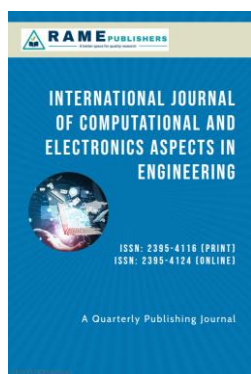


Performance Analysis of RIS-Assisted SISO Systems Under Different Small Scale Fading Channels

Roaa Ali Hussein * 

Department of Electronic and Communications Engineering Techniques, Polytechnic College Mosul, Northern Technical University, Iraq.

*Correspondence: roaa.eng8@ntu.edu.iq



Article – Peer Reviewed

Received: July 15, 2026

Accepted: September 13, 2026

Published: September 24, 2026

Copyright: © 2026 RAME Publishers

This is an open access article under the CC BY 4.0 International License.



<https://creativecommons.org/licenses/by/4.0/>

Cite this article: Roaa Ali Hussein, “Performance Analysis of RIS-Assisted SISO systems Under Different Small Scale Fading Channels”, *International Journal of Computational and Electronic Aspects in Engineering*, RAME Publishers, vol. 7, issue 4, pp. 437-449, 2026.

<https://doi.org/10.26706/ijceae.7.4.20260810>

Abstract: Reconfigurable Intelligent Surfaces (RISS) are a new and promising technology that can help wireless communication work better by smartly controlling how electromagnetic signals spread. This study looks into what happens to the RIS-SISO wireless communication system when four small-scale fading models are used: Rayleigh, Rician, Nakagami-m, and Two-Wave with Diffuse Power (TWDP). The system performance is first evaluated without RIS to establish a baseline for the four fading models. The effect of introducing a RIS is then investigated under the considered fading conditions. Then, the study also examines the effect of the number of RIS elements (NRIS). The results demonstrate that the four fading models exhibit different baseline Bit Error Rate (BER) characteristics, while maintaining consistent performance trends with increasing Signal to Noise Ratio (SNR). After introducing a 50-element RIS with phase control and its ability to enhance the effective channel. A substantial improvement in BER is achieved across all considered channels. At 10 dB SNR, the BER reduction reaches approximately 94.9% for Rayleigh, 96.6% for Rician, 96.2% for Nakagami-m, and 98.8% for TWDP, based on the adopted baseline comparison. Also, the capacity achieves (4) times compared without RIS configuration and showing that increasing the number of reflecting elements strengthens the RIS-assisted channel contribution. The power analysis further shows that increasing the NRIS enhances both the reflected-channel power and the effective channel power across the considered fading models. The Rician channel exhibits the highest power levels, while Nakagami-m and TWDP show closely related behavior, followed by the Rayleigh channel.

Keywords: RIS; Rayleigh; Nakagami-m; Rician; TWDP; SISO.

1. Introduction

Wireless communication systems have been seeing really remarkable developments lately, mostly because the number of users keeps growing, along with Internet of Things (IoT) applications and smart devices, you know. This overall increase pushes networks to deliver higher data rates, better dependability and less energy use at the same time [1], [2]. On top of that, the expectations for next generation wireless networks are not only about moving data anymore. They also have to carry services that come with strict low latency needs [3], [4], plus high spectral efficiency. So, naturally, researchers have been trying to look into fresh technologies, or other communication approaches that can keep up with these rising requirements and in the end improve the entire network performance, in a more stable way [5-9].

Even with the big improvements in modern communication technologies, the wireless channel still stays one of the key parts that, in practice, controls system performance. During propagation, the transmitted signal can get hit by reflection, scattering, and diffraction effects, kind of all at once, which then leads to multipath fading and so, noticeably affects how good the received signal looks, as well as the overall efficiency of data transfer. As a result, knowing what the various wireless channel models look like, and checking what they do to communication system performance has turned into a basic research focus in today's wireless communications, honestly [10].

To properly capture the kind of diverse wireless propagation environments you see in real life, many math channel models have been introduced. In particular, the Rayleigh and Rician fading models are very often used when one wants to describe what wireless fading “feels” like, where Rayleigh fading is for cases with no direct (No line-of-sight(NLOS), and Rician fading is for when there’s a stronger direct path also, alongside those scattered multipath components that never really stop. On top of that, the Nakagami-(m) model brings more flexibility for tuning fading severity and it can stand in for a broad range of propagation conditions without too much trouble. Lately, though, the Two-Wave with Diffuse Power (TWDP) model has been getting a lot of attention, mainly because it can mimic setups with more than one dominant signal component, plus diffuse scattered waves, so it ends up being quite useful when you evaluate wireless communication system performance under tangled and realistic propagation scenarios [11], [12].

In recent years, Reconfigurable Intelligent Surfaces, also known as RIS, have started to look like a promising way to boost how wireless communication actually works. The idea is based on having a huge count of programmable reflecting bits that can sort of smartly tune and redirect electromagnetic waves, depending on what the link needs. Because of that, the wireless propagation environment is no longer just something static, you know it can be actively guided and fine-tuned. Not just while the transmitter or the receiver are trying to fix channel problems on their own. In other words, this ability gives new chances to improve signal clarity, widen coverage, raise spectral efficiency and strengthen the overall dependability of wireless networks [5], [13].

The effectiveness of RIS technology largely depends on the phase control strategy applied to its reflecting elements. By appropriately adjusting the phase shifts, the reflected signals can be coherently combined at the receiver(RX), resulting in enhanced received signal power and improved communication quality. Numerous studies have demonstrated that optimized phase configuration can significantly improve spectral efficiency, increase channel capacity, and mitigate the adverse effects of fading. In contrast, random phase selection often leads to suboptimal performance due to the lack of constructive signal combining at the receiver [14], [15].

Recent studies have been leaning into, kinda expanding the role of RIS technology in sixth generation, (6G) wireless networks, mixing in artificial intelligence methods and more sophisticated control mechanisms for those reflecting elements. The idea is to squeeze better network efficiency, bump up signal quality, and at the same time cut down energy usage. Also, in new research there’s been a lot of emphasis on intelligent wireless environments, as this key enabler for Beyond 5G and 6G systems, where the communication surroundings can be tuned on the fly, to handle different performance demands. So yeah, that’s why RIS technology is now commonly viewed as a real cornerstone—one of the primary building blocks, for upcoming wireless communication networks [16], [17].

2. Literature review

In 2021, two different phase configuration methods for the RIS elements, namely coherent phase shifting and random phase shifting, were considered to study the performance of RIS-assisted wireless communication systems over Nakagami-(m) fading channels. In this paper, the aim of the study was to evaluate the system performance through outage probability, BER and channel capacity. To further describe these performance metrics under various propagation conditions, analytical formulas and closed-form approximations were developed. The results showed that coherent phase shifting achieves significantly better performance than random phase shifting. Furthermore, increasing the number of RIS elements improves communication reliability and enhances the channel capacity of the system, whereas the performance of the random phase configuration remains limited despite the increase in the number of reflecting elements [18].

To investigate the effectiveness of RIS-assisted communication systems over generalized fading channels with phase noise, a unified analytical framework was created in 2022. In this paper, we studied the outage probability and diversity order of RIS elements having ideal and non-ideal phase configurations for a unified fading model which can characterize different fading channel distributions. The effect of phase errors on the performance of the system was evaluated using analytical models, and the relationship between the communication reliability and the number of reflecting elements was investigated. Results show that the optimized phase configuration helps to achieve higher diversity gains and improves the overall system performance. In addition, it is shown that the adverse effect of phase noise can be alleviated by keeping the phase error differences of RIS elements in limited ranges [19].

In 2022, a novel passive beamforming technique to RIS-assisted communication systems was proposed, which does not require phase adjustment of each reflecting element. The approach was based on the control of the on/off states of the RIS elements with fixed phase values in order to reduce implementation complexity and increase system reliability. The system performance, taking into account phase faults and spatial correlation, was evaluated SNR and outage probability. The

results showed that the proposed approach is as effective as the conventional phase optimization approaches, less sensitive to practical constraints, and can provide significant improvements in several performance metrics [20].

In 2023, the impacts of phase errors and user position uncertainty were taken into account when analyzing the performance of RIS-assisted wireless communication systems in the presence of co-channel interference. The study examined the effects of several system factors on communication performance and generated closed-form analytical formulas for outage probability and channel capacity. Additionally, the impacts of surrounding interference and transmit power on transmission efficiency and communication dependability were assessed. The findings showed that while phase errors and co-channel interference significantly affect system performance, the efficient application of RIS technology helps to improve channel capacity and lower outage probability even in less-than-ideal wireless situations [21].

In [22], performance analysis of a RIS-assisted full-duplex communication network over spatially correlated Nakagami-(m) fading channels was performed in 2024. The mathematical models for the outage probability and average achievable rate of the uplink and downlink transmissions were derived and the influence of residual self-interference on the system performance was studied. Closed-form expressions were developed to characterize the received signal statistics and to analyze the effect of spatial correlation among RIS elements. The results revealed that spatial correlation and residual self-interference have a detrimental effect on system performance. However, the deployment of RIS was shown to improve the achievable rate and reduce the outage probability when the channel characteristics are appropriately controlled.

The work in 2024 applied channel modeling techniques under the N-Wave with Diffuse Power (N-WDP) model based on unsupervised learning methodologies to characterize the similar communication channel considering the effect of phase errors and correlation between NRIS. In addition, the secrecy outage probability with different propagation environments was analyzed to evaluate the system performance. The results showed that the fading parameters and number of reflecting elements have a direct impact on the system performance. Furthermore, it was shown that poor propagation conditions and increased correlation across the RIS elements degraded the performance compared to more stable communication scenarios [23].

In 2025 the Evaluation of RIS-assisted downlink communication systems over Rician fading channels was studied to reduce outage probability and maximize channel capacity. The research designed beamforming algorithms to send beamformer for fully digital and fully analog architectures by properly configuring the parameters of the RIS to achieve optimal performance. Also, the analysis of the features of the signal-to-noise ratio was performed to give analytical bounds for channel capacity and outage probability. The results demonstrated that in scenarios with strong line-of-sight components, optimal beamforming in combination with proper setting of the RIS can significantly increase channel capacity and enhance the reliable communication [24].

In [25], The work examined the effects of spatial correlation among RIS-assisted single-input single-output (SISO) communication systems elements and different fading settings on system performance while deriving closed-form analytical formulations for BER, channel capacity, and outage probability using the moment-generating function (MGF) approach. Furthermore, the performance metrics were analyzed in relation to the number of reflecting elements, inter-element spacing, and modulation order. The findings demonstrated that communication reliability can be improved by increasing NRIS and optimizing channel conditions and bit error rate can be decreased, channel capacity can be increased. On the other hand, it was discovered that reduced system performance when using greater modulation orders. Additionally, the study showed that Nakagami-(m) Rayleigh and Rician, channels are included in the accepted generalized fading model as special cases within a unified framework for assessing RIS-assisted communication systems

Many studies have confirmed the increasing interest in Reconfigurable Intelligent Surface (RIS) technology and its promising potential to improve the performance of wireless communication systems by increasing the channel capacity, reducing the error rate, and improving the communication reliability. Most of these studies have been focused on analyzing the performance of RIS in certain fading channel models such as Rician, Rayleigh, or Nakagami-(m). Several studies have also examined how phase optimization, the number of reflecting elements, and phase errors impact system performance. In contrast, some studies are dedicated to individual performance parameters such as channel capacity, BER, treating each metric separately.

Existing studies have investigated RIS-assisted communication under specific fading conditions; however, a unified evaluation covering multiple small-scale fading models remains limited. In this work, four different fading models, namely Rayleigh, Rician, Nakagami- m , and TWDP, are investigated under the same SISO RIS-assisted communication framework.

3. Methodology

3.1 System model

A single-input single-output (SISO) wireless communication system is considered in this study, where a Reconfigurable Intelligent Surface (RIS) is employed to assist the communication between the transmitter (TX) and the receiver (RX). The RIS is positioned between both ends of the communication link and is composed of (N) passive programmable reflecting elements as shown in fig. 1. These elements modify the phase of the incident electromagnetic waves and reflect them toward the receiver to create an additional propagation path. As a result, the received signal is formed from the combination of the direct transmission path and the RIS-assisted reflected path, allowing the wireless propagation environment to be favorably adjusted and improving the overall communication performance.

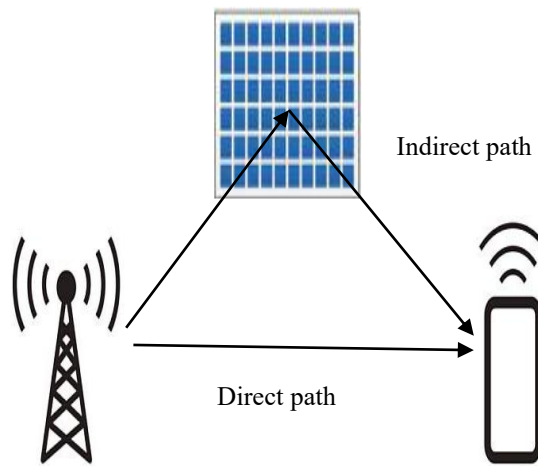


Figure 1. System model.

The transmitted binary sequence is grouped into pairs and mapped into Quadrature Phase Shift Keying (QPSK) symbols using the conventional Gray-coded modulation scheme [26]. The transmitted complex baseband symbol is expressed as in

$$x = \frac{(2b_1 - 1) + j(2b_2 - 1)}{\sqrt{2}} \quad (1)$$

where $b_1, b_2 \in \{0,1\}$ denote the transmitted bits and $j = \sqrt{-1}$. The normalization factor $1/\sqrt{2}$ ensures that the average symbol power is equal to unity before transmission through the wireless channel [26]

The received signal is modeled as the superposition of the transmitted signal after propagation through the wireless channel and the additive white Gaussian noise (AWGN). Accordingly, the received signal can be expressed as in (2)

$$y = hx + n \quad (2)$$

where y : the received signal, x is the transmitted QPSK symbol, h : the wireless channel coefficient, and n is the complex AWGN with zero mean and variance σ^2 .

3.2 Wireless Channel Model

Although conventional fading channel models such as Rayleigh, Rician, and Nakagami-m were developed several decades ago, they continue to play a fundamental role in modeling wireless propagation environments and are still widely adopted in recent studies, particularly for fifth- and sixth-generation (5G/6G) communication systems. As wireless networks continue to evolve, more sophisticated fading models, such as TWDP model, have been introduced to better represent complex multipath propagation scenarios. At the same time, the emergence of advanced technologies such as RIS has increased the need for accurate channel models capable of evaluating system performance under different propagation conditions. Therefore, this study considers four widely used fading channel models: Rayleigh, Rician, Nakagami-m, and TWDP, to investigate the impact of different propagation environments on the performance of the proposed RIS-assisted wireless communication system

3.2.1 Rayleigh fading channel

The Rayleigh model is widely used to characterize wireless propagation environments where NLOS component exists between TX and RX. In this case, the received signal is formed by the superposition of a large number of independently scattered multipath components. Consequently, the complex channel coefficient is modeled as a unit variance and complex Gaussian random variable with zero mean, which is expressed as $h_{Ray} \sim CN(0,1)$

In the MATLAB simulation, the Rayleigh channel coefficient is generated as in (3)

$$h_{Ray} = \frac{x + jy}{\sqrt{2}} \quad (3)$$

where x and y are independent Gaussian random variables with zero mean and unit variance [13]

3.2.2 Rician fading Channel

The Rician model describes propagation environments where a dominant LOS component coexists with multiple scattered multipath components. Compared with the Rayleigh model, the presence of the LOS path generally improves the received signal reliability and reduces the severity of fading. The complex channel coefficient is modeled as in (4) [27]

$$h_n = \sqrt{\frac{k_n}{1+k_n}} \bar{h}_n + \sqrt{\frac{k_n}{1+k_n}} \tilde{h}_n \quad (4)$$

where k_n : the Rician factor representing the power ratio between the LOS and scattered components, $\bar{h}_n$: the deterministic LOS component, and $\tilde{h}_n \sim CN(0, 1)$ represents the scattered component.

For the MATLAB simulation, the Rician channel is generated using a Rician factor of K, yielding

$$h_{Ric} = \sqrt{\frac{k}{k+1}} + \sqrt{\frac{1}{k+1}} \left(\frac{x + jy}{\sqrt{2}} \right) \quad (5)$$

Where $x, y \sim N(0, 1)$.

This implementation is mathematically equivalent to the analytical Rician channel model above, with K, k_n corresponding to the Rician factor.

3.2.3 Nakagami -m Fading Channel

The Nakagami-m model is widely adopted to characterize wireless channels with different fading severities due to its high flexibility in representing various propagation environments. The fading behavior is controlled by the parameter m, where smaller values correspond to more severe fading, while larger values indicate less severe channel fluctuations. In particular, this model reduces to the Rayleigh when $m = 1$ fading model.

In this model, the channel envelope is generated from a Gamma-distributed random variable. Accordingly, the channel coefficient is expressed as in (6)

$$h = r e^{j\theta} \quad (6)$$

where the channel amplitude is $r = \sqrt{x}$ with $x \sim \Gamma(m, \frac{1}{m})$ and $\theta \sim U(0, 2\pi)$.

In the MATLAB simulation, the fading coefficient is generated by drawing the channel amplitude from the Gamma distribution with fading parameter m, while the phase is uniformly distributed over $[0, 2\pi)$. This implementation accurately represents the complex Nakagami-m fading channel adopted throughout the performance evaluation [27]

3.2.4 (TWDP) fading model

The Two-Wave with Diffuse Power (TWDP) model represents a wireless channel consisting of two dominant specular components and a diffuse Gaussian component. It is characterized by the parameters K and Δ , which determine the fading behavior under different propagation conditions

The complex channel coefficient is expressed as in (7)

$$h = V_1 e^{j\phi_1} + V_2 e^{j\phi_2} + g \quad (7)$$

where V_1 and V_2 are the amplitudes of the two dominant specular components, ϕ_1 and ϕ_2 denote their phases, and $g \sim \text{CN}(0, 2\sigma^2)$ is the diffuse Gaussian component. The TWDP channel is characterized by (8) and (9)

$$K = \frac{V_1^2 + V_2^2}{2\sigma^2} \quad (8)$$

$$\Delta = \frac{2V_1V_2}{V_1^2 + V_2^2} \quad (9)$$

where K : the ratio of the total specular power to the diffuse power, Δ : the relative strength of the two dominant specular components. When $K=0$, the TWDP model reduces to the Rayleigh fading model, whereas $\Delta=0$ corresponds to the Rician fading model [28].

In this work, the parameters K and Δ are fixed according to the simulation parameters

3.3 Minimum Mean Square Error (MMSE) Equalization

After QPSK modulation and transmission through the wireless channel, a MMSE equalizer is employed at the receiver to mitigate the effects of channel fading and additive noise [29], [30]. For the considered channel, the MMSE equalization weight is calculated as in (10)

$$W = \frac{h^*}{|h|^2 + \sigma^2} \quad (10)$$

where h represents the channel coefficient and h^* is its complex conjugate. The equalized signal is then obtained as in (11) [30].

$$\hat{x} = Wy \quad (11)$$

where y : the received signal and is the estimated transmitted QPSK signal. The estimated signal is subsequently detected using the sign of its real and imaginary components, and the resulting symbols are used to calculate the BER.

The main simulation parameters adopted for the considered communication system are summarized in Table I. These parameters define the simulation settings used to evaluate the system performance under the considered fading conditions and RIS configuration

TABLE 1. Simulation Parameters

Parameters	Value
Number of transmitted symbols, N_{sym}	1×10^5
Modulation scheme	QPSK
Transmit power, P_t	1(normalized)
Number of RIS elements, N_{RIS}	50
RIS reflection coefficient, α	0.5
Rician K-factor	3
Nakagami-m parameter	1.5
TWDP K-factor	5
TWDP Δ	0.5
Receiver equalizer	MMSE

3.4 RIS-Assisted Channel Modeling

conventional communication system without RIS, the received signal is expressed as in (12)

$$y_{\text{NoRIS}} = h_d x + n \quad (12)$$

where h_d denotes the direct wireless channel between TX and RX, & x is the transmitted symbol, and n represents the additive white Gaussian noise (AWGN)

When the RIS is deployed, the received signal is affected by both the direct propagation path and the reflected path introduced by the RIS. Consequently, the equivalent channel can be written as

$$h_{eff} = h_d + \alpha h_{RIS} \quad (13)$$

where h_{RIS} denotes the equivalent reflected channel generated by the RIS and α is the RIS reflection coefficient [13].

According to the standard RIS signal model presented in [13], the equivalent channel is expressed as in (14)

$$h_{eff} = h_d + h_2^H \Theta h_1 \quad (14)$$

where h_d denotes the direct channel, h_1 is the channel between the transmitter and the RIS, h_2 is Hermitian transpose of the channel between the RIS and the receiver, Θ is the diagonal matrix containing the adjustable phase shifts of the RIS elements and $h_2^H \Theta h_1$ represents the RIS reflection matrix

The RIS reflection matrix is defined as

$$\Theta = \text{diag}(e^{j\theta_1}, e^{j\theta_2}, \dots, e^{j\theta_N}) \quad (15)$$

where N is the number of reflecting elements and θ_n is the adjustable phase shift of the n -th RIS element. Since the propagation environment is modeled using Rayleigh fading, each cascaded channel coefficient is assumed to follow a complex Gaussian distribution $h_{2,n}, h_{1,n} \sim CN(0,1)$ [31]

By expanding the matrix multiplication in (14), an equivalent element-wise representation can be obtained using standard matrix algebra which represents the contribution of each reflecting element to the received signal.

$$h_2^H \Theta h_1 = \sum_{n=1}^N h_{2,n} \theta_n h_{1,n} \quad (16)$$

To maximize the magnitude of the equivalent channel, each RIS element phase is selected to compensate for the phase of the corresponding cascaded channel and align the reflected signal with the direct channel. Consequently, the reflection coefficient is obtained as [17]

$$\theta_n = e^{j(\angle h_d - \angle(h_{1,n} h_{2,n}))} \quad (17)$$

Substituting (17) into (16), the reflected channel is obtained as

$$h_{RIS} = \sum_{n=1}^N h_{2,n} \theta_n h_{1,n} \quad (18)$$

The received instantaneous SNR used in the simulation is calculated as in (19)

$$\gamma = \frac{P_t |h_{eff}|^2}{\sigma^2} \quad (19)$$

where P_t is the transmit power and σ^2 is the noise power. The corresponding instantaneous channel capacity is calculated according to the Shannon capacity expression in (20)

$$C = \log_2(1 + \gamma) \quad (20)$$

in bits/s/Hz. The use of RIS phase optimization for improving channel capacity through constructive combining is consistent with established RIS capacity studies [32].

4. Results

Modern wireless communication systems have witnessed rapid advancements in techniques aimed at improving transmission quality and mitigating fading effects, especially with the emergence of Reconfigurable Intelligent Surface (RIS) technology as one of the promising solutions for next-generation networks. Therefore, this section focuses on analyzing the performance of several wireless channel models and investigating the impact of RIS technology on Bit Error Rate (BER) and channel Capacity under different propagation conditions. A series of simulations was carried out using Nakagami, Rayleigh, Rician, and TWDP channel models to evaluate system efficiency and compare the behavior of each channel before and after applying RIS.

4.1 BER Performance Comparison under Different Channels

First, the BER performance of the SISO system was evaluated over four different small-scale fading channels (TWDP, Rayleigh, Rician and Nakagami-m) without the introduction of the RIS. This served as a baseline to evaluate the subsequent impact of RIS-assisted transmission. As expected, the BER decreases as the SNR increases for all considered channel models, indicating improved detection performance under higher signal-to-noise conditions. However, noticeable differences can be observed among the fading channels.

In Fig. 2, The Rayleigh channel exhibits the highest BER over most of the considered SNR range. This behavior is associated NLOS and the resulting severe amplitude fluctuations. At 10 dB, the obtained BER is approximately 0.0770.

The Rician channel provides better performance than the Rayleigh channel, with a BER of approximately 0.0351 at 10 dB. The improvement is attributed to the presence of a dominant component in addition to the diffuse multipath component.

The Nakagami-m channel provides an intermediate performance between the Rayleigh and Rician cases for the selected value of $m = 1.5$. At 10 dB, the BER is approximately 0.0474. This indicates that the fading severity is strongly influenced by the selected Nakagami-m parameter.

Among the considered channel models, the TWDP channel achieves the lowest BER for the selected parameters, with a BER of approximately 0.0080 at 10 dB. This indicates a less severe fading condition for the adopted TWDP parameters ($K=5$ and $\Delta=0.5$).

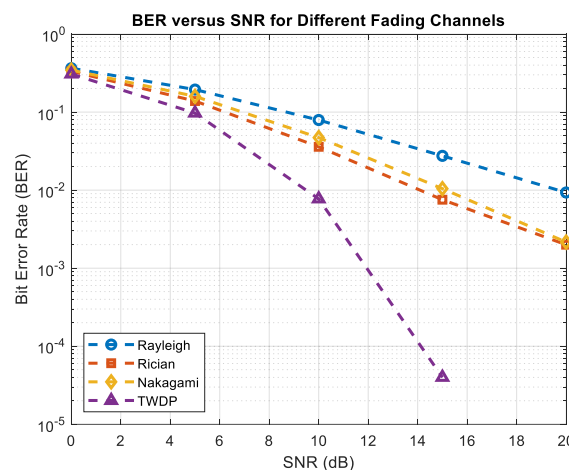


Figure 2. BER Performance Comparison for different fading

Having established the baseline performance of the four fading channels, the RIS is subsequently introduced to investigate its ability to improve the BER performance under the same channel conditions.

4.2 Impact of RIS on All Channel Models

After introducing the RIS, the BER decreases for all four fading channels. This improvement is mainly due to the phase adjustment of the RIS elements, which aligns the reflected signal with the direct signal and enables constructive combining.

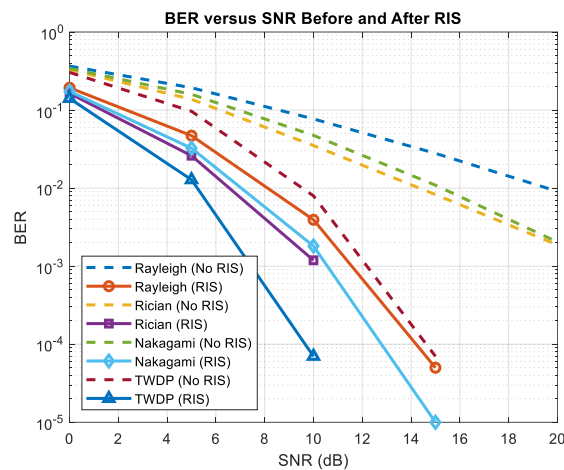


Figure 3. Bit Error Rate (BER) Vs. Signal to noise Ratio for all channels models before and after RIS

At 10 dB, the BER decreases from 0.0770 to 0.0039 for the Rayleigh channel, from 0.0351 to 0.0012 for the Rician channel, and from 0.0474 to 0.0018 for the Nakagami-m channel. For the TWDP channel, the BER decreases from 0.0080 to approximately 0.0001. These results demonstrate that the RIS provides a substantial improvement in link reliability under all four fading conditions. The difference in the improvement is mainly related to the characteristics of each fading channel. Rayleigh experiences more severe fading and does not contain a dominant line-of-sight component; therefore, the additional controllable RIS path provides a significant benefit. Rician already contains a dominant component, so its initial BER is lower, while the RIS provides an additional coherent path that further improves the performance. Nakagami-m has a fading severity controlled by the parameter m , and with $m = 1.5$, it shows an intermediate response to the RIS. TWDP, with the selected parameters $K = 5$ and $\Delta = 0.5$, already provides the lowest BER before RIS; therefore, its absolute improvement is more limited, although its final BER remains the lowest.

overall, the results confirm that the 50-element RIS improves the reliability of the SISO system under all considered fading conditions.

4.3 Effect of the Number of RIS Elements

Fig. 4 shows the BER performance for different numbers of RIS elements, $NRIS = 10, 20$, and 50 , under the four considered fading channels. A clear improvement in BER performance is observed as the number of RIS elements increases. At low SNR, the effect of increasing the $NRIS$ is particularly noticeable. For example, at 0 dB, the Rayleigh BER decreases from 0.0577, for $NRIS = 10$ to 0.0188 for $NRIS = 20$ and further to 0.0011 for $NRIS = 50$. Similar behavior is observed for the Rician, Nakagami-m, and TWDP channels.

By adjusting the phase of each element of RIS, the reflected signals are coherently combined at the receiver, resulting in a stronger effective channel as the $NRIS$ increases. The comparison among the four fading channels also indicates that the BER response depends on the underlying fading characteristics. The Rician channel exhibits lower BER values, whereas the Rayleigh channel shows higher BER values under same RIS configurations. Nakagami-m and TWDP exhibit intermediate and relatively similar behavior across the considered RIS configurations. This difference is related to the distinct statistical characteristics of the considered fading environments and their influence on the effective channel.

The benefit of increasing $NRIS$ is particularly evident at low SNR, where the additional reflected components provide a more noticeable improvement in the received signal quality. At higher SNR values, the BER becomes very small for most configurations within the simulated number of symbols, making the performance differences between different RIS sizes less distinguishable. Overall, increasing the number of RIS e from 10 to 20 and then to 50 improves the BER performance of the SISO system across all considered fading channels, while the comparison demonstrates that the underlying fading characteristics also affect the magnitude of the achieved improvement.

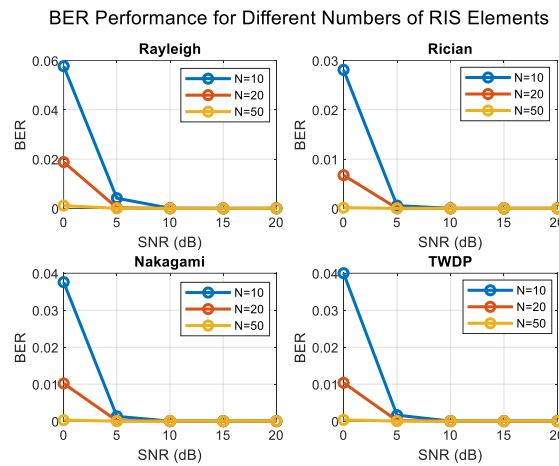


Figure 4. BER Performance for Different Number of RIS Elements

4.4 RIS and Effective channel power Gain Analysis

The RIS channel power represents the average power contributed by the reflected path through the RIS, while the effective channel power represents the overall received channel power after combining the direct and RIS-assisted components. These measures are used to evaluate the contribution of the RIS and to explain the resulting changes in system performance.

Fig. 5(a) and (b) show the variation of the RIS channel power and the effective channel power with the number of RIS elements. The results show a clear increase in both quantities as N_{RIS} increases from 10 to 50. For example, in the Rayleigh channel, the RIS channel power increases from 6.5525 to 12.7231 and then to 31.2188, while the effective channel power increases from 4.8370 to 7.2917 and 13.7238 for N_{RIS} 10, 20, and 50, respectively. A similar trend is observed for the Rician, Nakagami-m, and TWDP channels

The Rician channel achieves the highest effective channel power, reaching 16.8325 at N_{RIS} 50, while Nakagami-m and TWDP show relatively similar behavior and Rayleigh exhibits lower power levels. This difference is related to the statistical characteristics of the considered fading channels. Increasing N_{RIS} increases the number of coherently combined reflected components, thereby strengthening the effective channel and contributing to the BER improvement observed in Fig. 4.

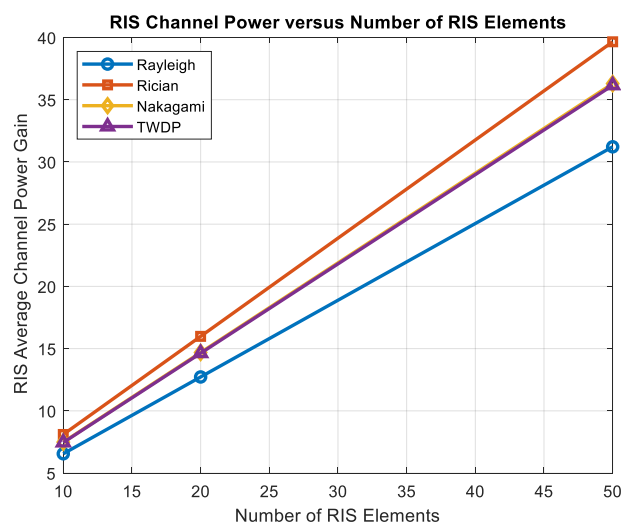


Figure 5a. channel power Gain Vs. Number of RIS Elements

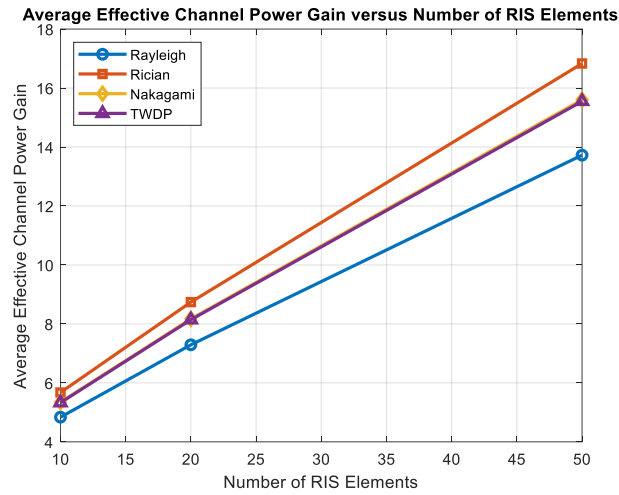


Figure 5b. Effective channel power Gain Vs. Number of RIS Elements

4.5 Channel Capacity Using RIS

Fig. 6 shows the channel capacity as a function of SNR for the four considered small-scale fading channels, with and without the 50-element RIS. The capacity increases consistently with SNR for all channels.

At 20 dB, the capacity increases from 5.88 to 17.28 bits/s/Hz for Rayleigh, from 6.28 to 17.64 bits/s/Hz for Rician, from 6.15 to 17.51 bits/s/Hz for Nakagami-m, and from 6.10 to 17.50 bits/s/Hz for TWDP

Without RIS, the capacity values remain relatively close, reflecting the similar average channel conditions under the considered normalized fading models. After introducing the RIS, a significant increase in capacity is observed for all four channels. Although the capacity values remain relatively close among the four fading channels, the RIS provides a clear capacity improvement across all considered fading conditions. Overall, the results confirm that the 50-element RIS can significantly enhance the spectral efficiency of the SISO system.

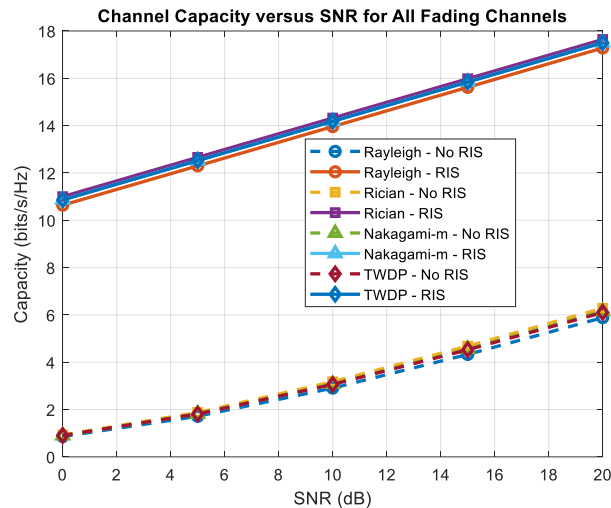


Figure 6. channel capacity Vs. SNR for all channels No RIS and RIS

5. Conclusions

The results demonstrate that the considered fading channels exhibit different performance characteristics in RIS-assisted SISO communication. Among the considered models, the Rician channel generally provides the best performance, while the Rayleigh channel exhibits the lowest performance in terms of the evaluated metrics. Nakagami-m and TWDP channels show intermediate behavior, with their performance remaining relatively close to each other. The power results confirm that increasing the RIS size strengthens the reflected and effective channels under all considered fading conditions. The

comparison also indicates that the channel fading characteristics influence the resulting power levels, with Rician showing the strongest response and Nakagami-m and TWDP maintaining similar behavior, whereas Rayleigh provides the lowest levels. The results also confirm that RIS deployment improves the performance of all four fading environments. The channel capacity increases across all considered fading environments, indicating improved spectral efficiency with RIS assistance. Overall, the comparison highlights the importance of the underlying fading characteristics when evaluating RIS-assisted wireless communication.

References

- [1] A. L. Challob, "Data Transfer in Smart Grids: Leveraging MIMO-OFDM for Enhanced Communication," *International Journal of Computational and Electronic Aspects in Engineering*, vol. 5, no. 4, pp. 154–164, 2024.
- [2] T. F. Y. Al Sharify and H. R. H. Al Dallal, "The Evolution of Communication Engineering in Iraq," *International Journal of Computational and Electronic Aspects in Engineering*, vol. 3, no. 3, pp. 55–62, 2022.
- [3] J. S. Alrubaye, "Enhancing Network Efficiency through Advanced Resource Allocation Techniques in Multi-hop V2I Routing," *International Journal of Computational and Electronic Aspects in Engineering*, vol. 5, no. 4, pp. 165–182, 2024.
- [4] M. K. Abbas, "Modelling WhatsApp Traffic Control Time-Based (WTCTB) for 5G Mobile Network," *International Journal of Computational and Electronic Aspects in Engineering*, vol. 4, no. 4, pp. 110–118, 2023.
- [5] M. D. Renzo, A. Zappone, M. Debbah, M. S. Alouini, C. Yuen, J. de Rosny, and S. Tretakov, "Smart radio environments empowered by reconfigurable intelligent surfaces: How it works, state of research, and road ahead," *IEEE Journal on Selected Areas in Communications*, vol. 38, no. 11, pp. 2450–2525, 2020.
- [6] R. A. Hussein and S. A. Ayoob, "Performance analysis of NOMA using different types receivers," in *Proc. 2021 4th Int. Conf. on Information and Communications Technology (ICOIAC)*, 2021.
- [7] B. J. Qeryaqos and S. A. Ayoob, "Proposed multiple reconfigurable intelligent surfaces to mitigate the inter-user-interference problem in NLOS," *Journal of Communications Software and Systems*, vol. 20, no. 3, pp. 245–252, 2024.
- [8] S. K. Ghanim, "Hybrid ResNet50 and DenseNet121 with Adaptive Weighted Feature Fusion in Infectious Chest Diseases Classification," *International Journal of Computational and Electronic Aspects in Engineering*, vol. 7, no. 2, pp. 211–226, June 2026.
- [9] M. K. Yousif, "Enhanced Diabetic Retinopathy Classification using Hybrid EfficientNetB0 with CBAM," *International Journal of Computational and Electronic Aspects in Engineering*, vol. 7, no. 2, pp. 176–188, May 2026.
- [10] M. A. ElMossallamy, H. Zhang, L. Song, K. G. Seddik, Z. Han, and G. Y. Li, "Reconfigurable intelligent surfaces for wireless communications: Principles, challenges, and opportunities," *IEEE Transactions on Cognitive Communications and Networking*, vol. 6, no. 3, pp. 990–1002, 2020.
- [11] M. K. Simon and M.-S. Alouini, *Digital Communication over Fading Channels*, 2nd ed. Hoboken, NJ, USA: Wiley, 2005.
- [12] G. D. Durgin, T. S. Rappaport, and A. de Wolf, "New analytical models and probability density functions for fading in wireless communications," *IEEE Trans. Commun.*, vol. 50, no. 6, pp. 1005–1015, Jun. 2002.
- [13] Q. Wu and R. Zhang, "Intelligent reflecting surface enhanced wireless network via joint active and passive beamforming," *IEEE Trans. Wireless Commun.*, vol. 18, no. 11, pp. 5394–5409, 2019.
- [14] C. Huang, A. Zappone, G. C. Alexandropoulos, M. Debbah, and C. Yuen, "Reconfigurable intelligent surfaces for energy efficiency in wireless communication," *IEEE Trans. Wireless Commun.*, vol. 18, no. 8, pp. 4157–4170, 2019.
- [15] S. Gong, X. Lu, D. T. Hoang, D. Niyato, L. Shu, D. I. Kim, and Y. C. Liang, "Toward Smart Wireless Communications via Intelligent Reflecting Surfaces: A Contemporary Survey," *IEEE Communications Surveys & Tutorials*, vol. 22, no. 4, pp. 2283–2314, 2020.
- [16] A. Kumar Singh, R. Patil, and S. Gupta, "A survey on intelligent reconfigurable/reflecting surface in 6G communication," in *Proc. 2025 3rd Int. Conf. on Device Intelligence, Computing and Communication Technologies (DICCT)*, Dehradun, India, 2025, pp. 470–475.
- [17] Y. E. Tok, A. G. Toprak, S. N. Karahan, et al., "Artificial intelligence for next-generation 6G technologies and networks," *Discov. Netw.*, vol. 2, p. 3, 2026.
- [18] D. Selimis, K. P. Peppas, G. C. Alexandropoulos, and F. I. Lazarakis, "On the performance analysis of RIS-empowered communications over Nakagami-m fading," *IEEE Commun. Lett.*, vol. 25, no. 7, pp. 2191–2195, Jul. 2021.
- [19] I. Trigui, W. Ajib, W.-P. Zhu, and M. Di Renzo, "Performance evaluation and diversity analysis of RIS-assisted communications over generalized fading channels in the presence of phase noise," *IEEE Open J. Commun. Soc.*, vol. 3, pp. 593–607, 2022.
- [20] A. Khaleel and E. Basar, "Phase shift-free passive beamforming for reconfigurable intelligent surfaces," *IEEE Trans. Commun.*, vol. 70, no. 10, pp. 6966–6976, Oct. 2022.
- [21] Y. Bian, D. Dong, J. Jiang, and K. Song, "Performance analysis of reconfigurable intelligent surface-assisted wireless communication systems under co-channel interference," *IEEE Open J. Commun. Soc.*, vol. 4, pp. 596–605, 2023.

- [22] T. Wang, G. Chen, and J. P. Coon, "Performance analysis of RIS-assisted full-duplex communication over correlated Nakagami-m fading channel," *IEEE Trans. Veh. Technol.*, vol. 73, no. 3, pp. 3430–3444, Mar. 2024.
- [23] J. D. Vega-Sánchez, A. Zambrano, R. Mena, and J. Oscullo, "Information-theoretic security of RIS-aided MISO system under N-wave with diffuse power fading model," *Engineering Proceedings*, vol. 77, no. 1, 2024.
- [24] K. K. Kota, P. D. Mankar, and H. S. Dhillon, "Characterization of capacity and outage of RIS-aided downlink systems under Rician fading," *IEEE Wireless Commun. Lett.*, vol. 14, no. 3, pp. 631–635, Mar. 2025.
- [25] S. Penchala, S. K. Bandari, A. Sarkhel, et al., "Performance evaluation of IRS-assisted system under spatially correlated generalized fading channel," *Wireless Pers. Commun.*, vol. 146, pp. 279–307, 2026.
- [26] J. G. Proakis and M. Salehi, *Digital Communications*, 5th ed. New York, NY, USA: McGraw-Hill, 2008.
- [27] W. Liu, Y. Cui, F. Yang, L. Ding, and J. Sun, "MLE-based device activity detection under Rician fading for massive grant-free access with perfect and imperfect synchronization," *IEEE Trans. Wireless Commun.*, 2024.
- [28] D. Dixit and P. R. Sahu, "Performance of QAM signaling over TWDP fading channels," *IEEE Trans. Wireless Commun.*, vol. 12, no. 4, pp. 1794–1799, Apr. 2013.
- [29] R. A. Hussein and S. A. Ayoob, "Doppler shift effect with non-orthogonal multiple access technology for 5G system," in *Proc. 2nd Int. Multi-Disciplinary Conf. Theme: Integrated Sciences and Technologies (IMDC-IST 2021)*, Sakarya, Turkey, 2022, pp. 7–9.
- [30] K. Swain and M. K. Sahoo, "FPGA Implementation of LMS Algorithm Used in Adaptive Equalizer," *International Journal of Computational and Electronic Aspects in Engineering*, vol. 1, no. 1, pp. 45–51, 2014.
- [31] A. Goldsmith, *Wireless Communications*. Cambridge, U.K.: Cambridge University Press, 2005.
- [32] N. S. Perović, M. Di Renzo, and M. F. Flanagan, "Channel capacity optimization using reconfigurable intelligent surfaces in indoor mm Wave environments," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Dublin, Ireland, 2020, pp. 1–7.