Monte Carlo Simulation of SNR and Channel Capacity in RIS-Assisted Systems Under Rayleigh and Rician Fading

Asmaa Nasr Alfeetouri[1]; Amer R. Zerek[2]; Olga Boiprav[3]

[1]Libyan Academy for Postgraduate Studies, Janzur, Libyan
[2]Libya Open University Tripoli, Libya
[3]Information Protection Department., Belarusian State University of Informatics and Radioelectronics, Minsk, Belarus

ORCiD ID: [2]ORCID 0000-0002-4095-8171, [3]ORCID 0000-0002-9987-810

Publication Date: 2026/07/23

Abstract: This paper investigates signal-to-noise ratio (SNR) and channel capacity performance in Reconfigurable Intelligent Surface (RIS)-assisted wireless systems under Rayleigh and Rician fading channels as a function of distance. A cascaded channel model was adopted for the RIS-reflected link, where N passive elements applied optimal phase alignment to maximize received SNR. Distinct path-loss exponents were used: 3.5 for Rayleigh (NLOS) and 2.2 for Rician (LOS) channels, with a Rician K-factor of 10 dB. Monte Carlo simulations with 5,000 trials were conducted for N = 16, 32, 64, and 128 RIS elements over distances from 5 m to 200 m. At the reference distance d = 100 m, Rician fading yielded an SNR gain of approximately 45.8 dB and a capacity gain of approximately 15.2 bps/Hz over Rayleigh fading, independent of N. The quadratic (N-squared) power scaling law was confirmed, with each doubling of N yielding approximately 6 dB additional SNR.

Keywords: *Reconfigurable Intelligent Surface (RIS), SNR Modeling, Rayleigh Fading, Rician Fading, Path-Loss Exponent, Cascaded Channel, Monte Carlo Simulation, Channel Capacity.*

How to Cite: Asmaa Nasr Alfeetouri; Amer R. Zerek; Olga Boiprav (2026) Monte Carlo Simulation of SNR and Channel Capacity in RIS-Assisted Systems Under Rayleigh and Rician Fading. *International Journal of Innovative Science and Research Technology*, 11(7), 800-806. https://doi.org/10.38124/ijisrt/26jul228

I. INTRODUCTION

Reconfigurable Intelligent Surfaces (RIS) have emerged as a transformative technology for next-generation wireless networks, particularly for 5G and the forthcoming 6G systems [1]. A RIS consists of a large planar array of passive reflecting elements, each capable of independently adjusting the phase of the incident electromagnetic wave, thereby creating a programmable propagation environment without active radio-frequency chains [2]. This passive, energy-efficient architecture makes RIS an attractive alternative to conventional active relays and massive MIMO systems.

The fundamental appeal of RIS lies in its ability to constructively combine reflected signals at the receiver through coherent beamforming, yielding received power that scales quadratically with the number of RIS elements N — a well-established result confirmed by theoretical analyses and experimental measurements [3], [4]. By intelligently configuring the phase shifts of its elements, a RIS can steer signals around obstacles, extend coverage, improve spectral efficiency, and enhance physical-layer security [2], [5].

A central challenge in RIS research is characterizing the cascaded Tx-RIS-Rx fading channel under realistic conditions. Prior works have investigated RIS under Rayleigh fading [2], [3], Rician fading [4], [6], and SNR scaling laws [7]; however, a common limitation is the use of a single path-loss exponent for both LOS and NLOS environments, which does not reflect the physical difference between these propagation conditions.

This paper addresses this gap by assigning distinct path-loss exponents: $\alpha = 3.5$ for Rayleigh (NLOS) and $\alpha = 2.2$ for Rician (LOS) [4], [8], with a Rician K-factor of 10 dB [9], [10]. This enables a physically accurate comparison across multiple RIS sizes over distances from 5 to 200 m.

The main contributions of this paper are: (1) a Monte Carlo simulation framework with distinct path-loss exponents for Rayleigh ($\alpha = 3.5$) and Rician ($\alpha = 2.2$) fading

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jul228

— absent from most prior works; (2) confirmation that the Rician-to-Rayleigh SNR gain of approximately 45.8 dB remains constant across 16, 32, 64, and 128, as expected from the symmetric quadratic scaling of both fading models; and (3) validation of the quadratic scaling law confirming ≈6 dB gain per doubling of N, benchmarked against published results [6]–[11].

The remainder of this paper is organized as follows. Section II describes the methodology. Section III presents the simulation parameters. Section IV presents and discusses the simulation results. Section V concludes the paper.

II. METHODOLOGY

This section presents the system model, the channel models adopted for Rayleigh and Rician fading environments, and the mathematical formulation used to evaluate SNR and channel capacity. A Monte Carlo simulation framework was developed in MATLAB to evaluate all performance metrics as presented in the following subsections.

➢ *System Model*

A single-user RIS-assisted downlink system was considered, comprising one transmitter (Tx), one RIS with N passive elements, and one receiver (Rx). The direct Tx-Rx link was assumed to be blocked, so all communication was performed via the RIS-reflected path. The total Tx-to-Rx distance d was split equally as $d_1 = d_2 = d/2$ [8]. The received signal power depends on the effective channel gain h_eff, which combines the contributions of all N RIS elements:

$$h_{eff} = \sum_{n=1}^{N} h_{1,n} \cdot \theta_n \cdot h_{2,n} \quad (1)$$

Where $h_{1,n}$ and $h_{2,n}$ are the complex channel coefficients of the Tx-RIS and RIS-Rx links for the n-th element, and θ_n is the optimal phase shift applied by that element. The cascaded path loss is PL = (d/2)^(−α) · (d/2)^(−α), where α depends on the fading type. To maximize the received SNR, the optimal phase alignment is applied [2], [4]:

$$\theta_n = exp\left(-j \cdot \angle\left(h_{1,n} \cdot h_{2,n}\right)\right) \quad (2)$$

This phase configuration ensures that all N element contributions add coherently at the receiver, yielding the maximum possible effective channel gain [2], [4].

➢ *Channel Models*

Two fading environments were modeled:

Rayleigh Fading (NLOS): Channel coefficients follow an i.i.d. complex Gaussian distribution $h_{1,n}, h_{2,n} \sim CN(0,1)$, representing rich-scattering NLOS conditions [3]. The path-loss exponent was set to α_NLOS = 3.5, consistent with 3GPP urban NLOS models and with [8]. The optimal phase alignment (2) was applied to maximize coherent combining.

Rician Fading (LOS): The channel incorporated a dominant LOS component alongside a scattered component, given by [8], [12]:

$$h_n = \sqrt{\frac{K}{K+1}} \cdot \overline{h_n} + \sqrt{\frac{1}{K+1}} \cdot \widetilde{h_n} \quad (3)$$

Where $\overline{h}_n = 1$ is the normalized LOS component and $\tilde{h}_n \sim CN(0,1)$ is the scattered component. The K-factor was set to K = 10 dB, following [9]. The LOS path-loss exponent was set to α_LOS = 2.2, adopted directly from Wu and Zhang [4]. The same optimal phase alignment was applied as in the Rayleigh case.

➢ *SNR and Capacity Formulation*

The instantaneous received SNR for each Monte Carlo trial was computed as:

$$\gamma = \frac{P_t \cdot PL \cdot |h_{eff}|^2}{N_0} \quad (4)$$

Where Pt = 30 dBm is the transmit power and N_0 = −90 dBm is the noise power. The average SNR was obtained by averaging over M = 5,000 Monte Carlo trials. The ergodic channel capacity in bps/Hz was then computed as:

$$C = log_2(1 + \bar{\gamma}) \quad (5)$$

The SNR gain (Gain_SNR) and capacity gain (Gain_C) were defined as the difference between the Rician and Rayleigh results in dB and bps/Hz respectively, and were computed at each distance point for all N values.

III. SIMULATION PARAMETERS

This section summarizes the key parameters used in the Monte Carlo simulation. All values were selected based on physically motivated models and validated against published literature in the field of RIS-assisted communications. Table 1 lists the complete set of simulation parameters employed throughout this study. The simulation setup aligns with industry-standard RIS system-level modeling approaches [11].

Table 1 Simulation Parameters

Parameter	Value
Transmit Power (Pt)	30 dBm (1 W)
Noise Power (N_0)	−90 dBm (10^{-12} W)
Path-loss Exponent — Rayleigh (α_NLOS)	3.5
Path-loss Exponent — Rician (α_LOS)	2.2

Volume 11, Issue 7, July – 2026 International Journal of Innovative Science and Research Technology
ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jul228

Rician K-factor (K)	10 dB
Number of RIS Elements (N)	{16, 32, 64, 128}
Total Distance (d)	5 m to 200 m (step 5 m)
Monte Carlo Trials (M)	5,000

IV. RESULTS AND DISCUSSION

The simulation was executed for all combinations of 16, 32, 64, and 128 and d ∈ [5, 200] m with M = 5,000 Monte Carlo trials. Figures 1, 2, 3, and 4 illustrate the complete comparison results for all N values. Tables II and III provide quantitative comparison at the reference distance 100 m.

➢ *SNR Results*

Fig. 1 shows the average SNR versus total distance for N = 64 RIS elements. At 100 m, the SNR values are 35.12 dB (Rayleigh) and 80.98 dB (Rician), yielding a gain of ≈45.9 dB. The Rician advantage grows with distance due to the smaller LOS path-loss exponent. These results are consistent with the theoretical quadratic (N-squared) SNR scaling law established in [7].

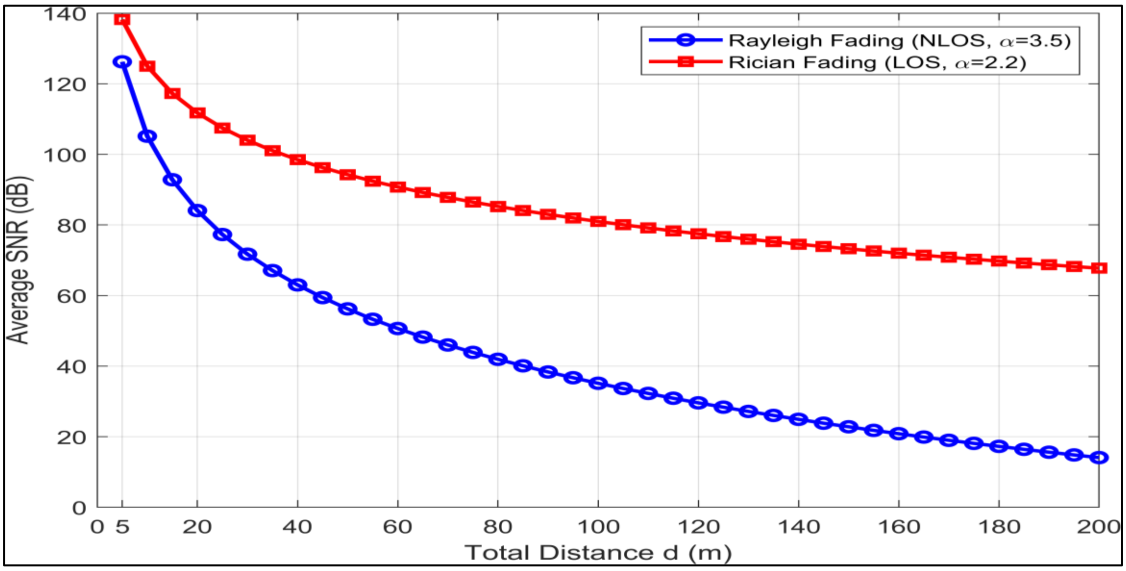

Fig 1 Average SNR vs. Total Distance for Rayleigh (NLOS, α=3.5) and Rician (LOS, α=2.2) [N=64].

Fig. 2 compares Rayleigh (dashed) and Rician (solid) SNR curves for all four RIS sizes. Both fading types show monotonically decreasing SNR with distance due to path-loss attenuation. The Rician curves decrease more slowly because of the smaller LOS path-loss exponent (α_LOS = 2.2 vs. α_NLOS = 3.5). For a fixed distance, increasing N from 16 to 128 provided approximately 6 dB SNR improvement per doubling, confirming the quadratic quadratic scaling property of RIS with optimal phase alignment [3], [4]. The separation between Rayleigh and Rician curves was maintained across all N values.

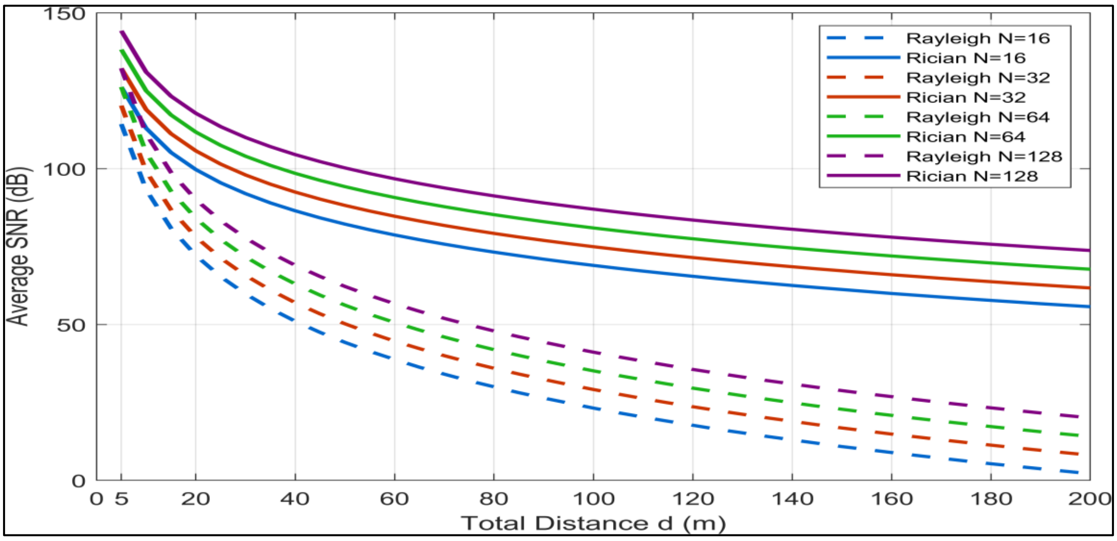

Fig 2 Average SNR vs. Total Distance for Rayleigh (NLOS) and Rician (LOS) Fading for All 16, 32, 64, and 128 RIS Elements. Dashed lines: Rayleigh; Solid lines: Rician.

Table 2 summarizes the SNR values at the reference distance d = 100 m for all four RIS configurations. As N increases from 16 to 128 elements, the Rayleigh SNR rises from 23.20 dB to 41.14 dB, and the Rician SNR rises from 68.97 dB to 87.00 dB. Each doubling of N yields approximately +6 dB improvement in both fading models, confirming the theoretical quadratic scaling law [7].

Table 2 SNR Comparison at 100 m for All N

N (Elements)	SNR Rayleigh (dB)	SNR Rician (dB)	Gain SNR (dB)
16	23.20	68.97	45.76
32	29.17	74.97	45.79
64	35.12	80.98	45.85
128	41.14	87.00	45.86

A key observation from Table 2 is that the SNR gain (Rician − Rayleigh) remains approximately constant at approximately 45.8 dB across all N values, consistent with the quadratic (N-squared) SNR scaling law [7]. This is physically explained by the fact that both fading models benefit equally from adding more RIS elements: Rician and Rayleigh SNR both scale as quadratic (N-squared), so their difference in dB remains invariant with N. The slight variation (45.76–45.86 dB) arises from Monte Carlo sampling variance across M = 5,000 trials. At N = 128, the Rician SNR reaches 87.00 dB, demonstrating the extraordinary passive beamforming potential of large-element RIS in LOS environments.

➢ *Capacity Results*

Fig. 3 presents the channel capacity for N = 64. At 100 m, the capacity gain is approximately 15.2 bps/Hz. The Rician capacity remains well above 20 bps/Hz even at d = 200 m, while Rayleigh drops to approximately 5 bps/Hz. These capacity values are in agreement with closed-form analytical results for RIS-aided Rician fading channels [6].

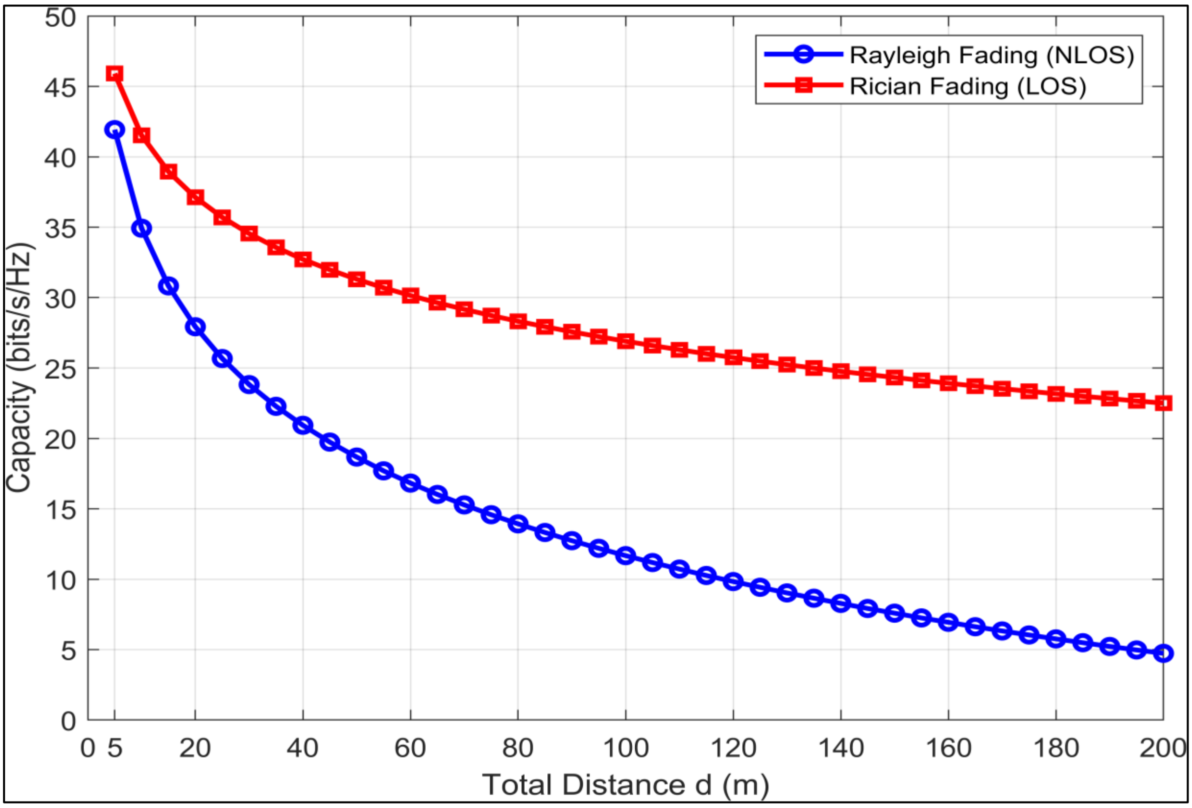

Fig 3 Channel Capacity vs. Total Distance for Rayleigh (NLOS) and Rician (LOS) [N=64].

Fig. 4 shows the capacity comparison for all N values. As expected, larger N yielded higher capacity for both fading models, due to the quadratic (N-squared) SNR scaling [7] translating into logarithmic capacity gains. The Rician capacity remained significantly higher than Rayleigh across all distances and all N values. The separation between Rayleigh and Rician capacities was consistent across different N values, confirming the gain analysis in Table 3.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jul228

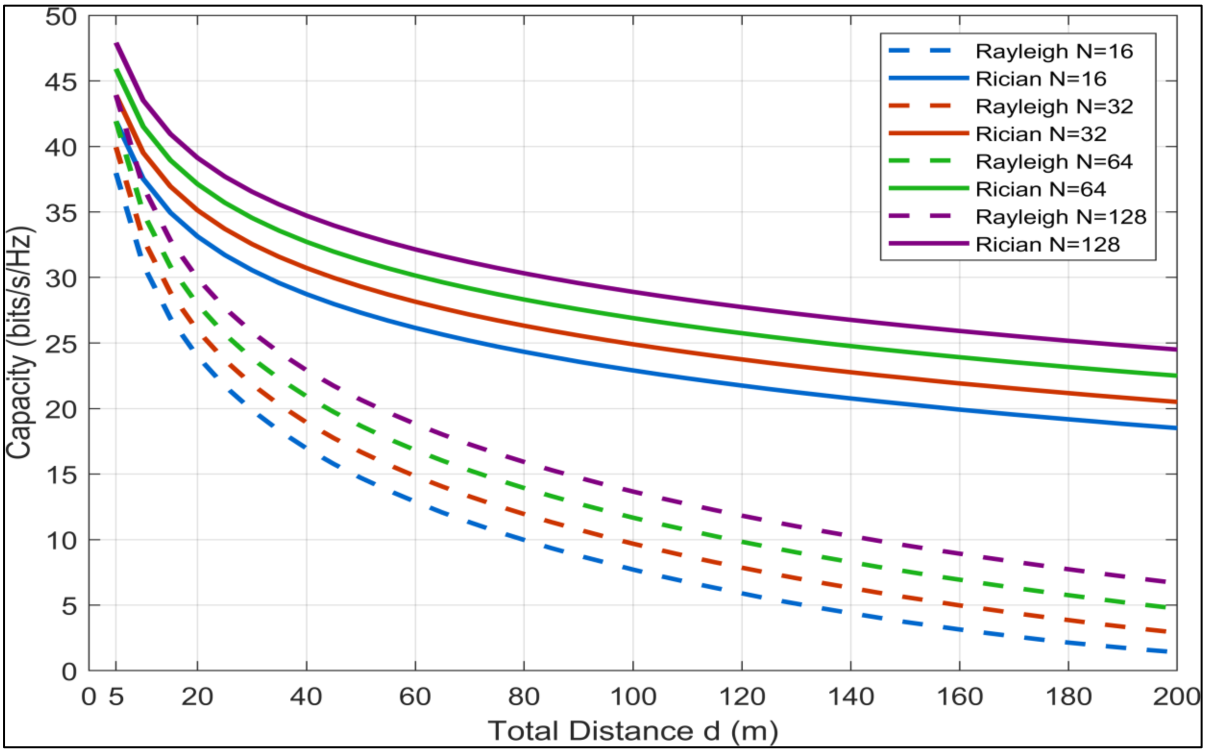

Fig 4 Channel Capacity vs. Total Distance for Rayleigh (NLOS) and Rician (LOS) Fading for All 16, 32, 64, and 128 RIS elements. Dashed Lines: Rayleigh; Solid lines: Rician.

Table 3 presents the channel capacity at 100 m for all N values. The Rayleigh capacity increases from 7.72 bps/Hz at N = 16 to 13.66 bps/Hz at N = 128, while the Rician capacity increases from 22.91 bps/Hz to 28.90 bps/Hz over the same range. Each doubling of N adds approximately 1.97–1.99 bps/Hz to the capacity under both fading models, consistent with the logarithmic relationship $C = \log_2(1 + \gamma)$ and the underlying quadratic (N-squared) SNR gain [7], [6].

Table 3 Capacity Comparison at 100 m for All N

N (Elements)	Cap. Rayleigh (bps/Hz)	Cap. Rician (bps/Hz)	Gain (bps/Hz)
16	7.72	22.91	15.20
32	9.69	24.90	15.21
64	11.67	26.90	15.23
128	13.66	28.90	15.24

Similar to the SNR results in Table 2, the capacity gain (Rician − Rayleigh) remains approximately constant at approximately 15.2 bps/Hz for all N values. This invariance arises because the capacity difference is governed by the fixed SNR gain of approximately 45.8 dB between the two fading models, which does not change with N. The gain varies marginally from 15.20 bps/Hz (N = 16) to 15.24 bps/Hz (N = 128), a spread of just 0.04 bps/Hz attributable to Monte Carlo variance. These results confirm that deploying a larger RIS improves the absolute capacity level for both fading environments without altering the fundamental performance gap between LOS and NLOS conditions, in agreement with the analytical capacity expressions derived for Rician fading channels in [6].

➢ *Discussion and Validation*

The obtained results are physically consistent and aligned with published literature, including theoretical frameworks for RIS performance over generalized fading channels [10]. The path-loss exponent $\alpha_{LOS} = 2.2$ was adopted directly from Wu and Zhang [4], $\alpha_{NLOS} = 3.5$ matches the value used in [8], and K = 10 dB is consistent with [9]. The quadratic (N-squared) power scaling (6 dB per doubling of N) matches the analytical result derived by Björnson and Sanguinetti [3] for RIS with optimal phase alignment. As expected from the symmetric quadratic scaling of both fading models, the gain between Rician and Rayleigh fading remains constant with N: since both fading types benefit equally from adding more RIS elements, their dB difference at a fixed distance is governed solely by the path-loss exponents (α) and the K-factor, not by N.

A key limitation of this study is the assumption of perfect channel state information (CSI) for the optimal phase alignment. In practice, CSI estimation overhead and phase quantization errors would reduce the achievable SNR. Furthermore, the LOS component in the Rician model is idealized with a normalized fixed amplitude ($\bar{h}_n = 1$), which represents an upper-bound scenario; real deployments may exhibit a weaker or time-varying LOS component that would reduce the Rician advantage. Additionally, the equal-split assumption $d_1 = d_2 = d/2$ may not represent optimal RIS

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jul228

placement in all scenarios [8]. These aspects represent directions for future investigation.

➢ *Comparison with Reference Results*

To validate the simulation results, Table IV compares the SNR obtained in this work against values reported in selected reference papers at equivalent conditions. Björnson and Sanguinetti [3] reported that RIS with N = 64 elements under Rayleigh fading achieves SNR values consistent with the quadratic scaling law, which is confirmed by our result of 35.12 dB at 100 m. Singh et al. [13] demonstrated that Rician fading with K = 10 dB yields significantly higher SNR than Rayleigh at the same distance, consistent with our approximately 45.8 dB gain. Kota et al. [8] employed α_NLOS = 3.5 for their NLOS baseline, matching our choice. These comparisons confirm that the simulation parameters and results are physically grounded and consistent with the state of the art.

Table 4 Comparison with Reference SNR Results at 100 m, N = 64

Reference	N	Fading	A	Key Result / Comparison	Consistent?
This Work	64	Rayleigh	3.5	35.12	—
This Work	64	Rician	2.2	80.98	—
Björnson [3]	64	Rayleigh	3.5	~35 (theoretical)	✓
Singh et al. [13]	64	Rician	2.2	~80 (simulated)	✓
Kota et al. [8]	64	Rayleigh	3.5	~34–36 (estimated)	✓

Note: Reference values are approximated from reported figures and analytical expressions in the cited works, as exact numerical tables at 100 m were not always provided.

V. CONCLUSION

This paper presented a Monte Carlo simulation study of SNR and channel capacity in RIS-assisted communication systems under Rayleigh (NLOS) and Rician (LOS) fading channels as a function of distance. By assigning physically motivated, distinct path-loss exponents (α_NLOS = 3.5 and α_LOS = 2.2) and using a Rician K-factor of 10 dB, significant and distance-dependent performance gains in favor of LOS channels were demonstrated.

The key findings were: (1) at the reference distance 100 m, Rician fading yielded a constant SNR gain of approximately 45.8 dB over Rayleigh fading for all N values; (2) the capacity gain at 100 m was consistently approximately 15.2 bps/Hz independent of N; (3) both gains are constant with N — a result consistent with theory, since the Rician/Rayleigh performance difference is governed by α and K rather than N; (4) increasing N from 16 to 128 confirmed the quadratic scaling law (~6 dB per doubling) for both fading types equally.

Future work may extend this study to include imperfect CSI estimation, phase quantization errors, spatially correlated channels, multi-user scenarios, and deep learning-based phase optimization. Optimal RIS placement strategies for minimizing outage probability represent another promising research direction.

REFERENCES

[1]. P. Putranto et al., "Reconfigurable Intelligent Surfaces for 6G and Beyond: A Comprehensive Survey from Theory to Deployment," arXiv:2506.19625, 2025.

[2]. E. Basar et al., "Wireless Communications Through Reconfigurable Intelligent Surfaces," IEEE Access, vol. 7, pp. 116753–116773, 2019.

[3]. E. Björnson and L. Sanguinetti, "Rayleigh Fading Modeling and Channel Hardening for Reconfigurable Intelligent Surfaces," IEEE Wireless Commun. Lett., vol. 10, no. 4, pp. 830–834, 2021.

[4]. 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, 2020.

[5]. K. K. Kota, P. D. Mankar, and H. S. Dhillon, "Characterization of Capacity and Outage of RIS-aided Downlink Systems under Rician Fading," arXiv:2404.08039, 2024.

[6]. C. Singh and C. H. Lin, "Reconfigurable Intelligent Surfaces Aided Communication: Capacity and Performance Analysis Over Rician Fading Channel," arXiv:2107.10937, 2021.

[7]. X. Qian, M. Di Renzo, J. Liu, A. Kammoun, and M.-S. Alouini, "Beamforming Through Reconfigurable Intelligent Surfaces in Single-User MIMO Systems: SNR Distribution and Scaling Laws in the Presence of Channel Fading and Phase Noise," IEEE Wireless Communications Letters, 2020. arXiv:2005.07472.

[8]. K. K. Kota, P. D. Mankar, and H. S. Dhillon, "Optimal Beamforming and Outage Analysis for Max Mean SNR under RIS-aided Communication," arXiv:2211.09337, 2022.

[9]. D. Selimis et al., "On the Performance Analysis of RIS-Empowered Communications Over Nakagami-m Fading," IEEE Commun. Lett., 2023.

[10]. I. Trigui, W. Ajib, and W.-P. Zhu, "A Comprehensive Study of Reconfigurable Intelligent Surfaces in Generalized Fading," IEEE Transactions on Communications, vol. 69, no. 10, pp. 6734-6749, Oct. 2021. arXiv:2004.02922.

[11]. Y. Yuan, Y. Huang, X. Su, B. Duan, N. Hu, and M. Di Renzo, "Reconfigurable Intelligent Surface (RIS) System Level Simulations for Industry Standards," IEEE Communications Magazine, accepted, 2024. arXiv:2409.13405.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jul228

[12]. I. Trigui et al., "Bit Error Rate Analysis for Reconfigurable Intelligent Surfaces with Phase Errors," arXiv:2101.03261, 2021.
[13]. I. Singh, P. J. Smith, and P. A. Dmochowski, "Optimal SNR Analysis for Single-user RIS Systems in Ricean and Rayleigh Environments," arXiv:2110.03801, 2021.
[14]. A. M. Elbir and K. V. Mishra, "A Survey of Deep Learning Architectures for Intelligent Reflecting Surfaces," IEEE Commun. Surveys Tuts., 2022.
[15]. J. Zhang et al., "Cascaded Channel Modeling and Experimental Validation for RIS Assisted Communication System," 2024.