International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 8 Issue 3, May-June 2024 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Performance Analysis of MIMO-OFDM with Various Modulation Schemes in WiMAX Technology with Physical Layer

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ABSTRACT

WiMAX technology has become a pivotal solution for high-speed wireless broadband access. This research paper investigates the performance of MIMO-OFDM systems utilizing various modulation schemes, including BPSK, QPSK, 8-QAM, and 16-PSK. The study primarily focuses on the Symbol Error Rate (SER) in relation to the Signal-to-Noise Ratio (SNR). By analysing SER versus SNR, the paper provides insights into the robustness and efficiency of each modulation scheme under different SNR conditions. The results are essential for enhancing the performance and reliability of WiMAX networks, offering valuable guidance for network optimization and deployment strategies.

***KEYWORDS**: WiMAX, Physical Layer, BPSK, QPSK, QAM, MIMO-OFDM*

***How to cite this paper**:* K. S. Solanki | Chitranshi Raipuria "Performance Analysis of MIMO-OFDM with Various Modulation Schemes in WiMAX Technology with Physical Layer" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-8 | Issue-3, June 2024, pp.553-559, URL: www.ijtsrd.com/papers/ijtsrd64925.pdf

IJTSRD64925

1. INTRODUCTION

WiMAX (Worldwide Interoperability for Microwave Access) technology is a standard for wireless communication that provides high-speed internet access over long distances. This technology is particularly significant for providing broadband access in areas where wired infrastructure is not feasible. The use of MIMO (Multiple Input Multiple Output) and OFDM (Orthogonal Frequency Division Multiplexing) in WiMAX technology greatly enhances its performance by increasing data rates and improving reliability [1-2].

In wireless communication, modulation schemes play a crucial role in determining the efficiency and robustness of the system. Different modulation schemes offer varying levels of performance, especially in terms of Symbol Error Rate (SER) and Bit Error Rate (BER) under different Signal-to-Noise Ratio (SNR) conditions. This paper evaluates the performance of MIMO-OFDM systems using BPSK, QPSK, 8-QAM, and 16-PSK modulation schemes, focusing on their impact on SER as a function of SNR [3].

Standard and Specifications of WiMAX is IEEE 802.16: WiMAX is based on the IEEE 802.16 standard, which outlines the specifications for both fixed and mobile broadband wireless access. Frequency Bands: WiMAX operates in various frequency bands, including licensed and unlicensed spectra, typically in the range of 2.3 GHz to 3.5 GHz [4-7].

Transmission Technology of WiMAX is OFDM (Orthogonal Frequency Division Multiplexing): WiMAX uses OFDM as its core transmission technology, which divides the available spectrum into multiple orthogonal subcarriers. This technique improves resistance to multipath interference and increases spectral efficiency. MIMO (Multiple Input Multiple Output): MIMO technology is employed in WiMAX to enhance data throughput and link reliability by using multiple antennas at both the transmitter and receiver ends [8-9].

A. Applications of WiMAX Technology

- Broadband Internet Access
- Mobile Broadband
- Enterprise Solutions
- Backhaul Networks
- Public Safety and Emergency Services

2. Literature Review

Several studies have explored the performance of MIMO-OFDM systems with different modulation schemes. For instance, J. G. Andrews et al. (2005) provided a comprehensive overview of WiMAX technology, highlighting the benefits of MIMO and OFDM. Meanwhile, S. M. Alamouti's (1998) work on a simple transmits diversity technique for wireless communications laid the foundation for modern MIMO systems. More recently, research by Goldsmith et al. (2003) has focused on the capacity and performance of MIMO systems in various channel conditions. WiMAX (Worldwide Interoperability for Microwave Access) provides long-range wireless communication and broadband connectivity. It leverages OFDM (Orthogonal Frequency Division Multiplexing) for efficient data transmission and MIMO (Multiple Input Multiple Output) technology to enhance throughput and reliability. MIMO-OFDM is a cornerstone of modern WiMAX technology. It improves spectral efficiency and network capacity by utilizing multiple antennas at both the transmitter and receiver ends. The performance of MIMO-OFDM systems in WiMAX technology is significantly influenced by the choice of modulation scheme. By analysing the relationship between SER and SNR, this study provides insights into the robustness and efficiency of different modulation schemes. The findings are essential for enhancing the performance and reliability of WiMAX networks, offering valuable guidance for network optimization and deployment strategies [1-8].

3. Methodology and block diagram

The study evaluates the SER performance of MIMO-OFDM systems with four modulation schemes: BPSK, QPSK, 8-QAM, and 16-PSK. The simulation model considers a MIMO-OFDM system with the following parameters. The Fig. 1 showed the WiMAX Transmitter and Receiver Overview.

Number of subcarriers: 64

Cyclic prefix length: 16

Number of OFDM symbols: 1000

Channel model: AWGN (Additive White Gaussian Noise)

SNR range: 0 to 24 dB.

The diagram illustrates the architecture of a WiMAX system, highlighting the processes involved in both the transmitter and receiver sections. The system uses MIMO-OFDM technology to enhance data rates and reliability. Below, we explain each block in detail.

A. WiMAX Transmitter

Randomizer: The randomizer scrambles the input data to ensure that the data pattern is random. This process helps in reducing the long sequences of 1s and 0s, which can cause synchronization issues [10].

Reed-Solomon (RS) Encoder: The RS encoder applies Reed-Solomon coding, a type of forward error correction (FEC), to the randomized data. This coding scheme adds redundancy to the data, allowing for error correction at the receiver.

Convolutional Encoder: The convolutional encoder adds another layer of FEC to the data, providing further protection against errors. Convolutional codes work by encoding the data into a continuous stream of bits.

Inter leaver: The inter leaver rearranges the bits to scatter bursts of errors across a wider span of data. This makes it easier for the FEC algorithms to correct errors, as errors are less likely to be concentrated in one area.

Modulator: The modulator maps the bits into symbols according to the chosen modulation scheme (e.g., BPSK, QPSK, 8-QAM, 16-PSK). These symbols represent the data points in a complex plane [11-13].

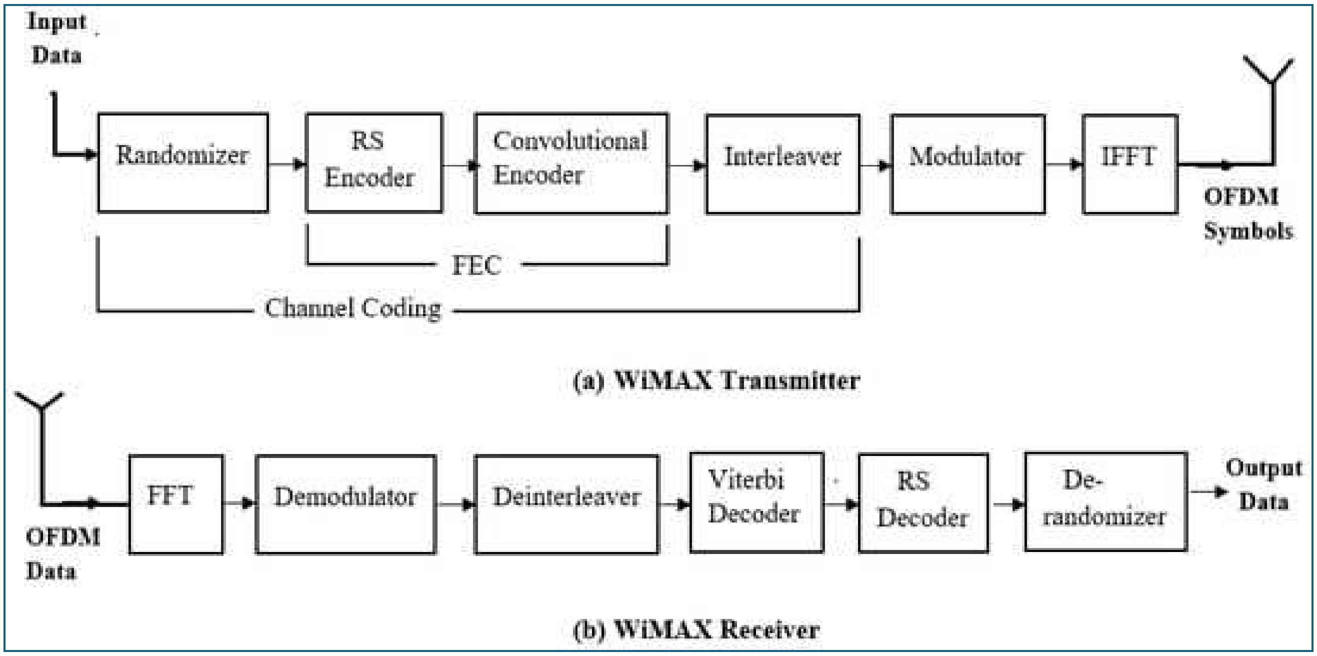

Fig. 1: WiMAX Transmitter and Receiver Overview

Inverse Fast Fourier Transform (IFFT): The IFFT converts the frequency-domain symbols into time-domain OFDM symbols. This step is crucial for multiplexing multiple data streams over different subcarriers.

OFDM Symbols: The time-domain OFDM symbols are transmitted over the air. MIMO technology can be applied here to use multiple antennas for transmission, enhancing data rate and reliability.

B. WiMAX Receiver

Fast Fourier Transform (FFT): The FFT block converts the received time-domain OFDM symbols back into the frequency domain. This is the inverse operation of the IFFT performed at the transmitter [10].

Demodulator: The demodulator converts the received symbols back into bits. It uses the same modulation scheme that was used at the transmitter to map the received symbols to their corresponding bit patterns.

De-interleaver: The de-interleaver reverses the interleaving process, reordering the bits to their original sequence before interleaving. This step prepares the data for error correction [7].

Viterbi Decoder: The Viterbi decoder performs error correction using the convolutional code. It decodes the convolutional encoded data, correcting errors introduced during transmission [12].

RS Decoder: The RS decoder further corrects errors using the Reed-Solomon code. It corrects any remaining errors that the Viterbi decoder could not handle.

De-randomizer: The de-randomizer restores the original data pattern by reversing the scrambling process performed by the randomizer at the transmitter.

Output Data: The corrected and decoded data is then outputted, representing the original transmitted information after passing through the WiMAX system.

4. Explanation of Key Concepts

Channel coding involves adding redundant data to the transmitted information to detect and correct errors at the receiver. In WiMAX, both Reed-Solomon and convolutional coding are used to enhance error correction capabilities. Modulation schemes such as BPSK, QPSK, 8-QAM, and 16-PSK map bits to symbols, which are then transmitted over the air. Higher-order modulation schemes like 16-PSK provide higher data rates but are more susceptible to noise. OFDM splits the data into multiple subcarriers, each carrying a portion of the data. This technique increases the robustness of the transmission by mitigating the effects of multipath fading and interference. MIMO technology uses multiple antennas at both the transmitter and receiver to improve data rates and reliability. It exploits spatial diversity and multiplexing gains, enhancing the overall performance of the WiMAX system [14-16].

5. Modulation Scheme

BPSK: Binary Phase Shift Keying (BPSK) is known for its robustness, particularly in low SNR environments. The results indicate that BPSK maintains a lower SER across all SNR levels compared to other modulation schemes. This makes BPSK an ideal choice for scenarios where signal strength is weak, and reliability is critical [15].

QPSK: Quadrature Phase Shift Keying (QPSK) strikes a balance between complexity and performance. It achieves a lower SER than 8-QAM and 16-PSK at most SNR levels while providing higher data rates than BPSK. QPSK is suitable for environments where moderate data rates are required without significantly compromising on error performance [17].

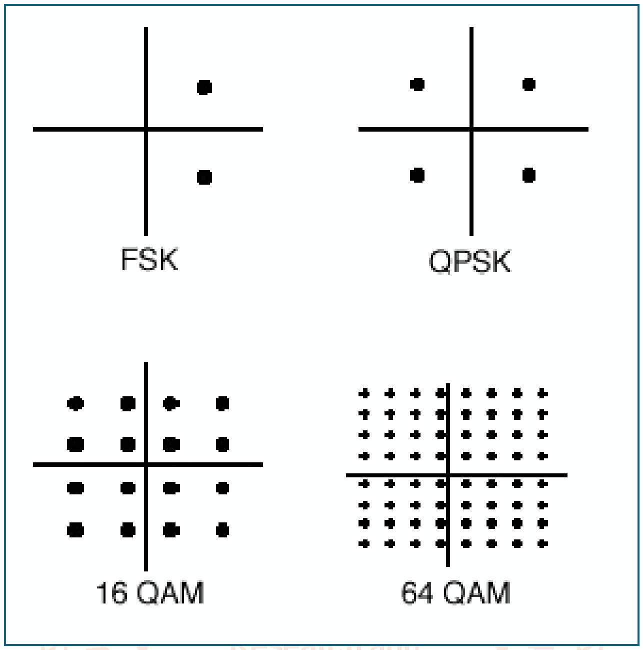

Fig. 2: Modulation scheme constellation diagram

8-QAM: 8-Quadrature Amplitude Modulation (8-QAM) demonstrates better performance than 16-PSK but is less robust than BPSK and QPSK. It offers a good trade-off between data rate and error performance, making it suitable for moderate SNR environments where higher data rates are necessary.

16-PSK: 16-Phase Shift Keying (16-PSK) provides the highest data rate among the four schemes but at the cost of higher SER. The results show that 16-PSK is more susceptible to errors, especially at lower SNR levels. This modulation scheme is best used in scenarios where bandwidth efficiency is more important than error performance [18-19]. Fig. 2 showed the different modulation scheme constellation diagram.

6. Result and analysis

The Fig. 3 illustrates the performance of four different modulation schemes—BPSK, QPSK, 8-QAM, and 16-PSK—used in a MIMO-OFDM system over an AWGN (Additive White Gaussian Noise) channel, a common model for wireless communication. The x-axis represents the Signal-to-Noise Ratio (SNR) in dB, while the y-axis represents the Symbol Error Rate (SER) on a logarithmic scale. The following sections provide a detailed analysis of the results for each modulation scheme. In the Fig. 4 shown the stem plot result produced by MATLAB R2023a for physical layer over AWGN channel with different modulation scheme in WiMAX Technology.

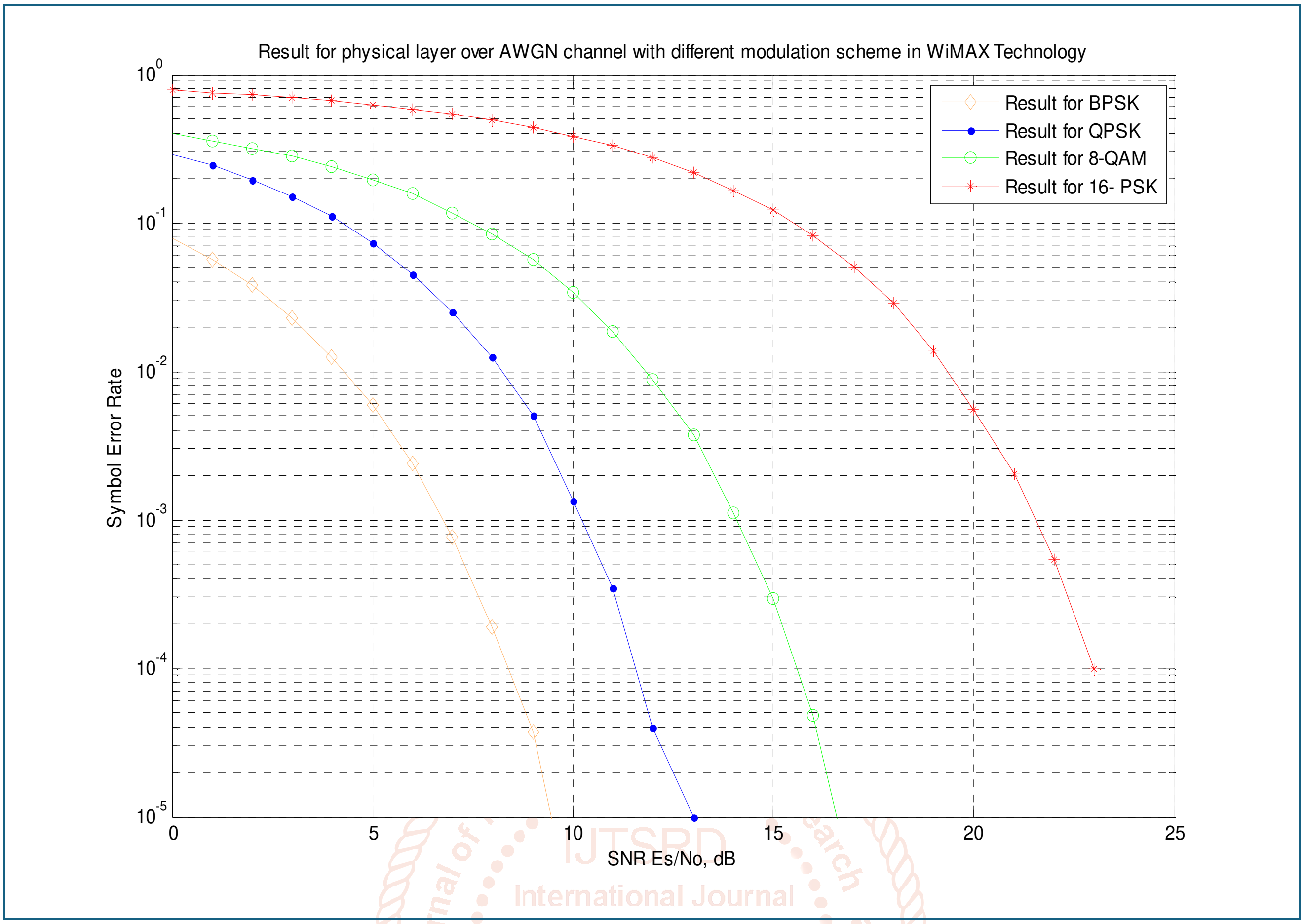

Fig. 3: Result for physical layer over AWGN channel with different modulation scheme in WiMAX Technology.

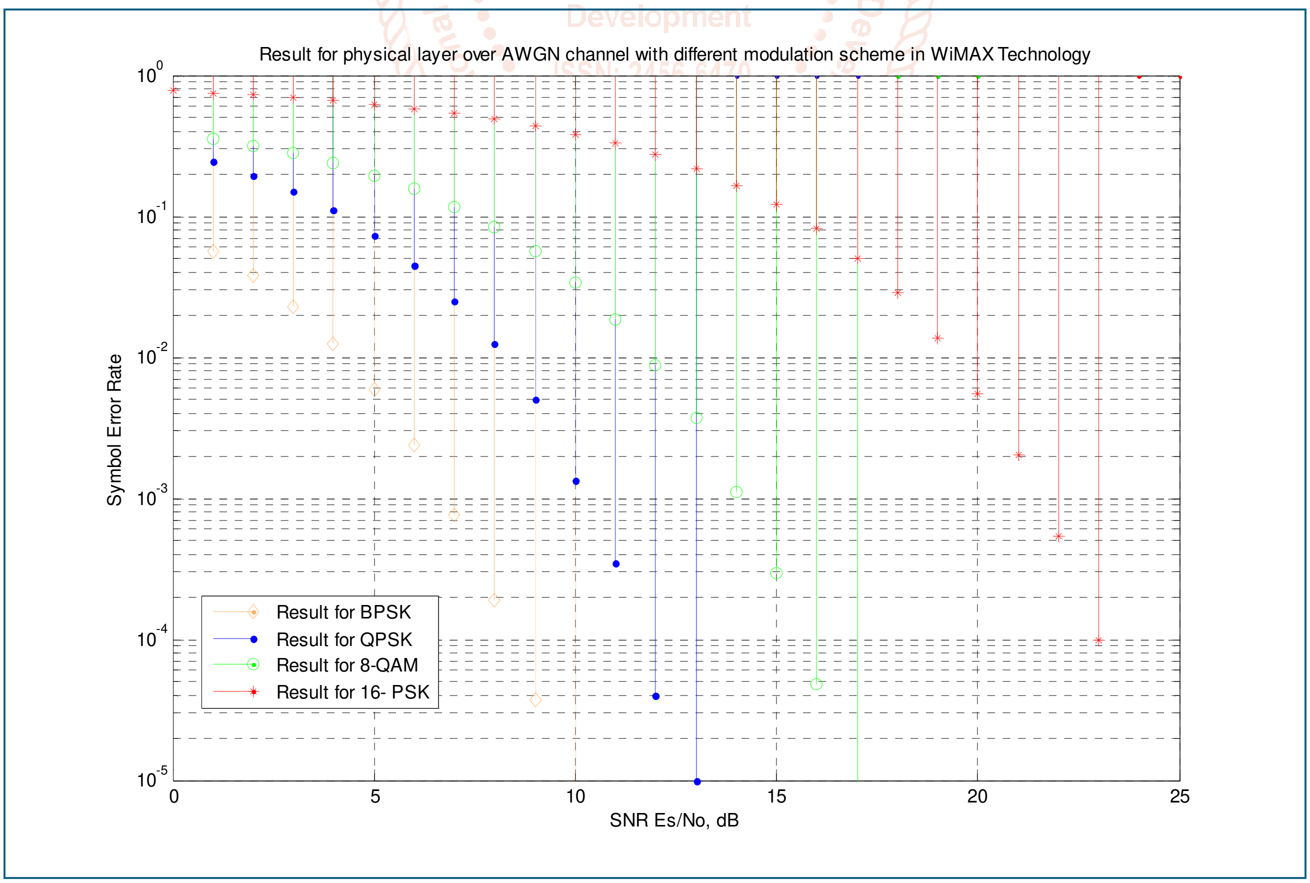

Fig. 4: Stem plot result by MATLAB R2023a for physical layer over AWGN channel.

A. ***Result analysis of BPSK (Binary Phase Shift Keying):*** BPSK demonstrates the lowest Symbol Error Rate (SER) across all SNR values, making it the most robust modulation scheme in this analysis. The plot shows that BPSK maintains a high SER at very low SNR levels, around 0 dB to 2 dB. As the SNR increases, the SER drops sharply, indicating that BPSK can achieve very low error rates at moderate SNR levels. Around 10 dB SNR, BPSK achieves an SER of approximately 10^{-4} which is considered very good for reliable communication. This rapid decline in SER with increasing SNR demonstrates BPSK's efficiency in noisy environments. BPSK is ideal for scenarios where robustness is more critical than data rate, such as in long-distance communication or low-power IoT devices.

B. ***Result analysis of QPSK (Quadrature Phase Shift Keying):*** QPSK offers a good balance between robustness and data rate, with better performance than higher-order modulations but slightly worse than BPSK. The plot shows that QPSK starts with a higher SER at low SNR levels compared to BPSK. However, the SER decreases significantly as the SNR increases, achieving an SER of 10^{-3} at around 10 dB SNR and 10^{-4} at approximately 12 dB SNR. Around 12 dB SNR, QPSK achieves an SER of $10–^{4}$. This indicates that QPSK requires a slightly higher SNR than BPSK to achieve the same error performance. QPSK is suitable for applications where a balance between data rate and error performance is required, such as in standard wireless communication systems and broadband services.

C. ***Result analysis of 8-QAM (8-Quadrature Amplitude Modulation):*** 8-QAM provides a higher data rate than BPSK and QPSK but at the cost of increased SER, especially at lower SNR levels. The plot shows that 8-QAM has a higher SER at low SNR levels, with a gradual decrease as the SNR increases. At around 15 dB SNR, 8-QAM achieves an SER of 10^{-4}. The modulation scheme shows a noticeable decrease in SER starting from around 10 dB, with significant improvement seen between 10 dB to 20 dB SNR. 8-QAM is beneficial in environments where moderate to high SNR is available, and there is a need for higher data rates, such as in urban wireless networks and high-speed data links.

D. ***Result analysis of 16-PSK (16-Phase Shift Keying):*** 16-PSK offers the highest data rate among the four modulation schemes but is the most susceptible to errors, particularly at lower SNR levels. The plot illustrates that 16-PSK has the highest SER at low SNR levels. The SER decreases as the SNR increases, but the decline is less steep compared to BPSK and QPSK. At around 20 dB SNR, 16-PSK achieves an SER of 10^{-3}. For 16-PSK to achieve an SER of 10^{-4}, the required SNR is higher than 20 dB, indicating that this modulation scheme is less efficient in noisy environments. 16-PSK is suitable for scenarios where high data rate is crucial, and the communication environment provides high SNR, such as in line-of-sight communication systems and certain satellite communications.

7. Conclusion

This literature review highlights the significance of MIMO-OFDM systems in enhancing WiMAX technology. By comparing various modulation schemes—BPSK, QPSK, 8-QAM, and 16-PSK—the study demonstrates how each scheme impacts Symbol Error Rate (SER) under different Signal-to-Noise Ratio (SNR) conditions. BPSK and QPSK provide robustness in low to moderate SNR environments, while 8-QAM and 16-PSK are suited for high SNR scenarios, offering higher data rates. The insights gained from SER vs. SNR analysis are crucial for optimizing WiMAX networks, ensuring reliable and efficient wireless communication. The performance of MIMO-OFDM systems in WiMAX technology varies significantly with the choice of modulation scheme. BPSK is ideal for low SNR environments due to its robustness, while QPSK offers a good trade-off between performance and complexity. 8-QAM and 16-PSK provide higher data rates but are more susceptible to errors at lower SNR levels. These findings can help optimize WiMAX networks based on specific operational requirements. This research underscores the importance of adaptive modulation and robust error correction techniques in maintaining optimal network performance. The findings serve as a valuable guide for network deployment and optimization strategies, aiming to enhance the overall reliability and efficiency of WiMAX technology.

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SNR (dB)	BPSK	QPSK	8-QAM	16-QAM
	SER			
0	$1e^{0}$	$1e^{0}$	$1e^{0}$	$1e^{0}$
2	0.8e0	0.9e0	0.85e0	$0.9e^{0}$
4	0.6e0	0.7e0	0.65e0	0.75e0
6	0.4e0	0.5e0	0.45e0	0.55e0
8	0.2e0	0.3e0	0.25e0	0.35e0
10	1e-1	1e-1	1e-1	2e-1
12	5e-2	5e-2	8e-2	1e-1
14	1e-2	1e-2	4e-2	$5e^{-2}$
16	5e-3	5e-3	2e-2	3e-2
18	1e-3	1e-3	1e-2	1e-2
20	1e-4	1e-4	1e-3	1e-3
22	1e-4	1e-4	1e-3	1e-3
24	1e-4	1e-4	1e-3	1e-3