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Deep Q-Network Enabled RIS-CNOMA System with Receiver Diversity Techniques under Nakagami-m Fading channel

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Abstract

This paper presents an intelligent optimization framework for a Reconfigurable Intelligent Surface supported Cooperative Non-Orthogonal Multiple Access System operating under Nakagami-$\boldsymbol{m}$ fading environment. In traditional approaches, key system parameters such as RIS phase configurations and power allocation coefficients are typically predetermined, which restricts adaptability in dynamic wireless conditions. To overcome this limitation, a Deep Q-Network (DQN) based strategy is proposed to enable real-time adaptation of these parameters by interacting with the channel environment. In addition, receiver diversity methods, including Maximal Ratio Combining , Selection Combining , and Equal Gain Combining are incorporated to further enhance signal reception and combat fading effects for both the nearby user and the distant user. The system performance is evaluated with respect to outage probability across different signal-to-noise ratio (SNR). The simulation results show that the proposed DQN-enabled RIS-CNOMA system offers up to 95% reduction in outage probability and improves system reliability by 90%–95% compared to conventional non-learning-based schemes. Overall, the proposed learning-driven framework offers an adaptive and efficient solution to increase the effectiveness of RIS-assisted CNOMA systems

in realistic fading scenarios, making it a promising solution for future wireless communication networks.

Keywords: RIS, CNOMA, DQN, Nakagami-m Fading, Outage Probability, Diversity Techniques, 5G and Beyond Networks

1 Introduction

The continuous advancement of wireless communication toward fifth-generation (5G) and beyond has intensified the demand for higher data rates, massive connectivity, ultra-reliable communication, and efficient spectrum utilization. Conventional communication techniques face significant challenges in meeting these requirements due to limited spectral resources and unpredictable wireless channel conditions. To overcome these limitations, emerging innovative communication methods such as Reconfigurable Intelligent Surfaces and NOMA have attracted considerable research attention as promising enablers for next-generation wireless networks[1,7]. Reconfigurable Intelligent Surfaces (RIS) introduce a paradigm shift by transforming the wireless environment into a programmable entity. An RIS consists comprises several low-cost passive reflecting elements capable of individually controlling the phase of incoming signals[2,3]. Through smart phase shift optimization, RIS can provide signal propagation, extend coverage, suppress interference, and improve link reliability, especially in scenarios with severe blockage or weak direct links. Due to its passive operation and low energy consumption, RIS is considered an energy-saving and cost-efficient technique for enhancing wireless communication systems[3,5,8]. On the other hand, By applying power-domain multiplexing, NOMA allows multiple users to share common time-frequency resources, thereby improving spectral efficiency. In NOMA communication systems, power allocation is performed based on user channel conditions. More power is assigned to far users with poor channel quality, whereas near users with better channel conditions are allocated less power. The receiver applies Successive Interference Cancellation (SIC) to decode the overlapping transmitted signals. Furthermore, Cooperative NOMA (CNOMA) enhances system reliability by enabling the near user forwards information to support the far user, thereby improving fairness and coverage[4,6]. The integration of RIS with CNOMA creates a powerful framework that combines intelligent signal reflection with efficient multiple access, leading to significant improvements in spectral efficiency and coverage. However, the performance of RIS-assisted CNOMA systems is highly dependent on optimal configuration of system parameters including RIS signal phase control and power allocation coefficients. Traditional approaches often rely on fixed or heuristic-based designs, which are not suitable for dynamic wireless environments characterized by time-varying channel conditions [9].

In addition to these challenges, wireless channels are inherently affected by multipath fading, which degrades signal quality and increases the probability of communication failure.The Nakagami-m fading distribution is widely used due to its flexibility in representing various fading scenarios ranging from severe to moderate conditions.

To overcome fading effects, receiver diversity techniques including MRC, SC, and EGC are widely used. Among these, MRC offers optimal performance by coherently combining multiple received signal paths to obtain maximum signal strength relative to noise, while SC and EGC provide alternative optimization between performance and complexity. To address the limitations of conventional optimization methods,This work proposes a reinforcement learning-based approach using DQN intelligent framework for RIS-assisted CNOMA systems under Nakagami-m fading conditions[11,12]. The DQN algorithm enables adaptive decision-making by learning optimal policies for RIS phase adjustment and power allocation through interaction with the wireless environment. Unlike static schemes, the proposed approach dynamically responds to channel variations, thereby improving system adaptability and efficiency. Furthermore, the proposed system incorporates receiver diversity techniques, including MRC, SC, and EGC, to enhance robustness against fading and improve signal reception for the near user as well as the far user. The performance of system is evaluated through outage probability analysis over various SNR conditions[13,14]. values using MATLAB-based simulations. The results demonstrate that the DQN-enabled RIS-CNOMA system significantly outperforms conventional non-learning-based approaches. Additionally, the integration of diversity combining techniques further enhances system reliability. In summary, this work presents a comprehensive and intelligent framework that integrates reinforcement learning, RIS technology, CNOMA, and receiver diversity techniques to tackle the issues related to next-generation mobile communication systems.The proposed approach offers improved spectral efficiency, enhanced reliability, and adaptive performance under realistic fading environments, making it a strong candidate for future wireless network deployments[15,16].

1.1 RELATED WORK

1.1.1 Reconfigurable Intelligent Surface (RIS)

A Reconfigurable Intelligent Surface (RIS) is a smart programmable surface consisting of many passive reflecting elements. Each element has the ability to independently adjust the phase or amplitude of incident electromagnetic waves, thereby influencing how signals are reflected within the wireless environment. By carefully configuring these elements, RIS can strengthen the received signal, suppress interference, and enhance overall communication quality without relying on active transmission. Through dynamic adjustment of its reflection characteristics, RIS can reshape the wireless channel in real time. This enables signals to be steered toward desired users while minimizing the impact of obstacles and unfavorable channel conditions. In this way, RIS converts the inherently random and fluctuating nature of wireless propagation into a more controlled and optimized communication process In contrast to traditional relays or base stations, RIS does not require energy-intensive radio-frequency circuitry, which helps in reducing both power consumption and system complexity. Owing to its passive operation, cost-effectiveness, and ease of deployment, RIS is widely regarded as a key technology to enhance the efficiency and overall performance of future wireless networks.

1.1.2 Cooperative Non-Orthogonal Multiple Access (CNOMA)

Non-Orthogonal Multiple Access supports simultaneous user transmission over shared resources using different transmission power levels. Typically, users receiving stronger signal quality, known as near users, are allocated less power, whereas users experiencing poor channel conditions, referred to as distant users are provided with greater transmission power to ensure reliable communication. This power-domain multiplexing improves spectral efficiency and supports a greater number of users within the same bandwidth, making it well suited for future wireless communication systems [10]. Cooperative NOMA (CNOMA) further enhances system performance by incorporating user cooperation along using Successive Interference Cancellation (SIC). In this scheme, the near user first applies SIC to decode the signal transmitted to the far user by removing interference originating from the superimposed transmission. After successfully decoding, the close-range user forwards the user located farther away information, acting as a relay. This cooperative process improves signal quality for the far user and extends coverage, especially in challenging channel conditions. As a result, CNOMA with SIC enhances fairness among users and significantly reduces outage probability compared to conventional NOMA systems.

1.1.3 Deep Q-Network (DQN)

Deep Q-Network (DQN) is a learning-based method that integrates reinforcement learning techniques with deep neural networks to manage complex control and optimization problems. In standard Q-learning, the values are stored in a table corresponding to different action state combinations, which becomes impractical as the number of possible states increases. To overcome this limitation, DQN uses a neural network instead of a lookup table to approximate the Q-values, making it suitable for large-scale and continuous problem settings. In this learning framework, the agent communicates with its environment by analyzing the present state, selecting an appropriate action, and obtaining feedback provided as a reward.The aim is to progressively develop a strategy that achieves the maximum total reward. To enhance learning stability, DQN utilizes techniques such as replaying stored past experiences during training and maintaining a separate target network, both of which help to avoid unstable updates and improve convergence. In RIS-assisted CNOMA systems, DQN can be applied to intelligently adjust important system parameters such as the configured phase shifts of the RIS elements and the distribution of transmission signal power among users. By continuously adapting to changing channel conditions, the learning agent improves system performance with respect to reliability and signal quality. In comparison with conventional methods with fixed configurations, DQN provides a more adaptive and efficient approach for managing the complexities of dynamic wireless communication environments.

The paper is divided as follows: Section I provides an overview of previous research related to RIS and CNOMA. receiver diversity techniques, and deep reinforcement learning approaches in wireless communication systems. Section II presents the proposed DQN-enabled RIS-assisted CNOMA system model under Nakagami-m fading,

including the system architecture and signal transmission process. Section III develops the mathematical formulation of the system, including channel modeling, received signal expressions, ratio between signal power and noise power analysis, as well as outage probability derivation incorporating receiver diversity methods including Maximum Ratio Combining (MRC), Selection Combining (SC), and Equal Gain Combining (EGC). Section IV describes by using a Deep Q-Network approach optimization framework, including the design of the state representation, action selection space, reward model, and training procedure and simulation results and evaluates system performance in terms of outage behavior of both nearby and remote users under varying SNR conditions, along with a comparative analysis of diversity techniques and conventional non-learning-based schemes. Finally, Section V conclusion with an overview of the main findings and suggestions for further research.

1.2 System Description

This work considers a downlink communication framework based on a Cooperative NOMA system supported by RIS operating in a Nakagami-m fading conditions. The system is composed of a base station (BS), an Reconfigurable Intelligent Surface containing N passive reflecting elements, and two users, including a nearby user(U_1) and a far user (U_2). The RIS enhances the wireless channel by smartly controlling the phase of the reflected signals, thereby enhancing signal strength and coverage area, particularly in challenging propagation environments. At the transmitter, the system applies superposition coding to transmit combined signals to both users with different transmission powers allocation factors. The near user performs using Successive Interference Cancellation (SIC), both signals are decoded at the near user, while the long-distance user directly decodes its target signal. To improve signal reception, multiple diversity combining techniques are considered at the receiver, including Maximum Ratio Combining, Selection Combining, and Equal Gain Combining. MRC combines all received signal components by weighting them according to channel conditions, achieving maximum Signal-to-Noise Ratio (SNR). In contrast, SC selects the strongest received signal path, offering lower complexity with moderate performance. EGC combines multiple signals with equal weighting, providing a balance between performance and computational efficiency. These diversity techniques help reduce the impact of multipath signal fading while enhancing overall network reliability. Furthermore, a Deep Q-Network (DQN) is integrated into the system to dynamically optimize RIS phase shifts and power allocation. The DQN learns improved control strategies through continuous learning from the environment and adapts to varying channel conditions, enabling improved outage performance and efficient resource utilization. The Nakagami-m fading model is utilized because of its flexibility in representing different wireless channel conditions. The combined use of RIS, CNOMA, diversity techniques, and learning-based optimization provides a reliable and adaptive model well suited for next-generation wireless networks.

1.2.1 Signal Transmission Model

The BS transmits a superimposed NOMA signal intended for both users, which is given by

$$X = \sqrt{P}\,(\sqrt{a_1}s_1 + \sqrt{a_2}s_2)$$

where P represents the total transmission power, while $a1$and $a2$ indicate the power allocation factors such that $a_2 > a_1$, and s_1, s_2 represent the information symbols for the near and far users, respectively.

1.2.2 Channel Model with RIS

The wireless channels are considered to experience Nakagami-m fading. The equivalent channel between the base station and the user via RIS can be represented as

$$h_{\mathrm{RIS},k} = \sum_{n=1}^{N} h_{BR,n}\, e^{j\theta_n}\, h_{RU_k,n}, \quad k \in \{1,2\}$$

where the channel gains from the BS to the RIS and from the RIS to user k are represented respectively, and θ_n indicates the adjustable phase shift of the n^{th} RIS element. The channel gain is modeled according to the Nakagami-m fading distribution as

$$|h|^2 \sim \mathrm{Gamma}(m, \Omega/m)$$

where m refers to the Nakagami fading parameter and Ω corresponds to the average channel power.

2 Performance Analysis

2.1 SNR Analysis

At the near user (U_1), the Signal to Noise Ratio corresponding to the far user's signal is represented by

$$\gamma_{1\to 2} = \frac{a_2 P|h_1|^2}{N_0}$$

After applying successive signal interference removal, the SNR value for detecting its own signal becomes

$$\gamma_1 = \frac{a_1 P|h_1|^2}{N_0}$$

At the far user (U_2), the obtained SNR at the receiver is given as

$$\gamma_2 = \frac{P|h_2|^2}{N_0}$$

2.2 Outage Probability

Outage probability refers to the likelihood that the received SINR becomes lower than a specified threshold value γ_{th}:

$$P_{\text{out}} = \Pr(\gamma < \gamma_{\text{th}})$$

2.3 DQN-Based Optimization

To optimize system performance, the Deep Q-Network approach is used to adaptively adjust RIS phase shifts and power allocation. The Q-value is mathematically defined as

$$Q(s, a) = \mathbb{E}\left[\sum_{t=0}^{\infty} \gamma^t r_t\right]$$

The DQN is trained by minimizing the loss function

$$L(\theta) = \mathbb{E}\left[(y - Q(s, a; \theta))^2\right]$$

where the target value is

$$y = r + \gamma \max_{a'} Q(s', a'; \theta^-)$$

The reward function is designed to minimize outage probability:

$$r = -(P_{\text{out},1} + P_{\text{out},2})$$

By continuously interacting with the environment, the DQN learns optimal policies for RIS configuration and power allocation, resulting in improved system performance.

2.3.1 Maximum Ratio Combining (MRC) Diversity Technique

In modern wireless systems, signal transmission is often affected due to multipath propagation, which leads to fluctuations in signal strength and degrades overall communication reliability. To mitigate these effects, receiver diversity techniques are employed, where multiple different received copies of the signal are utilized to enhance performance. From various diversity schemes, Maximum Ratio Combining is widely used due to its optimal performance is enhanced by the received signal quality. In this technique, all available signal branches are coherently combined by assigning appropriate weights proportional to their respective channel gains. Unlike Selection Combining, which selects only the strongest signal, MRC utilizes all received signal components, thereby achieving better performance. Mathematically, the combined SNR in MRC can be expressed as

$$\gamma_{\text{MRC}} = \sum_{i=1}^{L} \gamma_i$$

here, L represents the total diversity branches, and γ_i corresponds to the SNR value of the i^{th} branch. By combining multiple independently faded signal paths,

MRC significantly improves signal quality, enhances reliability, and reduces outage probability. Due to its effectiveness in combating fading, MRC is particularly suitable for RIS-assisted CNOMA systems operating under Nakagami-m fading conditions.

2.3.2 Selection Combining (SC) Diversity Technique

In wireless communication systems, multipath propagation causes fluctuations in signal strength, degrading communication reliability. To overcome this, receiver diversity techniques utilize multiple received signal copies to improve performance. Selection Combining (SC) is a simple and low-complexity diversity technique in which the receiver chooses the branch with the maximum Signal-to-Noise Ratio (SNR). Unlike Maximum Ratio Combining, SC does not combine signals but chooses the best available branch. Mathematically, the received SNR after applying SC is expressed as

$$\gamma_{\mathrm{SC}} = \max_{i \in \{1,2,\ldots,L\}} \gamma_i$$

where L represents the number of diversity branches and γ_i is the SNR of the i^{th} branch. By selecting the strongest signal path, SC improves reliability and reduces outage probability under fading conditions, making it suitable for RIS-assisted CNOMA systems under Nakagami-m fading.

2.3.3 Equal Gain Combining (EGC) Diversity Technique

Inside wireless communication systems, signal fading in multipath channels causes variations in signal strength, which degrades communication reliability. To address this issue, receiver diversity techniques combine multiple received signal copies to improve performance. Equal Gain Combining is a diversity method in which all received signal branches are aligned in phase before combining and combined with equal weights. Unlike Maximum Ratio Combining, EGC does not require channel amplitude information, which reduces implementation complexity while still providing performance improvement over Selection Combining. Mathematically, the output SNR for EGC is given by

$$\gamma_{\mathrm{EGC}} = \frac{\left(\sum_{i=1}^{L} \sqrt{\gamma_i}\right)^2}{L}$$

where L represents the total number of diversity branches and γ_i denotes the received SNR for the i^{th} branch. By coherently combining signals with equal gain, EGC improves signal quality and reduces outage probability under fading conditions. It offers a balance between performance and complexity, making it suitable for RIS-enabled CNOMA systems over Nakagami-m fading channels.

2.4 Working Principle

In the proposed RIS-assisted CNOMA system, multiple independently faded signal components are received through direct transmission, RIS-reflected links, and cooperative relaying. Each propagation path experiences a distinct instantaneous the received Signal-to-Noise Ratio (SNR), represented by $\gamma_1, \gamma_2, \ldots, \gamma_L$, where L represents the

total number of diversity branches. In order to effectively utilize these multiple signal copies, receiver diversity techniques like MRC, SC, and EGC are implemented. In MRC, all received signals are coherently combined with weights proportional to their respective channel gains, thereby maximizing the overall SNR. In contrast, Selection Combining (SC) chooses only the signal branch with the strongest SNR, while EGC combines all branches with equal weighting after phase alignment. The resulting combined SNR for different diversity schemes can be expressed as

$$\gamma_{\mathrm{MRC}} = \sum_{i=1}^{L} \gamma_i, \quad \gamma_{\mathrm{SC}} = \max_{1 \le i \le L} \gamma_i, \quad \gamma_{\mathrm{EGC}} = \frac{\left(\sum_{i=1}^{L} \sqrt{\gamma_i}\right)^2}{L} \tag{1}$$

By leveraging multiple independently faded paths, these diversity techniques significantly enhance signal quality, improve reliability, and reduce outage probability, with MRC providing the highest performance gain among the considered methods.

2.4.1 Performance in Nakagami-m Fading Channels

In practical wireless environments, signal propagation is affected by multipath fading, which can be effectively described using the Nakagami-m distribution. This model is highly flexible and can represent a wide range of fading conditions by adjusting the fading parameter m. The cumulative distribution function (CDF) of the instantaneous SNR for a single branch is given by

$$F_\gamma(\gamma) = 1 - \exp\left(-\frac{m\gamma}{\bar{\gamma}}\right) \sum_{k=0}^{m-1} \frac{1}{k!} \left(\frac{m\gamma}{\bar{\gamma}}\right)^k \tag{2}$$

here m refers to the fading severity value and $\bar{\gamma}$ represents this average SNR. For diversity combining with L independent branches, the overall SNR depends on the selected combining scheme. The system performance is evaluated using outage probability is the probability that the received SNR becomes lower than the threshold value γ_{th}, represented as

$$P_{\mathrm{out}} = P\left(\gamma_{\mathrm{comb}} < \gamma_{\mathrm{th}}\right) \tag{3}$$

where γ_{comb} corresponds to the combined SNR obtained using MRC, SC, or EGC. By exploiting multiple signal paths, diversity combining significantly reduces outage probability and enhances communication reliability under Nakagami-m fading conditions.

2.4.2 DQN-Based Optimization Mechanism

To further improve system performance, a Deep Q-Network (DQN) is integrated into the RIS-assisted CNOMA framework to enable intelligent and adaptive optimization. The DQN agent interacts with the wireless environment and learns optimal policies for RIS phase shift configuration and power allocation based on observed channel conditions and SNR values. The Q-learning value function is written as

$$Q(s,a) = \mathbb{E}\left[\sum_{t=0}^{\infty} \gamma^t r_t\right] \tag{4}$$

in which s represents the current state of the system, a denotes the decision taken, r_t denotes the reward obtained at time t, and γ represents the discount factor. The network learns optimal parameters through loss function minimization

$$L(\theta) = \mathbb{E}\left[(y - Q(s,a;\theta))^2\right] \tag{5}$$

where target value is given by

$$y = r + \gamma \max_{a'} Q(s', a'; \theta^-) \tag{6}$$

The reward function is designed to minimize outage probability while maximizing system reliability and spectral efficiency. By continuously updating its policy through interaction with the environment, the DQN enables dynamic adaptation to time-varying channel conditions, leading to improved performance compared to conventional static optimization approaches.

2.5 Working Methodology of DQN-Based RIS-CNOMA System

The proposed work investigates a Deep Q-Network (DQN)-enabled Cooperative Non-Orthogonal Multiple Access supported by RIS system incorporating receiver diversity techniques under Nakagami-m fading conditions. In this framework, a central transmission unit simultaneously forwards superimposed signals to both a nearby user and a far user based on the NOMA principle, where users share the same resources but are allocated different power levels according to their channel conditions. The RIS, composed of multiple passive reflecting elements, intelligently adjusts phase shifts to enhance signal propagation. Unlike conventional approaches, both RIS phase configuration and power allocation are dynamically optimized using a DQN agent to adapt to time-varying channel conditions. Communication between the nodes occurs in two phases. During the first transmission phase, the base station communicates a superimposed NOMA signal to both users via direct and RIS-assisted links. The RIS adaptively tunes its phase shifts based on the actions selected by the DQN agent to maximize signal strength at the receivers. At the user side, receiver diversity methods including Maximum Ratio Combining (MRC), Selection Combining (SC), and Equal Gain Combining (EGC) are applied to combine signals from multiple paths. The near user performs Successive Interference Cancellation by first detecting the signal intended for the far user and then retrieving its respective information. In second phase, the nearby user serves as a relay node and forwards the recovered signal to the far user. The far user receives transmitted signals from the base station (direct transmission and RIS-assisted relay links). These signals are combined using the selected diversity technique (MRC, SC, or EGC), resulting in improved Signal-to-Noise Ratio (SNR) and enhanced reliability. Among these techniques, MRC provides the highest performance, while SC and EGC offer reduced complexity with moderate performance gains. All wireless channels are modeled using Nakagami-m fading to capture realistic propagation

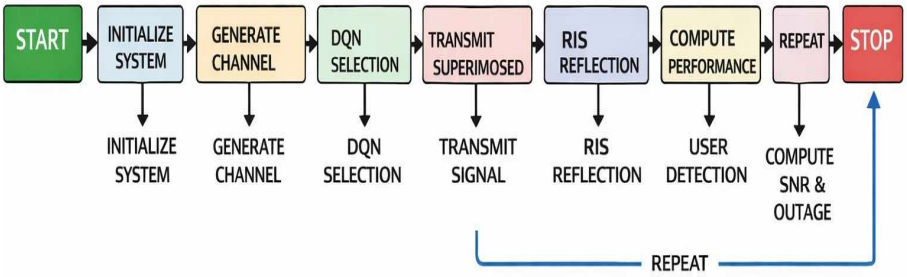


Fig. 1 Block diagram of DQN-enabled RIS-Assisted CNOMA System with Receiver diversity

conditions. The system performance is measured using parameters such as SNR and outage probability, where outage probability indicates the probability of the received SNR being below a predefined threshold required for successful communication. The DQN agent continuously interacts with the environment to learn optimal policies for RIS phase adjustment and power allocation, with the objective of minimizing outage probability and improving overall system performance.

Simulation results demonstrate that the proposed DQN-enabled RIS-CNOMA system with receiver diversity significantly outperforms conventional non-learning-based approaches. The integration of DQN with RIS and diversity combining techniques effectively reduces outage probability and enhances communication reliability under dynamic fading environments.

3 Results and Analysis

This section evaluates the performance of the proposed DQN-enabled RIS-assisted CNOMA system under Nakagami-m fading conditions. The analysis includes MATLAB-generated outage probability graphs showing variation with SNR for both nearby and distant users under different receiver diversity techniques (MRC, SC, and EGC). A comparative study is performed between the proposed DQN-based approach and conventional non-learning-based schemes. Additionally, tabular comparisons and corresponding graphical representations are provided to highlight the performance improvements achieved with respect to outage probability reduction and system reliability enhancement.

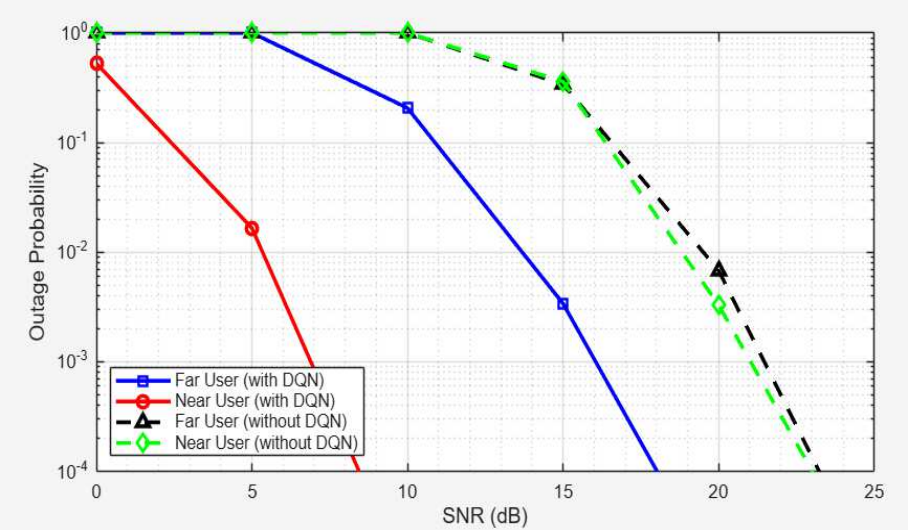


Fig. 2 Performance comparison of near and far users based on outage probability with and without DQN in a RIS-assisted CNOMA system under varying SNR conditions.

The Fig.3 shows the outage probability performance of the RIS-CNOMA system with and without DQN optimization for both near and far users at different SNR levels. At 10 dB SNR, the system using DQN achieves significantly lower outage probabilities compared to the system without DQN, which indicates better signal reliability and communication quality. The outage probability for the near user is approximately($10^{-2.5}$) and for the far user is ($10^{-1.7}$), whereas the system without DQN shows much higher values close to (100). When the SNR increases to 20 dB, the outage probability decreases further, indicating improved system performance. With DQN optimization, the near user reaches an outage probability of(10^{-4}) and the far user reaches (10^{-3}), reflecting more efficient power allocation and better signal transmission. In comparison, the system without DQN still shows higher outage probabilities of around ($10^{-2.5}$) and ($10^{-2.2}$). At 30 dB SNR, both systems show better performance due to the stronger signal conditions, but the DQN-based approach continues to perform better. The outage probabilities decrease to (10^{-5}) for the near

user and (10^{-4}) for the far user. These results demonstrate that integrating DQN with RIS-CNOMA enhances communication reliability, improves system efficiency, and significantly reduces outage probability, particularly at higher SNR levels. The results are presented in Table.1.

SNR (dB)	**With DQN**		**Without DQN**	
	Near User	**Far User**	**Near User**	**Far User**
10 dB	$10^{-2.5}$	$10^{-1.7}$	10^{0}	10^{0}
20 dB	10^{-4}	10^{-3}	$10^{-2.5}$	$10^{-2.2}$
30 dB	10^{-5}	10^{-4}	10^{-4}	10^{-3}

Table 1 Outage Probability With and Without DQN

The performance of the DQN Based RIS-assisted CNOMA system is evaluated in terms of outage probability under Nakagami-m based fading model conditions. The Fig. 4 to 6 gives the results of each diversity technique. The Fig. 7 and 8 shows the Outage Probability of Near and Far user with all diversity techniques. It can be observed that the outage probability reduces with an increase in SNR, indicating improved system reliability. Among the applied diversity approaches, MRC delivers the best performance, and EGC performs next after MRC, while SC shows relatively higher outage probability. The inclusion of DQN further improves system performance by enabling adaptive adjustment of system parameters, resulting in reduced outage probability. This improvement is observed for both near and far users, with the near user consistently performing better due to favorable channel conditions. Overall, the combination of diversity techniques and DQN enhances communication reliability in dynamic wireless environments. The diversity techniques compassion presented in Table.2.

SNR	**Maximal Ratio Combining**				**Selection Combining**				**Equal Gain Combining**			
	Near User		**Far User**		**Near User**		**Far User**		**Near User**		**Far User**	
	With DQN	Without DQN	With DQN	Without DQN	With DQN	Without DQN	With DQN	Without DQN	With DQN	Without DQN	With DQN	Without DQN
20db	10^{-3}	10^{-1}	$10^{-1.8}$	10^{0}	10^{-2}	10^{0}	$10^{-1.5}$	10^{0}	10^{-1}	10^{-1}	10^{-1}	10^{0}
30db	10^{-5}	10^{-4}	10^{-3}	10^{-1}	10^{-3}	10^{0}	10^{-2}	10^{0}	10^{-2}	10^{-2}	10^{-2}	10^{-1}

Table 2 Performance comparison of different combining schemes with and without DQN

The results obtained from the table and corresponding bar graphs Fig. 9 to 11 clearly demonstrate that the outage performance improves with increasing SNR for both near and far-end users. The near user consistently achieves lower outage probability compared to the far user due to better channel conditions. Furthermore, the incorporation of DQN leads to a noticeable improvement in performance by reducing outage probability across all SNR levels. The bar graph provides a clear visual confirmation of this trend, highlighting the effectiveness of adaptive optimization. Overall, the results

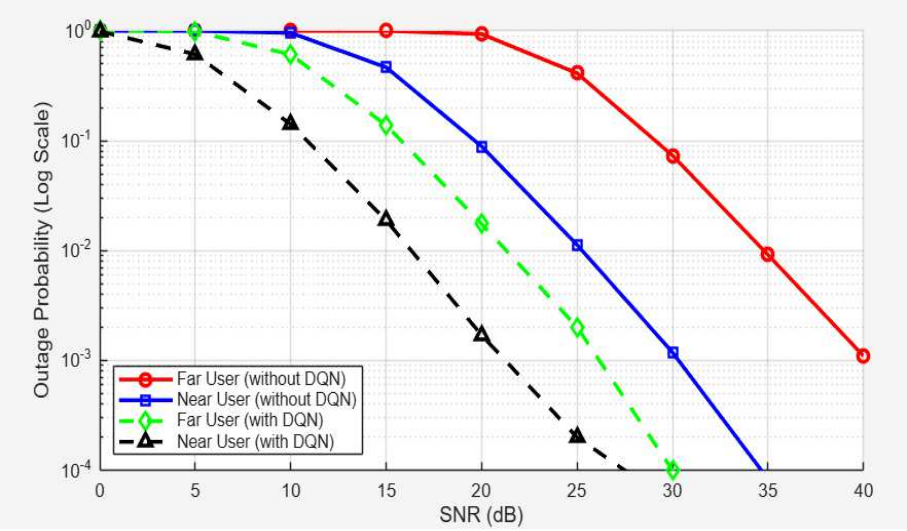


Fig. 3 Performance comparison of near and far users based on outage probability with and without DQN in a RIS-assisted CNOMA system employing Maximum Ratio Combining (MRC) under Nakagami-m fading conditions.

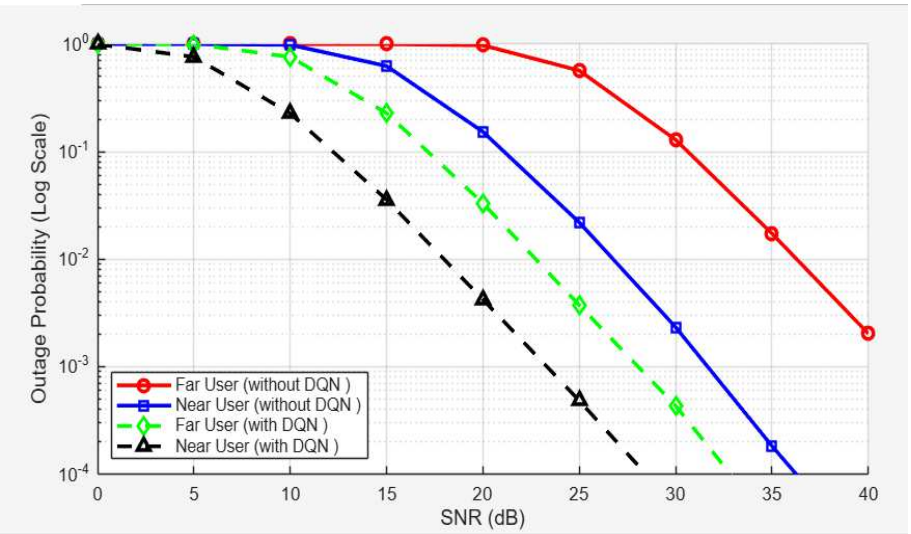


Fig. 4 Performance comparison of near and far users based on outage probability with and without DQN in a RIS-assisted CNOMA system employing Selective Combining (SC) under Nakagami-m fading conditions.

demonstrate that the proposed method improves system reliability and efficiency in RIS-assisted CNOMA systems.

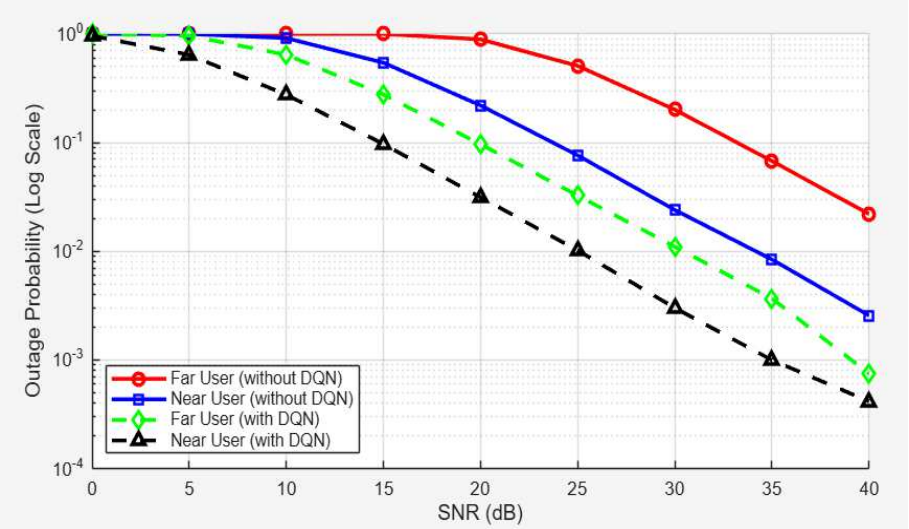


Fig. 5 Performance comparison of near and far users based on outage probability with and without DQN in a RIS-assisted CNOMA system employing Equal Gain Combining (EGC) under Nakagami-m fading conditions.

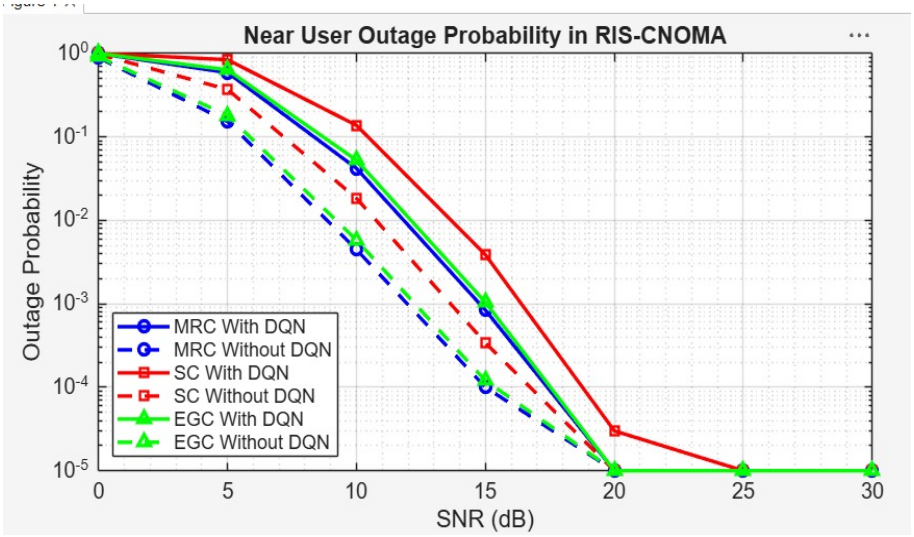


Fig. 6 Outage Probability Performance of Near User in RIS-CNOMA with and without DQN under MRC, SC, and EGC Techniques

4 CONCLUSION

This paper addresses the increasing demand for high data transmission rates, reliability, and efficient spectrum utilization in next-generation wireless data transmission systems by merging Reconfigurable Intelligent Surface technology with Cooperative

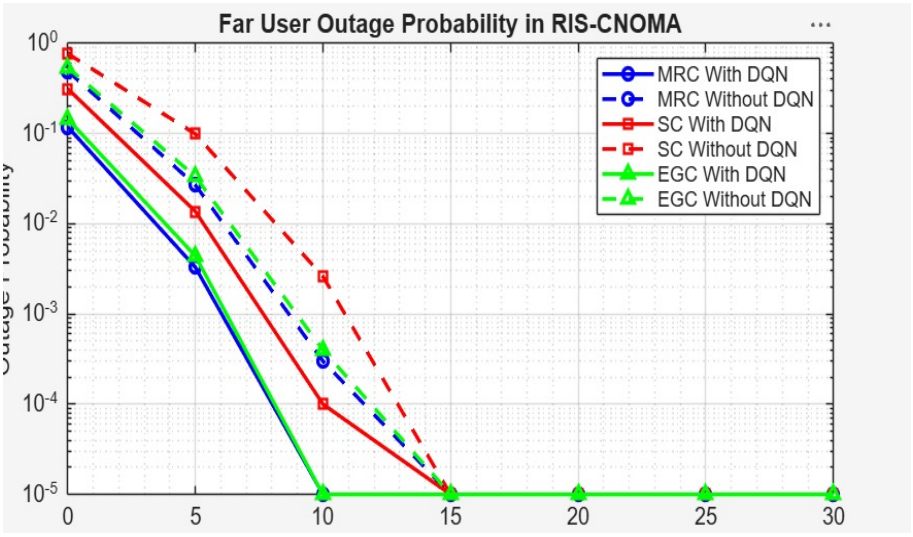


Fig. 7 Outage Probability Performance of Far User in RIS-CNOMA with and without DQN under MRC, SC, and EGC Techniques

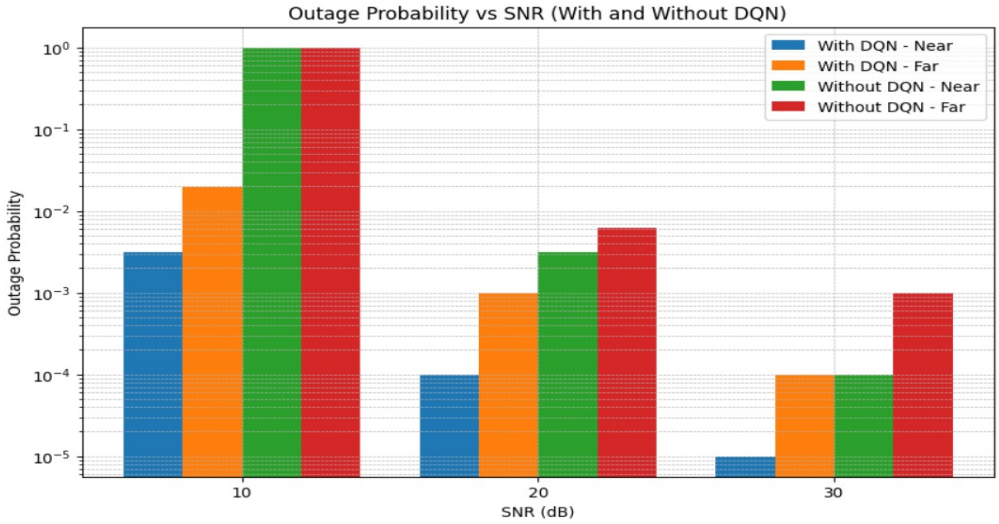


Fig. 8 Outage Probability with and without DQN

NOMA System. Unlike conventional approaches with fixed configurations, the proposed framework employs a Deep Q-Network (DQN) to dynamically optimize RIS phase shifts and power allocation, enabling adaptive operation under varying channel conditions. To combat the effects of multipath fading modeled using Nakagami-m distribution, receiver signal combining techniques including Maximum Ratio Combining, Selection Combining, and Equal Gain Combining are incorporated.

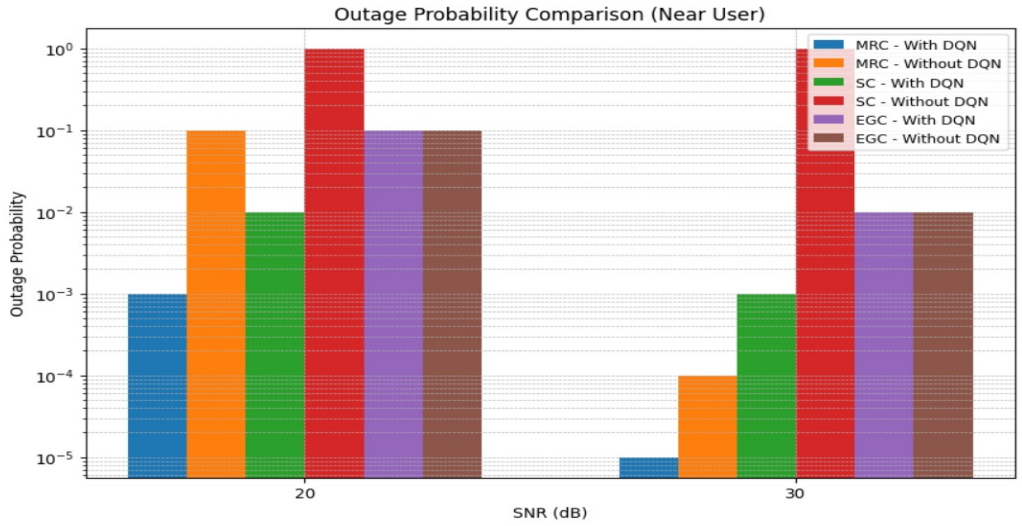


Fig. 9 Outage Probability of Near user with Diversity techniques

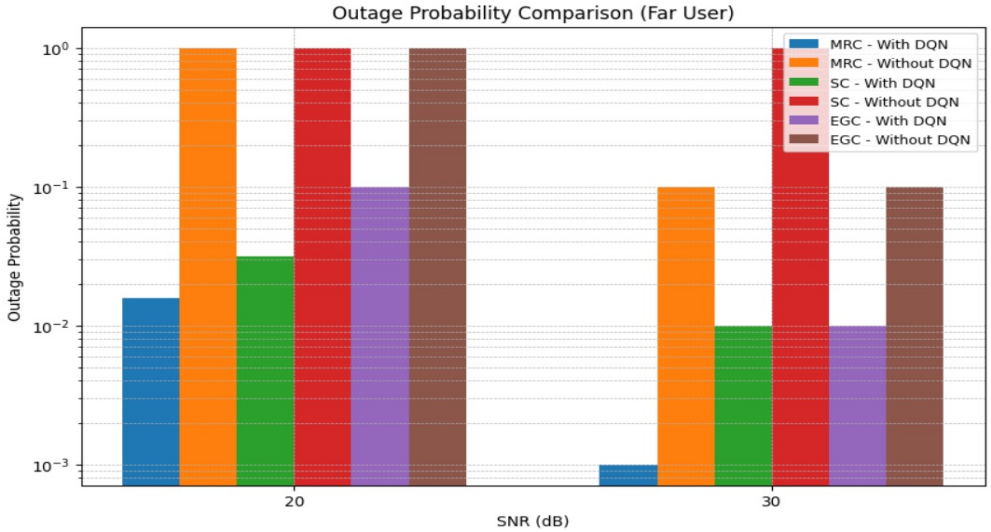


Fig. 10 Outage Probability of Far user with Diversity techniques

The outage probability at 30dB if we observe at near user it enhances to 48% and at far user it is 46% . The performance evaluation in terms of outage probability demonstrates that the proposed DQN-enabled RIS-CNOMA system significantly improves communication reliability, with MRC achieving the best performance among the considered techniques. Overall, the integration of intelligent learning, RIS-assisted

communication, and diversity combining provides an effective solution to the limitations of conventional wireless systems. The proposed approach enhances spectral efficiency, reduces outage probability, and ensures reliable communication, making it a promising candidate for future-generation wireless communication technologies.

5 Future Scope

The proposed *DQN-driven RIS-assisted CNOMA framework with Reciver Diversity Techniques* operating under *Nakagami-m* fading provides a strong foundation for intelligent wireless system design. Building on this framework, several research future directions may be investigated to further enhance performance, scalability, and real-time deployment capability:

1. Incorporate advanced reinforcement learning techniques like *Deep Deterministic Policy Gradient (DDPG)*, *Proximal Policy Optimization (PPO)*, and *Actor-Critic* architectures to support continuous control of RIS phase shifts and enable more accurate optimization strategies.
2. Evaluate system behavior under various fading environments, including *Rayleigh*, *Rician*, and *Weibull* models, in order to analyze robustness across different propagation conditions in both clear line-of-sight and non-line-of-sight communication cases.
3. Design and analyze hybrid diversity schemes by combining *MRC* with other approaches such as *Equal Gain Combining (EGC)* along with *Selection Combining (SC)*, with the objective of balancing performance improvements against computational requirements.
4. Investigate the effects of practical limitations such as *imperfect channel state information (CSI)*, estimation inaccuracies, and hardware non-idealities to better understand real-world system performance.
5. Extend the framework to *multi-user* and *multi-cell* communication systems to examine scalability, interference handling, dynamic resource allocation, and fairness among users in dense network deployments.
6. Explore advanced RIS configurations, including *active* and *hybrid RIS* architectures, to improve signal enhancement capabilities while maintaining energy efficiency.
7. Assess the applicability of the proposed approach in emerging domains such as *6G communication systems*, *Internet of Things (IoT)* applications and *vehicle-to-everything (V2X)* communication systems networks, particularly under rapidly changing and heterogeneous environments.
8. Implement and validate the proposed model using real-time experimental platforms such as *software-defined radio (SDR)* to verify performance beyond simulation-based analysis.

These future research directions aim to further strengthen the adaptability, efficiency, and practical feasibility of the DQN-based RIS-CNOMA system, allowing it to become a promising solution for next-generation wireless communication systems for future wireless networks communication technologies.

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Declarations

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- Ethics approval and consent to participate : All Authors are willing for all types of Ethics Approvals.
- Consent to Participate : All authors are contributed to write and submitting the manuscript.
- Consent for publication : All authors are willing to do the required Consent for publication.
- Data availability : The datasets analysed during the study are available from the corresponding author upon reasonable request.
- Materials availability : The materials used is original and confidential
- Code availability : The code developed for this manuscript is original and confidential.
- Author contribution : Ramadevi. M, the main author publishing research paper as part of academics and all others contributed to the idea's discussion, article writing, and review process. All authors read and approved the final manuscript. All authors are agreeing the terms and conditions of Journal on Advances in Signal Processing, Spring Nature publications.
- Competing interests: All authors declare that they have no significant competing presentation of the work described in this manuscript.

References

[1] L. Yang, J. Yang, W. Xie, M. O. Hasna, T. Tsiftsis and M. D. Renzo, "Secrecy Performance Analysis of RIS-Aided Wireless Communication Systems," in IEEE Transactions on Vehicular Technology, vol. 69, no. 10, pp. 12296-12300, Oct. 2020, doi: 10.1109/TVT.2020.3007521.

[2] L. B. Ranchhodbhai, D. Sadhwani and R. Singh, "Performance Analysis of Active RIS-Aided Wireless Communication Systems Over Nakagamim Fading Channel," in IEEE Open Journal of Vehicular Technology, vol. 6, pp. 2539-2553, 2025, doi: 10.1109/OJVT.2025.3609899.

[3] S. Lin, X. Li, H. Xu and S. Jin, "Energy Efficiency Optimization in RIS-Assisted Communication Systems With RIS Power Budget," in IEEE

Transactions on Vehicular Technology, vol. 75, no. 2, pp. 3434-3439, Feb. 2026, doi: 10.1109/TVT.2025.3603852.

[4] T. Wei et al., "Machine Learning-Enabled RIS-Assisted mmWave NOMA Systems: RIS Partitioning, Beamforming Design, and Power Allocation," in IEEE Transactions on Communications, vol. 73, no. 9, pp. 7617-7632, Sept. 2025, doi: 10.1109/TCOMM.2025.3554673.

[5] J. Zuo, Y. Liu and N. Al-Dhahir, "Reconfigurable Intelligent Surface Assisted Cooperative Non-Orthogonal Multiple Access Systems," in IEEE Transactions on Communications, vol. 69, no. 10, pp. 6750-6764, Oct. 2021, doi: 10.1109/TCOMM.2021.3098684.

[6] M. Zhan, "Research on Anti-Interference Technology for Multi-User Wireless Communication Based on DQN," 2024 International Conference on Computer Communication, Networks and Information Science (CCNIS), Singapore, Singapore, 2024, pp. 200-204, doi: 10.1109/CCNIS64984.2024.00043.

[7] Q. Wu and R. Zhang, "Towards smart and reconfigurable environment: Intelligent reflecting surface aided wireless network," *IEEE Commun. Mag.*, vol. 58, no. 1, pp. 106–112, Jan. 2020.

[8] M. Ramadevi, A. N., S. Gadde and V. Maheshwari, "Analysis of RIS-Aided CNOMA System with Selection Combining Under Nakagami Fading Channel," 2026 7th International Conference on Mobile Computing and Sustainable Informatics (ICMCSI), Goathgaun, Nepal, 2026, pp. 686-692, doi: 10.1109/ICMCSI67283.2026.11412694.

[9] J. O. Mark and B. B. Samir, "Performance analysis of M-ary digital modulation techniques over Nakagami-m and Rician fading environment with maximal ratio combining diversity," 2010 International Conference on Intelligent and Advanced Systems, Kuala Lumpur, Malaysia, 2010, pp. 1-6, doi: 10.1109/ICIAS.2010.5716140.

[10] A. Bessate, A. Madani, F. E. Bouanani and M. Elomari, "Effective Capacity of Maximal Ratio Combining Subject to the Fading Impairment," 2024 7th International Conference on Advanced Communication Technologies and Networking (CommNet), Rabat, Morocco, 2024.

[11] Y. -y. Zhang and S. -y. Hong, "Performance of WCDMA systems based on a novel generalized selective combining diversity technique," 2010 3rd IEEE International Conference on Ubi-Media Computing, Jinhua, China, 2010, pp. 72-76, doi: 10.1109/UMEDIA.2010.5543931.

[12] A. Chauhan, M. I. Hasan, S. Singh, I. H. Khan and R. Ya, "Mean SNR Analysis of Different Diversity Combining Techniques Under Nakagamim Fading Channels- A Review," 2024 International Conference on Computer, Electronics, Electrical Engineering and their Applications (IC2E3), Srinagar Garhwal, Uttarakhand, India, 2024, pp. 1-6, doi: 10.1109/IC2E362166.2024.10826717.

[13] Q. Ding, H. Shi and Y. Lian, "Outage probability and achievable rate analysis for massive MIMO downlink with mixed-DAC and MF precoding," in China Communications, vol. 17, no. 8, pp. 95-105, Aug. 2020, doi: 10.23919/JCC.2020.08.008.

[14] Y. Dhungana and C. Tellambura, "New Simple Approximations for Error Probability and Outage in Fading," in IEEE Communications Letters, vol. 16, no. 11, pp. 1760-1763, November 2012, doi: 10.1109/LCOMM.2012.092112.121280.

[15] R. M. Thomas and S. Malarvizhi, "Resource Allocation in Wireless Powered Communication Networks with Power Minimization," 2022 International Conference for Advancement in Technology (ICONAT), Goa, India, 2022, pp. 1-6, doi: 10.1109/ICONAT53423.2022.9726084.

[16] N. Choudhary, S. Joshi and V. K. Chaubey, "Outage Analysis of an IRS-Assisted 5G and Beyond Wireless Communications System," 2023 IEEE 97th Vehicular Technology Conference (VTC2023-Spring), Florence, Italy, 2023.