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A Comprehensive Survey on Non-Orthogonal Multiple Access (NOMA) for 5G Networks

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Abstract: *The rapid development of 5G wireless communication networks, driven by the increasing demands of mobile internet and the Internet of Things (IoT), necessitates innovative solutions to meet stringent performance requirements. Non-Orthogonal Multiple Access (NOMA) has emerged as a promising technology to address these challenges by enabling efficient use of spectral resources through the sharing of resource blocks by multiple users. This survey comprehensively analyses various user pairing and power allocation strategies in NOMA, highlighting their effects on system capacity, spectral efficiency, and user fairness. Additionally, the integration of NOMA with advanced 5G technologies such as MIMO, cognitive radio, and cooperative communication is explored, addressing key challenges and potential solutions. The survey identifies significant research gaps, including the need for scalable user pairing algorithms, advanced power allocation methods, effective interference management, and robust security mechanisms. This review aims to provide insights into optimizing NOMA performance and guiding future research to enhance 5G networks.*

Keywords: Non-Orthogonal Multiple Access(NOMA), 5G Networks, Wireless Communication, Internet of Things(IoT), Massive Input Massive Output

I. INTRODUCTION

The development of fifth generation (5G) wireless communication networks is subject to strict constraints due to the fast growth of the Internet of Things (IoT) and mobile Internet. The main source of this demand is anticipated to be the anticipated 1000-fold growth in data traffic by 2020 [1]. The following text offers a succinct summary of the critical performance metrics, or key performance indicators (KPIs), that are necessary to enable 5G systems to function. It is projected that the spectral efficiency gain will be five to fifteen times higher than over 4G. Ten times more than that of 4G, the minimum connection density objective is established at 106/km2. Low latency (radio delay of less than 1 ms), cost efficiency at least 100 times higher than 4G, and support for a broad range of interesting applications are some of the expected features of 5G. Inventive solutions must be developed in order to satisfy these demanding requirements. The Nonorthogonal Multiple Access (NOMA) technology family is presently being investigation as a possible remedy to tackle the difficulties encountered by 5G. The idea of NOMA is to enable more connections than the orthogonal resources (time, frequency, or code) that are available can handle. Code-based NOMA and power-based NOMA are the two primary categories of NOMA approaches [2].

Non-Orthogonal Multiple Access, or NOMA, is a very promising 5G communication enabling technology. The multiple access strategy outlined here is distinct and guarantees effective use of the available spectrum. The concept falls into two main categories: CD-NOMA uses the code domain multiplexing approach, whereas PD-NOMA uses the power domain multiplexing technique. The multiple access strategy known as CD-NOMA expands on the idea of orthogonal resource blocks, which comprise spreading code, time slot, frequency band, and orthogonal spatial degree of freedom. Many UL and DL multiple access techniques are included in the system, including sparse code multiple access (SCMA), low-density spreading aided OFDM (LDSOFDM), multi-user shared access (MUSA), successive interference cancellation aided multiple access (SAMA), and low-density spreading CDMA (LDS-CDMA). Among the NOMA techniques that

have been thoroughly examined in recent research are PD-NOMA, CD-NOMA, bit division multiplexing (BDM), compressive sensing (CS)-based NOMA, signature-based NOMA (S-NOMA) [3], spatial division multiple access (SDMA), pattern division multiple access (PDMA), and spreading-based NOMA.

In order to accommodate more users than could be supported by the current orthogonal time-, frequency-, or code-domain resources, the notion of non-orthogonal multiple access, or NOMA, was invented. The main idea of NOMA is to allow users to distribute non-orthogonal resources among themselves, even if this makes the receiver more complicated. Receiver complexity must rise in order to efficiently discriminate non-orthogonal signals. In recent years, a great deal of study has been done on the NOMA solutions [4]. The two primary groups into which the solutions may be divided are code domain NOMA and power-domain NOMA. Low-density spreading (LDS), sparse code multiple access (SCMA), multi-user shared access (MUSA), and sequential interference cancellation adaptable multiple access (SAMA), and other access techniques are included in the groupings.

A proposed 5G multiple access solution called Power Domain Non-Orthogonal Multiple Access (PD-NOMA) seeks to solve the spectrum inefficiencies related to orthogonal multiple access (OMA) technologies [5]. The goal is accomplished by combining several users with different channel gains into a single resource block (RB) that includes code, frequency, and time. This is done by using multiplexing methods. This method can potentially reach hitherto unheard-of traffic volumes, improve spectral efficiency (SE), and ease device-to-device communication. In PD-NOMA, different power values are used to allow more than one user to use the same spectrum. For user detection, the system makes use of superposition coding and successive interference cancellation (SIC) at the receiver.

The 3GPP LTE version 15 standard includes a new multiple access technology called Non-Orthogonal Multiple Access (NOMA). the standardization of it for use in 5G and LTE has been evaluated. A connection analysis between cooperative NOMA, multiple-input multiple-output (MIMO), and cognitive radio (CR) systems is also included in this work. The majority of research has mostly concentrated on Non-Orthogonal Multiple Access (NOMA) within individual cells. [6] of the major advantages and difficulties of a multi-cell NOMA scenario was done. Inter-cell interference (ICI) is a significant problem in multi-cell NOMA systems because it causes users who are close to cell boundaries to experience lower data rates. Power domain multiplexing (NOMA) and spatial diversity enhancers (CoMP) are combined in the hybrid multi-cell DL NOMA/coordinated multi-point (CoMP) technique.

By employing sophisticated receivers to efficiently reduce intra- and inter-cell interference, NOMA technology improves spectral efficiency (SE). Furthermore, NOMA guarantees a minimum necessary rate, encouraging user fairness. In contrast to the water filling technique, the NOMA concept is predicated on the idea of assigning more power to users with lower channel gains and less power to consumers with greater channel gains [7]. The phrase above guarantees a balanced relationship between treating users fairly and the system's overall effectiveness. Multiple users can access the same resources simultaneously thanks to NOMA (Non-Orthogonal Multiple Access) technology. It's crucial to remember that user interference might happen. A specialized receiver known as sequential interference cancellation (SIC) is used to reduce inter-user interference [8-9]. The NOMA (Non-Orthogonal Multiple Access) user with significant signal power uses the SIC (Successive Interference Cancellation) approach while transmitting in the Downlink (DL) mode. Successive interference cancellation (SIC) is used by the base station (BS) when transmitting in the uplink (UL) mode. By using multiplexing methods, the channel capacity is increased since information from several users may be decoded more easily. Hybrid OMA-NOMA is one possible way to handle the receiver's growing complexity as a result of a bigger user base. Alternatively, the necessity for a discernible variation in channel strength across paired users is addressed to improve Power Domain Non-Orthogonal Multiple Access (PD-NOMA) performance [10]. Hybrid OMA-NOMA is made possible by NOMA's adaptability to different access tactics, which sets it apart from other approaches that are currently in use.

Resource allocation issues in NOMA

In NOMA (Non-Orthogonal Multiple Access), multiple users share the same Resource Block (RB) by pairing users based on distinct channel gains, with different power allocations to enhance resource utilization, reduce interference, and increase system capacity. A Successive Interference Cancellation (SIC) receiver detects messages for all users from a superimposed signal. Efficient user pairing and power allocation (PA) methods are crucial [11]. User pairing in NOMA

multiplexes users with different channel gains in the power dimension. Higher power is allocated to weak channel gain users and lower power to strong channel gain users, ensuring fairness. Weak users decode the superimposed signal by treating strong users' signals as interference, while strong users apply SIC to decode their signals. The greater the difference between the channel gains of paired users, the better the SIC implementation and overall increase in some capacity. Challenges arise when mid-gain users are either paired together, leading to capacity reduction due to degraded SIC performance, or left unpaired, preventing them from benefiting from NOMA's capacity gains [12].

Optimization techniques address these challenges. One approach maximizes the sum of in-pair users' channel gain differences while ensuring a minimum gain difference threshold. The Uniform Channel Gain Difference (UCGD) method arranges users by channel gains, splits them into two groups, and pairs from maximum to minimum within these groups to include mid-cell users and improve capacity. A hybrid pairing approach combines near-far pairing with UCGD. Vertical pairing sequentially pairs ordered users to accommodate more NOMA users and reduce co-channel interference [13]. A Particle Swarm Optimization (PSO)-based approach solves user clustering to minimize downlink power under Quality of Service (QoS) constraints. Dynamic pairing and beamforming designs aim to maximize the minimum rate among users, ensuring fairness.

Analytical techniques also provide solutions. One approach addresses mid-cell users by proposing virtual pairing for unpaired weak users, multiplexing similar gain far users with a strong gain near user in nonoverlapping frequency bands. Another three-user pairing scheme improves cell-edge user performance by pairing with two cell-center users, avoiding high complexity. Pairing users based on Channel Quality Indicator (CQI) maximizes sum capacity in uplink NOMA, ensuring compatibility with LTE. The Channel State Sorting Pairing Algorithm (CSS-PA) pairs users with the most disparate channel conditions to increase capacity and fairness. Cognitive Radio (CR)-inspired NOMA pairs the highest gain user with the second highest gain user, prioritizing the weaker user's channel condition [14].

Motivation and contribution

The rapid advancement of mobile internet and IoT has set stringent demands for 5G wireless communication, including a dramatic increase in data traffic, enhanced spectral efficiency, connectivity density, low latency, and cost efficiency. Non-Orthogonal Multiple Access (NOMA) has emerged as a promising solution to these challenges. By enabling more users to share the same resource block through superposition coding and successive interference cancellation (SIC), NOMA significantly improves spectral efficiency and supports massive connectivity. NOMA's integration with technologies like MIMO and cognitive radio enhances its potential, addressing issues such as inter-cell interference. By balancing power allocation based on channel gains, NOMA ensures both high system throughput and user fairness, making it a pivotal technology for achieving the ambitious goals of 5G networks.

This survey comprehensively analyzes different user pairing strategies in NOMA, highlighting their effects on system performance and user fairness.

The paper evaluates various power allocation methods, emphasizing their role in optimizing resource utilization and reducing interference.

This survey explores the integration of NOMA with key 5G technologies, addressing challenges and opportunities to enhance overall network performance.

II. RELATED WORK

Non-Orthogonal Multiple Access (NOMA) offers significant potential for improving spectral efficiency (SE), guaranteeing user fairness, mass connectivity, decreasing latency, raising data rates, boosting capacity, and boosting overall performance when combined with other critical 5G enabling technologies. Leveraging the power domain to serve numerous consumers at once may also be beneficial [15-19]. Numerous studies have been carried out about non-orthogonal multiple access (NOMA). Within the power domain, NOMA uses successive interference cancellation (SIC) at receivers and superposition coding at transmitters. Improving cellular networks' spectrum efficiency is the aim of this approach. An idea utilizing Power Division Multiple Access (PDMA) and dubbed Non-Orthogonal Multiple Access (NOMA)-based Random Access (RA) with Multichannel ALOHA (NOMA-ALOHA) was proposed [20]. The goal of integrating Block Coding (BC) with Non-Orthogonal Multiple Access (NOMA) is to improve the system's overall performance. The study's conclusions show that a hybrid backscatter-based NOMA system performs better than a

transmission system based on energy harvesting. Non-orthogonal multiple access (NOMA) systems have effectively integrated simultaneous relaying (SR), as evidenced by a number of research studies that have been published in the literature.

The ergodic rate and outage probability closed-form formulae were developed in order to examine the SR-NOMA system's performance when a parasitic setup is present. The authors examined cellular and Internet of Things networks from the perspective of a symbiotic system [21-25]. The authors used the system model to calculate the coexistence outage probability for the symbiotic system. "Downlink" describes the process of sending data or information to a receiving station or device from a satellite or other communication equipment. The author took into consideration a single receiver, backscatter device, Non-Orthogonal Multiple Access (NOMA) Simultaneous Reception (SR) system. The requirement to examine system performance in the Nakagami-m fading channel drove the creation of outage probability equations. The author adjusted the system's performance and power efficiency taking into account a primary NOMA network with a backscatter device [26-29]. Two non-orthogonal multiple access (NOMA) main users and a base station (BS) that supports tags are involved in the commensal single-radio (SR) setup. In order to maximize the system rate when coping with subpar successive interference cancellation (SIC), the power allocation factor and the tag's reflection coefficient were both changed simultaneously. However, parasitic SR communication is the main focus of most current research and development.

The first to discover the potential of Non-Orthogonal Multiple Access (NOMA) for 5G cellular networks. Furthermore, it has been shown that in terms of capacity and user-fairness, Non-Orthogonal Multiple Access (NOMA) performs better than Orthogonal Multiple Access (OMA) [30-33]. Ever since its beginnings, researchers have been actively looking for ways to advance the NOMA idea and turn it into a state-of-the-art worldwide radio access mechanism. Originally, single-input single-output (SISO) systems were the main focus of NOMA research, with a particular emphasis on power allocation and user fairness. The NOMA algorithm takes consumer fairness into account in addition to maximizing the overall rate of power allocation. Because the stronger user always gets full power, NOMA does not have an advantage over OMA when the goal is to maximize the overall rate. A dynamic method for power distribution in NOMA (Non-Orthogonal Multiple Access) systems is presented in the study. This strategy aims to guarantee that strong and weak user individual rates in NOMA (Normal Multiple Access) systems are greater than those in OMA systems. The maximum-minimum data rate and the minimum-maximum outage probability are included in the calculation outlined in [34-35] as indicators for assessing user fairness. Both situations include non-convex problems, yet both difficulties can be solved with low-complexity polynomial algorithms.

By combining NOMA with multi-input multi-output (MIMO) technology, its performance may be further improved. MIMO-NOMA is used to group users into clusters, and NOMA is only used for users in the same cluster. Finding the best user pairing is a difficult task as it requires a thorough examination. In this version, a random pairing technique is used to reduce the computational load. This method's objectives are to evenly distribute the load and maximize the system's overall efficiency. Moreover, a user pairing strategy is suggested as a way to attain almost ideal performance, according to [36]. The core of this method is the relationship between the gain differential and the channel. Following the user matching process, each cluster's members will share a precoding vector. A vector can be used to convert a single MIMO (multiple-input multiple-output) channel into numerous SISO (single-input single-output) channels for simultaneous use. Therefore, it may be said that NOMA is better than OMA [37]. A thorough framework for Multiple-Input Multiple-Output Non-Orthogonal Multiple Access (MIMO-NOMA) is examined in the study. To reduce inter-cluster interference, the system uses signal alignment-based detection algorithms and zero-forcing precoding. Perfect instantaneous channel state information (CSI), which might not be possible in MIMO settings, is assumed in this work. Sun et al.'s work concentrated on using statistical Channel State Information (CSI) to maximize a two-user Multiple-Input Multiple-Output Non-Orthogonal Multiple Access (MIMO-NOMA) system's ergodic capacity. The authors studied power distribution strategies while taking into account the weak user's minimum rate need and the overall transmit power limits. They investigated both optimum and low-complexity suboptimal techniques [38-42].

A NOMA technique for a large-scale MIMO system is suggested, taking into account the constraints of a limited feedback channel. The programs mentioned above have a particular emphasis on single-cell systems. An issue that frequently arises in multi-cell networks is inter-cell interference (ICI). The usefulness of Non-Orthogonal Multiple

Access (NOMA) in lowering interference is now being investigated by the researchers. In order to reduce Inter-Cell Interference (ICI) in a two-cell Multiple-Input Multiple-Output Non-Orthogonal Multiple Access (MIMO-NOMA) network, the study presents two coordinated beamforming approaches. Furthermore, NOMA has shown promise for visible light and millimeter wave (mmWave) communications [43]. In their study, compare and assess the basic ideas behind Non-Orthogonal Multiple Access (NOMA) and Orthogonal Multiple Access (OMA). The research looks at Power Domain-NOMA (PD-NOMA) and Code Domain-NOMA (CD-NOMA) in terms of their performance, complexity, and spectrum efficiency. The authors of about various user pairing strategies, power allocation algorithms, and actual implementation issues associated with downlink PD-NOMA. The effectiveness of multiple-input multiple-output (MIMO-NOMA) and MIMO orthogonal multiple access (MIMO-OMA) techniques is contrasted.

The reference [44] carried out a comprehensive examination of the core ideas, most recent developments, and possible future paths in NOMA (Non-Orthogonal Multiple Access). In terms of information theory, the study not only contrasts NOMA with OMA but also assesses the fundamental concepts of NOMA. The analysis and comparison of NOMA system designs' receiver complexity, system performance, and spectrum efficiency was also done. In order to address these difficult difficulties, the authors have summarized a number of open-ended problems and offered recommendations for viable approaches and future research topics [45-46]. A thorough integration of Non-Orthogonal Multiple Access (NOMA) with a number of cutting-edge methods is shown in the paper. Energy harvesting, millimeter wave (mmWave), visible light communication (VLC), cognitive radio (CR), physical layer security (PLS), and mobile edge computing (MEC) are some of these strategies. The research investigates the use of many cutting-edge technologies in rate-optimal power-domain non-orthogonal multiple access (PD-NOMA) techniques. Multiple-input multiple-output (MIMO), cognitive radio (CR), massive MIMO (mMIMO), millimeter wave (mmWave), visible light communication (VLC), mobile edge computing (MEC), unmanned aerial vehicles (UAV), and underwater wireless communication (UWC) are some of these technologies. The myths surrounding traditional NOMA have been investigated by the authors, along with the advantages of combining NOMA with ML and DL methods.

NOMA was used by the authors of [47] to significantly improve spectrum efficiency. The NOMA techniques utilized in 5G networks for spectrum sharing were examined by the researchers. They concentrated on important topics related to the development of 5G technology and the difficulties in studying Non-Orthogonal Multiple Access (NOMA). Welch-bound equality spread multiple access (WSMA)-based multiuser-MIMO (MU-MIMO) and non-orthogonal multiple access (NOMA) were the subjects of a simulation research. The main topic of discussion was the Third Generation Partnership Project (3GPP) standard's Non-Orthogonal Multiple Access (NOMA) feature. Furthermore, several tactics were employed to tackle the difficulties linked to reducing complexity and latency in both uplink and downlink Non-Orthogonal Multiple Access (NOMA) scenarios. The study addresses a number of subjects, such as NOMA restrictions, practical applications, signaling issues, security techniques, and resource allocation. Numerous subjects, including optimization, machine learning, matching theory, game theory, and graph theory, have been the subject of recent research. A thorough examination of PD-NOMA-based VLC systems is given in the work [48-49], which also highlights a number of technical difficulties and limits. These include the clipping effect, security issues, and power allocation. For Non-Orthogonal Multiple Access (NOMA) systems based on Visible Light Communication (VLC), the drawbacks and possible directions for future research have been noted. The authors analyzed problems related to open research, mitigation techniques, and the use of VLC systems based on PD-NOMA. The academic study carried out by the writers offers a thorough examination of PD-NOMA in the framework of cooperative networks. In order to improve the capabilities of 5G networks, the researchers have concentrated on applying deep learning techniques to non-orthogonal multiple access (NOMA). This thoroughly analyzed DL-based NOMA systems in a different work. Future research trends, possible obstacles, opportunities for integration with other promising technologies, and important performance measures were all thoroughly reviewed by the researchers [50]. Table 1 shows the survey table.

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Table 1: Survey table

Reference	Method	Advantages	Disadvantages	Research Gap
[14]	PSO-Based User Clustering	Minimizes downlink power under QoS constraints	Complexity increases with number of users	Developing scalable, low-complexity solutions
[15]	Sum Gain Maximization	Ensures significant channel gain differences for pairing	May not perform well with dynamic user distributions	Adapting to dynamic and heterogeneous network environments
[16]	Vertical User Pairing	Accommodates large number of users, reduces co-channel interference	Potential for increased interference in certain conditions	Effective interference management techniques
[17]	Dynamic Pairing and Beamforming	Maximizes minimum rate among users, enhances fairness	Computational complexity, requires precise channel state information	Simplifying computational requirements, improving CSI accuracy
[18]	Virtual Pairing	Utilizes unpaired spectrum efficiently	Implementation complexity, potential for reduced performance in varying conditions	Refining implementation for diverse scenarios
[19]	CQI-Based Pairing	Ensures backward compatibility with LTE, maximizes sum capacity	May not fully exploit potential of NOMA in varying conditions	Enhancing flexibility and performance under diverse conditions
[20]	Channel State Sorting Pairing Algorithm (CSS-PA)	Increases capacity, ensures user fairness	Complexity in sorting and pairing process	Developing efficient and scalable sorting algorithms
[21]	Cognitive Radio-Inspired NOMA	Prioritizes weaker user's channel condition, improves fairness	Complexity in managing dynamic power allocations	Streamlining dynamic power allocation methods

III. RESEARCH GAP

Optimization of User Pairing Techniques: There is a need for more efficient and scalable user pairing algorithms that can handle a larger number of users while maintaining system capacity and fairness, especially in dynamic network environments.

Advanced Power Allocation Methods: Current power allocation techniques need further refinement to better balance system throughput and user fairness under varying channel conditions and user distributions.

Interference Management: Effective methods to mitigate both inter-cell and intra-cell interference in multi-cell NOMA networks remain underexplored, requiring innovative solutions to improve overall network performance.

Integration with Emerging Technologies: The seamless integration of NOMA with other advanced 5G technologies like MIMO, millimeter-wave communication, and cognitive radio presents challenges that need to be addressed to fully leverage their combined benefits.

Complexity and Scalability: The complexity of implementing NOMA in large-scale networks with numerous users poses significant challenges. Research is needed to develop low-complexity, scalable solutions that can be practically deployed.

Quality of Service (QoS) Assurance: Ensuring consistent QoS for all users in a NOMA system, particularly in scenarios with diverse service requirements and varying channel conditions, remains a critical research gap.

Security and Privacy Concerns: With the increased sharing of resources among multiple users, NOMA systems are more vulnerable to security and privacy issues. Developing robust mechanisms to safeguard against these vulnerabilities is essential.

IV. CONCLUSION

This survey has thoroughly examined Non-Orthogonal Multiple Access (NOMA) as a key enabler for 5G wireless communication networks, addressing the pressing need for enhanced spectral efficiency, user fairness, and massive connectivity. By allowing multiple users to share the same resource block through innovative user pairing and power allocation strategies, NOMA significantly improves system capacity and performance. The integration of NOMA with advanced technologies such as MIMO, cognitive radio, and cooperative communication further enhances its potential, addressing critical challenges such as inter-cell and intra-cell interference. Despite the advancements, several research gaps remain, including the need for more efficient and scalable user pairing algorithms, refined power allocation methods, and effective interference management techniques. Additionally, ensuring consistent Quality of Service (QoS) and addressing security and privacy concerns are crucial for the widespread adoption of NOMA in 5G networks. This survey provides a comprehensive overview of the current state of NOMA research, highlighting its advantages, limitations, and the critical areas that require further investigation. By addressing these challenges, future research can pave the way for more robust and efficient NOMA implementations, ultimately contributing to the successful deployment of 5G and beyond.

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