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A CRITICAL ANALYSIS OF NON-ORTHOGONAL MULTIPLE ACCESS TECHNIQUES WITH COGNITIVE RADIO INFLUENCE

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Abstract

The rapid growth in the use of mobile devices and wireless services has led to a shortage of available spectrum for communication. To solve this issue, Cognitive Radio (CR) has been introduced. CR is a type of wireless communication that allows transmitters/receivers to detect vacant channels and avoid occupied ones, maximizing the use of available radio-frequency spectrum. Various proposed techniques mentioned here to improve spectral efficiency, with Non-Orthogonal Multiple Access (NOMA) having potential for use in the 5G network as it can accommodate more users. However, integrating NOMA techniques into CR networks presents significant technical challenges. To enhance NOMA's performance, Multiple Input and Multiple Output (MIMO) techniques are being employed in CRNs. Studies show that MIMO techniques can significantly improve the performance of CRNs with NOMA. This paper reviews the areas in which Cognitive Radio inspired NOMA can be used to improve both Spectral Efficiency (SE) and Energy Efficiency (EE). In addition, our paper also covers the challenges and potential research directions for the future.

Keywords: Cognitive Radio, NOMA, SWIPT, MIMO, Green Communication, CR-NOMA. Energy Efficiency, Spectral Efficiency

1. Introduction

Cognitive radio possesses the ability to perceive and comprehend its surrounding operational and geographical conditions. By dynamically and autonomously altering its operational parameters and protocols, and learning from previous experiences, cognitive radio can adapt to its environment and make decisions accordingly. It can also facilitate spectrum sharing between licensed and unlicensed users, a technique known as dynamic spectrum sharing.

Cognitive radio evolved from Software Defined Radio (SDR) and has three main techniques: Underlay, Overlay, and Interweave. In Underlay and Overlay techniques, both cognitive (secondary) and non-cognitive (primary) users can transmit simultaneously, as long as the interference remains below acceptable limits. However, simultaneous transmission is not possible with Interweave technique.

The NOMA technique is widely recognized for efficient spectrum utilization in 5G wireless networks [4]. It operates on the power domain and is based on Orthogonal Frequency Division Multiplexing (OFDM). While each user can utilize all available subcarriers in OFDM, multiple users can share the same subcarrier in NOMA, thereby increasing spectrum efficiency. One of the variations of NOMA is CR-NOMA (Cognitive Radio-NOMA), which supports intelligent spectrum sharing and minimizes multiuser interference, improving spectrum sharing and user connectivity.

The paper introduces the concepts of NOMA, CR-NOMA, and CR-MIMO-NOMA technology in sections 2, 3, and 4. Section 5 presents a review of Cognitive Radio inspired NOMA technologies, and section 6 concludes the paper by discussing future directions.

2. Non-Orthogonal Multiple Access (NOMA)

Non-Orthogonal Multiple Access (NOMA) is a wireless communication technique that allows multiple users to share the same frequency resources, which increases the spectral efficiency of wireless networks [14]. NOMA works in the power domain and allows multiple users to transmit on the same subcarrier with different power levels [4]. This approach makes better use of the available bandwidth by allowing multiple users to share the same frequency resources, which reduces the need for additional spectrum allocation. There are several benefits to NOMA, but there are also some implementation obstacles, such as the need for instantaneous CSI, optimal pilot allocation, and hardware complexity [14].

NOMA is built on top of Orthogonal Frequency Division Multiplexing (OFDM), which is a widely used modulation technique for wireless communications. In OFDM, each user is assigned different subcarriers, which they can use to transmit data. However, in NOMA, multiple users can share the same subcarrier by dividing it into different power levels. This means that a stronger signal can be sent to one user and a weaker signal to another user over the same subcarrier. The receiver then separates the signals using signal processing techniques.

There are several variations of NOMA, including clustered NOMA, cooperative NOMA, and CR-NOMA. Clustered NOMA divides users into clusters and assigns different power levels to each cluster. Cooperative NOMA, on the other hand, allows users to share their power resources to enhance the transmission quality of weaker users. CR-NOMA, or Cognitive Radio-NOMA, is a variant of NOMA that enables intelligent spectrum sharing by cognitive radios, which can detect and avoid interference in the shared spectrum. CR-NOMA is an emerging technology that is expected to play a significant role in improving the efficiency of wireless communication networks and plays an important role in future wireless communication networks.

3. Cognitive Radio – Non Orthogonal Multiple Access

The combination of Non-Orthogonal Multiple Access (NOMA) and Cognitive Radio (CR) technologies has shown great potential for enhancing the efficient utilization of available spectrum resources. NOMA allows for simultaneous transmission of multiple users, while CR intelligently manages the spectrum usage to ensure that primary and secondary users can share the available resources in an optimal way.

With Cognitive NOMA, the benefits are numerous. Firstly, the spectrum efficiency is greatly improved. This is due to the fact that in cognitive NOMA networks, primary and secondary users can actively transmit simultaneously while maintaining acceptable reception quality. This means that the available spectrum resources are utilized more efficiently, resulting in better overall performance.

Secondly, cognitive NOMA is capable of supporting massive connectivity. With the emergence of 5G networks, there is a growing need for networks that can support a large number of smart devices, such as Augmented Reality (AR), virtual reality (VR), online healthcare, and the Internet of Things (IoT) [1]. Cognitive NOMA networks are able to fulfill this need by providing the necessary connectivity and ensuring that all devices can communicate effectively.

Thirdly, cognitive NOMA enables low latency, which is crucial for many applications, especially those that require real-time communication. In traditional Orthogonal Multiple Access (OMA) systems, only one secondary user can transmit using an available resource block, which can result in significant transmission delays. However, in cognitive NOMA, multiple secondary users can be connected simultaneously, reducing transmission delay and improving overall performance.

Lastly, cognitive NOMA also guarantees improved user fairness. By intelligently managing the spectrum usage, CR ensures that all users, both primary and

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secondary, have equal opportunities to access the available resources, resulting in a fair and equitable distribution of the available spectrum.

The combination of NOMA and CR has the potential to revolutionize the way spectrum is utilized [8] in wireless communication systems. As technology continues to advance, there are many different aspects that can be explored to further enhance the performance of cognitive NOMA in 5G and beyond.

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

The ever-increasing demand for higher data rates and reliable connectivity has led to the exploration of innovative technologies that can enhance spectral and energy efficiency in wireless communication systems. One such area of research is the use of MIMO NOMA (Multiple-Input Multiple-Output Non-Orthogonal Multiple Access) and CR (Cognitive Radio) based NOMA. Multiple Input Multiple Output (MIMO) antenna systems have recognized huge attention in wireless communications [5].

MIMO NOMA is a technique that employs multiple antennas at both the transmitter and receiver ends to improve the data throughput, reliability and energy efficiency of a wireless communication system. In MIMO NOMA, non-orthogonal signals from multiple users are transmitted simultaneously using the same frequency band, leading to a significant improvement in spectral efficiency.

To meet the requirements of next-generation wireless communication systems like 5G and beyond, it is imperative to improve the spectral and energy efficiency further. To achieve this, MIMO, CR, and NOMA can be used simultaneously to facilitate the use of spectrum, energy, and other resources in the most efficient way possible. This will be the next generation research area in communication.

The combination of MIMO, CR, and NOMA holds great promise for the future of wireless communication systems. By exploring these technologies, researchers can develop innovative solutions that can enhance the efficiency of spectrum and energy utilization, leading to better performance and improved user experience.

5. An overview of the research and development of Cognitive NOMA technology.

The current status of Cognitive Non-Orthogonal Multiple Access (Cognitive NOMA) research and development is being widely investigated to enhance the efficiency of wireless communication systems. Cognitive NOMA combines Cognitive Radio (CR) and Non-Orthogonal Multiple Access (NOMA) principles to enable multiple users to share available spectrum resources simultaneously and intelligently. Researchers are exploring various areas to improve the performance of Cognitive NOMA, including the development of novel algorithms and protocols for dynamic spectrum sharing, resource allocation, and interference management, as well as the investigation of MIMO techniques in Cognitive NOMA. Additionally, research is being conducted to apply Cognitive NOMA to various fields, including the Internet of Things (IoT), augmented reality (AR), and virtual reality (VR) [8].

Below is a review of different areas in communication systems where CR-NOMA techniques can be applied:

Multi-User Shared Access (MUSA): In MUSA systems, multiple users share the same resource block. CR-NOMA can improve the system's performance by allowing non-orthogonal access and enabling user cooperation through Successive Interference Cancellation (SIC).

Cooperative NOMA (C-NOMA): In C-NOMA systems, users work together to enhance system performance. CR-NOMA can further improve the performance by developing more efficient user selection and power allocation algorithms, and investigating the application of C-NOMA in multi-cell scenarios.

Dynamic Spectrum Sharing (DSS)-NOMA: In DSS-NOMA systems, resources are dynamically allocated to users based on their needs. CR-NOMA can optimize resource allocation and interference management, and implement DSS-NOMA in practical wireless networks.

Non-Orthogonal Multiple Access (NOMA) with Cognitive Radio: NOMA with cognitive radio can dynamically allocate resources, manage interference, and develop channel estimation algorithms to improve system performance.

Spectrum Sensing NOMA (SS-NOMA): In SS-NOMA systems, users can sense the spectrum and access it dynamically. CR-NOMA can develop more efficient resource allocation and interference management algorithms and investigate SS-NOMA in multi-cell scenarios.

Hybrid Cognitive Radio-NOMA: Hybrid techniques of CR-NOMA can be used to improve network performance by investigating the impact of hybrid techniques on network performance and optimizing resource allocation and interference management.

Adaptive Resource Allocation for Cognitive Radio-NOMA: Machine learning algorithms such as reinforcement learning and deep learning can be used to develop more efficient adaptive resource allocation algorithms. The impact of different learning algorithms on network performance can be investigated.

Cognitive Radio-NOMA with Power Control: Power control algorithms can be optimized to improve network performance. CR-NOMA can also develop more efficient interference management algorithms.

Cognitive Radio-NOMA for Heterogeneous Networks: Different coordination schemes can be investigated to improve network performance. CR-NOMA can also develop more efficient resource allocation and interference management algorithms.

Cognitive Radio-NOMA for 5G and Beyond: CR-NOMA can be used to dynamically allocate resources, manage interference, and improve ultra-low latency communication. The impact of CR-NOMA on 5G and beyond networks can also be investigated.

Table 1: Various techniques along with their respective descriptions and potential avenues for future research

Technique	Description	Future Research Directions
Subset-based Joint Antenna Selection (SJ-AS) Algorithm and max-min approach	The proposed algorithm improves the signal to noise ratio of the secondary user and reduces time complexity for antenna selection to O(N(M+K+2)) compared to O(NMK)[9] in the existing algorithm. N, M, and K represent the number of antennas used by BS, PU, and SU, respectively.	SJ-AS performs better than the others. The other algorithms include max-min approach, random selection, and exhaustive search (ES) algorithm
Zero-Forcing Beamforming (ZFBF)	The proposed method enhances the existing zero-forcing beamforming (ZFBF) scheme [10] by addressing the physical layer security issue in a two-cell MIMO network using NOMA in CRN. It outperforms the coordinated beamforming method and is effective in multi-cell scenarios, unlike existing methods that only work in single-cell networks.	
ZFBF and MMSE	New beamforming technique proposed for secure information exchange within/between cells, outperforms existing methods including zero	The suggested method can be applied to IoT-based cognitive radio networks.

	forcing [2]and coordinated beamforming, and performs better than CoBF [11] cascading ZFBF [2].	
Cooperative transmission using multicast technique	This scheme achieves the highest diversity order for the secondary user and improves performance as more secondary users are added. It is the first cooperative transmission scheme for CR-NOMA systems	In future work, it is important to focus on the channel condition because the multicast transmission capacity is limited by the user with the weakest channel.
All CR-NOMA techniques	It is a survey paper that aims to highlight the most recent research initiatives on NOMA methodologies in CR.	Resource allocation and optimization, mmW communications, massive MIMO, energy harvesting, spectrum sensing
Conventional NOMA techniques	It is suggested to use a CR-NOMA strategy to increase throughput and outage probability when adapting various services.	The FD and EH model that has been proposed can be used in the communication networks of the next generation.
Using the technique of PDF and CDF	The proposed system involves a cooperative CR-NOMA setup with and without a device-to-device (D2D) link. The outage probability without the D2D link can be determined using probability density function (PDF) and cumulative distribution function (CDF).	
Simultaneous Wireless Information and Power Transfer (SWIPT) principle	New protocol enables simultaneous multicast to primary and secondary groups, outperforms existing methods without SWIPT and non-cooperative NOMA.	ML used for system parameter optimization, ongoing research on efficient multicast using SWIPT and CR-NOMA.
Conventional CR inspired techniques	This review article discusses the advantages and difficulties of CRS.	Making decisions about the availability of spectrum or the design of a centralized or distributed network, using machine learning, interprotocol interaction, security, and location determination
Stochastic Geometry	This paper presents outage probability expressions for two scenarios: 1) fixed transmit power of the primary transmitters (PTs) and 2) transmit power of the PTs that is proportional to the secondary base station (BS). The paper also includes a diversity analysis for both scenarios.	The direction of future study will be towards power allocation coefficient optimization.
Power Allocation (PA) algorithm using conventional	Paper proposes a PA algorithm for NOMA system. Compared with FTPC algorithm, new algorithm is shown to be superior with linear time complexity.	Fairness among users in terms of transmission power or throughput is one of the research areas for PA in

NOMA techniques		a CR-NOMA system.
Tchebycheff method, SWIPT, Successive Convex Approximation (SCA) algorithm	A complex optimization problem related to NOMA-CRN system with energy harvesting is formulated and solved using a weighted Tchebycheff method to achieve better results. The problem is then converted into a single objective optimization problem, and a successive convex approximation (SCA) algorithm is used to solve it.	Future research can focus on balancing the tradeoff between the rate of information decoding and the amount of energy harvested in NOMA-CRN systems. This can involve exploring new algorithms and techniques, as well as incorporating machine learning and artificial intelligence to optimize both objectives.
Cooperative relay strategy	The proposed cooperative relay strategy improves the performance of inter-network and intra-network interference and reduces outage probabilities.	Interference management, Energy efficiency, Imperfect CSI, Relay selection, PHY layer Security.
Two power allocation schemes: CR-NOMA-D-M and CR-NOMA-D-U	The paper enhances the outage performance, diversity order, and secrecy outage probability of unicast users and multicast users in CR-NOMA-F-M [12], surpassing the existing scheme.	Future research can expand on the proposed MISO-NOMA networks with multicast and unicast transmission to include MIMO-NOMA networks.
Conventional CR-NOMA techniques	This review article discusses the implementation frameworks of NOMA over CR, its feasibility, differences between CR-NOMA and CR networks, and implementation issues of CR-NOMA.	Issues with cross-layer design maybe a future study topic.
NOMA and relay selection strategy	This is the first study to utilize performance gap (outage performance, throughput) between primary and secondary devices in an EH assisted CR-NOMA scheme.	Instead of focusing on a single user, the CR-NOMA model should take into account multiple users.
Relay strategy is used in CR-D2D-NOMA network	This study investigates the outage performance of CR-NOMA wireless networks with D2D links in secondary networks over Rayleigh fading channels. The performance of CR-NOMA is compared to that of CR-OMA, motivated by prior work [13]	The proposed work is designed for two users, but it can be expanded to include multiple users.
MM (minimization-maximization) technique using convex approximation	The paper explains power allocation and relay precoder design for CR-NOMA to maximize the sum-rate of cognitive destination nodes, while keeping interference to the primary node below a predefined threshold	

6. Conclusion

The table above provides a summary of recent research papers that apply cognitive non-orthogonal multiple access (NOMA) to various areas of communication systems. The proposed algorithm outperforms all existing algorithms in terms of outage probability for antenna selection (AS) strategies [3]. We consider that Base Station (BS), Primary User (PU) and Secondary User (SU) are equipped with N, M and K antennas, respectively. The SJ-AS and max-min approaches have a time complexity of O(N(M+K+2)), but in cases where N=M=K, the time complexity reduces to O(N2) instead of O(N3). However, while NOMA structure provides higher spectral efficiency, it comes at the cost of increased interference, which can lead to security issues in the network [2]. To address this, researchers are exploring green communication, which aims to improve performance while considering energy constraints. In remote areas with limited battery power, green communication can be applied to achieve better performance. Instead of iterative matrix operations, the power allocation (PA) algorithm is used [7], which leverages conventional NOMA techniques. This approach results in a linear time complexity of O(N), where N is the number of secondary users.

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