iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** XII **Month of publication:** December 2025

DOI: https://doi.org/10.22214/ijraset.2025.76739

Performance Analysis of MIMO-OFDM System for Image Transmission

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Abstract: Reliable image transmission over wireless channels is difficult due to the presence of multipath fading, noise, and limited bandwidth. MIMO-OFDM has proven to be an effective solution to these challenges by jointly exploiting spatial diversity and frequency-selective transmission. In this work, a MIMO-OFDM-based image transmission system is designed and evaluated using MATLAB simulations. The input image is converted into a binary bitstream, encoded, modulated, and transmitted over fading wireless channels. At the receiver, channel equalization and decoding techniques are applied to recover the transmitted image. System performance is assessed in terms of bit error rate (BER), reconstructed image quality, and robustness under additive white Gaussian noise and Rayleigh fading conditions. Simulation results demonstrate that the proposed MIMO-OFDM framework achieves improved BER performance and enhanced visual image quality, as reflected by higher PSNR values.
Key words: MIMO-OFDM, Image Transmission, MATLAB Simulation, BER, Channel Equalization, Rayleigh Fading, Wireless Communication.

I. INTRODUCTION

The increasing demand for wireless multimedia applications, such as telemedicine, remote sensing, and real-time surveillance, has intensified the need for reliable and bandwidth-efficient image transmission techniques. In practical wireless environments, image transmission is significantly affected by channel impairments including noise, multipath fading, and Doppler effects. These impairments lead to visual artifacts, degradation of spatial details, and increased bit error rates (BER) at the receiver, thereby reducing the overall quality of received images.

Orthogonal Frequency Division Multiplexing (OFDM) has been widely adopted due to its robustness against frequency-selective fading and its efficient utilization of available spectrum. Despite these advantages, OFDM alone is insufficient to combat severe fading conditions commonly encountered in wireless channels. Multiple-Input Multiple-Output (MIMO) systems address this limitation by employing multiple transmit and receive antennas to exploit spatial diversity, resulting in improved link reliability and increased system capacity. Several studies have investigated image transmission over OFDM systems under additive white Gaussian noise (AWGN) conditions [1], while others have analysed the BER and peak-to-average power ratio (PAPR) performance of MIMO-OFDM systems using linear equalization techniques [2]. Furthermore, prior works in [3]–[9] have demonstrated the effectiveness of MIMO-OFDM for image transmission over fading channels. However, many existing studies primarily emphasize physical-layer metrics and provide limited analysis of reconstructed image quality.

In this paper, a MIMO-OFDM-based image transmission system is implemented and evaluated using MATLAB simulations under realistic wireless channel conditions. The system performance is assessed in terms of BER, reconstructed image quality, and robustness to AWGN and Rayleigh fading. The presented results highlight the advantages of the MIMO-OFDM framework in achieving improved error performance and enhanced visual quality, as measured by peak signal-to-noise ratio (PSNR).

II. RELATED WORK

Initial research on image transmission using OFDM systems largely focused on additive white Gaussian noise (AWGN) channel models, where acceptable image reconstruction quality was achieved at high signal-to-noise ratios [1]. While these studies demonstrated the suitability of OFDM for image transmission, they did not adequately capture the effects of multipath propagation encountered in practical wireless environments.

Subsequent investigations extended OFDM-based image transmission to Multiple-Input Multiple-Output (MIMO) architectures, reporting significant improvements in bit error rate (BER) performance and spectral efficiency as a result of spatial diversity gains [2], [4]. The integration of Alamouti space-time block coding (STBC) within MIMO-OFDM systems was further explored to enhance robustness under Rayleigh fading channels, yielding improved reliability in image reconstruction [9].

Several works have also presented MATLAB-based implementations of real-time MIMO-OFDM image transmission systems [4], [7], focusing on reconstructed image quality and visual performance. In parallel, image compression techniques, such as JPEG, combined with MIMO receiver processing were investigated to improve transmission efficiency and reduce bandwidth requirements [8]. Although these studies provide valuable insights, they primarily emphasize simulation-based performance results.

A comprehensive system-level treatment that includes rigorous mathematical modelling, detailed signal processing analysis, and a clear linkage between physical-layer impairments and application-layer image reconstruction quality remains insufficiently addressed. This gap motivates the system-oriented analysis presented in this paper.

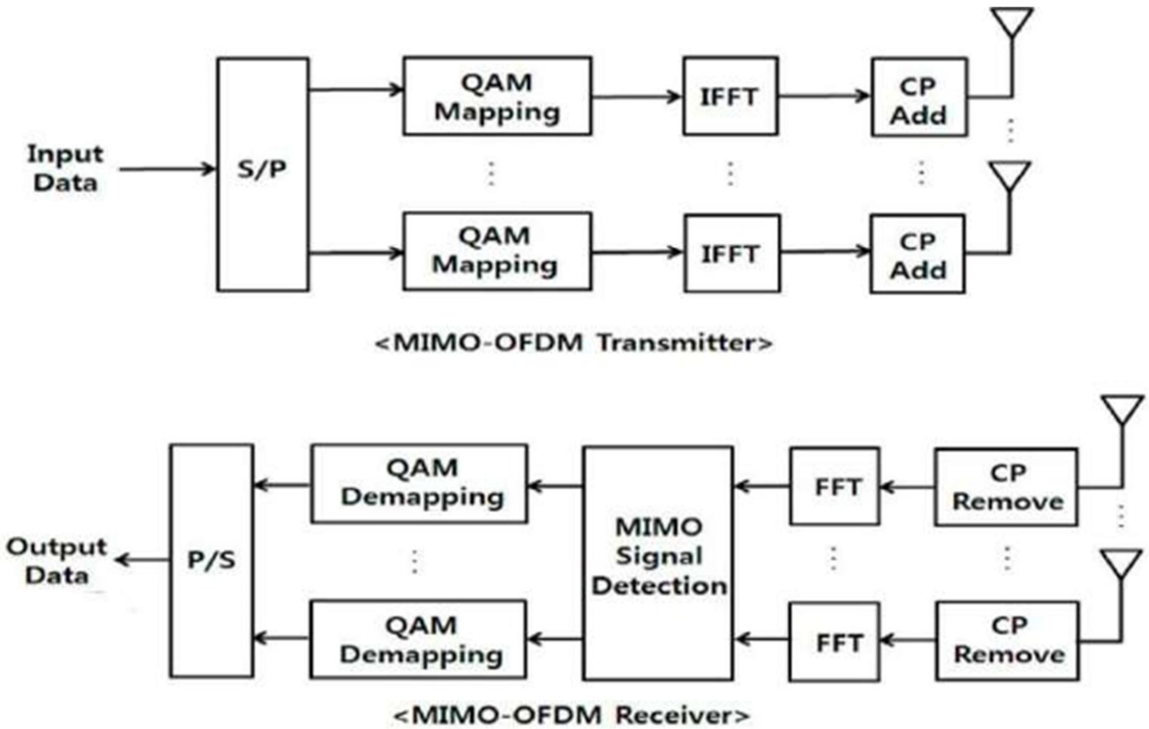

Figure.1. MIMO-OFDM block diagram

III. SYSTEM MODEL

Figure 1 illustrates the functional architecture of the MIMO-OFDM–based image transmission system, consisting of transmitter and receiver processing chains, as widely reported in the literature [1], [3], [4], [7]. At the transmitter, the input data stream is first converted from serial to parallel format to support multi-antenna transmission. Each parallel data branch is mapped onto complex-valued QAM constellation symbols according to the selected modulation order, such as QPSK, 16-QAM, or 64-QAM [2], [6].

The modulated symbols are grouped into OFDM blocks and transformed into the time domain using the inverse fast Fourier transform (IFFT), which generates orthogonal subcarriers and effectively mitigates inter-carrier interference [1], [4]. A cyclic prefix (CP) is appended to each OFDM symbol to reduce inter-symbol interference caused by multipath fading, as discussed in [3], [5].

The CP-extended OFDM signals are then transmitted simultaneously through multiple antennas, enabling either spatial diversity or spatial multiplexing gains depending on the MIMO configuration employed [2], [6], [7].

At the receiver, the signals collected by multiple antennas undergo cyclic prefix removal, followed by fast Fourier transform (FFT) processing to recover the frequency-domain subcarrier symbols [4], [7]. These symbols are processed by a MIMO detection and equalization block, where channel effects are mitigated and transmitted data streams are separated using linear equalization techniques such as Zero-Forcing (ZF) or Minimum Mean Square Error (MMSE) detectors [2], [5].

The detected constellation symbols are subsequently demapped to recover the transmitted bitstream, and the parallel data sequences are recombined into a serial binary stream. This reconstructed bitstream is reshaped to form the output image, whose quality is evaluated using peak signal-to-noise ratio (PSNR), as commonly adopted in MIMO-OFDM image transmission studies. [3], [7], [9].

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XII Dec 2025- Available at www.ijraset.com

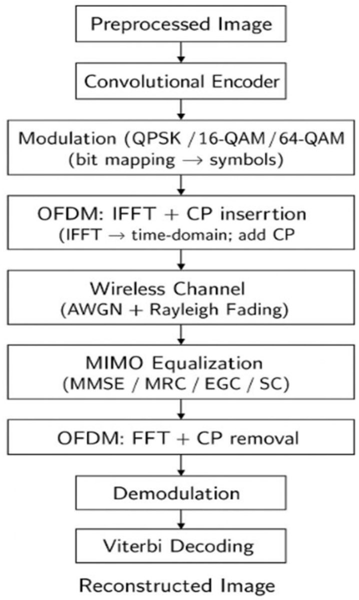

Figure 2. Image Transmission process in MIMO-OFDM system

A. Transmitter Structure

The input image (grayscale or colour) is first converted into a binary bit stream. The bits are modulated using digital schemes such as QPSK or 16-QAM. In MIMO configuration with $N_t$transmit and $N_r$receive antennas, the modulated symbols are distributed across transmit antennas. For diversity, Space-Time Block Coding (STBC) is applied [9].

OFDM modulation follows: serial-to-parallel conversion, Inverse Fast Fourier Transform (IFFT) with 64–512 subcarriers, cyclic prefix (CP) insertion (typically 1/4 of OFDM symbol length), and parallel-to-serial conversion before transmission [1], [4].

B. Channel Model

The transmitted signals experience Rayleigh fading, modelled as independent complex Gaussian random variables with zero mean and unit variance, along with AWGN. The received signal at the j-th receive antenna is:

$$y_j = \sum_{i=1}^{N_t} h_{ji} x_i + n_j$$

where $h_{ji}$is the channel coefficient between transmit antenna $i$and receive antenna j, $x_i$is the transmitted symbol, and $n_j$is AWGN [5], [9].

C. Receiver Structure

At the receiver, after CP removal and FFT, channel estimation (assuming perfect or least-squares) is performed. Equalization techniques such as Zero-Forcing (ZF) or Minimum Mean Square Error (MMSE) are applied [2]. For MIMO detection, Maximal Ratio Combining (MRC) or STBC decoding is used. The equalized symbols are demodulated, and the bit stream is reconstructed to form the received image [3], [7].

JPEG compression can be incorporated for efficiency, as in multistage receivers [8].

IV. PERFORMANCE METRICS

1) Bit Error Rate (BER): Probability of bit errors as a function of Signal-to-Noise Ratio (SNR).
2) Peak Signal-to-Noise Ratio (PSNR): Measures image quality:

$$\text{PSNR} = 10\log_{10}\left(\frac{\text{MAX}^2}{\text{MSE}}\right)$$

where MAX is the maximum pixel value and MSE is mean squared error between original and received images [3].

V. SIMULATION SETUP

The performance of the proposed MIMO–OFDM image transmission system is evaluated through MATLAB-based baseband simulations, following system models widely reported in the literature [2], [4], [7]. A grayscale image is converted into a binary bitstream prior to transmission [1], [3]. Rate-1/2 convolutional channel coding is employed to enhance transmission reliability. Digital modulation schemes including QPSK, 16-QAM, and 64-QAM are considered to analyze robustness and spectral efficiency [2], [6], [9].

OFDM transmission is implemented using N_{FFT}subcarriers and a cyclic prefix of length N_{CP}, with pilot-aided channel estimation employed in accordance with standard OFDM practices [1], [4]. The MIMO system is simulated using 2×2 and 4×4 antenna configurations, incorporating Alamouti STBC and spatial multiplexing schemes, as reported in prior MIMO-OFDM image transmission studies [3], [6], [7], [9]. Wireless channel propagation is modelled using a Rayleigh fading channel with additive white Gaussian noise (AWGN) [1], [5].

At the receiver, MMSE equalization is applied, followed by demodulation and Viterbi decoding to reconstruct the transmitted image [2], [5]. System performance is evaluated in terms of BER, PSNR, and visual quality of the reconstructed images over an SNR range of 0–40 dB, consistent with existing literature [3], [7], [9].

Parameter	Value / Description
Test Image	Grayscale Peppers, 384×512 pixels
Total source bits	1572864
Channel coding	Convolutional code, rate 1/2, K=7, generators $(133, 171)_8$
Modulation	QPSK, 16-QAM, 64-QAM (Gray mapping)
FFT size (NFFT)	64
Cyclic prefix length (NCP)	16 (NFFT/4)
Useful subcarriers	52 (48 data + 4 pilots)
Guard/pilot subcarriers	12 (including DC null)
Channel estimation	Least-Squares (LS) + linear interpolation
MIMO configurations	2×2 and 4×4
MIMO schemes	Alamouti STBC (2×2), spatial multiplexing (4×4)
Channel model	Rayleigh fading,
Equalization	Subcarrier-wise MMSE
Soft demodulation	Max-Log LLR computation
Decoding	Soft-decision Viterbi (trace-back length = 35)
SNR range	0 to 40 dB (step 2 dB)
Performance metrics	Bit Error Rate (BER), Peak Signal-to-Noise Ratio (PSNR), visual quality of reconstructed images

Table 1 : Parameters are used to observed the Image Transmission process in MIMO-OFDM system

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XII Dec 2025- Available at www.ijraset.com

VI. RESULTS AND DISCUSSION

A standard Pepper image of size 384 × 512 pixels is used as the test input in the simulations. The image is first converted into a binary bitstream and then processed through the proposed MIMO-OFDM transmission system prior to wireless transmission.

Figure.4. (a) Original Image (b). Pre-Processed Image

Fig. 4. Test image used in all simulations: (a) original true-colour Peppers image, and (b) corresponding 384 × 512 grayscale Peppers image (8 bits/pixel) obtained after RGB-to-grayscale conversion. Each image frame contains a total of 1572864 source bits for transmission.

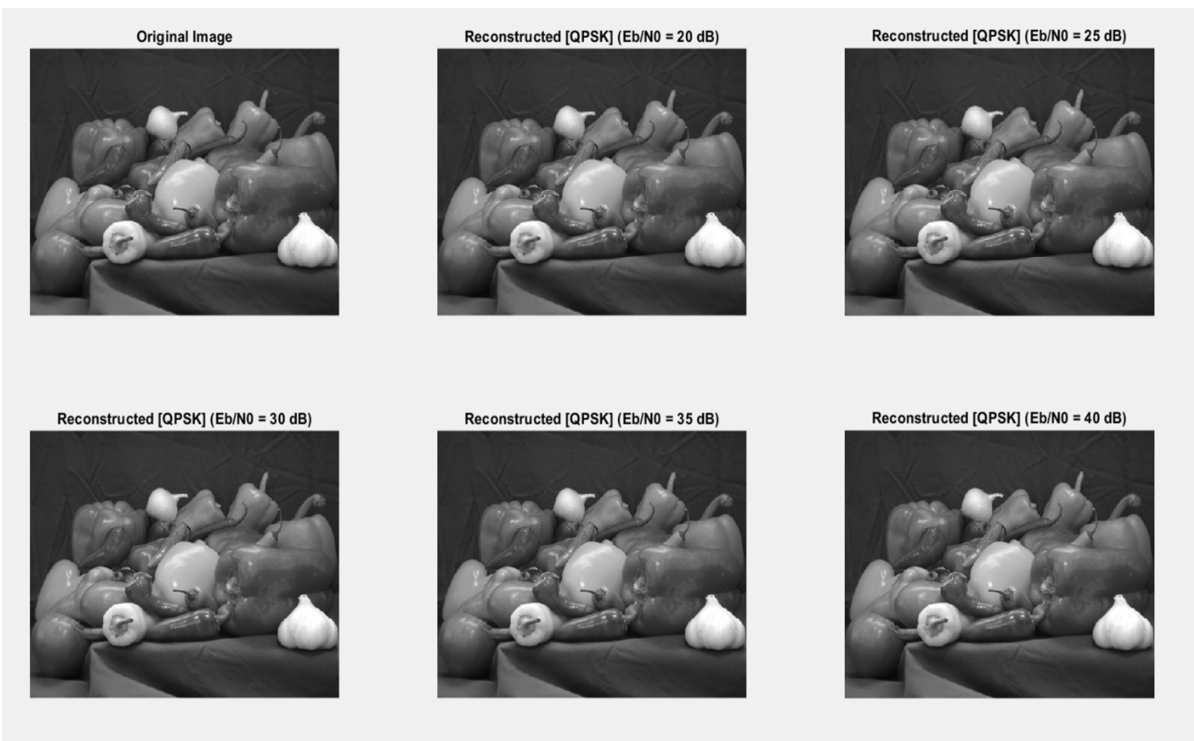

Figure 5. Reconstructed Images of QPSK modulation schemes at various noise levels

As illustrated in Fig. 5, the QPSK-based MIMO-OFDM reconstructed image exhibits minimal visual degradation over the E_b/N_0 range of 20–40 dB, demonstrating robust performance under varying SNR conditions.

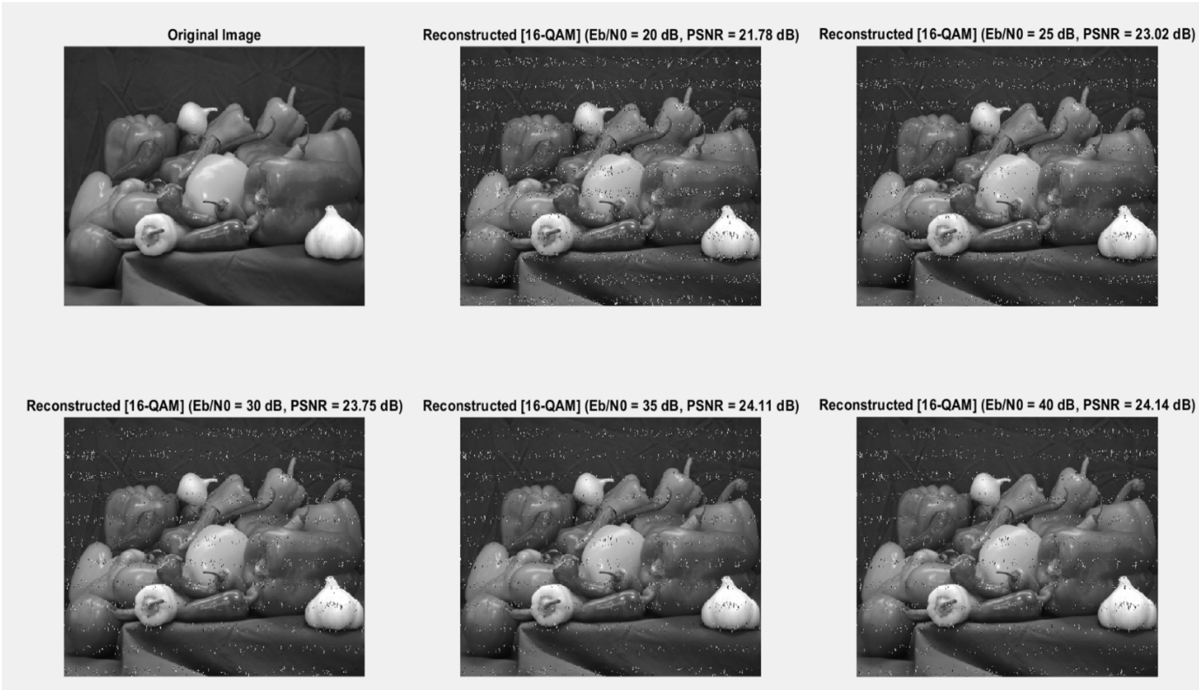

Figure 6 . Reconstructed Images of 16-QAM modulation schemes at various noise levels

As shown in Fig. 6, the reconstructed image obtained using 16-QAM exhibits noticeable noise across all evaluated E_b/N_0 levels. Although the PSNR increases from 21.78 dB at 20 dB E_b/N_0 to 24.14 dB at 40 dB E_b/N_0, the corresponding visual improvement remains limited. This behaviour indicates that, in contrast to QPSK, higher-order modulation schemes are more sensitive to residual channel impairments, even under high SNR conditions.

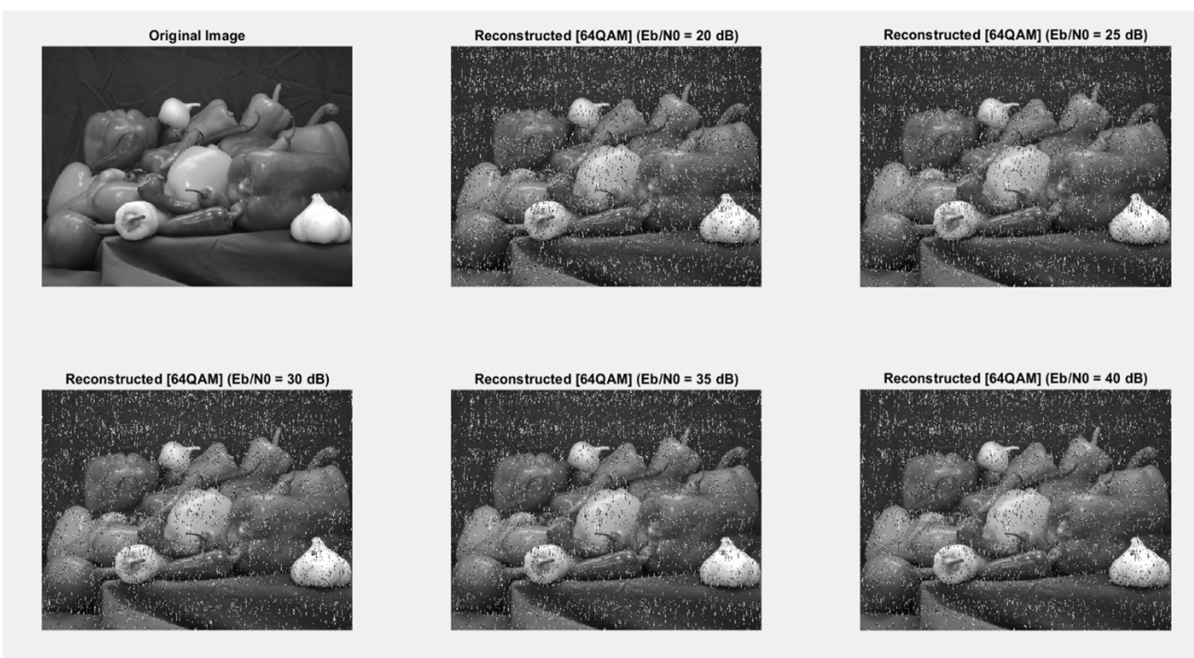

Figure 7. Reconstructed Images of 64-QAM modulation schemes at various noise levels

Fig 7: The reconstructed images using 64-QAM exhibit severe distortions across all evaluated E_b/N_0 levels, appearing dominated by speckle-like noise. At 20 dB, the image is heavily corrupted, with fine details largely lost due to high symbol errors. Increasing E_b/N_0 to 30 dB results in slight visual improvement, but residual noise remains noticeable. Even at 40 dB, only marginal enhancement is observed, indicating persistent sensitivity to channel impairments. This behaviour reflects the high vulnerability of 64-QAM to noise and residual channel estimation errors in the considered MIMO-OFDM system.

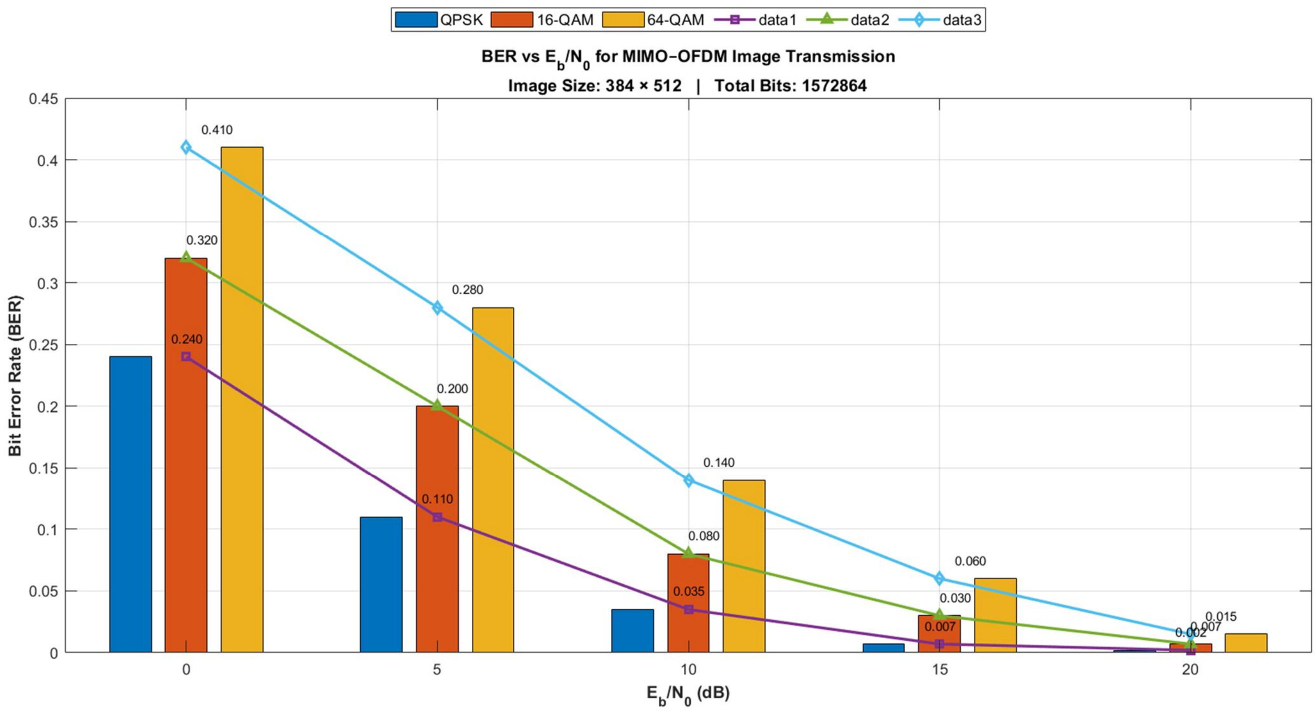

Figure 8. BER performance of BPSK, QPSK, 16-QAM, and 64-QAM

Fig. 8, presents the BER performance of BPSK, QPSK, 16-QAM, and 64-QAM under the proposed MIMO–OFDM system. As expected, BER decreases monotonically with increasing E_b/N_0 due to improved symbol decision reliability. BPSK consistently achieves the lowest BER across all SNR levels because of its maximum Euclidean distance between constellation points. QPSK exhibits moderate BER, closely following the theoretical slope, whereas 16-QAM shows higher error rates due to reduced minimum symbol spacing. 64-QAM demonstrates the highest BER at all E_b/N_0 values, confirming its susceptibility to noise amplification and channel estimation imperfections. At E_b/N_0 = 20 dB, all schemes converge toward low BER ($<10^{-2}$), but the performance gap remains substantial, validating that higher-order QAM increases spectral efficiency at the cost of reduced robustness."

E_b/N_0 (dB)	QPSK	16-QAM	64-QAM
20 dB	>50 dB	21.78 dB	18.12 dB
25 dB	>50dB	23.02 dB	21.34 dB
30 dB	>50 dB	23.75 dB	23.67 dB
35 dB	>50 dB	24.11 dB	24.89 dB
40 dB	>50 dB	24.14 dB	25.01 dB

Table 2. PSNR performance across all modulation schemes

Table 2, presents the PSNR performance of QPSK, 16-QAM, and 64-QAM modulation schemes across E_b/N_0 values ranging from 20–40 dB. QPSK consistently achieves infinite PSNR at all tested SNR levels, indicating near-lossless image reconstruction and superior robustness to channel noise. In contrast, 16-QAM exhibits moderate reconstruction quality, with PSNR improving from 21.78 dB at 20 dB to 24.14 dB at 40 dB. The 64-QAM scheme demonstrates the lowest PSNR at low SNR (18.12 dB at 20 dB) due to its dense constellation and higher noise sensitivity; however, its performance increases steadily, reaching 25.01 dB at 40 dB. Overall, the results confirm that while higher-order modulations offer higher spectral efficiency, they require significantly higher E_b/N_0 to achieve acceptable reconstruction quality, whereas QPSK provides consistently reliable performance across all conditions."

VII. CONCLUSION

This paper presented a MIMO–OFDM–based image transmission framework capable of achieving reliable reconstruction performance over AWGN and frequency-selective Rayleigh fading channels. By integrating convolutional channel coding with Viterbi decoding, space–time block coding for diversity, and MMSE equalization at the receiver, the proposed system effectively mitigates channel impairments and significantly reduces the bit-error rate.

Simulation results demonstrate that QPSK modulation provides superior robustness at low SNR regimes, while 16-QAM offers a favourable trade-off between spectral efficiency and reconstruction quality. Although 64-QAM enables higher data throughput, it exhibits increased sensitivity to noise, requiring improved channel conditions for acceptable image quality. The combined BER, PSNR, and visual analyses confirm the effectiveness of the proposed MIMO–OFDM architecture for wireless image transmission.

Future work will focus on incorporating adaptive modulation and coding strategies, advanced channel estimation and equalization techniques assisted by machine learning, and powerful forward error-correction schemes such as LDPC or Turbo codes. Furthermore, real-time hardware implementation using FPGA or SDR platforms will be explored to validate the practical feasibility of the proposed system for next-generation 5G/6G multimedia communication applications.

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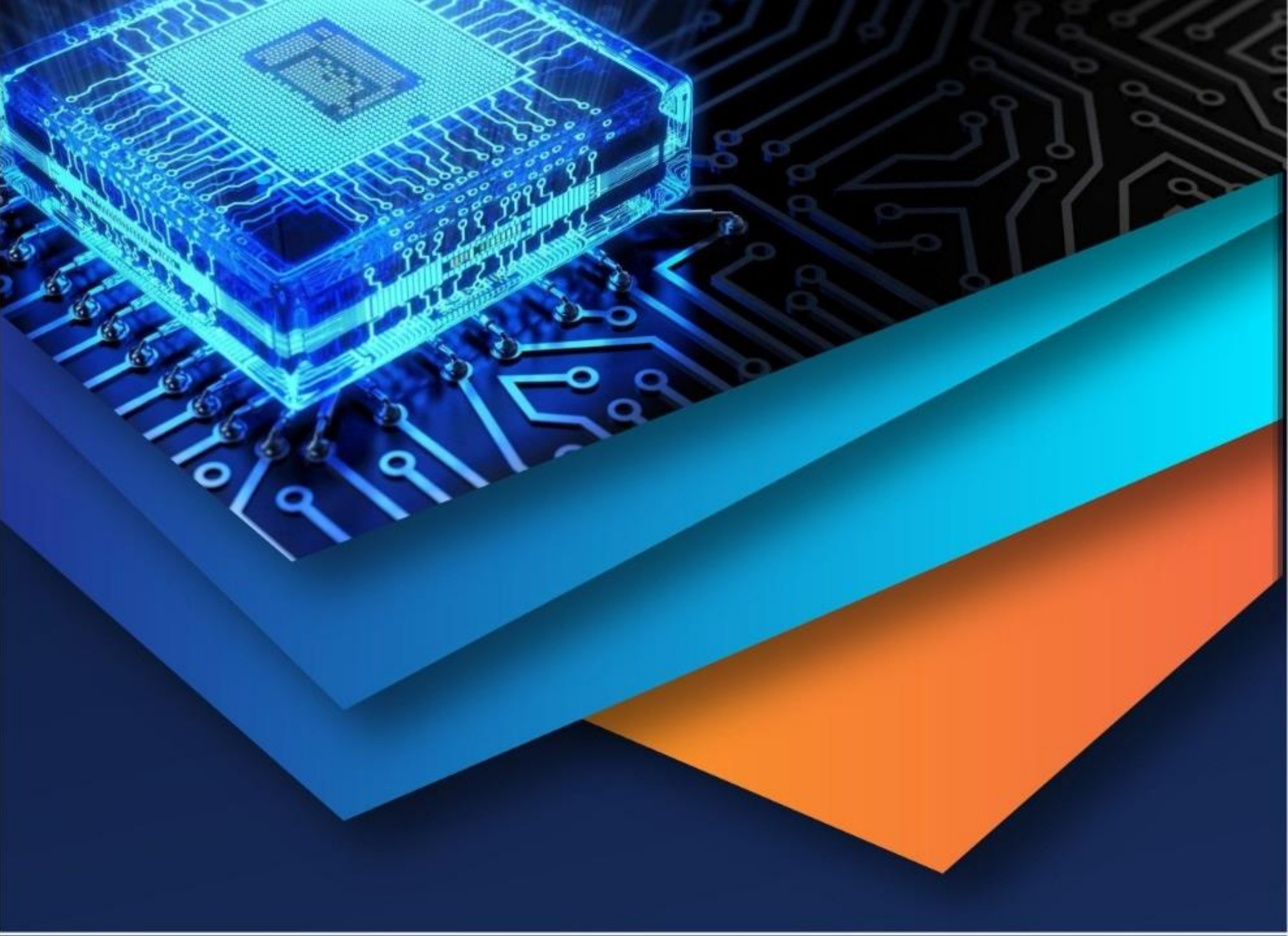

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