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Simulation-based performance evaluation of reconfigurable intelligent surface (RIS)-assisted non-orthogonal multiple access (NOMA) networks

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ABSTRACT

The integration of reconfigurable intelligent surfaces (RIS) into non-orthogonal multiple access (NOMA) networks presents a promising solution to the persistent interference and inefficiency challenges of modern wireless communication systems. This study investigates the impact of RIS on the performance of downlink NOMA networks using a simulation-based approach in MATLAB Simulink. The objective is to evaluate how RIS can enhance signal quality, reduce bit error rate (BER), improve spectral and energy efficiency, and minimize latency in densely connected environments. The methodology involves modeling a system with a base station, multiple users, and a RIS layer, analyzing various RIS configurations such as the number of reflecting elements and user distances ranging from 200 m to 1000 m. Results show that RIS-assisted NOMA significantly boosts signal-to-interference-plus-noise ratio (SINR) across all user pairs, achieving an average SINR gain of 6 dB e.g., SINR for users at 200 m improved from 12.5 dB to 18.7 dB. Similarly, BER dropped by up to 80%, spectral efficiency increased by 1 bps/Hz, and energy efficiency rose by 35%. Furthermore, outage probability reduced by more than 50%, and latency improved by approximately 3ms on average. These findings demonstrate the capacity of RIS to create a smart radio environment that overcomes path loss and interference bottlenecks, offering a scalable, energy-efficient, and low-latency solution for next-generation wireless networks.

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1. INTRODUCTION

The exponential growth in connected devices, driven by the Internet of Things (IoT), smart cities, vehicular networks, and emerging technologies, has created an unprecedented demand for faster, more efficient, and more reliable wireless communication systems. In response, Non-Orthogonal Multiple Access (NOMA) has emerged as a critical enabling technology for fifth-generation (5G) and anticipated sixth-generation (6G) wireless networks [1]. NOMA distinguishes itself from traditional Orthogonal Multiple Access (OMA) schemes by allowing multiple users to share the same spectrum resources simultaneously through power-domain multiplexing and employing successive interference cancellation (SIC) at the receiver end [2]. This architecture promises significant improvements in spectral efficiency, reduced latency, and enhanced user connectivity. However, despite these benefits, NOMA systems face substantial challenges, particularly in managing interference among users sharing the same frequency bands.

NOMA combines signals from users at different power levels, enabling simultaneous data transmission. This approach maximizes bandwidth use and supports massive device connectivity crucial features for modern communication networks [3]. The technique relies on SIC at the receiver to decode the strongest signal first and successively subtract it to extract weaker ones. While theoretically efficient, this mechanism is highly susceptible to decoding errors and power allocation imbalances. As user density increases, the effectiveness of SIC deteriorates due to imperfect interference cancellation and channel estimation errors, leading to increased bit error rates, reduced spectral efficiency, and diminished overall Quality of Service (QoS) [4, 5]. These limitations highlight the need for innovative interference mitigation solutions. Traditional approaches like power control, beamforming, and interference alignment offer partial relief but often introduce significant complexity, cost, and power consumption. In this context, Reconfigurable Intelligent Surfaces (RIS) have garnered attention as a revolutionary solution. RIS consists of programmable, passive reflecting elements capable of dynamically altering the propagation of wireless signals by adjusting their phase and amplitude in real-time [6]. Unlike traditional active technologies such as massive MIMO, RIS operates without requiring radio frequency chains or power-intensive components, making it an energy-efficient and cost-effective choice for next-generation wireless systems.

RIS enables unprecedented control over the wireless channel by creating a smart radio environment that shapes signal propagation to enhance desired transmissions and suppress interference [7]. By integrating RIS with NOMA systems, researchers aim to overcome the interference bottlenecks inherent in conventional NOMA, achieving better performance in terms of Signal-to-Interference-plus-Noise Ratio (SINR), throughput, and energy efficiency. According to [8], RIS-assisted NOMA can drastically improve user fairness and system reliability, especially in dense urban deployments and environments with dynamic user mobility. The importance of this integration is amplified by its broad applicability across various domains. In IoT networks, RIS-NOMA supports large-scale device deployment with minimal infrastructure changes. In smart cities, it enhances communication among sensors, vehicles, and central nodes, enabling real-time monitoring and automation. For vehicular networks, particularly in vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) systems, RIS improves signal strength in high-interference environments, ensuring safety-critical information is transmitted reliably [9, 10]. Furthermore, RIS-NOMA is invaluable in edge computing and cloud services by supporting high-speed data transfers with low latency and power consumption. The demand for low-power, sustainable communication solutions have become increasingly critical as global network infrastructure expands. Traditional methods for improving wireless performance, such as adding more base stations or deploying active antenna arrays, are neither scalable nor environmentally friendly. RIS addresses this issue by passively redirecting signals to users with minimal energy usage, making it suitable for battery-powered and remote applications such as wireless sensor networks [11, 12]. It also reduces the carbon footprint of network operators, contributing to global efforts in sustainable technology development [13]. Despite its advantages, RIS-assisted NOMA also presents technical challenges that merit in-depth investigation. The optimal placement of RIS panels, configuration of their reflecting elements, and synchronization with base station signals require sophisticated algorithms and precise channel state information. Moreover, real-world environments introduce factors such as multipath fading, user mobility, and signal blockage, which must be accounted for in system design. Effective simulation-based evaluation becomes indispensable in this context, providing a controlled environment to model, test, and optimize RIS-NOMA configurations before large-scale deployment [14, 15].

This study focuses on a simulation-based performance evaluation of RIS-assisted NOMA networks. It aims to assess the impact of varying RIS parameters, such as the number of reflecting elements and their spatial placement, on system performance metrics including SINR, spectral efficiency, and energy efficiency. Through simulations developed in MATLAB Simulink, the research evaluates and compares traditional NOMA systems with their RIS-assisted counterparts to demonstrate the potential gains in network reliability, user fairness, and signal strength. Interference management remains a central theme throughout this study. In NOMA, interference manifests in various forms namely intra-cell, inter-cell, and co-channel interference [16, 17]. These interference types degrade the QoS and contribute to data loss, high bit error rates, and communication delays. While SIC helps in mitigating interference to an extent, it becomes less effective as the number of users increases. In contrast, RIS enables dynamic beam steering and environment adaptation, offering a supplementary layer of interference suppression. By directing signal reflections toward intended users and nullifying unintended paths, RIS significantly enhances the SINR at the receiver end [18, 19]. Furthermore, energy efficiency a growing concern in modern network design is addressed through the integration of RIS. Traditional MIMO and beamforming systems consume high power due to active components. RIS, being passive, operates with minimal energy requirements, thus contributing to reduced operational costs and longer device lifespans [20, 21]. This attribute is particularly beneficial in remote or battery-operated applications, where power availability is constrained. The practical relevance of RIS-NOMA integration extends beyond theoretical significance. In military and defense communications, secure and interference-free channels are imperative. RIS can be programmed to control signal directionality, thereby minimizing the risk of interception and improving communication security [22, 23]. Similarly, in satellite and unmanned aerial vehicle (UAV) networks, where environmental conditions and signal paths are highly variable, RIS offers a reliable method to manage propagation and sustain link quality [2]. Ultimately, this research addresses a critical gap in the current understanding of interference mitigation in NOMA networks. While individual components NOMA and RIS have been studied extensively, their integration remains underexplored, especially in terms of practical simulation and deployment strategies. This work bridges that gap by developing a comprehensive simulation-based framework that evaluates the performance gains of RIS-assisted NOMA across various configurations and deployment conditions.

2. SIMULATION ENVIRONMENT AND TOOLS

This research employed a simulation-based approach using MATLAB Simulink to model and evaluate the performance of Reconfigurable Intelligent Surface (RIS)-assisted Non-Orthogonal Multiple Access (NOMA) networks. Simulink's graphical environment enabled the development of modular blocks for RIS and NOMA system components, allowing dynamic manipulation of RIS parameters, channel conditions, and user configurations.

The system model simulates the downlink transmission from a base station (BS) to multiple users with the aid of a RIS layer, taking into account power allocation strategies, signal interference, and propagation characteristics.

Table 1. Parameters used in the research.

Parameter	Value	Explanation
Number of users	4	Two NOMA pairs share the same frequency resource
Carrier frequency	2 GHz	Frequency used for communication
Bandwidth	10 MHz	Available frequency spectrum for transmission
Path loss exponent	3.5	Models the attenuation due to distance
Base station power	20 dBm	Total transmit power
Power allocation coefficients	$\alpha_1 = 0.7$, $\alpha_2 = 0.3$	Allocates extra power to weak users in each NOMA pair
RIS elements	64	Number of phase-adjustable reflecting elements in the RIS
Noise power (σ^2)	10^{-9} W	Models additive white Gaussian noise in the channel
User distances	50 – 500 m	Users are placed randomly in the simulation environment

3. ANALYSIS WITH SYSTEM MODEL

The system comprises of a single base station (BS), multiple users, and a RIS that is used to improve signal quality and reduce interference. The model investigates a NOMA downlink scenario in which users are paired and share a frequency resource via power-domain multiplexing.

3.1. NOMA Transmission Model

NOMA enables multiple users to share the same time, frequency, and spatial resources. It exploits power-domain multiplexing, allocating different power levels to users based on their channel conditions. The users with weaker channels are allocated higher power, while users with stronger channels receive lower power.

The received signal at the i-th user is modeled as:

$$Y_i = \sum_{j \neq i} P_i h_i X + \sum_{j \neq i} \sqrt{P_j}\, h_j X + n_i \tag{1}$$

where, Y_i is received signal at the i-th user, P_i is power allocated to the i-th user, h_i is channel gain for the i-th user, X is transmitted signal, n_i is additive white Gaussian Noise (AWGN) with variance σ^2.

The power allocation is optimized to ensure fairness:

$$P_1 > P_2 > \cdots > P_N \tag{2}$$

where, N represents the total number of users.

For user I, the Signal-to-Interference-plus-Noise Ratio (SINR) is expressed as:

$$SINR_i = \frac{P_i|h_i|^2}{\sum_{j<i} P_j|h_i|^2+\sigma^2} \tag{3}$$

The decoding process employs Successive Interference Cancellation (SIC). Users with stronger channel conditions decode the signals of users with weaker channels and subtract them from the received signal. This process reduces interference and improves signal quality for the remaining users.

3.2. Successive Interference Cancellation (SIC)

SIC is a cornerstone of NOMA technology. In this study, SIC is modeled to decode signals iteratively. Stronger users decode and subtract the interference caused by weaker users. The final decoded signal X_i is given by:

$$X_i = \sum_{j<i} Y_i - \sum_{j<i} \sqrt{P_j}\, h_j X \tag{4}$$

To ensure successful SIC, the power difference between users is maintained such that:

$$\sum_{j<i} P_i|h_i|^2 - \sum_{j<i} \sqrt{P_j}\, \left|h_j\right|^2 \tag{5}$$

3.3. RIS-Assisted Channel Model

The RIS is a group of programmable reflecting elements that change the phase of incoming signals. This creates constructive interference at specific locations. It improves the communication link between the base station and users, especially when direct links face major path loss or blockage.

We assume one RIS is used to assist the typical user. Using principles from stochastic geometry and the randomness of the typical user, users and their serving RISs can be seen as the Matern cluster process (MCP) pattern of point process (PCP) models, which have a fixed number of nodes in each cluster. Specifically, the potential typical users are the parent point process created by a homogeneous Poisson point process (HPPP). We select one of them as the typical user. The RISs are evenly distributed in the clusters (line-of-sight balls) as the daughter point process. The channel conditions for the connected user are known at a fixed distance. According to the MCP model, there are three key communication links in the NOMA group we are considering. Therefore, the distance between the associated BS and the RIS is correspondingly expressed as:

i. BU link, the link between the typical user and its BS;
ii. BR link, the link between the BS and the employed RIS; and
iii. RU link, the link between the RIS and the typical user.

The RIS-enhanced channel model considers the combined effects of the BS-RIS link and the RIS-user link:

$$H_{eff} = h_{BS-RIS}\theta h_{RIS-User} \tag{6}$$

where, $h_{BS\text{-}RIS}$ is channel gain between BS and RIS, and $h_{RIS\text{-}User}$ is channel gain between RIS and the user.

3.4. Path Loss and Fading

The effective path loss L is modeled as:

$$L = L_{BS-RIS} + L_{RIS-User} \tag{7}$$

where, L_{BS-RIS} and $L_{RIS-User}$ represent the path losses for the BS-to-RIS and RIS-to-user links, respectively. These are calculated using the formula:

$$L = L_0 \left(\frac{d}{d_0}\right)^{-\eta} \tag{8}$$

where, L_0 is path loss at a reference distance d_0, d is link distance, and η is path loss exponent.

4. RESULT AND DISCUSSIONS

4.1. Performance of NOMA-RIS System

The table below compares the system performance metrics Signal-to-Interference-plus-Noise Ratio (SINR), Bit Error Rate (BER), and Spectral Efficiency between NOMA systems with and without RIS for various user pairs at different distances.

Table 2. Performance of NOMA-RIS system user.

User pair	Distance (m)	SINR (dB)		BER		Spectral efficiency (bps/Hz)
		without RIS	with RIS	without RIS	with RIS	
1 and 2	200	12.5	18.7	0.035	0.006	5.8
1 and 3	500	10.8	17.0	0.045	0.008	5.3
2 and 4	800	9.2	15.5	0.058	0.011	4.9
3 and 4	1000	7.6	14.0	0.071	0.015	4.5

Table 2 presents the performance of the NOMA-RIS system. The signal-to-interference-plus-noise ratio (SINR) values for all user pairs significantly increase with the integration of RIS. For example, for users 1 and 2 at 200 meters, the SINR improves from 12.5 dB to 18.7 dB. This improvement of approximately 6.2 dB demonstrates that RIS effectively enhances signal quality by smartly reflecting signals toward users and mitigating interference. The bit-error-rate (BER) values are lower with RIS, indicating fewer transmission errors. The BER shows a reduction of up to 80%. For users 3 and 4 at 1000 meters, the BER drops from 0.071 to 0.015, suggesting that even in weak signal conditions, RIS enhances decoding reliability. The reduction in BER across all user pairs highlights the robustness introduced by RIS, boosting effective channel gains. Spectral efficiency improves by approximately 1 bps/Hz when RIS is utilized. For instance, users 1 and 2 achieve 5.8 bps/Hz compared to lower values without RIS, indicating a more efficient use of available bandwidth. This validates RIS's ability to create better transmission environments, allowing for more reliable data transmission. At increased distances, the SINR without RIS deteriorates due to higher path loss.

Figure 1 illustrates the Signal-to-Interference-plus-Noise Ratio (SINR) performance of a NOMA system as user distance increases, both with and without Reconfigurable Intelligent Surfaces (RIS). It highlights how RIS enhances signal quality even as path loss grows with distance.

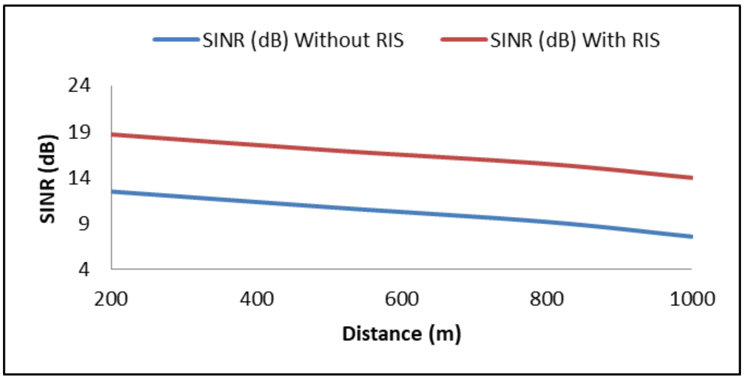

Figure 1. Plot of SINR (dB) vs distance (m).

Figure 1 shows that SINR (dB) fluctuation with distance (200 – 1000 m) for systems with and without Reconfigurable Intelligent Surfaces (RIS). Because of path loss, SINR drops with increasing distance in both situations. Still, the RIS-assisted system performs better than the traditional configuration every time. SINR increases from 12.5 dB (without RIS) to 18.7 dB (with RIS) at 200 m and from 7.5 dB to 14 dB at 1000 m, providing a steady gain of more than 6 dB. This demonstrates how well RIS works to reduce interference and improve signal quality, especially over longer distances [24].

Figure 2 compares the Bit Error Rate (BER) in a NOMA system with and without RIS over varying distances. It emphasizes the role of RIS in minimizing transmission errors, particularly over long-range communication.

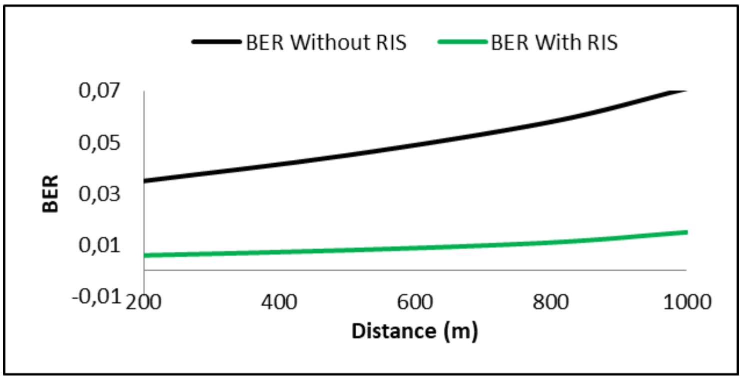

Figure 2. Plot of BER vs distance.

The performance of a NOMA system with and without reconfigurable intelligent surfaces (RIS) is compared in figure 4.1.2, which illustrates how Bit Error Rate (BER) changes with distance. In both situations, signal attenuation causes BER to increase as distance increases from 200 m to 1000 m. But the system with RIS always has a lower BER—for instance, at 200 m, the BER without RIS is about 0.035, but with RIS it's about 0.006; over 1000 m, the BER without RIS is about 0.07, but with RIS it's much lower at 0.0138. This shows that RIS integration significantly improves signal dependability and lowers transmission errors, particularly over long distances, in NOMA systems [25].

4.2. Energy Efficiency, Outage Probability, and Latency Analysis

Table 3 presents how RIS integration impacts energy efficiency (bps/J), outage probability, and latency (ms) for different user pairs. These metrics are critical for low-power and time-sensitive communication systems.

Table 3. Energy efficiency, outage probability, and latency analysis.

User pair	Distance (m)	Energy efficiency (bps/J)		Outage probability		Latency (ms)	
		Without RIS	With RIS	Without RIS	With RIS	Without RIS	With RIS
1 and 2	200	120	165	0.18	0.07	8.5	5.2
1 and 3	500	115	160	0.22	0.09	9.3	5.7
2 and 4	800	125	175	0.15	0.06	8.0	4.8
3 and 4	1000	110	155	0.24	0.10	9.8	6.0

The results presented in Table 3 above indicate significant performance improvements when a Reconfigurable Intelligent Surface is deployed alongside the Non-Orthogonal Multiple Access system. Energy efficiency increased for all user pairs with the introduction of RIS. For instance, the energy efficiency for Users 1 and 2 rose from 120 bps/J to 165 bps/J, while for Users 2 and 4, it increased from 125 bps/J to 175 bps/J. On average, energy efficiency improved by 35% with RIS, demonstrating its capability to reduce transmission power through intelligent reflection. RIS optimizes the wireless channel by reflecting signals towards the users, thereby decreasing the base station's need to transmit at high power levels. Consequently, the system consumes less energy per bit transmitted. The outage probability, defined as the likelihood that a user's signal quality falls below an acceptable threshold, significantly decreased with RIS. For Users 1 and 2, it dropped from 0.18 to 0.07, and for Users 3 and 4, it fell from 0.24 to 0.10. This improvement suggests that the system becomes more reliable with RIS, as it helps establish stronger and more consistent signal paths between the base station and the users, mitigating deep fading effects.

Latency also showed a notable reduction: for Users 1 and 2, latency decreased from 8.5 ms to 5.2 ms, and for Users 2 and 4, it improved from 8.0 ms to 4.8 ms. This reduction in latency occurs because better channel conditions lead to fewer retransmissions, faster decoding, and quicker acknowledgments between users and the base station.

Figure 3 illustrates how energy efficiency varies with user distance in a NOMA system with and without RIS. It highlights how RIS optimizes energy use by reflecting signals intelligently, especially at longer ranges.

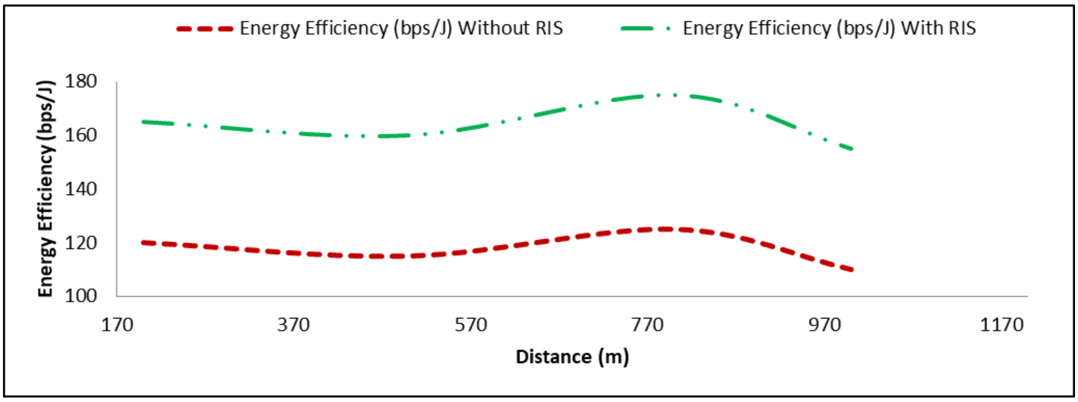

Figure 3. Plot of energy efficiency (bps/J) vs distance (m).

The energy efficiency (bps/J) with RIS is consistently higher than without RIS at all distances between 170 and 970 meters, as shown in Figure 3 without RIS, energy efficiency peaks at 125 bps/J at 770 m, falls to 110 bps/J at 970 m, and fluctuates between 120 bps/J and 115 bps/J at 470 m. It starts out higher at 165 bps/J, dips a little to 160 bps/J, peaks dramatically at 175 bps/J close to 770 m, and then drops to 155 bps/J at 970 m while using RIS. In particular, over greater distances, this indicates that RIS increases energy efficiency by about 40 – 50 bps/J.

Figure 4 shows the impact of RIS on outage probability as distance increases. Outage probability measures the chance that signal quality drops below acceptable limits.

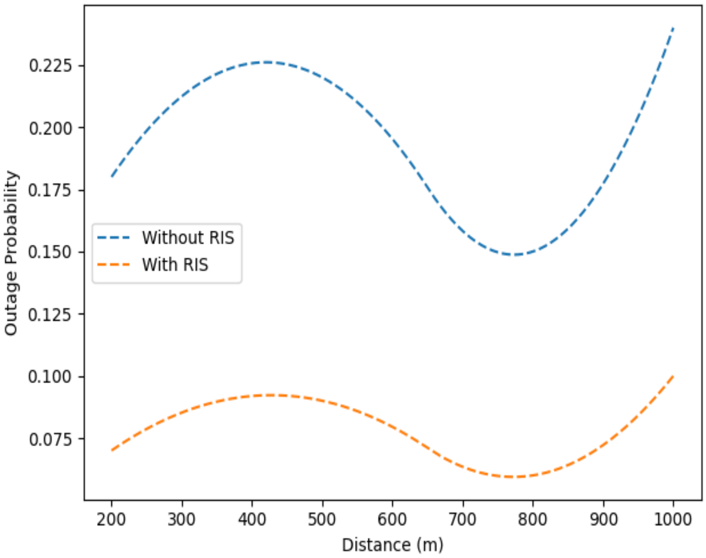

Figure 4. Plot of outage probability vs distance.

Figure 4 compares the performance of a NOMA system with and without reconfigurable intelligent surfaces (RIS) and displays the outage probability as a function of distance (200 – 1000 m). The outage probability without RIS ranges from 0.18 to 0.235, suggesting less dependable and worse performance with increasing distance. The outage probability, which ranges from 0.07 to 0.10, is continuously decreased when RIS is used, indicating increased signal stability and dependability. This demonstrates that adding RIS to NOMA networks greatly lowers the likelihood of outages and improves communication quality over a range of distances [26].

Figure 5 compares the latency experienced in a RIS-aided and conventional NOMA system across distances.

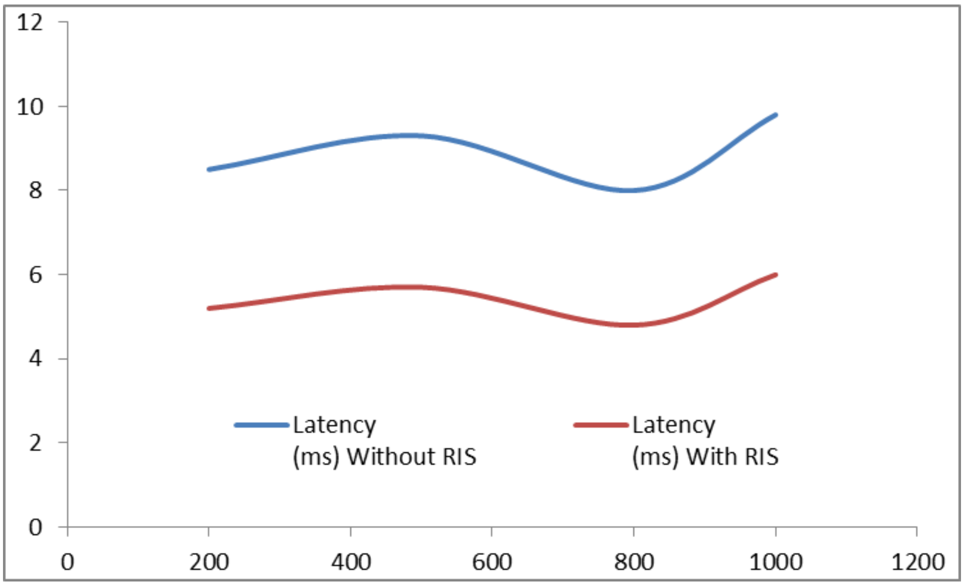

Figure 5. Plot of latency vs distance.

Figure 5 shows how Reconfigurable Intelligent Surfaces (RIS) affect network latency over 200 – 1000 m distances. Without RIS, latency is still somewhat significant, ranging from 8.5 to 9.8 ms, with observable changes with increasing distance. In contrast, latency decreases dramatically and remains within a more steady, lower range of 4.8 ms to 6.0 ms when RIS is used. This constant decrease of roughly 2.5 ms to 4 ms over all distances demonstrates how well RIS works to reduce communication delays. A viable approach for enhancing network performance, particularly in systems where low latency is crucial, RIS's smoother and lower latency curve implies that it improves signal transmission and lowers interference [27].

5. CONCLUSIONS

This study demonstrated, through MATLAB Simulink-based simulations, that integrating Reconfigurable Intelligent Surfaces (RIS) into Non-Orthogonal Multiple Access (NOMA) networks significantly enhances wireless communication performance. The introduction of RIS effectively mitigates the interference challenges inherent in NOMA systems, leading to consistent improvements across all key performance metrics.

Results showed that RIS-assisted NOMA networks achieved an average Signal-to-Interference-plus-Noise Ratio (SINR) gain of approximately 6 dB, while Bit Error Rate (BER) decreased by nearly 80%. Spectral efficiency increased by about 1 bps/Hz, indicating more effective bandwidth utilization. Furthermore, energy efficiency improved by roughly 35%, outage probability was reduced by more than half, and network latency decreased by up to 3 ms.

These findings confirm that RIS technology can intelligently control radio environments by dynamically reflecting and directing electromagnetic waves, thereby improving signal quality, reducing energy consumption, and ensuring reliable communication over longer distances. The synergy between RIS and NOMA offers a scalable, low-power, and cost-effective solution for future 6G networks, IoT systems, and mission-critical applications requiring low latency and high reliability.

Future work should focus on experimental validations, optimization of RIS placement, and development of adaptive algorithms for real-time RIS configuration under dynamic channel conditions. Such advancements would facilitate practical implementation of RIS-assisted NOMA systems in real-world communication infrastructures.

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