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A Comprehensive Overview of Power Domain NOMA in 5G

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ABSTRACT

Non-orthogonal multiple access (NOMA) is a relevant technology for realizing the primary goals of next-generation wireless networks, such as high connectivity and stability. This paper focuses on the foundational principles of Power Domain NOMA (PD-NOMA), a promising technique for meeting the needs of fifth Generation (5G) in real-world applications. PD-NOMA offers flexibility in allocating radio resources to enhance user access performance. By enabling several users to utilize the same radio resources, PD-NOMA achieves improved spectrum efficiency. This paper considers the practical aspects of PD-NOMA system design, exploring various network scenarios. This paper primarily focuses on PD-NOMA that uses the superposition coding (SC) at the transmitter side in addition to the successive interference cancellation (SIC) at the receiver side. The paper also provides a theoretical formulation and solutions for downlink PD-NOMA and addresses potential areas for future research. Finally, the paper concludes by summarizing the key findings and implications of the study.

Keywords: *5G, NOMA, Power domain, user pairing, successive interference cancellation.*

1. Introduction

It is widely acknowledged that every decade witnesses the emergence of a new wireless communication network standard to accommodate the exponential growth of digital devices worldwide. The current standard, 4G LTE, has proven inadequate to meet the escalating demands for massive connectivity posed by the increasing mobile devices, Internet of Things (IoT) devices, evolution of computational devices, and large-scale cloud connectivity. As a solution to address these challenges, the 5G wireless network standard has been proposed as a completely new implementation rather than an incremental upgrade to 4G. Ongoing research efforts are focused on developing various solutions to tackle the following challenges in 5G networks: achieving high data rates 1,000 times faster than existing 4G, reducing latency to 1 millisecond for round trip transmission, enhancing user quality of experience (QoE), lowering energy consumption, and supporting enormous connectivity with various quality of service (QoS) for millions of equipment per square kilometer. The vision of 5G wireless networks encompasses several aspects. Firstly, it aims to establish an extremely effective mobile communication network that ensures best performance while minimizing investment costs. This includes achieving a desirable data transmission unit cost that is inversely proportional to the amount of data required, an urgent requirement for mobile communication system operators. Secondly, it envisions an extremely fast mobile communication system composed of the following generation of small size cells densely deployed to provide continuous coverage, even in urban areas. Lastly, it aims to enable millimeter-wave (mm Wave) bands (20 – 60 GHz) for data access speeds of up to 10 Gbps and higher bandwidth. To materialize a clear roadmap towards realizing the vision of 5G networks, extensive research endeavors have been underway in the domain of 5G systems, with a particular emphasis on Multiple Access Techniques. These research efforts aim to enable more efficient achievement of large-scale connectivity.

In recent times, Orthogonal Multiple Access (OMA) techniques have traditionally been the go-to strategy for obtaining satisfactory throughput execution in packet domain functions, accompanied by an uncomplicated receiver design. These techniques have been instrumental in shaping the radio access schemes used in cellular networks [22], [2]. Presently, extensive global efforts are underway to study 5G to push the evolution of wireless and mobile communication systems beyond 2023. Notably, 5G networks are expected to support communications in specialized systems that aren't adequately addressed by 4G networks. Consequently, 5G is anticipated to deliver large data rate (ranging from 10-20 Gbps at the network level and 1 Gbps for user experience), enhance user QoE, minimize latency (achieving 1 millisecond round trip latency), and reduce energy consumption [18], [10]. Notwithstanding the numerous advantages, one common obstacle that 5G encounters is the efficient utilization of spectrum resources to manage the substantial traffic generated by mobile internet usage. Additionally, a challenge arises in the context of IoT development, especially in terms of how to create connections between devices and users while ensuring low latency plus accommodating different service requirements. In traditional OMA techniques, the granularity and quantity of orthogonal resources directly impact the greatest number of users that can be supported. Consequently, multiple radio access schemes have been suggested in the state of the art to enhance the capacity of 5G systems [7]. NOMA emerges as a promising solution for the future of following generation mobile communication networks by utilizing a novel domain that was not previously exploited in earlier systems. Power-Domain NOMA possesses the capability to enable multiple users to access the entirety of time and frequency resources, thereby enhancing spectral efficiency. In comparison to OMA, NOMA effectively addresses the demanding requirements of 5G networks, such as ultra-high connectivity and ultra-low latency, by granting users with robust channel state information (CSI) access to those with CSI [23]. Numerous NOMA systems have been explored for 5G, demonstrating important performance enhancements in terms of system capacity and the throughput to communicate mobile equipment when compared to OMA in Long Term Evolution (LTE). Furthermore, the non-orthogonal scheme of NOMA ensures compatibility with existing technologies like orthogonal frequency division multiple access (OFDMA) and sparse-code frequency division multiple access (SC-FDMA), facilitating smooth backward compatibility. NOMA techniques are classified into two main categories: power domain multiplexing (PDM) and code-domain multiplexing (CDM). PDM-NOMA leverages SIC to handle users with preferable channel conditions [9]. PDM-NOMA offers the advantage of flexible resource allocation, enhancing the execution of NOMA. Moreover, CDM-NOMA employs coding/spreading techniques to introduce redundancy, enabling user separation at the receiver.

While NOMA is still in its precocious stages in the context of 5G, a comprehensive understanding of recent research advancements is highly desirable. Therefore, the paper mainly focuses on PD-NOMA, specifically addressing channel allocation, power control, and user pairing facets. These facets of PD-NOMA are considered the most crucial technical issues to be addressed in order to face the needs of real-world 5G applications.

In this paper, Section 2 provides an overview of a conventional PD-NOMA system. Section 3 describes the PD-NOMA user pairing, power control, and channel allocation. Section 4 delves into the challenges faced by PD-NOMA and identifies potential areas for future research. Finally, Section 5 serves as the conclusion of the paper.

2. PD-NOMA System Model

2.1. Single Cell

NOMA, as a technique, has the capability to face the requirements of 5G networks effectively. Its mechanisms primarily involve multiplexing multiple users by assigning different power levels based on their individual channel conditions, thereby optimizing the overall system performance [31]. Extensive study has been conducted to explore the possible benefits of PD-NOMA in various scenarios and for uplink and downlink transmissions. It is crucial to deem the practical ways of system scheme to confirm the feasibility of implementing PD-NOMA advantages in real-world systems. In order to gain a deeper understanding of the theoretical framework underlying the conception of PD-NOMA, this study examines a representative one cell PD-NOMA scenario that operates in the PD and involves two users. The scheme explores the functionalities of both the transmitter and receiver, shedding light on their operations and interactions. Figure 1 illustrates the scenario where both users, denoted as U1 and U2, are part of the same cell. They are scheduled to use the same time and frequency resources, and the modulated signals are immediately superimposed. This depiction visually represents the concept of users sharing the same resources in PD-NOMA.

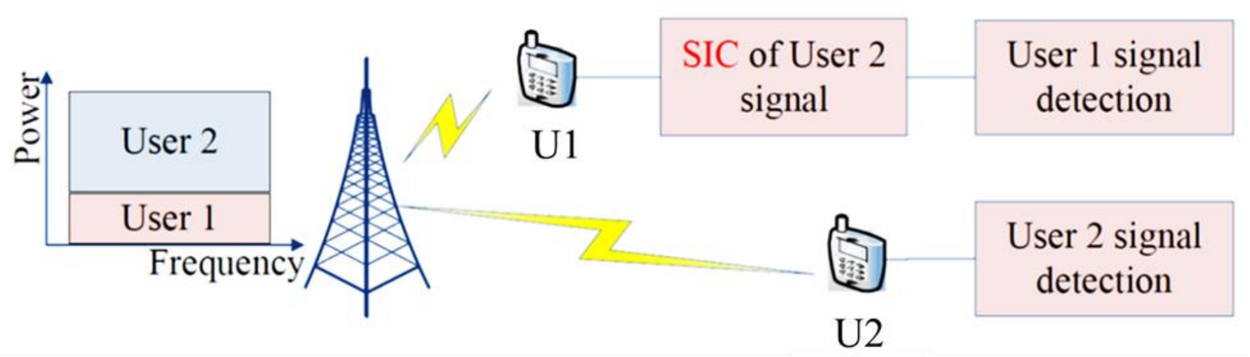

Figure 1: Setup of the transmitter in PD-NOMA

The symbols transmitted by the base station (BS) can be mathematically represented as [24]:

$$x(j) = \sqrt{\delta}x_{U1}(j)\sqrt{1-\delta x_{U2}(j)} \tag{1}$$

The resulting symbol from the linear superposition, denoted as $x(j)$, is a complex-valued symbol associated with a specific symbol index j. It is formed by combining the complex-valued modulated symbols of $U1$ and $U2$, represented as $x_{U1}(j)$and $x_{U2}(j)$ respectively. The symbol index j indicates the specific time instance of the symbol. In the PD-NOMA scheme, the transmission power allocated to the first user, $U1$, is represented by the ratio parameter δ . It is important to note that $U1$ is assumed to be in the center of the cell and received a lower power compared to the second user, $U2$, who is at the edge of the cell. In this scenario, $U2$ is assigned a higher power level. This power allocation strategy facilitates signal separation at the receiver. To ensure effective separation of the user signals, δ is assumed to be less than 0.5, indicating that $U1$ has a lower power allocation compared to $U2$. The sum of the powers allocated to both users depends on the maximum transmission power constraint of the BS. The power allocation scheme takes into account the distance of the users from the BS and their respective channel conditions to optimize the overall system performance. Therefore, by adjusting the power allocation between users based on their location and channel conditions, PD-NOMA achieves signal separation at the receiver, allowing for efficient decoding and improved overall system performance. The specific power allocation ratio, a, and the total power allocated to both users are determined by considering the BS's maximum transmission power constraint.

To successfully decode the desired signal for very user, such as $U1$, it is necessary to reconstruct and eliminate the interference caused by the signal of another user, specifically $U2$, at the receiver end. When the modulation and code scheme (MCS) for $U2$ is predetermined without considering its channel conditions, and if $U1$ has superior channel conditions compared to $U2$, there is a higher probability of $U1$ correctly capturing $U2$'s signal. In this scenario, $U1$'s own signal is assumed to be completely cancelled, resulting in received signal to interference and noise power ratios ($SINRs$) for $U1$ in OMA and PD-NOMA that can be defined as the following:

$$SINR_{U1,NOMA} = \delta \times SINR_{U1,OMA} \tag{2}$$

Conversely, at the receiver side, U2 has the capability to consider U1's signal as unwanted noise plus accurately decode its own intended signal. As a result, the received power signal to interference and noise power ratios for U1 in OMA and PD-NOMA is defined in the following manner:

$$SINR_{U2,NOMA} = \frac{1-\delta}{\delta + \frac{1}{SINR_{U2,OMA}}} \tag{3}$$

The operations in the downlink PD-NOMA of the transmitter and receiver are represented by Figure 2 (a) and (b) respectively.

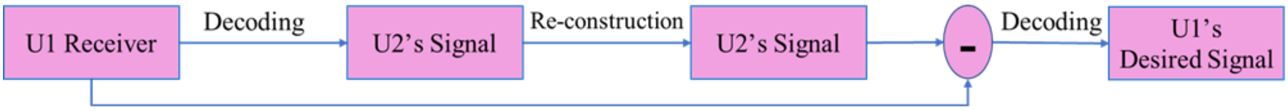

Figure 2: (a) U1 Receiver Process

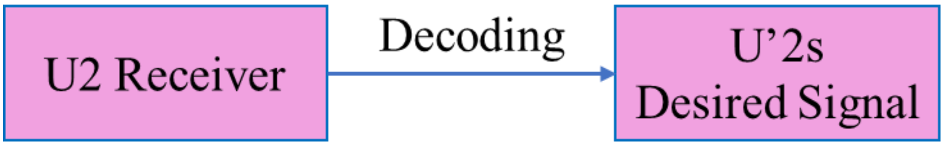

Figure 2: (b) U2 Receiver Process

Based on the users' channel gain conditions, the BS classifies users as either users of cell edge or users of cell center. To achieve PD-NOMA user pairing, users are scheduled together on the same time and frequency resources through employing a threshold coupling loss. By comparing the coupling loss to the predetermined threshold, the BS can determine whether a user belongs to the cell edge or the cell center categories. The practical scheduler controls the power allocation to co-scheduled PD-NOMA users., which reduces computational complexity. Following that, the BS makes scheduling decisions, taking into account factors such as proportional fairness for multiple users. Before applying the selected scheduling algorithm, a group of users is chosen and the related power allocation ratio is determined. To address both inside the cell and inter-cell interference, LTE-Advanced Released 12 introduced interference cancellation (IC) receivers. As a result, IC enables user implementations to effectively minimize interference within cells and between users in NOMA systems.

2.2. Multi-Cell

PD-NOMA offers an advantage compared to the OFDMA, where each user is assigned a single sub-channel, through enabling multiple users to be multiplexed on the same sub channel, thus improving spectrum efficiency [8]. However, Users at the cell edge receive higher power allocation in the downlink PD-NOMA, leading to interference with neighboring cells. To illustrate this, let's consider a cellular network with 2 cells and 4 users. Figure 3 shows a scenario with multi-cell PD-NOMA, each cell consists of two users. User 1 and user 2 are served by BS1, while user 3 and user 4 are served by BS2. In this setup, a significant interference between users 1 and 3 is predictable, potentially degrading the performance of PD-NOMA. To reduce inter-cell interference, PD-NOMA users' signals must be pre-coded jointly across neighboring cells. For PD-NOMA, in [15] a precoding system with low complexity is suggested, In Figure 3, the multi-cell precoder is utilized to the users of cell edge, particularly users 1 and 3.

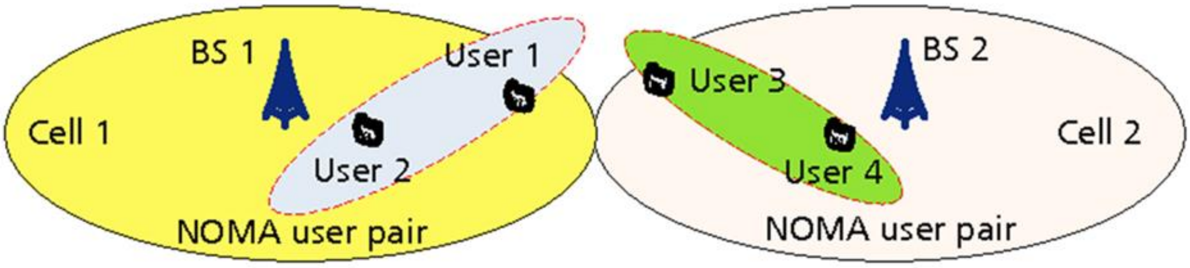

Figure 3: Multi Cell scheme in PD-NOMA

To optimize the performance of a PD-NOMA system, it is important to employ power allocation schemes that are both effective and simple. In PD-NOMA, the allocation of power to one user affects the achievable throughput of other users due to power domain multi-user (MU) multiplexing. In [4], a power allocation scheme called Fractional Transmit Power Allocation (FTPA) is suggested. FTPA takes into account the instantaneous channel conditions of the multiplexed users and allocates power to each user proportionally based on their path loss increased to the power δ FTPA. This approach optimizes the targeted execution estimation metric. To prevent exhaustive user selection, the proposal suggests a predetermined user grouping strategy depended on channel conditions, combined with fixed per group power allocation (FPA). This allows for the realization of significant gains in PD-NOMA with reduced overhead. Another approach for achieving low complexity power allocation in PD-NOMA is through an iterative sub-optimal algorithm depended on Difference of Convex (DC) programming [19]. This technique decomposes the topical function for optimum power allocation into DC functions, which are then repeatedly solved using successive convex approximation to obtain an effective sub-optimum result. Similarly, a sub-optimal method based on a tree-based search and inverted SIC order is also available from the perspective of weighted sum rate maximization [8]. In this method, user weights are not taken into account during power allocation between the multiplexed users, resulting in reduced complexity while still aiming to maximize the sum rate.

2.3. Basic PD-NOMA model formula

In [26], a single cell scenario is used as a typical example to illustrate the notion of downlink PD-NOMA. The system consists of M users' equipment denoted as UE_i, where i belongs to the set $M = \{1,2,3, \dots ..M\}$. There is one BS involved in the communication, and the users employ SIC at their receivers. All users obtain signals simultaneously from the BS while adhering to total power restrictions. The channels are sorted based on certain criteria**:**

$$0 \leq |h_1|^2 \leq |h_2|^2 \leq \cdots \leq |h_M|^2$$

SC is used at the BS in addition to SIC decoding is used at the users, the PD-NOMA enables concurrent transmission to the whole users, utilizing the whole bandwidth (BW) for data transmission. In this scheme, the BS combines the data of M users using linear superposition and allocates a fraction α_i of the BS power P to every user UE_i (where P_i = α_i P). At the receiver side, each user decodes the signals of the weaker users. Specifically, user UE_i can decode the signals of users $UE_m$with $m < i$. The signals of the weaker users are extracted from the received signal to decode the signal of user UE_i, while treating the signals of the stronger users UE_m with $m < i$ as interference. The received signal at user UE_i can be mathematically expressed as:

$$y_i = h_i x_s + n_i \tag{4}$$

$$x_s = \sum_{i=1}^{M} \sqrt{\alpha_i P}\, x_i \tag{5}$$

The transmitted signal x_s from the BS is a result of superimposing the individual signals x_i for user UE_i. Each user UE_i experiences additive white Gaussian noise (AWGN) represented by n_i, with a zero mean and variance σ_n^2. When the SC at the BS and the SIC at UE_i are executed successfully, the achievable data rate for user UE_i within a 1 Hz BW can be calculated as follows:

$$R_i = \log_2(1 + \frac{\alpha_i P |h_i|^2}{P|h_i|^2 \sum_{k=i+1}^{M} \alpha_k + \sigma_n^2}) \tag{6}$$

The expression [19] represents the data rate assigned to user UE_M :

$$R_M = \log_2(1 + \frac{\alpha_M P |h_M|^2}{\sigma_n^2}) \tag{7}$$

Before its own signal being decoded, this user follows a sequential process of decoding and eliminating the signals from other users. It is worth noting that although a user may have superior channel conditions, this doesn't necessarily correspond to a powerful signal. In reality, a strong user is assigned a lower transmit power, while a weak user is allocated a higher power, this results in an improved SINR. So, PD-NOMA adheres to the fundamental notion of SIC, where the decoding starts with the strongest signal. Both users simultaneously utilize the entire system transmission bandwidth, assuming a 1Hz overall bandwidth. Given that UE_1has a greater channel gain than UE_2, SIC is initially employed to decode the signal intended for UE_1. Subsequently, the decoded signal is subtracted from the received signal of UE_2. The resulting signal is then used to decode the signal intended for UE_2. As SIC is not performed for UE_2, its signal is immediately decoded. Hence, the achievable data rates for UE_1 and UE_2 are determined through equations (8) plus (9) as the following:

$$R_1 = \log_2(1 + \frac{P_2 |h_2|^2}{\sigma_n^2}) \tag{8}$$

$$R_2 = \log_2(1 + \frac{P_1 |h_1|^2}{P_2 |h_1|^2 + \sigma_n^2}) \tag{9}$$

In the case of applying OMA, UE_1 is allocated a bandwidth of ω Hz, while the remaining bandwidth of $(1 - \omega)$ Hz is assigned to UE_2. The achievable data rates for users UE_1 and UE_2 can be calculated using equations (10) and (11).

$$R_1 = \omega \log_2(1 + \frac{P_2 |h_2|^2}{\sigma_n^2}) \tag{10}$$

$$R_2 = (1 - \omega) \log_2(1 + \frac{P_2 |h_2|^2}{\sigma_n^2}) \tag{11}$$

The equations (8) and (9) demonstrate that the PD-NOMA system adjusts the throughput of every user through controlling the power allocation ratio $\frac{P_1}{P_2}$. This approach ensures a trade-off between overall throughput and fairness among users, making it a derived power allocation scheme. In the presence of an asymmetric channel, the signal to noise ratios (SNRs) of both users are different, the calculated values of R_1 and R_2 from equations (8) and (9) are significantly higher than those obtained from equations (10) and (11). This numerical comparison represents a specific status of analyzing the MU channel capacity. Thus, when the channels for the two users exhibit dissimilarity, PD-NOMA proves to be very efficient in terms of achieving system level throughput.

3. Critical Aspects of PD-NOMA

3.1. user pairing

In PD-NOMA, user pairing is a crucial aspect that involves grouping users into pairs based on their channel conditions. The objective is to maximize the overall system capacity and improve the fairness of resource allocation among users. [1] presents a comprehensive study on user pairing and power allocation techniques for PD-NOMA systems. It discusses different user pairing algorithms, including random pairing, greedy pairing, and clustering-based pairing. The authors also suggest a joint user pairing and power allocation scheme to maximize the sum rate of the system. The performance of various pairing schemes is evaluated through simulations, providing valuable insights into the impact of user pairing on system performance.

3.2. channel allocation

In the downlink scenario, power allocation to users based on their CSI is crucial for achieving robust performance. This necessitates the development of proper mechanisms for CSI feedback, channel estimation schemes, and reference signal design. However, the benefits of NOMA have mainly been proven under the assumption of perfect CSI acquisition at the transmitter, which is not realistic. [12] One possible solution is to utilize a limited feedback channel for acquiring CSI, but this needs more bandwidth to transfer channel quality indicators. User selection schemes and appropriate power allocation become more important when the transmitter is operating under defective CSI or with limited feedback. Another challenge arises in multi-carrier communications, where the peak to average power ratio (PAPR) can lead to significant signal distortion in power amplifiers. Techniques to mitigate PAPR and optimize NOMA performance need to be investigated. To enhance capacity gain, the concept of relaying can be applied in non-orthogonal coordinated transmission among a macro cell and small size cells. Hybrid schemes that combine topological interference management and NOMA principles have shown promise in terms of sum rate performance.

3.3. Power control

Power control in PD-NOMA is a vital aspect that ensures efficient power allocation among users sharing the same resource block. The objective of power control is to assign power levels in a way that exploits the channel conditions of different users to achieve multiplexing gain and enhance system performance. [30] focuses on the power allocation problem in PD-NOMA for 5G networks. It addresses the challenge of computing optimal power allocation strategies in large-scale systems efficiently. The authors propose a low complexity power allocation algorithm based on fractional programming, which achieves a near-optimal performance. The tractability and computation efficiency of the algorithm are analyzed, providing insights into power control techniques in PD-NOMA. The authors in [27] model a game-theoretic technique for power control in PD-NOMA for downlink transmissions in 5G systems. They present the power control problem as a non-cooperative game among users and formulate a Nash equilibrium-based power allocation algorithm. The proposed algorithm achieves a balance between system performance and fairness among users. The effectiveness of the game-theoretic power control scheme is validated through simulations.

4. PD-NOMA: Challenges & Future Works

4.1. Practical Channel Model

To meet the increasing demand for data in modern wireless networks, the next generation of wireless technology, known as 5G, requires both an efficient radio access method and access to a wide range of available frequencies. Currently, it is evident that 5G networks will utilize the untapped mm Wave frequency bands to accommodate the growing data traffic. Furthermore, the infrastructure of 5G networks is looking forward to shift from traditional copper and fiber connections to wireless connections using mm Wave technology, enabling quick deployment and establishing a mesh-like network topology. The mm Wave frequency range, spanning from 30 to 300 GHz, presents a novel opportunity for cellular networks, offering a substantial amount of available bandwidth. It is crucial to comprehend the challenges associated with mm Wave cellular communications, particularly the behavior of the wireless channels, in order to develop efficient 5G mobile systems and backhaul techniques [20]. Previous studies on NOMA, a promising technique for 5G networks, have assumed AWGN with Rayleigh fading channels. However, for an additional realistic analysis, it is necessary to incorporate measured values of path loss and delay spread [21] to accurately model the radio channel characteristics in the mm Wave frequency band.

4.2. Uniform Fairness

In mm Wave cellular networks, it has been observed that signal outages are prevalent at distances exceeding 175 meters [20]. The occurrence of outages is heavily influenced by the surrounding environment, and if there are additional local obstacles, the actual outage rates may be even higher. Therefore, it would be highly valuable to develop a NOMA scheme that can ensure users, particularly those located between 150 meters and the cell boundary in mm Wave cellular networks, have consistent and uniform outage experiences. Designing such a NOMA scheme to mitigate the impact of outages and provide reliable connectivity to users in these specific areas would be a significant contribution to the field. By carefully considering the characteristics of the mm Wave environment and developing novel techniques, it is possible to enhance the whole system performance and ensure a more consistent user experience, even in challenging conditions.

4.3. Resources Allocation

To meet the demanding requirements of 5G systems, like low latency, high data rates, and reliability, effective resource management becomes crucial due to limited resources. Wireless resource management encompasses a group of processes aimed at determining the allocation of timing and quantity of resources for each user [14], taking into account the specific resource types involved. One essential resource is the available BW, which plays a significant role in the effective management of a communication system. In the context of resource management, the total system bandwidth is typically divided into smaller chunks, with each chunk allocated to specific users or groups of users, as seen in NOMA. Moreover, the number of packets assigned to every user may vary dynamically over time. Thus, achieving optimal power allocation and user-pairing between users in NOMA necessitates sophisticated algorithms that can optimize performance while minimizing resource utilization. From a mathematical optimization perspective, resource allocation in NOMA can be searched. For instance, the authors in [16] investigated channel allocation and joint power in NOMA for 5G systems. Their study considered user power control and SIC to address the power and channel allocation issue. Another area that remains relatively unexplored is power allocation in NOMA based cognitive radio systems [28], which presents opportunities for further research and investigation. By delving into mathematical optimization theories and developing advanced algorithms, researchers can advance the field of resource allocation in NOMA, contributing to improved system performance, efficient resource utilization, and enhanced overall network capabilities in 5G and beyond.

4.4. Effect of Transmission Distortion

The transmission of source data like video and voice through communications channel is typically subject to loss and distortion. During propagation to the receiver, the transmitted data inevitably experiences various forms of distortion. To address this lossy transmission, significant theoretical efforts have been devoted to assessing source fidelity over fading channels. Different approaches involving channel coding and source coding have been developed to reduce end to end distortion. Nevertheless, these approaches often lead to conflicting requirements in terms of preferred distortion levels, cost, and complexity. By the authors in [5], the source distortion was compared for two concepts of channel capacity: outage capacity and ergodic capacity. It was observed that both information capacity and distortion are influenced by the outage probability. Interestingly, maximizing the outage rate through outage probability can not necessarily result in the low expected distortion [5], [11]. Therefore, there is scope for investigation to maximize the outage probability in a NOMA, aiming to achieve the maximal outage rate while maintaining a suitable level of distortion. Exploring this optimization of outage probability within a NOMA scheme can contribute to finding a balance between achieving high outage rates and ensuring acceptable levels of distortion. By investigating the relationship between outage probability and expected distortion, it is possible to develop strategies that strike an optimal trade-off, resulting in improved performance and quality of transmission for source information over fading channels.

4.5. Error Propagation

It is commonly understood that when an error happens in SIC, it is likely to cause incorrect decoding of all other user information. However, this issue can be mitigated by employing a more robust code, such as growing the block length, particularly when the number of users is relatively small [6]. If certain users experience performance degradation, nonlinear detection schemes may also be used to prevent error propagation. In a study [3] using computer simulations, the authors demonstrated that the impact of error propagation on NOMA performance is minimal. This is because, during NOMA scheduling, a user with a weak channel is assigned to a user with a strong channel, which helps compensate for the error propagation. These findings were obtained under the assumption of a worst-case scenario, If the decoding of the weak user at the first level of the strong user's receiver fails, it inevitably leads to the failure of decoding the strong user at the second stage. While there have been some analytical works investigating SIC error propagation in basic multiple-input multiple-output (MIMO) systems [17], [13]. Currently, there is a dearth of substantial study that offers a mathematical understanding of the implications of imperfect SIC on NOMA systems. Consequently, there exists an intriguing research opportunity to conduct a mathematical analysis and investigate the effects of imperfect SIC on the performance of NOMA systems.

4.6. SIC Decoding Complexity

Compared to orthogonal schemes, employing SIC for signal decoding introduces additional implementation complexity. In SIC, the receiver should decode the signal of other users before decoding its signal [6]. Because the number of users in the target cell rises, this complexity further escalates. However, a potential solution is to cluster users into several groups, with each cluster comprising a small number of users experiencing poor channel conditions. Within each group, a group-wise SIC operation can be performed, striking a balance between performance improvement and implementation complexity.

Further research on the MIMO implementation of such hybrid methods is worth exploring. However, determining a fair power allocation method for dense networks remains a challenge. For NOMA to be adopted in 5G, it must also demonstrate robustness in terms of system scalability to support diverse radio environments and heterogeneous traffic. While theoretical studies have verified NOMA's performance, practical experiments and over-the-air demonstrations are necessary to showcase its potential in real-world 5G mobile networks. Although some prototypes, such as the software-defined radio (SDR) NOMA introduced by [25], have been developed, further experiments are needed to validate NOMA's capabilities in practical scenarios.

Other future research opportunities include the evaluation of NOMA performance in the presence of beamformers and MU-MIMO. NOMA is looking forward to achieve greater benefits when combined with MU-MIMO. In this scenario, users multiplexing in the PD utilizing NOMA is independent of users multiplexing in the spatial domain utilizing MU-MIMO. The co-scheduled user equipment in NOMA is supposed to utilize the same beamformer, allowing the UE at the cell center to decode transmissions intended for the user equipment at the cell edge. Additionally, analyzing the execution of a cooperative NOMA, particularly in dynamic interfering environments, represents another prospective research area. Investigating the group of PD-NOMA with other kinds of MA techniques, such as both traditional OMA techniques and newly improved 5G MA schemes, is also worth exploring [29]. Moreover, as user clustering or pairing is believed to decrease the complexity of the system, it is essential to develop new low-complexity algorithms to achieve optimum user clustering.

5. Conclusion

In this paper, the concept of PD-NOMA is introduced as a promising contender for next radio access technique (RAT) in the realm of 5G mobile communication systems. The key idea of PD-NOMA is to serve several users simultaneously through the same radio resources while minimizing inter-user interference. In contrast to traditional OMA schemes, where every user is allocated dedicated radio resources, PD-NOMA utilizes power-domain superposition to combine the message signals of several users. These superposed signals are then decoded at the receivers using SIC in a MU scenario. By leveraging the PD, NOMA enables superior spectral efficiency through allowing every user access to all sub-carrier channels. This PDM scheme is well-suited for 5G technologies as it optimizes resource use. The notion of PD-NOMA is initially explained in a single-cell scenario, assuming transmitter and receiver antennas. In a multi-cell scenario, PD-NOMA further enhances spectrum efficiency by multiplexing several users on the same sub-channel. To optimize the execution of PD-NOMA system, less complex power allocation schemes can be utilized. However, it's important to note that power allocation to one user may impact the throughput of other users due to power-domain MU multiplexing. Overall, PD-NOMA shows promise in improving the efficiency and capacity of 5G systems by enabling simultaneous transmission to several users over the same radio resources while effectively managing interference. Further research can focus on developing optimized power allocation schemes and exploring the performance of PD-NOMA in practical scenarios.

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