multi-antenna concept for this problem, Liu et. al. [53] have investigated a dynamic user allocation and power optimization problem by considering the fairness issue in cluster-based MIMO-NOMA systems in which an NP-hard optimization problem is formulated. The authors have proposed a two-step sub-optimal method for solving the dynamic user allocation problem for the user fairness. Moreover, have optimized the power allocation coefficients by invoking a bisection search based algorithm to maximize the signal-to-interference-and-noise-ratio (SINR) of the worst user in each cluster three efficient user allocation algorithms are designed to seek a trade-off between computational complexity and throughput of the worst user. Further, Ali et. al. [54] dynamically group the users receive antennas into a number of clusters equal to or more than the number of BS transmit antennas where a beam-forming vector is shared by all the receive antennas in a cluster. A linear beam-forming technique is proposed which significantly cancel the inter-cluster interference by exploiting the all receive antennas. Moreover, for inter- and intra-cluster power allocation, the dynamic power allocation solutions are provided where the key intent is to maximize the overall cell capacity. Further in [55], the authors have extended this problem for the uplink and downlink both the scenarios and have investigated the problem of dynamic user clustering for both uplink and downlink NOMAs, where a sum-throughput maximization problem in a cell is formulated in such a way that the user clustering (i.e., grouping users into a single cluster or multiple clusters) and power allocations in NOMA clusters can be optimized under transmission power constraints, minimum rate requirements of the users, and SIC constraints.

The power allocation techniques with user fairness are explored for NOMA however, CR-NOMA power allocation strategies are well explored which needs to be synchronized with reference to NOMA users fairness demand.

6.12 Wireless power transfer to NOMA

The exponential increase in the tiny battery operated devices such as internet of things (IoT), wireless sensor networks (WSNs), body area networks (BANs) demands the energy-efficient communication in addition to the spectral efficient communication. Due to the tiny size of the device, the battery size needs to be small which means the limited battery life and charging the battery is almost an impossible task due to remote and inaccessible locations. The prominent solution for this problem is provided by the simultaneous wireless information and power transfer (SWIPT) phenomenon where the information and power to the recipient user are transmitted wirelessly. The concept of SWIPT is well explored in the recent years [56, 57]. The implementation of SWIPT in NOMA is an interesting problem and a step towards this is taken by the researchers [58-60].

The authors have investigated a wireless-powered uplink communication system with NOMA which comprises one base station and multiple energy harvesting users and key intent is on the data rates optimization and fairness increase. The authors have formulated optimization problem and perceived that it can be solved optimally and efficiently by using linear programming methods or convex optimization, which witnesses the ease of practical implementation of the proposed scheme. The proposed scheme outperforms the orthogonal multiple access scheme, however, there is dependence between sum-throughput, minimum data rate, and harvested energy. Moreover, the convergence speed of the proposed greedy algorithm is evaluated, and it is shown that the required number of iterations is linear with respect to the number of users.

Liu et. al. [59] have exploited the cooperation for simultaneous wireless information and power transfer (SWIPT) in the NOMA networks where users are spatially randomly located. A novel protocol is proposed in which NOMA users close to the source act as energy harvesting relays to help the far NOMA users. The location of the users has a prominent role in this protocol, therefore, three user selection schemes based on the user distances from the base station are proposed. The performance of the proposed protocol is analyzed through the derived closed-form expressions of the outage probability and system throughput. It is concluded that the use of SWIPT does not harm the diversity gain when compared to the conventional NOMA. The SWIPT-NOMA is in its infant stage and needs to explore more to achieve the mature stage for practical implementation. In addition, the SWIPT-CR-NOMA demands more research efforts for practical implementation.

6.13 Multi-cell NOMA with coordinated multipoint transmission

Since in the downlink NOMA, the BS allocates transmit power in such a way that the SIC decoding is performed according to an ascending order of the channel gains of the NOMA users [16]. The power allocation strategy results in a low received signal-to-intra-cell-interference ratio for lower channel gain users (e.g., cell-edge users) who are also susceptible to the inter-cell interference. Therefore, intercell interference management is a crucial phenomenon in multi-cell downlink NOMA systems. In addition to this, the popularity of phantom cell communication where the cell is divided into small cells to accommodate more number of users provokes to manage the effect of inter-cell interference.

In order to consider this scenario, the authors have proposed a framework to use coordinated multi-point (CoMP) transmission technology in downlink multicell NOMA systems considering distributed power allocation at each cell. The CoMP transmission is used for users experiencing strong receives signals from multiple cells while each cell adopts NOMA for resource allocation to its active users. The numerical results witnesses the numerical results quantify the spectral efficiency gain of the proposed CoMP-NOMA models over CoMP-OMA. Finally, this article is concluded by identifying the potential major challenges in implementing CoMP-NOMA in future cellular systems.

6.14 Multiple-carrier NOMA

The multi-carrier access in the communication system is a real and practical scenario which needs to be investigated for the CR-NOMA users also. Recent works presented on multi-carrier NOMA in the literature are as follows. Hsueh and Chen [60] have proposed a CR-NOMA scheme based on multiuser orthogonal frequency division multiplexing scheme to reduce the total transmit power. In the proposed framework, each subcarrier is assigned to two users (PU and CU) for data transmission and transmits data with a lower order of a modulation mode. Since the PU has 1st preference to use channel and CU accesses some of the channels simultaneous to the PU. The key concern of the proposed scheme is that how the PU and CU perform resource allocation under different subcarriers and channel gains. The proposed scheme outperforms the OFDM scheme in terms of transmitting power or capacity equivalently. The authors in [61] have investigated an optimal resource allocation for multicarrier (MC) multiple-input single-output-NOMA (MISO-NOMA) downlink systems. The resource allocation design for the maximization of the weighted system throughput is formulated as a non-convex optimization problem taking into account the QoS requirements of the downlink receivers. The formulated problem is solved by using monotonic optimization. Chatziantoniou et. al. [62] have proposed a novel transmission scheme which combines NOMA and multi-carrier index keying (MCIK). This scheme is proposed as a mechanism to enable multiple access for dense wireless device-to-device (D2D) systems that require high energy efficiency and effective interference management. The practical and effective nature of multi-carrier CR-NOMA further encourages the researchers to explore in this field.

6.15 Cross-layer design

The Cognitive radio is a framework which needs to work on almost all layers of the open system interconnection (OSI) Model [63, 64]. The spectrum sensing is a process which is physical layer phenomenon. However, the accessing and sharing of spectrum using appropriate spectrum accessing technique is a medium access control (MAC) layer phenomenon. The routing information exchange of path and its reconfiguration are the functions of network layer. The CU pair link establishment and providing the reliable communication without affecting the PU communication becomes the function of transport and session layer. In addition to this, the spectrum mobility is a phenomenon which comprises all the operations of cognitive cycle. Therefore, the spectrum mobility is a phenomenon which works on all layers of OSI model. On the other hand, the NOMA appears to work on the physical layer in order to support the SIC at transmitter and SC at the receiver.

On the other hand, the NOMA is assumed to be a Physical and MAC layer mechanism till now in the literature where the single channel/spectrum is utilized by more than one CU non-orthogonally. The data is provided from the end-user to the system which is on the application layer and further decoding of data, clustering, transmission etc. functions are performed at the lower layers [40].

From here it is perceived that the CR and NOMA both are working on different layers of the OSI model. Therefore, the CR-NOMA needs the cross-layer designing of the protocols so that proper synchronization between two technologies can be achieved. An effort towards providing the cross-layer design for NOMA with the help of software-defined networking is presented in [40] where the functions at different layers are controlled through the software. However, in the CR-NOMA, in addition to controlling the functions at different layers, the CU needs to perform all other function of spectrum accessing and management. Therefore, the cross-layer design for CR-NOMA is an open and potential research issue.

6.16 MIMO-NOMA-CR

The researchers have well explored the MIMO-NOMA to improve the spectral and energy efficiency of the network in the recent past. Recently, the efforts to exploit the CR in NOMA are performed [31, 32] to resolve the issue of power allocation to NOMA-users and reports the improvement in the performance. The 5G demands huge improvement in the spectral efficiency, energy efficiency etc. and in order to achieve this demand, the simultaneous use of MIMO, CR, and NOMA will be a milestone in the field of communication. Therefore, in MIMO+CR+NOMA, the open research challenge is how to exploit one technique in another one.

VII. CONCLUSION

The cognitive radio and NOMA are the promising candidates to fulfill the demand of high spectral efficiency, however, more spectral efficient frameworks are desired for the next generation communication systems. The potential way to achieve this demand is simultaneous use of the CR and NOMA, therefore, the important frameworks of simultaneous exploitation of both the techniques are proposed in this paper. The CR-NOMA improves the spectrum efficiency and massive connectivity as compared to that of the CR and NOMA techniques. Moreover, the prominent and challenging issues regarding the implementation and feasibility of the proposed frameworks are illustrated. Such as, the CR and NOMA needs to be synchronized to each other with reference to the different layers of OSI model, therefore a research for the cross layer design is a potential research issue.

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