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Simulation of BER Performance for BPSK and QPSK over SISO and SIMO (1×2, 1×4) Systems for Image Transmission under Flat Fading Channel Conditions

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محاكاة أداء معدل الخطأ في البت (BER) لأنظمة BPSK و QPSK عبر أنظمة (SISO) و (SIMO 1×2, 1×4) لنقل الصور تحت ظروف قناة التلاشي المسطح (Flat Fading)

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Abstract:
This study presents a detailed simulation-based analysis of Bit Error Rate (BER) performance for Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK) modulation schemes, focusing on their application in image transmission over wireless communication systems. The performance evaluation is conducted over both Single-Input Single-Output (SISO) and Single-Input Multiple-Output (SIMO) configurations, specifically 2 and 1×4 antenna systems, under the influence of flat fading channel conditions. The primary objective is to assess how the introduction of receive diversity via multiple antennas impacts the robustness and efficiency of data transmission. The study replicates realistic wireless channel conditions by employing a flat Rayleigh fading model, allowing for an accurate evaluation of modulation performance in fading environments. Simulation results indicate that SIMO systems, particularly those with higher diversity orders (e.g., 1×4), exhibit significantly improved BER performance compared to SISO systems. Both BPSK and QPSK show enhanced resilience to channel impairments when used with multiple receive antennas. While BPSK demonstrates superior error performance in severe fading conditions, QPSK offers higher spectral efficiency with a moderate trade-off in BER. Furthermore, the study examines the degradation of image quality as a function of channel fading severity, offering practical insights for the design of reliable wireless image transmission systems.

Keywords: Bit Error Rate (BER), Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), Single-Input Single-Output (SISO), Single-Input Multiple-Output (SIMO), Flat Fading Channel, Image Transmission.

الملخص
تقدم هذه الدراسة تحليلاً مفصلاً قائماً على المحاكاة لأداء معدل الخطأ في البت (BER) لمخططات التعديل بإزاحة الطور الثنائي (BPSK)والإزاحة الرباعية للطور(QPSK) ، مع التركيز على تطبيقاتها في نقل الصور عبر أنظمة الاتصالات اللاسلكية. تم إجراء تقييم الأداء عبر تكوينات الأنظمة أحادية المدخلات والمخرجات (SISO) والأنظمة أحادية المدخلات ومتعددة المخرجات(SIMO) ، وتحديداً أنظمة الهوائيات (1×2) و (1×4)، تحت تأثير ظروف قناة التلاشي المسطح. الهدف الأساسي هو تقييم مدى تأثير إدخال تنوع الاستقبال (Receive Diversity) عبر الهوائيات المتعددة على متانة وكفاءة نقل البيانات. تحاكي الدراسة ظروف القناة اللاسلكية الواقعية باستخدام نموذج "رايلي" للتلاشي المسطح(Flat Rayleigh Fading) ، مما يتيح تقييماً دقيقاً لأداء التعديل في بيئات التلاشي. تشير نتائج المحاكاة إلى أن أنظمةSIMO ، وخاصة تلك ذات رتب التنوع الأعلى (مثل 1×4)، تظهر تحسناً كبيراً في أداء معدل الخطأ في البت (BER) مقارنة بأنظمة SISO. أظهر كل من BPSK و QPSK مرونة معززة تجاه اختلالات القناة عند استخدامهما مع هوائيات استقبال متعددة. وبينما أظهر BPSK أداءً فائقاً في مواجهة الأخطاء في ظروف التلاشي الشديدة، وفر QPSK كفاءة طيفية أعلى مع مقايضة معتدلة في معدل BER. علاوة على ذلك، تفحص الدراسة تدهور جودة الصورة كدالة لشدة تلاشي القناة، مما يقدم رؤى عملية لتصميم أنظمة موثوقة لنقل الصور لاسلكياً.

الكلمات المفتاحية :معدل الخطأ في البت(BER) ، التعديل بإزاحة الطور الثنائي(BPSK) ، التعديل بإزاحة الطور الرباعي(QPSK) ، نظام أحادي المدخلات والمخرجات(SISO) ، نظام أحادي المدخلات ومتعدد المخرجات(SIMO) ، قناة التلاشي المسطح، نقل الصور.

1. Introduction

In the field of wireless communication, the accurate assessment of Bit Error Rate (BER) is crucial for evaluating the performance of different modulation schemes and channel configurations. BER represents the proportion of bits received incorrectly over a communication channel and serves as a direct indicator of transmission quality and system reliability. As modern communication systems increasingly support high-speed data, video, and image transmission, minimizing BER becomes essential to maintain service quality in diverse environments [1, 2]. Digital modulation schemes are fundamental to modern wireless systems, as they determine how binary data is represented on analog carrier signals. They play a key role in optimizing bandwidth usage, improving data rates, and enhancing the robustness of transmissions against channel impairments such as noise and interference. By selecting an appropriate modulation scheme, engineers can balance trade-offs between performance, complexity, and spectral efficiency [3, 4]. With the rapid growth of wireless technologies and demand for multimedia communication, the evaluation of modulation techniques under realistic channel conditions is more important than ever [5, 6]. An in-depth understanding of BER performance under different operating conditions provides critical insights into the design of reliable communication systems. This includes the effect of modulation choice, channel model, and antenna configuration on overall system behavior. Simulation-based BER analysis is a practical approach to test system performance and validate design strategies before physical deployment [5-9]. In particular, understanding how systems behave in challenging fading environments helps inform choices for real-world applications such as mobile video streaming, sensor networks, and image transmission. To ensure effective image transmission, modulation techniques such as Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK) are often used. BPSK uses two phase states to represent binary data, making it relatively simple and highly robust against noise. QPSK, by contrast, uses four phase states to represent two bits per symbol, effectively doubling the data rate compared to BPSK while maintaining a similar bandwidth footprint [10-12]. These modulation techniques offer a balance between performance and complexity and are widely implemented in various wireless communication standards. The Single-Input Single-Output (SISO) system, which uses one antenna for both transmission and reception, represents the simplest wireless configuration. However, SISO systems are susceptible to channel fading, which can cause severe degradation in signal quality. To improve reliability and mitigate fading effects, Single-Input Multiple-Output (SIMO) systems use multiple antennas at the receiver side. This introduces spatial diversity, which allows the receiver to combine multiple independently faded copies of the transmitted signal and reduce the probability of error [13].

In this research, SIMO configurations of 1×2 and 1×4 are considered, involving one transmitting antenna and two or four receiving antennas, respectively. These setups offer a practical and cost-effective means of improving system performance, particularly when expanding the number of transmit antennas (as in MIMO systems) is not feasible. The comparison between SISO and SIMO systems allows for an analysis of how increasing receiver diversity influences BER performance under flat fading conditions. Flat fading, also known as non-frequency-selective fading, affects all frequency components of a signal equally, introducing amplitude and phase distortions due to multipath propagation. Incorporating this model into simulations ensures a realistic representation of wireless channel behavior. Image transmission is chosen as the application focus because of its sensitivity to bit errors, which can significantly degrade visual quality. Evaluating the BER performance of BPSK and QPSK in both SISO and SIMO configurations under flat fading provides meaningful insights into the development of more robust and efficient wireless image transmission systems.

2. Theory and Concepts

This section provides a brief overview of key terms and concepts relevant to this research, laying the theoretical foundation necessary for understanding the subsequent analysis.

2.1 Bit Error Rate (BER)

Bit Error Rate (BER) is a fundamental performance metric widely used in digital communication systems to assess transmission quality. It is defined as the ratio of the number of incorrectly received bits to the total number of transmitted bits during a specific time or over a given data block. BER provides a direct measure of the error performance and reliability of a communication link, where a lower BER indicates a higher quality and more reliable data transmission channel [7, 10]. The BER is influenced by multiple factors including the modulation scheme employed, channel conditions, signal-to-noise ratio (SNR), interference from other signals, and the design of the receiver's detection algorithms [11, 14, 15]. For example, modulation schemes with higher-order constellations typically achieve greater spectral efficiency but at the expense of increased sensitivity to noise and fading, resulting in a higher BER under poor channel conditions. Conversely, simpler modulation schemes, while more robust, may limit data throughput [16]. Evaluating BER performance is essential for comparing and optimizing different modulation schemes and communication system architectures. It helps engineers identify trade-offs between data rate, complexity, and error resilience, ultimately guiding the design of robust communication systems tailored for specific application requirements. In this study, BER analysis plays a central role in assessing how BPSK and QPSK modulations perform over SISO and SIMO systems, particularly in the presence of flat fading channels.

2.2 Modulation Schemes

This section introduces the two modulation schemes analyzed in this study—Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK). These schemes are widely used in wireless communication systems due to their balance between complexity, spectral efficiency, and robustness.

2.2.1 Binary Phase Shift Keying

Binary Phase Shift Keying (BPSK) is one of the simplest digital modulation schemes. It represents binary data by shifting the phase of a carrier wave between two values, typically 0° and 180°, corresponding to the binary symbols 0 and 1, respectively [5]. Because BPSK uses only two distinct phases, it transmits 1 bit per symbol. The key advantage of BPSK lies in its relative simplicity and robustness to noise, making it suitable for low data-rate and power-constrained applications. However, due to its limited phase states, BPSK is more susceptible to noise and fading compared to higher-order modulation schemes [15]. In practical terms, when the input binary data switches from 0 to 1 or from 1 to 0, the modulated signal undergoes a phase shift of 180°, effectively encoding the bit transitions into distinct carrier phase changes [12, 15, 17].

2.2.2 Quadrature Phase Shift Keying

Quadrature Phase Shift Keying (QPSK) extends the concept of phase modulation by utilizing four distinct phase shifts—typically 0°, 90°, 180°, and 270°—to represent data. This allows QPSK to encode 2 bits per symbol, effectively doubling the data rate compared to BPSK for the same symbol rate [8, 14]. By mapping two bits onto each phase state, QPSK achieves improved spectral efficiency, making it a popular choice for modern wireless systems. However, the increased number of phase states requires a higher signal-to-noise ratio (SNR) to maintain reliable communication, rendering it somewhat more sensitive to channel impairments than BPSK [8, 14]. In the QPSK scheme, the four possible bit combinations—00, 01, 10, and 11—are each assigned to a unique phase shift, enabling efficient and compact representation of binary data [15, 17].

2.3 Single-Input Single-Output

Single-Input Single-Output (SISO) refers to a fundamental wireless communication system configuration where a single antenna is used for both transmitting and receiving signals. This setup represents the most basic form of point-to-point wireless communication, in which the transmitter sends signals through one antenna, and the receiver captures them via another single antenna, establishing a one-to-one communication link [16]. SISO systems are favored for their simplicity, ease of implementation, and low cost, making them prevalent in many early-generation and low-complexity wireless applications. Despite these advantages, SISO systems inherently face significant limitations in terms of reliability, coverage, and data throughput, especially under challenging channel conditions such as multipath fading, shadowing, and interference. Because SISO systems lack spatial diversity, they cannot mitigate the detrimental effects of fading and signal attenuation caused by the wireless propagation environment. This absence of diversity results in frequent deep fades where the signal strength drops sharply, increasing the likelihood of errors during data transmission and thereby degrading the Bit Error Rate (BER) performance [18]. Consequently, SISO links often suffer from reduced robustness, leading to potential outages or poor quality of service in mobile and urban scenarios where fading is severe. Moreover, the spectral efficiency of SISO is limited by the single transmission path, restricting the maximum achievable data rates. As wireless communication demands evolve towards higher data throughput and better reliability, more sophisticated antenna configurations—such as Single-Input Multiple-Output (SIMO), Multiple-Input Single-Output (MISO), and Multiple-Input Multiple-Output (MIMO) systems—have been developed. These advanced systems exploit spatial diversity and multiplexing to significantly improve system capacity, link reliability, and resistance to channel impairments [12, 16]. Despite these challenges, SISO remains a fundamental model for understanding wireless communication principles and serves as a baseline for performance comparisons against more complex multiple-antenna systems.

2.4 Single-Input Multiple-Output

Single-Input Multiple-Output (SIMO) is a wireless communication system configuration in which a single antenna is used for transmitting signals, while multiple antennas are deployed at the receiver side. This architecture leverages receiver-side spatial diversity to improve signal reception and combat the adverse effects of wireless channel impairments, particularly multipath fading [19]. In SIMO systems, the transmitted signal travels over multiple propagation paths and is received independently by each antenna. These multiple copies of the signal, each experiencing different fading conditions, are then processed at the receiver using diversity combining techniques such as Maximum Ratio Combining (MRC), Selection Combining (SC), or Equal Gain Combining (EGC). These methods help to enhance the signal-to-noise ratio (SNR) and reduce the Bit Error Rate (BER), significantly improving communication reliability and system performance [8]. One of the key advantages of SIMO systems is that they offer better performance than SISO systems without increasing the complexity at the transmitter side, which is particularly beneficial in scenarios where transmitter resources are constrained—such as mobile or sensor devices. By utilizing multiple antennas only at the receiver end, SIMO provides a cost-effective and power-efficient solution to enhance communication robustness in fading environments. SIMO configurations such as 1×2 and 1×4 (one transmits antenna and two or four receive antennas, respectively) are widely used in practice, especially in mobile communication standards like LTE and Wi-Fi. These setups allow the system to exploit spatial diversity, improve signal clarity, and support higher data integrity, making them well-suited for applications requiring reliable data transmission, such as image or video communication over wireless channels [18-20]. In this study, SIMO is employed to investigate how receiver diversity influences the BER performance of BPSK and QPSK modulation schemes under flat fading channel conditions, providing a practical comparison against traditional SISO systems.

2.5. Channels

In wireless communication systems, a channel represents the physical medium or propagation path through which electromagnetic signals are transmitted from a sender (transmitter) to a receiver. The nature of the channel has a profound impact on the quality, reliability, and efficiency of the communication system. Different environments introduce various impairments such as noise, interference, and signal fading, which must be understood and mitigated for effective system design and performance evaluation. Wireless channels are inherently dynamic and affected by several phenomena, including path loss, shadowing, multipath propagation, and Doppler shifts. To model these effects and study the behavior of communication systems under realistic conditions, various mathematical models are employed. Among the most used are the Additive White Gaussian Noise channel (AWGN) and the flat fading channel [10, 12, 16].

These models serve distinct purposes:

- The AWGN channel is idealized and primarily used for theoretical analysis, as it only introduces random Gaussian noise without considering multipath fading or mobility effects.
- The flat fading channel, on the other hand, captures more realistic behavior of wireless propagation, particularly in environments where the transmitted signal is subject to constructive and destructive interference due to multipath.

Understanding both models allows engineers and researchers to assess system robustness, design efficient modulation and coding schemes, and simulate performance in both ideal and harsh channel conditions.

The following subsections discuss these two important channel models in detail.

2.5.1. Additive White Gaussian Noise (AWGN) Channel

The Additive White Gaussian Noise (AWGN) channel is one of the most fundamental and widely used models in the study and simulation of digital communication systems. It serves as a benchmark for evaluating the theoretical performance of modulation schemes and error control coding techniques in idealized conditions. This model assumes that the only impairment to signal transmission is a linear addition of white Gaussian noise, thereby ignoring more complex real-world phenomena such as fading, interference, and multipath propagation [8, 12].
In this model, the received signal $r(t)$ is expressed as:

$$r(t) = s(t) + n(t) \tag{1}$$

Where $s(t)$ is the transmitted signal and $n(t)$ is the Gaussian noise component with a zero meaning. The term "additive" implies that the noise is added to the signal without altering its characteristics. "White" indicates that the noise has equal intensity at all frequencies, resembling a flat power spectral density. "Gaussian" refers to the fact that the amplitude of the noise follows a normal distribution, which is consistent with many naturally occurring random processes in communication electronics [13, 19]. The AWGN channel is often used as a reference model in performance analysis due to its simplicity and analytical tractability. While it does not account for real-world channel effects such as time-varying fading, shadowing, or frequency-selectivity, it provides a baseline that allows researchers to understand the intrinsic behavior of modulation schemes under ideal noise-limited conditions. This is particularly useful in the early stages of system design and algorithm development. Despite its idealized nature, the AWGN model closely approximates certain practical scenarios, such as deep-space communication, satellite links, and wired communication systems (like optical fibers), where the primary source of degradation is thermal noise rather than multipath interference [8, 12]. Furthermore, the model is essential in generating theoretical Bit Error Rate (BER) performance curves that are widely used in communication system design to predict performance at varying Signal-to-Noise Ratios (SNRs). In summary, the AWGN channel provides a crucial starting point for assessing the effectiveness of digital modulation techniques such as BPSK and QPSK. While it lacks the complexity of fading models, its role in benchmarking and comparative analysis is indispensable [1, 12].

2.5.2. Fading Channel

In wireless communication systems, a fading channel refers to the variation in the amplitude, phase, and delay of a radio signal as it propagates through a transmission medium. These fluctuations typically occur due to multipath propagation, where the transmitted signal reaches the receiver via multiple paths caused by reflection, diffraction, and scattering from surrounding objects such as buildings, trees, and terrain irregularities [20]. Fading is generally categorized into large-scale fading and small-scale fading. Large-scale fading is associated with path loss due to distance and shadowing from obstacles, whereas small-scale fading refers to the rapid signal variations over short distances or time intervals. In this study, we focus on small-scale fading, particularly Rayleigh fading, which is one of the most used models in wireless communication research. A Rayleigh fading channel assumes that there is no direct Line-of-Sight (LOS) path between the transmitter and receiver. Instead, the signal arrives at the receiver as a combination of numerous reflected and scattered paths, each with its own amplitude and phase. The envelope of the received signal under this condition follows a Rayleigh distribution, making this model highly relevant for urban and indoor environments where LOS is typically obstructed [19]. Rayleigh fading introduces deep fades and rapid fluctuations in signal power, significantly impacting communication system performance, especially in mobile or dynamic scenarios. These fluctuations can cause increased bit error rates (BER) and degraded signal quality if not properly mitigated through diversity schemes (e.g., SIMO, MIMO) or channel coding. Modeling the flat fading channel as Rayleigh fading provides a realistic and challenging environment for evaluating the robustness of modulation schemes such as BPSK and QPSK, especially when assessing BER performance in both SISO and SIMO configurations. Therefore, incorporating Rayleigh fading into simulations helps mirror real-world wireless scenarios more accurately and supports the development of more reliable communication systems [5, 13, 19, 21].

3. Simulation and Results

This section presents the simulation environment, configuration parameters, and results obtained from evaluating the Bit Error Rate (BER) performance during image transmission over a flat fading Rayleigh channel. The focus is on comparing the BER outcomes for BPSK and QPSK modulation schemes under SISO and SIMO (1×2 and 1×4) configurations.

3.1 Simulation Setup

The simulation was developed and executed in MATLAB 2020b, utilizing the Communications System Toolbox, which provides robust functions for simulating and analyzing digital communication systems.

- Channel Model: The wireless channel was modeled as a flat fading Rayleigh channel. This type of channel simulates the effects of multipath propagation in environments with no dominant line-of-sight path, thereby introducing realistic amplitude and phase variations into the transmitted signal.
- Modulation Schemes: Two modulation schemes were tested:
    - Binary Phase Shift Keying (BPSK)
    - Quadrature Phase Shift Keying (QPSK)
- System Configurations:
    - SISO (Single-Input Single-Output): One transmits, and one receives antenna.
    - SIMO (Single-Input Multiple-Output): One transmits antenna and multiple receive antennas (1×2 and 1×4).
- Image Data: The standard ‘Cameraman’ grayscale image (256×256 pixels), widely used in MATLAB and image processing research, was employed as the source data for transmission. This image was converted into a binary stream for modulation and transmission.
- Noise Model: An Additive White Gaussian Noise (AWGN) component was added to simulate real-world interference and thermal noise.
- Simulation Parameters:
    - SNR range: From –30 dB to +30 dB, in increments of 3 dB.
    - Channel type: Rayleigh flat fading with no Doppler shift (static multipath conditions).
    - Receiver: Used Maximum Ratio Combining (MRC) for SIMO to optimally combine multiple received signals.

3.2 BER Performance Evaluation

The BER was evaluated to quantify the accuracy of received bit streams after demodulation, compared to the original image data. For each SNR level, the simulation transmitted and received multiple image blocks to ensure statistical significance and consistency in the results.

- BER Calculation:

$$BER = \frac{\text{Number of Bit Errors}}{\text{Total Number of Transmitted Bits}}$$

- Key Observations:
    - BPSK consistently outperformed QPSK at lower SNR values due to its simpler constellation and greater resilience to noise.
    - SIMO systems (1×2 and 1×4) demonstrated significant performance improvements compared to SISO, particularly in Rayleigh fading conditions. The diversity gain helped mitigate the impact of deep fades and signal degradation.
    - Increasing the number of antennas receive (from 2 to 4) further reduced BER, validating the advantage of spatial diversity in fading environments.

The results from the simulations are presented in Section 3.3 through graphical representations, illustrating the relationship between BER and SNR for each tested configuration. These graphs clearly illustrate the trade-offs between modulation complexity, diversity gain, and system reliability.

3.3. Results

The simulation results illustrate the Bit Error Rate (BER) performance of Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK) modulation schemes under both Single-Input Single-Output (SISO) and Single-Input Multiple-Output (SIMO) configurations. The BER was evaluated across a wide range of Signal-to-Noise Ratio (SNR) values, spanning from -30 dB to +30 dB with increments of 3 dB. This extensive SNR range was selected to thoroughly examine the system's robustness and reliability under diverse noise conditions, from extremely poor to favorable channel qualities. By analyzing the BER behavior over this spectrum, the study provides detailed insight into how modulation schemes and antenna configurations influence communication performance. The results demonstrate how increasing receiver diversity in SIMO systems impacts error rates compared to the baseline SISO system, particularly under flat fading channel conditions that simulate realistic wireless environments. This comprehensive assessment offers a deeper understanding of system capabilities and trade-offs, guiding the design of more effective wireless communication systems. Figure 1 presents the BER vs. SNR curve for BPSK in the SISO system. The results demonstrate a gradual decline in BER as the SNR increases, confirming the expected trend where improved signal quality yields fewer bit errors. Figure 2 displays the reconstructed image after transmission and reception under the same configuration, highlighting the visual quality of the demodulated image at higher SNR levels. This result validates the numerical BER data, showing that a lower BER correlates with a clearer and more accurate image reconstruction.

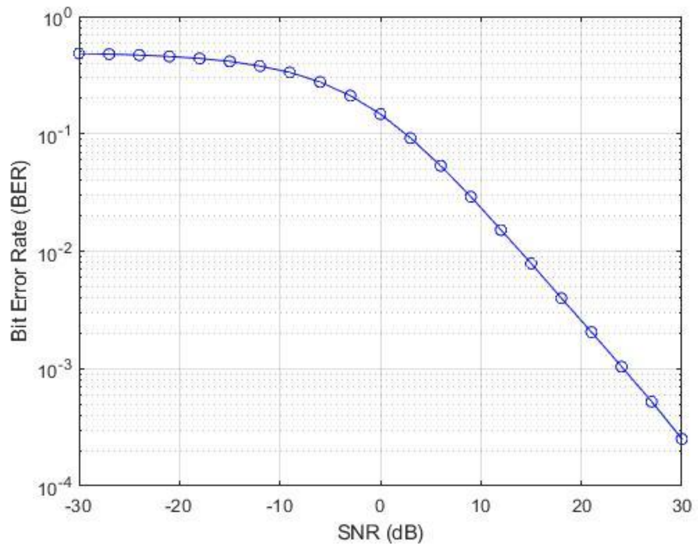

Figure 1: BER performance of BPSK in SISO system under 21 values of SNR

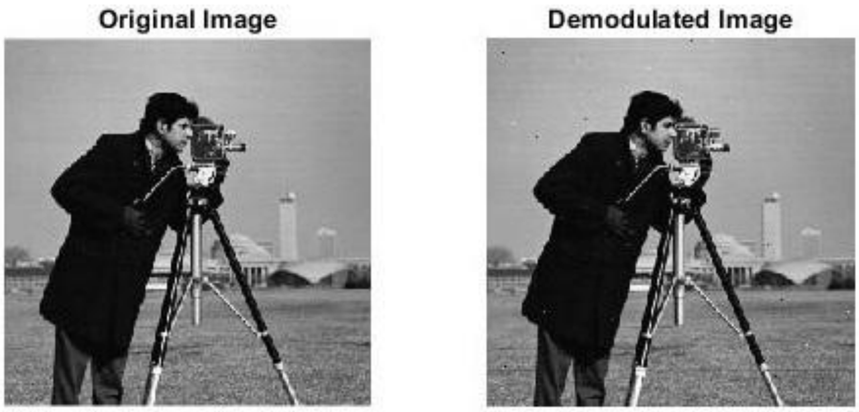

Figure 2: Demodulated image BPSK SISO system with the best BER performance.

Figure 3 illustrates the BER performance of QPSK in the SISO system across eleven SNR test values ranging from -30 dB to 30 dB in 3 dB steps, while Figure 4 presents the best-demodulated image obtained under optimal SNR conditions.

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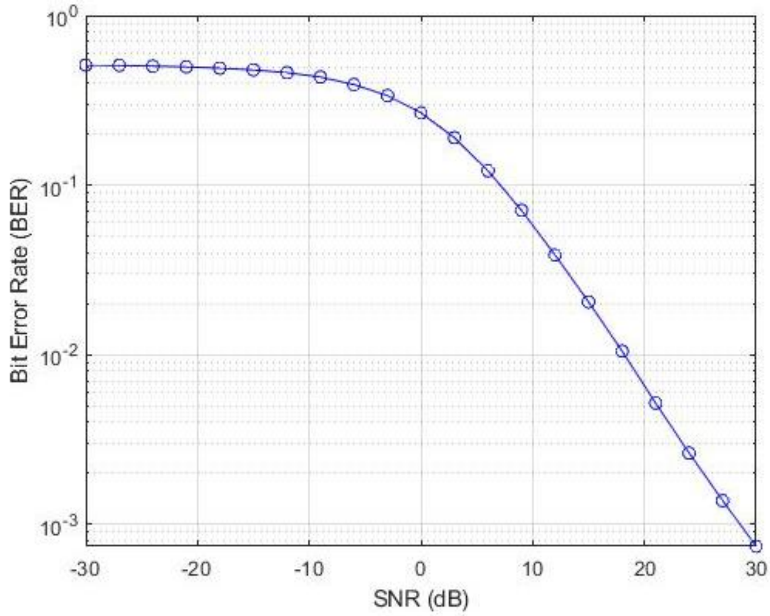

Figure 3: BER performance of QPSK in SISO system under 21 values of snr

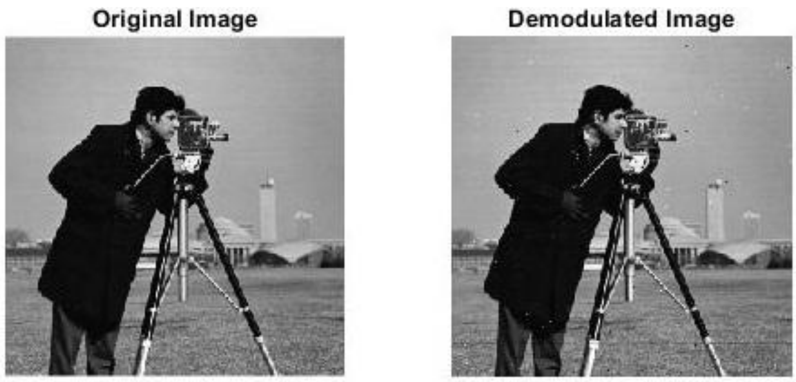

Figure 4: Demodulated image QPSK SISO system with the best BER performance.

Figure 5 depicts the BER performance of the BPSK SIMO system with a 1×2 antenna configuration, while Figure 6 presents the best demodulated image obtained by merging the outputs received from both antennas.

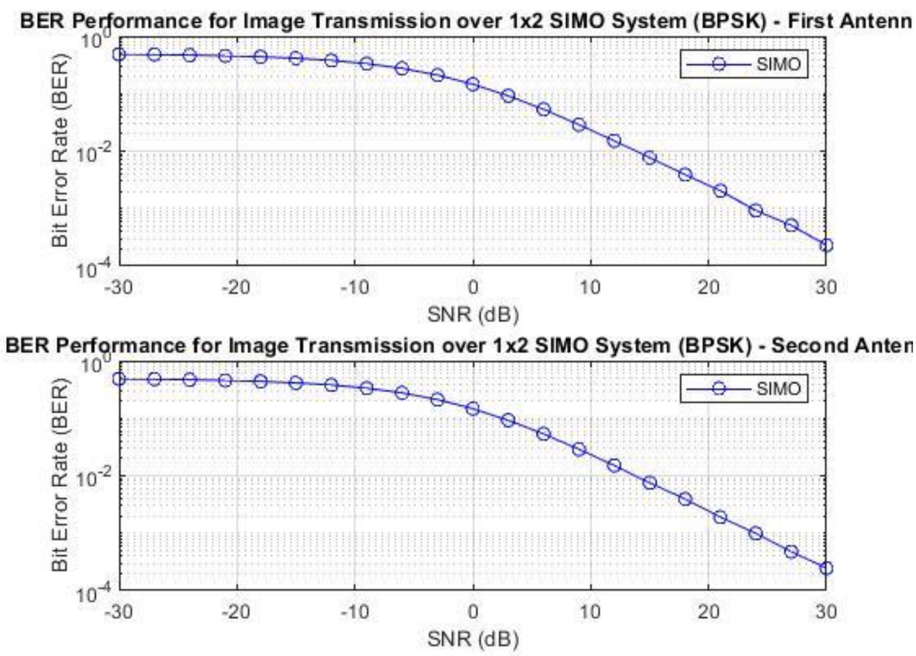

Figure 5: BER performance of BPSK in SIMO 1*2 system under 21 values of SNR

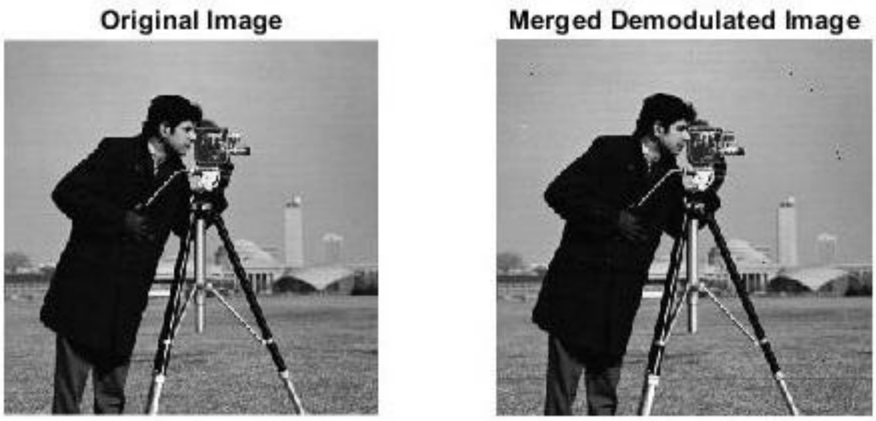

Figure 6: Demodulated image BPSK SIMO 1*2 system with the best BER performance for each antenna.

Figure 7 illustrates the BER performance of the QPSK SIMO system with a 1×2 antenna configuration across 21 SNR values ranging from –30 dB to 30 dB in 3 dB steps, while Figure 8 shows the best demodulated image obtained by combining the outputs from the two receiver antennas.

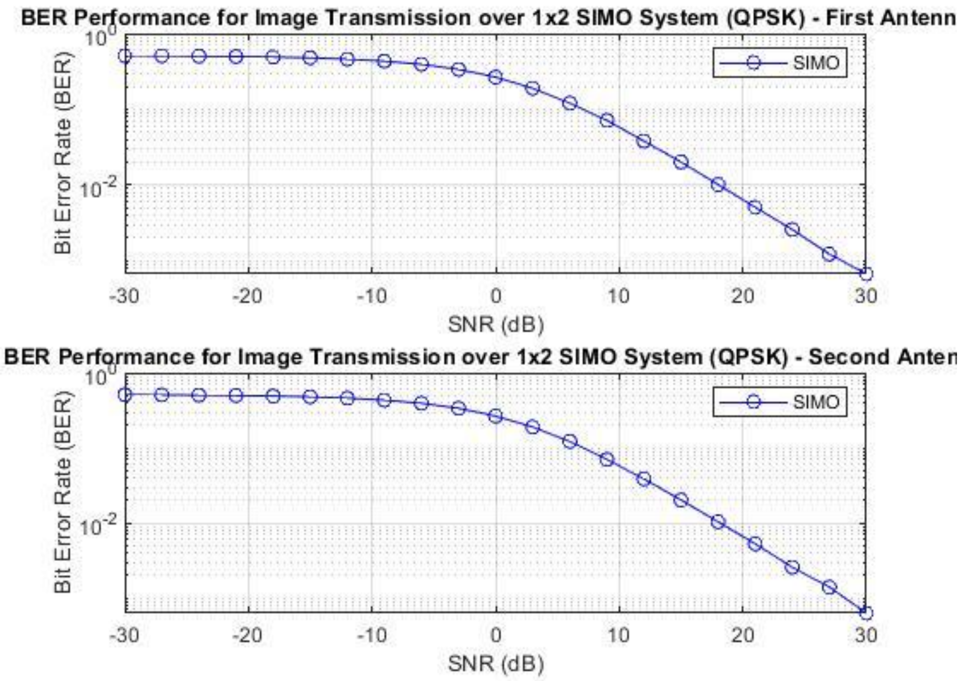

Figure 7: BER performance of QPSK in SIMO 1*2 system under 21 values of SNR

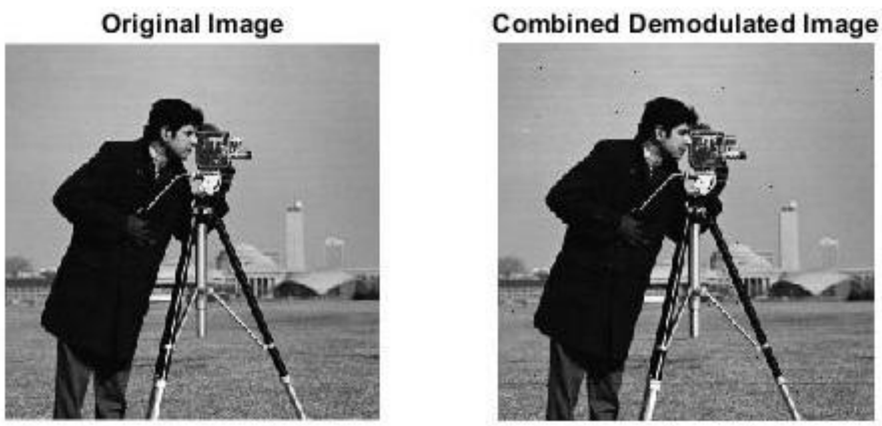

Figure 8: Demodulated image QPSK SIMO 1*2 system with the best BER performance for each antenna.

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Figure 9 depicts the BER performance of the QPSK SIMO system with a 1×4 antenna configuration, while Figure 10 presents the best demodulated image obtained after merging the outputs from the four receiver antennas.

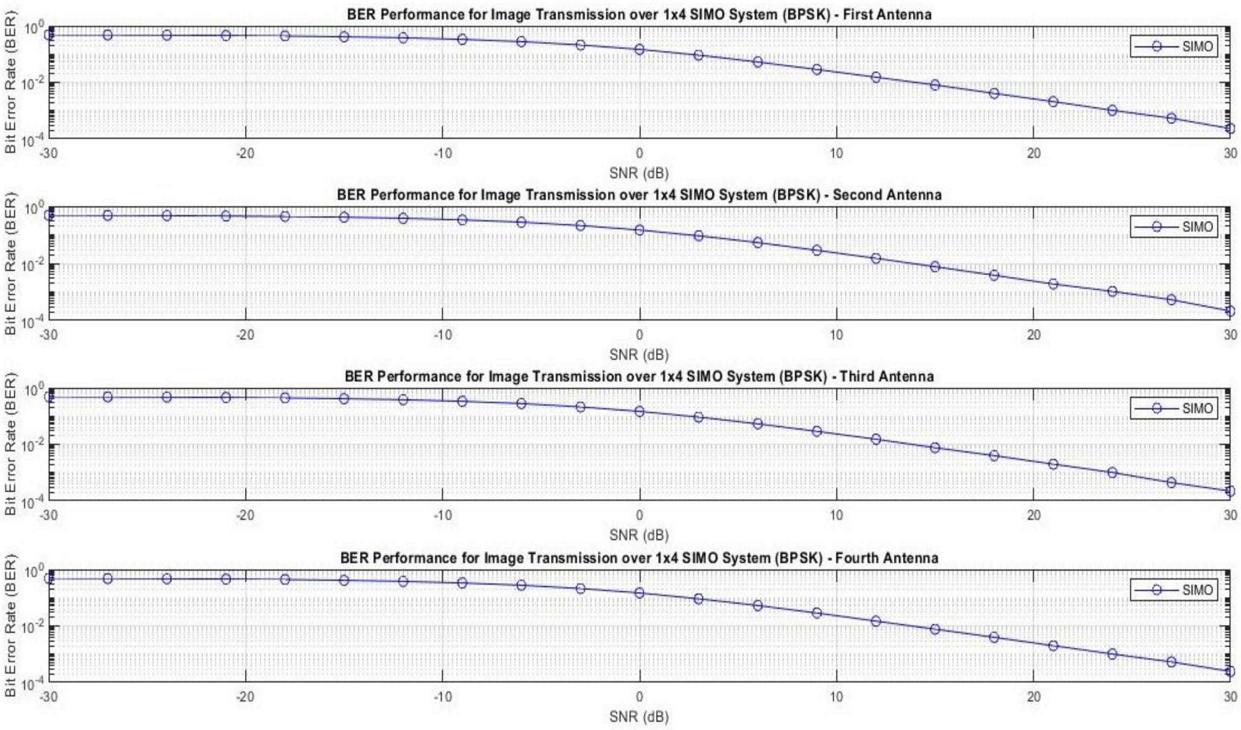

Figure 9: BER performance of BPSK in SIMO 1*2 system under 21 values of SNR

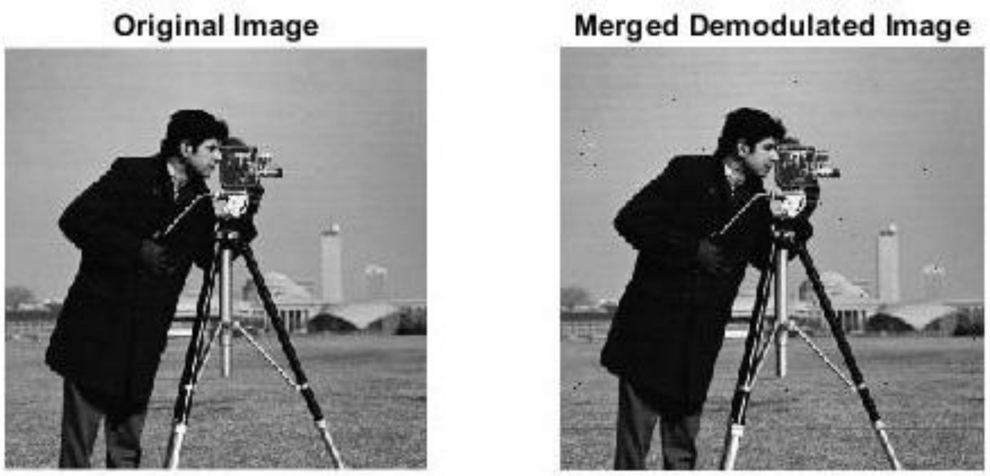

Figure 10: Demodulated image BPSK SIMO 1*2 system with the best BER performance for each antenna

Finally, Figure 11 illustrates the BER performance of the QPSK SIMO system with a 1×4 antenna configuration across 21 SNR test values (ranging from -30 dB to 30 dB in 3 dB steps), while Figure 12 displays the best demodulated image obtained after merging the outputs from all four receiver antennas.

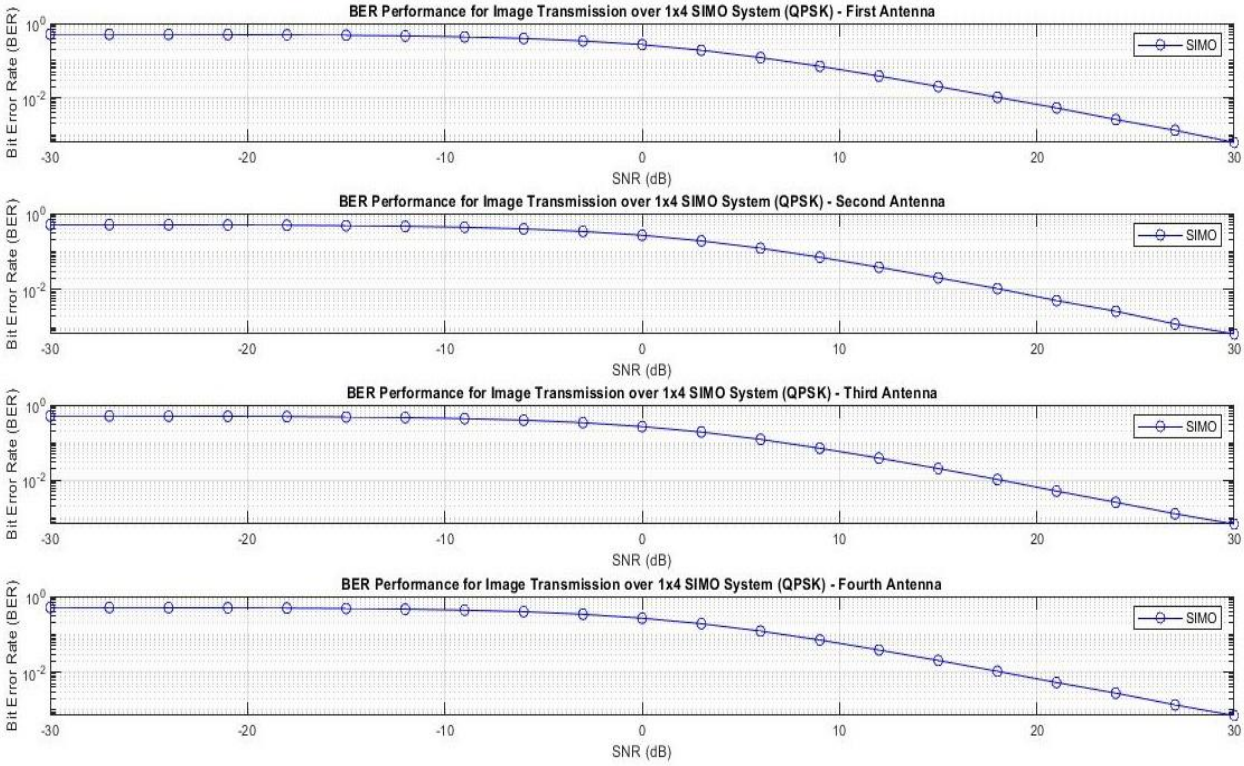

Figure 11: BER performance of QPSK in SIMO 1*2 system under 21 values of SNR

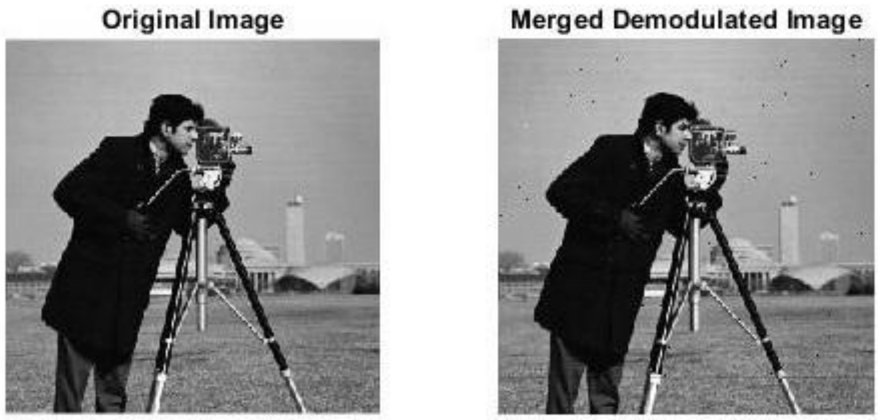

Figure 12: Demodulated image QPSK SIMO 1*4 system with the best BER performance for each antenna

The results revealed that both BPSK and QPSK modulation schemes demonstrated reliable performance in terms of Bit Error Rate (BER) under flat fading channel conditions. As anticipated, QPSK consistently outperformed BPSK across all scenarios. This improvement is attributed to QPSK's ability to transmit two bits per symbol, thereby offering higher spectral efficiency and better utilization of bandwidth, while still maintaining acceptable error performance under varying Signal-to-Noise Ratio (SNR) levels. In the SIMO configurations, significant performance enhancements were observed compared to the SISO system. In particular, the 1×2 antenna configuration led to noticeable improvements in BER. The additional reception antenna provided spatial diversity, allowing the system to more effectively mitigate the effects of multipath fading and noise. This diversity gain helped reduce the probability of simultaneous deep fades affecting the received signal, thereby enhancing signal reliability. Moreover, further gains were made when increasing the number of receiver antennas to 1×4. The 1×4 SIMO system achieved the lowest BER values across all tested SNR ranges, illustrating the clear advantage of adding more receiver branches. This trend confirms the theoretical expectation that greater antenna diversity enhances system robustness by offering multiple independently faded signal copies, which can be optimally combined at the receiver to improve detection accuracy.

Overall, the simulation results underscore the importance of receiver diversity in wireless communications. They validate the effectiveness of SIMO systems, particularly when combined with more advanced modulation schemes like QPSK, for improving communication reliability and efficiency in environments characterized by fading and noise.

4. Conclusion

This study thoroughly evaluated the Bit Error Rate (BER) performance of Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK) modulation schemes in both Single-Input Single-Output (SISO) and Single-Input Multiple-Output (SIMO) configurations for image transmission over flat fading channels. The simulation results provided several key insights. Firstly, while both BPSK and QPSK demonstrated reliable performance under flat fading conditions, QPSK consistently outperformed BPSK due to its higher spectral efficiency, transmitting two bits per symbol and thus supporting faster data rates. Secondly, the use of SIMO systems with multiple receiving antennas notably improved communication reliability compared to the traditional SISO setup. By leveraging antenna diversity, SIMO configurations effectively mitigated the detrimental effects of fading, leading to significantly reduced BER values. Moreover, the degree of performance enhancement was positively correlated with the number of receiver antennas. The 1×4 SIMO system showed superior BER performance over the 1×2 configuration, highlighting the advantages of increased spatial diversity in improving system robustness.

In summary, the results underscore the value of integrating SIMO architecture and QPSK modulation to enhanced image transmission quality in challenging wireless environments characterized by flat fading. These findings provide valuable guidance for the design and optimization of future wireless communication systems aimed at delivering reliable and high-quality multimedia data under realistic channel conditions.

Abbreviations

AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
LOS	Line of Sight
MIMO	Multiple-Input Multiple-Output
QPSK	Quadrature Phase Shift Keying
SISO	Single-Input Single-Output
SIMO	Single-Input Multiple-Output
SNR	Signal-to-Noise Ratio

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