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Non-Orthogonal Multiple Access for 6G Wireless Networks: A Review of Signal Processing Techniques, Applications, and Future Directions

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Abstract

Non-orthogonal multiple access (NOMA) has been proposed as a means of serving multiple users within the same time-frequency-code resource block by exploiting the power domain, in contrast to the strict resource orthogonality enforced by conventional orthogonal multiple access (OMA) schemes. Originally studied as a candidate multiple access technique for fifth-generation (5G) networks, NOMA continues to attract sustained research interest as a foundational building block for sixth-generation (6G) systems, where massive device connectivity, spectral efficiency, and user fairness are primary design objectives. This paper reviews the fundamental principles of power-domain NOMA, including superposition coding and successive interference cancellation, and surveys its integration with complementary 6G-enabling technologies, namely massive multiple-input multiple-output (MIMO) systems, millimeter-wave and near-field communication, and reconfigurable intelligent surfaces. The role of deep learning in NOMA resource allocation, power control, and decoding is discussed, along with physical layer security considerations specific to NOMA's superposed signaling structure. The paper concludes with an assessment of open challenges, including receiver complexity, error propagation in successive interference cancellation, and the practical trade-offs that continue to shape the evolution of NOMA toward next-generation multiple access (NGMA) frameworks for 6G.

Keywords: non-orthogonal multiple access, NOMA, 6G, successive interference cancellation, power-domain multiplexing, massive MIMO, physical layer security.

1. Introduction

Multiple access techniques govern how a shared wireless medium is divided among competing users, and each cellular generation has historically been associated with a change in this underlying scheme, from frequency-division multiple access in first-generation systems through code-division and orthogonal frequency-division multiple access in subsequent generations. Orthogonal multiple access (OMA) schemes allocate each user a distinct, non-overlapping resource, such as a time slot, subcarrier, or spreading code, which simplifies receiver design but fundamentally limits the number of users that can be served per resource block and can leave capacity underutilized when users experience highly asymmetric channel conditions.

Non-orthogonal multiple access (NOMA) departs from this principle by deliberately allowing multiple users to share the same time-frequency resource, typically distinguishing them in the power domain through superposition coding at the transmitter and successive interference cancellation (SIC) at the receiver. By exploiting differences in channel gain among users, power-domain NOMA can, at least in principle, achieve a larger sum rate and improved fairness relative to OMA under the same bandwidth constraint, which has motivated extensive investigation of NOMA as an enabling multiple access technology first for 5G and, increasingly, for 6G.
As the wireless research community looks toward 6G, NOMA is being studied less as a standalone technique and more as a design principle that interacts with, and is often combined with, other key 6G technologies, including massive MIMO, millimeter-wave and near-field communication, reconfigurable intelligent surfaces, and machine learning-based resource management. This review is organized as follows. Section 2 reviews related survey literature. Section 3 presents the fundamental principles of NOMA. Section 4 discusses NOMA's integration with other 6G-enabling technologies. Section 5 reviews physical layer security in NOMA systems. Section 6 discusses open challenges, and Section 7 concludes the paper.

2. Related Work

Several survey papers have documented the evolution of NOMA research. Early surveys focused on power-domain NOMA fundamentals and its application to 5G networks, covering performance analysis, resource allocation, and multiple-input multiple-output extensions of the basic two-user NOMA model. Subsequent work extended this scope toward 6G, discussing the evolution of NOMA into a broader next-generation multiple access (NGMA) framework that also encompasses code-domain schemes such as sparse code multiple access, and toward deployment scenarios involving near-field propagation, where the spherical-wave channel model associated with extremely large-scale antenna arrays introduces new opportunities for distinguishing users in the distance domain in addition to the conventional angle domain. Other recent surveys have specifically examined deep learning-based approaches to NOMA resource allocation and decoding, and physical layer security techniques tailored to NOMA's superposed signaling structure across deployment scenarios including massive MIMO, full-duplex relaying, millimeter-wave communication, reconfigurable intelligent surfaces, vehicular communication, and unmanned aerial vehicle networks. This paper builds on that body of work by presenting an integrated, up-to-date view that connects NOMA fundamentals, its combination with complementary 6G technologies, and its associated security considerations within a single review.

3. Fundamentals of NOMA

3.1 Power-Domain Superposition and Successive Interference Cancellation

In the canonical power-domain NOMA setup, a base station transmits a superposition of signals intended for two or more users within the same time-frequency resource, allocating a larger share of transmit power to users with weaker channel conditions and a smaller share to users with stronger channel conditions. At the receiver side, users with stronger channels apply successive interference cancellation, decoding and subtracting the signal intended for weaker users before decoding their own signal, while users with weaker channels decode their own signal directly, treating the stronger users' signal as additional noise. This power allocation and decoding order together determine the achievable rate region for the served users, and their joint optimization, subject to fairness or quality-of-service constraints, remains a central resource allocation problem in NOMA system design.

3.2 Multi-Carrier and Multiple-Input Multiple-Output NOMA

The basic two-user, single-carrier NOMA model generalizes naturally to multi-carrier systems, in which users are grouped into clusters on each subcarrier and power-domain NOMA is applied within each cluster, and to multiple-input multiple-output systems, in which spatial beamforming is combined with power-domain multiplexing to serve users that are separated in both the spatial and power domains. These generalizations increase the achievable sum rate and the number of users served per resource block, but also increase the complexity of joint power allocation, user clustering, and beamforming design, which has motivated a substantial body of optimization and, increasingly, machine learning-based research.

4. Integration with 6G-Enabling Technologies

4.1 NOMA and Massive MIMO

Combining NOMA with massive MIMO allows spatial beamforming to separate user clusters while power-domain NOMA is applied within each cluster, increasing the total number of users served per time-frequency resource beyond what either technique achieves independently. This combination is particularly relevant for 6G scenarios emphasizing massive connectivity, such as dense Internet-of-Things deployments, though it introduces additional complexity in jointly designing beamforming vectors, user clustering, and power allocation.

4.2 NOMA in Near-Field and Millimeter-Wave Systems

As antenna arrays grow toward the extremely large scales anticipated for 6G, near-field propagation effects, in which the channel depends on both the angle and the distance of a user relative to the array, introduce a new degree of freedom that NOMA can exploit: users located at different distances along the same angular direction, who would be indistinguishable to a conventional far-field beamformer, can in principle be separated using near-field beamforming combined with power-domain multiplexing. This has motivated recent research into NOMA schemes explicitly designed for near-field communication, extending NOMA's applicability beyond the angular-domain user separation assumed in conventional far-field analysis.

4.3 NOMA with Reconfigurable Intelligent Surfaces
Reconfigurable intelligent surfaces (RIS) have also been studied in combination with NOMA, where the surface's ability to reshape the propagation channel can be used to further differentiate users' effective channel gains, improving the power-domain separability that NOMA's successive interference cancellation relies on. This combination is reported to be particularly beneficial in scenarios where users have naturally similar channel conditions, since without sufficient channel gain disparity, power-domain NOMA offers little advantage over conventional OMA.

4.4 Deep Learning for NOMA Resource Allocation and Detection
Because joint user clustering, power allocation, and beamforming design in NOMA systems is a non-convex, often combinatorial problem that must be solved rapidly under changing channel conditions, deep learning and reinforcement learning techniques have increasingly been applied to approximate near-optimal solutions with reduced computational latency relative to classical optimization. Reported applications include learned power allocation policies, neural user clustering, and deep learning-based signal detection intended to reduce the error propagation that can occur in successive interference cancellation when an early decoding decision is incorrect.

5. Physical Layer Security in NOMA Systems
The broadcast and superposition-based structure of NOMA introduces physical layer security (PLS) considerations distinct from those in OMA systems, since multiple users' signals are transmitted simultaneously over the same resource and a user performing successive interference cancellation necessarily decodes information intended for other users as an intermediate step. Recent surveys examine PLS methodologies adapted to this structure, including secure beamforming, artificial noise injection, cooperative jamming, and RIS-assisted secrecy enhancement, across deployment scenarios such as massive MIMO, full-duplex relaying, millimeter-wave communication, vehicular networks, and unmanned aerial vehicle communication. These techniques generally aim to preserve the throughput and connectivity advantages of NOMA while limiting the information that a weaker or untrusted user, or an external eavesdropper, can extract from the superposed signal.

6. Open Challenges
Despite two generations of sustained research attention, several challenges continue to limit the practical deployment of NOMA at scale. Receiver complexity remains a concern, since successive interference cancellation requires each user to decode and, for stronger users, cancel other users' signals, increasing computational and latency overhead relative to OMA receivers, particularly as the number of superposed users grows. Error propagation is a related issue: an incorrect decoding decision at one stage of successive interference cancellation propagates to all subsequent decoding stages, degrading performance for weaker users in the cancellation order. Standardization

remains incomplete, with NOMA present in some standards, such as multi-user superposition transmission in LTE-Advanced and layered division multiplexing in the ATSC 3.0 broadcast standard, but not yet adopted as a primary multiple access scheme in 3GPP New Radio specifications. Finally, the practical gain of NOMA over well-optimized OMA baselines remains sensitive to the channel gain disparity among grouped users, meaning that realized gains in field deployments may be more modest than idealized two-user analyses suggest.

7. Conclusion

Non-orthogonal multiple access remains one of the most extensively studied multiple access candidates for 6G wireless networks, evolving from a standalone power-domain multiplexing scheme into a design principle that interacts closely with massive MIMO, near-field and millimeter-wave communication, reconfigurable intelligent surfaces, and machine learning-based resource management. This review has summarized NOMA's fundamental principles, its integration with complementary 6G technologies, and the physical layer security considerations that arise from its superposed signaling structure. Continued progress on reducing receiver complexity, mitigating error propagation, and clarifying NOMA's role within emerging standardization efforts will determine the extent to which its theoretical gains translate into practical 6G deployment.

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