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Advances in MISO-NOMA for Cell-Edge User Performance: A Comprehensive Review

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Abstract: *This review examines how multiple-input single-output non-orthogonal multiple access addresses the performance challenges faced by cell-edge users in future wireless networks. As the industry moves toward 6G, the demand for spectral efficiency highlights the limitations of traditional orthogonal methods, particularly for users suffering from severe path loss and interference. NOMA improves user fairness by enabling power-domain multiplexing, which can increase supported user density and provide throughput gains for edge users. The study synthesises various technical strategies, including advanced beamforming, adaptive power allocation, and cooperative relaying integrated with wireless power transfer. These models use near users as relays to enhance the connectivity of distant users and significantly reduce outage probability. Finally, the analysis considers practical impairments and multi-cell interference management, identifying future research directions in artificial intelligence and mobility to ensure equitable service throughout the entire network coverage area.*

Keywords: MISO-NOMA, Cell-Edge Users, Beamforming, Spectral Efficiency and Wireless Communication Networks

INTRODUCTION

The relentless demand for ubiquitous high data rates and massive connectivity has driven the evolution of wireless networks from 4G to 5G and now towards 6G. Despite remarkable progress in spectral efficiency and system capacity, a fundamental challenge persists users located at the cell edge experience significantly degraded performance compared to those near the base station. This disparity stems from severe path loss, inter-cell interference, and a limited signal-to-interference-plus-noise ratio, which collectively undermine the quality of service for cell-edge users. Addressing this performance gap is critical for ensuring equitable user experience and realising the full potential of next-generation wireless systems.

Non-orthogonal multiple access has emerged as a promising solution to this challenge, enabling multiple users to share the same time-frequency resource block through superposition coding and successive interference cancellation at the receiver. Unlike orthogonal multiple access techniques, NOMA can improve user fairness optimally through flexible power allocation (Shin et al., 2017). By allocating higher power to users with poor channel conditions, NOMA compensates for distance effects on channel quality and offers more equitable service. Empirical studies demonstrate that NOMA-based approaches can achieve cell-edge user throughput gains of approximately 20% to 21% compared to conventional orthogonal signalling (Hojeij et al., 2015a, 2015b). Furthermore, NOMA can support approximately 50% more users per cell than OMA while maintaining high probability of service (You & Yuan, 2020), making it particularly attractive for dense network deployments.

The integration of NOMA with multiple-input single-output systems, known as MISO-NOMA, further enhances the potential for cell-edge performance improvement. MISO-NOMA leverages spatial degrees of freedom through transmit beamforming to direct signal power towards intended users while suppressing interference from others. This combination is especially beneficial for cell-edge users, who can exploit spatial diversity gains to overcome their inherent channel disadvantage. Recent work has demonstrated that cooperative MISO-NOMA schemes employing transmit antenna selection and simultaneous wireless information and power transfer can significantly reduce outage probability for cell-edge users while maintaining quality of service for near users (Nhu et al., 2017). Coordinated beamforming techniques in multi-cell MIMO-NOMA systems have also proven effective in increasing cell-edge user throughput and improving overall user fairness (Shin et al., 2016).

However, realising the full benefits of MISO-NOMA for cell-edge users presents several technical challenges. The conventional SIC ordering, which follows ascending channel gain order, inherently places cell-edge users at a disadvantage as they must decode their signals while treating stronger users' signals as interference (Kilzi et al., 2019). This makes cell-edge users particularly vulnerable to residual inter-user interference and inter-cell interference. Moreover, the requirement that cell-center users must successfully decode the cell-edge user's signal before performing SIC imposes stringent SINR conditions that may not always be satisfied in practice (Şenel et al., 2019). Imperfect channel state information, hardware impairments, and the complexity of joint optimisation across beamforming, power allocation, and user pairing further complicate practical deployment.

This comprehensive review examines the state of the art in MISO-NOMA techniques designed to enhance cell-edge user performance. By synthesising findings from recent research and identifying critical research gaps, this review aims to provide researchers and practitioners with a clear roadmap for advancing MISO-NOMA technology toward robust, fair, and efficient service for all users, particularly those at the cell edge who stand to benefit most from these innovations.

Fundamentals of MISO-NOMA

The core of MISO-NOMA lies in the simultaneous transmission of multiple signals from a base station equipped with multiple antennas to several single-antenna users. This is achieved using superposition coding at the transmitter and successive interference cancellation at the receiver. In a typical downlink scenario, the base station exploits channel state information to pair users with diverse channel conditions, specifically a near user with strong gain and a cell-edge user with weak gain.

A critical aspect of this architecture is the decoding order. To maximise efficiency, the user with the stronger channel typically decodes the signal of the weaker user first, subtracts it from the received signal, and then decodes its own information. This process effectively removes the interference caused by the cell-edge user's signal at the near user's receiver (Şenel et al., 2019). Recent studies have also applied the concept of quasi-degradation to characterise the performance gap between NOMA and optimal dirty-paper coding, demonstrating that MISO-NOMA can achieve near-optimal rates under specific channel conditions (Chen et al., 2016).

Cell-Edge Performance Challenges

Despite its potential, several physical and technical barriers hinder cell-edge performance in MISO-NOMA. The most prominent issue is the inherent vulnerability of cell-edge users to both intra-cell and inter-cell interference. Under standard SIC ordering, cell-edge users must decode their signals while treating the signals of stronger users as noise, which can severely limit their achievable data rates (Kilzi et al., 2019).

Furthermore, the performance of NOMA is highly sensitive to the accuracy of channel state information. In practical multi-cell deployments, the coordination of interference becomes a complex optimisation problem. For instance, while NOMA provides significant gains in isolated cells, the presence of inter-cell interference in dense networks can degrade the SINR of edge users to the extent that NOMA gains are diminished unless coordinated beamforming is employed (Shin et al., 2016, 2017).

Beamforming and Precoding Strategies

Beamforming is a vital tool for managing interference and enhancing signal strength at the cell edge. By designing precise beamforming vectors, the base station can direct energy towards the cell-edge user while maintaining the quality of service for the near user. Strategies such as zero-forcing and matched filtering are often used as benchmarks, but more advanced techniques such as energy-efficient beamforming have been developed to maximise global energy efficiency under specific rate constraints (Al-Obiedollah et al., 2019).

Recent research has also focused on joint beamforming and power allocation algorithms. For example, branch and bound techniques have been proposed to maximise the sum rate of users with better channel conditions while strictly guaranteeing the minimum requirements for users experiencing poor channel conditions (Cui et al., 2016). Optimal beamforming designs have even been shown to achieve the same performance as dirty-paper coding for two-user MISO-NOMA systems, significantly simplifying the complexity of transmitter design (Zhu et al., 2020).

Power Allocation Methods

Power allocation is the primary mechanism through which NOMA ensures fairness. By assigning a higher power level to users with low channel gains, the system compensates for the effects of distance and path loss (Hojeij, 2018). This adaptive power distribution is fundamental to preventing user starvation, a common problem in OMA systems where only the user with the best channel might be scheduled to maximise capacity (Richard, 2021).

Optimisation-based power allocation methods, such as those using water filling or weighted sum-rate maximisation, allow the system to reach a balance between overall throughput and edge-user reliability. In scenarios with many users, uniform power allocation sometimes emerges as a practical alternative to ensure all users meet their required data rates, although weighted optimisation based on user distance generally yields the best fairness outcomes (Hojeij et al., 2015a, 2015b).

User Pairing and Scheduling

The effectiveness of NOMA is deeply tied to how users are paired or clustered. Effective user pairing strategies often group users with a significant difference in channel gains to maximise the efficiency of SIC. Pairing a cell-edge user with a very strong near user allows for a more distinct power separation in the superposed signal, which facilitates easier decoding and better interference management. Research has shown that when users are grouped effectively, NOMA can maintain a high probability of supporting all users even when the number of users per cell increases beyond the capacity of OMA (You & Yuan, 2020).

Cooperative and Relay-Assisted Approaches

To further assist cell-edge users, cooperative NOMA schemes have been proposed where the near user, having already decoded the edge user's signal for SIC, acts as a relay. This relaying operation significantly enhances the reliability of the edge user's connection. Schemes utilising transmit antenna selection and decode-and-forward relaying have demonstrated substantial improvements in outage probability (Nhu et al., 2017).

In these cooperative models, the near user serves as a bridge, helping the cell-edge user overcome the severe fading and path loss associated with long-distance transmission (Albdairat et al., 2023). Such approaches are particularly valuable in IoT and low-power networks where the edge devices may have limited reception capabilities (Bagheri, 2024).

SWIPT and Energy-Aware Designs

The integration of simultaneous wireless information and power transfer into MISO-NOMA systems addresses the energy constraints of relaying nodes. In these designs, the near user harvests energy from the base station's signal to power its relaying activities for the cell-edge user (Nhu et al., 2017). This creates a self-sustaining cooperative environment that improves the edge user's performance without draining the near user's battery. Studies have derived closed-form expressions for system throughput and energy efficiency in these SWIPT-enabled networks, proving that they can offer superior performance compared to non-cooperative NOMA (Albdairat et al., 2023; Bagheri, 2024).

Robustness and Practical Impairments

Practical implementation of MISO-NOMA must account for hardware impairments and imperfect CSI. Many theoretical gains of NOMA are predicated on perfect channel knowledge; however, estimation errors and residual SIC interference can significantly reduce these benefits. Robust beamforming and resource allocation techniques are therefore necessary to ensure that the system remains stable and cell-edge users are not unfairly penalised by channel uncertainty (Cui et al., 2016).

Multi-Cell and Interference Management

In multi-cell environments, inter-cell interference often dominates the noise floor for edge users. Coordinated multipoint and coordinated beamforming are essential for managing this interference. By sharing channel information across base stations, the network can perform joint scheduling and beamforming to protect edge users from the signals of neighbouring cells (Kilzi et al., 2019). Coordinated beamforming has been shown to increase cell-edge throughput and improve user fairness across the entire network (Shin et al., 2016).

Optimisation and AI-Based Solutions

The complexity of joint beamforming, power allocation, and user pairing often leads to non-convex optimisation problems that are difficult to solve in real time. Recent advancements have turned to artificial intelligence and deep learning to approximate optimal solutions with low computational overhead. These AI-driven approaches are promising for dynamic environments where channel conditions change rapidly, allowing the system to adapt its resource allocation to maintain cell-edge performance without the need for exhaustive searches.

Performance Benchmarking

To accurately evaluate MISO-NOMA advancements, several key metrics are used. These include:

I. Outage Probability: The likelihood that a user fails to meet their target data rate.

II. Cell-Edge Throughput: The specific data rate achieved by users at the periphery of the cell.

III. Jain's Fairness Index: A measure of how equitably resources are distributed among all users.

IV. Energy Efficiency: The ratio of the data rate to the power consumed.

Comparison tables in recent literature often show that while cooperative and beamforming-assisted NOMA have higher complexity, they provide the most significant gains in reliability for edge users compared to simple power allocation (Hojeij et al., 2015; Nhu et al., 2017).

Table 1: Comparative Evaluation of Cell-Edge User Performance Enhancement Approaches in NOMA Systems.

Approach	Cell-edge gain	Complexity	Practical robustness	Main limitation
Power allocation	High.	High.	Moderate.	May reduce fairness for strong users.
Beamforming	High.	Medium–high.	Good with CSI.	Sensitive to channel estimation.

Cooperative NOMA	Very high.	High.	Sensitive to imperfections.	Extra delay and relay overhead.
AI-based optimisation	High.	Medium.	Promising.	Needs training data and validation.

Open Research Problems

Significant gaps remain in the literature, particularly regarding the connectivity probability of cell-edge users and the impact of mobility; most current studies focus on static users, but the high-speed movement of users at the cell edge can introduce Doppler shifts and rapid channel variations, challenging the stability of SIC and beamforming. Additionally, finding the optimal balance between computational complexity and the gains achieved through multi-cell coordination remains a key concern for practical deployment.

Future Directions

Looking ahead, the use of intelligent reflecting surfaces and unmanned aerial vehicles as mobile relays offers exciting possibilities for enhancing cell-edge coverage. Furthermore, the development of semantic communications and integrated sensing and communication could provide new ways to optimise resource allocation by focusing on the meaning of the data and the physical environment rather than just raw bit rates.

Conclusions

Improving cell-edge user performance is a multi-faceted challenge that requires the harmonious integration of beamforming, power control, and cooperative relaying. MISO-NOMA provides a robust framework for addressing these issues, offering significant spectral efficiency and fairness gains over traditional OMA. As research moves toward 6G, the focus must shift toward making these advanced techniques more robust to practical impairments and sufficiently efficient for real-time operation in dense, heterogeneous networks.

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