A Review of Cognitive Radio Inspired NOMA Techniques

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Abstract.
The explosive growth of mobile devices, as well as the increasing demand for wireless services, has created a situation of serious spectrum shortage. A solution to this problem is the introduction of cognitive radio (CR). Cognitive radio (CR) is a form of wireless communication in which a transmitter/receiver can intelligently detect which communication channels are in use and which are not, and instantly move into vacant channels while avoiding occupied ones. This optimizes the use of available radio-frequency (RF) spectrum. Researchers have proposed several techniques to achieve high spectral efficiency. Among then non-orthogonal multiple access (NOMA) has the capabilities to be adapted in the 5G network. It has the potential to increase the number of users in the system. Integrating NOMA techniques into CR networks incurs severe technical challenges. Further to enhance the performance of NOMA, the MIMO techniques to CRNs will employ. It was shown that the performance of a Cognitive Radio Network (CRNs) with NOMA can be significantly improved by using MIMO techniques.
In this paper, we review the areas covered by Cognitive Radio inspired NOMA in order to improve spectral efficiency (SE) and energy efficiency (EE). The challenges and future research directions are also discussed in our paper.

Keywords: Cognitive Radio, Non-Orthogonal Multiple Access (NOMA), SWIPT, Green Communication, PHY Layer Security, CR-NOMA. Beamforming, Relay strategy, Energy Efficiency.

1. Introduction

Cognitive radio is aware of its operational and geographical environment. It has the capability of understanding the environment and takes the decision. In other words it dynamically and autonomously changed its operational parameters and protocols and

learns from its previous experiences. It is capable of spectrum sharing between licensed and un-licensed users. This technique also called dynamic spectrum sharing.
Cognitive radio (CR) comes after Software Defined Radio (SDR) for radio communication. There are three different Cognitive Radio Techniques. These are Underlay, Overlay, and Interweave. In underlay and overlay techniques the cognitive (secondary) and non-cognitive (primary) user can transmit simultaneously. It should be noted that the interference lies below an acceptable limit in underlay technique while in Interweave technique simultaneous transmission is not possible.
Non-orthogonal multiple access (NOMA) technique widely recognized for efficient spectrum utilization in 5G wireless networks. It works on the power domain. NOMA is built over Orthogonal Frequency Division Multiplexing OFDM. In OFDM each user can utilize all the available subcarriers whereas in NOMA multiple users can utilize the same subcarrier which increases spectrum efficiency. One of the variations of NOMA is CR-NOMA (Cognitive Radio- NOMA). It supports intelligent spectrum sharing and minimizes multiuser interference. Subsequently improves spectrum sharing and number of user connectivity.
In section 2, 3 and 4 we introduce the concept of NOMA, CR-NOMA and CR-MIMO-NOMA technology. In section 5, we introduce the review of Cognitive Radio inspired NOMA technologies. Section 6 concludes the paper with future direction.

2. Non-Orthogonal Multiple Access

For a massively connected network the existence of huge mobile devices invites the requirements of NOMA. In NOMA multiple accesses helps to improve spectral efficiency as well as low latency which is far beyond concept in OMA network [25]. The superiority of NOMA over OMA can be summarized as spectral efficiency, throughput, user fairness, low latency, massive connectivity, computability etc [25]. Many advantages in NOMA besides some challenges in terms of NOMA implementation includes hardware complexity, error propagation in SIC implementation, optimal pilot allocation, and instantaneous CSI requirement [25]. Future direction for NOMA research includes different techniques with NOMA for using it in different application of next generation communication system. These techniques are CR, MIMO, and New Radio (NR) etc.

3. Cognitive Radio-Non Orthogonal Multiple Access

NOMA and CR has the capability for efficient spectrum utilization. In NOMA multiple users' transmission can happen simultaneously. Here CR comes into picture. In cognitive NOMA intelligent spectrum sharing is possible. Benefits of the CR based NOMA systems are listed below. Improved Spectrum Efficiency: Spectrum utilization improved tremendously in Cognitive NOMA networks where PUs and SUs can active simultaneously acceptable reception quality. Massive Connectivity: 5G supports a huge number of smart devices, such as augmented reality (AR), virtual reality (VR), on-line health care, and Internet of things (IoTs). This massive connectivity can be fulfilled by cognitive NOMA networks [1]. Low Latency: In cognitive NOMA the secondary user's transmission delay can be reduced by multiple SUs can be connected simultaneously whereas in OMA only one SU can transmit by using an available resource block. Better Fairness: It guarantees improved user fairness. There are many different aspects to improve the performance of cognitive NOMA in 5G and above.

Cognitive Radio is capable of changing the communication channel, when it seems that the current channel is busy eventually helps the secondary user for accessing the channel intelligently. In NOMA multiple accesses can possible simultaneously in the same power level. So in Cognitive NOMA multiple accesses can possible in an intelligent way for both primary as well as secondary users to get better spectrum utilization [14].

4. Cognitive Radio-Multiple Input Multiple Output-Non Orthogonal Multiple Access

MIMO NOMA is an explored area for improving spectral and energy efficiency. Another research area is CR based NOMA. The 5G and the above techniques require the improvement in the spectral efficiency, energy efficiency etc. MIMO, CR, and NOMA, all of them we can use simultaneously to facilitate the use of spectrum, energy etc. This will be the next generation research area in communication.

5. State of Art on Cognitive Non-Orthogonal Multiple Access

In this section, we present the review of CR with NOMA techniques. The comparison table shows a brief idea of different areas in communication system where CR-NOMA techniques can be applied to get better performance. The knowledge of existing techniques which can be applied in the area of next generation communication networks can be a good introduction to start research in this domain. The comparison table is shown below.

Table 1. Comparison Table of different CR-NOMA technology.

Paper	Technique	Description	Future Research Direction
[3]	SJ-AS Algorithm and max-min approach	The proposed algorithm maximizes the signal to noise ratio of the secondary user. The time complexity for antenna selection is improved in the proposed work that is O(N(M+K+2)) whereas in the existing algorithm, it is O(N*M*K)[20]. Where the number of antennas used by BS, PU and SU.	SJ-AS outperforms among all the existing algorithms, max-min approach, random selection and exhaustive searched (ES) algorithm.
[2]	ZFBF technique	The proposed method is a generalized framework of the existing ZFBF scheme. It focuses on the problem of physical layer security and is used in a two-cell MIMO, NOMA based CRN. The proposed method is compared with the coordinated beamforming method [21] and shows better result. All the existing approaches works on single cell networks whereas the proposed scheme works on multi-cell scenario.	
[4]	ZFBF and MMSE method	A new beamforming technique is proposed to secure an information exchange within the same cells and neighboring cells. The method provide better result compared with the existing zero forcing [2] technique. The method is compared with CoBF [22] and cascading ZFBF [2] and performs better.	The proposed method can be used in IoT-based cognitive radio networks.
[5]	Cooperative transmission by using multicast technique	It achieve the maximum diversity order at secondary user. Increasing the number of SUs performance will also increase. There is no other cooperative transmission scheme exists in CR-NOMA system up to this.	Future work should focus on the channel condition because capacity of the multicast transmission is dominated by SU with weakest channel.
[6]	All CR-NOMA techniques	It is a survey report aiming to point out the latest research efforts on NOMA techniques in CR.	Spectrum sensing, Massive MIMO, Energy harvesting, mmW communications, Cooperative transmission, Resource allocation and optimization
[7]	Conventional NOMA techniques	A CR-NOMA scheme is proposed to improve throughput and the outage probability to adapt multiple services.	The proposed FD and EH model can be applied in the next generation communication networks.
[8]	Using the tech-	In the proposed system, they consider a cooperative	

	nique of PDF and CDF	CR-NOMA system using with and without a D2D link. The outage probability without D2D link can be calculated by PDF and CDF.	
[9]	SWIPT principle	A new protocol is proposed which supports simultaneous multicast services to PU-MG and SU-MG. The proposed method performs better in comparison with the existing OMA without SWIPT and non-cooperative NOMA without SWIPT method.	Machine learning techniques can be useful for optimizing various system parameters. Analyze different machine learning algorithm and check for optimality. SWIPT+CR-NOMA is an open research area to design bandwidth efficient multicast services.
[10]	Conventional CR inspired techniques.	This is a review paper on overview and challenges of CRS.	Decision making on Spectrum availability or centralized/distributed network, Machine learning, Interprotocol Interaction, Security, Spectrum Sensing, Location determination,
[11]	Stochastic Geometry is used	This paper describes the expressions of the outage probability. The two scenarios are described 1.Fixed transmit power of the PTs and 2. Transmit power of the PTs are proportional to the secondary BS. It describes the diversity analysis of both of the two situation.	Optimization the power allocation coefficients are the future research direction.
[12]	PA algorithm is used which exploits the conventional NOMA techniques.	This paper works on a PA algorithm for a NOMA-based system. The proposed algorithm compared with the existing FTPC algorithm and proves its superiority with linear time complexity.	The research areas for PA in a CR-NOMA system are providing fairness among users either in terms of transmission power or throughput.
[13]	Tchebycheff method, SWIPT, SCA Algorithm	A multi-objective resource optimization non-convex problem is formulated using NOMA-CRN system under a practical non-linear energy harvesting model. A weighted Tchebycheff method is applied to convert the problem into single objective optimization problem and get superior result. A successive convex approximation (SCA) algorithm is proposed.	Future research direction can exploit the tradeoff between the harvesting energy and the rate of the information decoding users.
[14]	Cooperative Relay strategy	The proposed cooperative relay strategy addressed the inter-network and intra-network interference and lowers the outage probabilities.	Interference management, Energy efficiency, Imperfect CSI, Relay selection, PHY layer Security.
[15]	Two power allocation scheme CR-NOMA-D-M and CR-NOMA-D-U	This paper improves the outage performance of multicast users, diversity order and secrecy outage probability of the unicast users compared to existing CR-NOMA-F-M[23] scheme.	Future research work can be extended to MIMO-NOMA networks from the proposed MISO-NOMA networks with multicast and unicast transmission.

[16]	Conventional CR-NOMA techniques	In this review article the frameworks of NOMA implementation over CR, feasibility of proposed frameworks, differences between CR-NOMA and CR network and implementation issues of CR-NOMA are discussed.	Cross layer design issues Could be future research area.
[17]	NOMA and relay selection strategy	This is the first work based on EH assisted CR-NOMA scheme by exploiting performance gap(outage performance , throughput) between PD and SD.	Multiple users of the CR-NOMA model should be considered instead of single user.
[18]	Relay strategy is used in CR-D2D-NOMA network	The outage performance of CR-NOMA wireless networks over Rayleigh fading channels is examined. The work is motivated from [24] and focus on device to device(D2D) links in secondary network. The comparison is shown betw een the performance of CR-NOMA and CR-OMA.	The proposed work is for two users. This can be extended to multiple users.
[19]	Convex approximation miniorization-maximization(MM) technique	Power allocation and relay precoder design for CR-NOMA technique is described. It maximizes the sum-rate of the cognitive destination nodes with the condition of maintaining interference to the primary node below a predefined threshold.	

In the above table we summarize the latest papers from different areas of communication system where cognitive NOMA is applied. In [3], the lemma 3 proves that the proposed algorithm gives the lower outage probability than the entire existing algorithm for Antenna Selection (AS) strategy. The SJ-AS and max-min approach takes O(N(M+K+2)) time complexity. In any case if N=M=K, then the time complexity becomes $O(N^2)$ instead of becomes $O(N^3)$. In [2], they provide spectral efficiency at the cost of interference using NOMA structure which leads to security issues in the network. Recently people are thinking about green communication since energy is a constraint in terms of efficiency. For a remote area where we have to consider about battery power which is limited green communication can be applied to get better performance. In [12], instead of iterative matrix operation, Power allocation (PA) algorithm is used which exploits the conventional NOMA techniques. This technique leads to a liner time complexity that is O(N), where N = number of secondary users.

6. Conclusion and Future Work

In this paper we present a short description on NOMA, CR-NOMA and CR-MIMO-NOMA techniques. Subsequently review of CR-NOMA techniques with future research direction in communication system.

The future research work related to CR-NOMA techniques are as follows, power allocation, user clustering, green communication etc. In case of PHY layer security, addition of beamforming technique to NOMA will be a good research area. A very few work has been done using SWIPT technique in green multicasting for energy harvesting model. Relay selection in cognitive NOMA system for energy efficiency can be a good research area in next generation communication system.

Abbreviation

SJ-AS algorithm : subset-based Joint Antenna Selection algorithm
BS : Base Station
PU : Primary User
SU : Secondary User
ZFBF : Zero-Forcing Beamforming
MMSE : Minimum Mean Squared Error
FD : Full-duplex
EH : Energy Harvesting
PDF : Probability Density Function
CDF : Cumulative Distribution Function
SWIPT : Simultaneous Wireless Information and Power Transfer
OMA : Orthogonal Multiple Access.
PT : primary transmitter
FTPC : Fractional Transmits Power Control
PA : Power Allocation
SCA : Successive Convex Approximation
PD : Primary Destination
SD : Secondary Destination

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