Performance Analysis of 2X2 MIMO System using 8 –APSK Modulation over AWGN and Fading Channel

Sana Ahmed Abdaljlil[1], Olga Boiprav[2] and Amer R. Zerek[3]

[1] Aerospace Information Research Institute (AIRCAS)
Beijing, China
sana.abdaljil@mails.ucas.ac.cn
ORCID 0000-0003-1504-3647
[2] Information Protection Deprt.
Belarusian State University of Informatics and Radioelectronics
Minsk, Belarus
smu@bsuir.by
ORCID 0000-0002-9987-810
[3] Libya Open University
Tripoli, Libya
profzerek@gmail.com
ORCID 0000-0002-4095-8171

Article Info

Article history:

Received , 20/09/2025
Revised , 25/10/2025
Accepted , 02/11/2025

Keywords:

MIMO;
M-ary APSK;
AWGN;
Fading;
BER;
E_b/N_o;
Wireless Communication.

ABSTRACT

This paper presents a performance analysis of a 2x2 Multiple Input Multiple Output (MIMO) system using M-ary Amplitude Phase Shift Keying (M-APSK) modulation over Additive White Gaussian Noise (AWGN) and fading channels. The study investigates the Bit Error Rate (BER) of the system and the energy per bit to noise power spectral density ratio (E_b/N_o), along with constellation diagrams under various communication channel conditions. Simulation results show that the 8-APSK modulation technique, when combined with MIMO technology, leads to significant improvements in spectral efficiency and error performance compared to traditional modulation systems. This improvement is particularly evident in environments characterized by high levels of noise and fading, where maintaining signal integrity is crucial. These results highlight the great potential of 8-APSK in modern wireless communication systems. This technique is especially beneficial for applications requiring high data rates and reliable performance, making it suitable for emerging technologies such as 5G and beyond. Ultimately, this research emphasizes the importance of advanced modulation techniques like 8-APSK in addressing the challenges of contemporary wireless communications, paving the way for more efficient and reliable data transmission in diverse environments.

I. Introduction

The continued growth in wireless communications technologies has been driven by the ever-increasing demand for higher data rates, improved spectral efficiency, and reliable connectivity in diverse and challenging environments. From mobile broadband to Internet of Things (IoT) applications, the need for efficient and robust communications systems is more important than ever. To meet these demands, researchers and engineers have turned to advanced modulation and multiple-input-multiple-output (MIMO) techniques as cornerstones of modern wireless communications systems. MIMO systems, which use multiple antennas at both the transmitter and receiver, have revolutionized wireless communications by offering significant improvements in capacity, diversity, and interference management. When combined with sophisticated modulation schemes, MIMO systems can achieve unprecedented levels of performance, especially in environments plagued by noise, fading, and other channel attenuation. [1, 2, 3, 4]. Among various modulation techniques, M-ary Amplitude Phase Shift Keying (APSK) has emerged as a promising candidate for high data rate applications. APSK modulation, which combines both amplitude and phase variations, provides a flexible and efficient way to encode information, making it well-suited for modern communication systems. Where this work is limited to a one modulation scheme, specifically 8-APSK, and does not encompass other modulation schemes. Specifically, 8-APSK modulation offers an attractive trade-off between spectral efficiency and error performance. By utilizing a well-designed constellation diagram, 8-APSK can transmit more bits per symbol compared to traditional modulation schemes, while maintaining robustness against noise and channel distortions. This makes it an ideal choice for integration with MIMO systems, where the goal is to maximize throughput and reliability without compromising signal integrity. [5,6].

The rest of this paper is organized as follows: Section II provides a background on MIMO systems and 8-APSK modulation, highlighting their key features and advantages. Section III describes the system model and methodology used in this study. Section IV presents the simulation results and discusses their implications. Finally, Section V concludes the paper by summarizing the key findings and outlining potential directions for future research.

II. Multi-Input Multi-Output

MIMO is an antenna technology used in wireless communications, where multiple antennas are deployed at both the Transmitter (Tx) and Receiver (Rx) sides. The MIMO system employs *m* antennas at the transmitter and *n* antennas at the receiver, resulting in an $m \times n$ configuration. [7].

A separate communication channel exists between each transmit and receive antenna. The main goal of the MIMO system is to improve the overall throughput of the wireless link. However, there are other variations of MIMO systems, including Multi-Input Single-Output (MISO), Single-Input Multi-Output (SIMO), and Single-Input Single-Output (SISO) channels. While MIMO channels offer several advantages, such as mitigating fading effects, enhancing quality of service, increasing spectral efficiency and data rates, and reducing bit error rates, they also enable the achievement of higher data rates, among other benefits. Despite these advantages, MIMO systems also have certain drawbacks, including higher costs, increased resource and hardware requirements, and elevated power demands due to the complexity of processing involved. This complexity can significantly reduce battery life. In this thesis, a MIMO system. [8].

Each transmit-receive antenna pair in a MIMO system operates over a distinct communication channel. The primary objective of MIMO technology is to enhance the overall throughput of the wireless link. MIMO systems come in various configurations, including Multi-Input Single-Output (MISO), Single-Input Multi-Output (SIMO), and Single-Input Single-Output (SISO). Compared to these configurations, MIMO systems offer several advantages, such as improved mitigation of fading effects, enhanced quality of service, increased spectral efficiency, higher data rates, and reduced bit error rates. However, these benefits come with certain disadvantages. MIMO systems are costlier, require more resources and hardware, and demand higher power due to the complexity of their processing. This increased complexity can significantly shorten battery life. [9, 10].

For a MIMO system with multiple antennas on both sides of the transmitter and receiver as shown in Figure. 1 where the order of diversity is equal to the number of T_x antennas multiplied by the number of R_x antennas ($m_t \times n_r$) which is the number of possible independent paths between Tx and Rx so that each of the T_x antennas sends a copy of the message that will pass through different paths to reach the R_x antennas, so there are multiple paths for each R_x antenna from the T_x antenna, then the available total number of independent paths is the order of diversity ($m_t \times n_r$). [9,7,10, 11, 12].

Referring to figure 1 where H_{ij} represents a complex number that characterizes the communication channel gain between the i^{th} and j^{th} transmit and receive antennas respectively. At a specific time instant, suppose the symbols S_1, S_2, S_3, …. S_{mt} are transmitted simultaneously through m_t antennas, and then the received signal at antenna n_r can be mathematically expressed as:

$$R_i = \sum_{i=1}^{m_t} H_{ij} S_i + N_j \tag{1}$$

Where i= 1,2,3, … m_t transmitter antennas and j= 1, 2, 3, ...n_r receiver antennas, *Rj* is the received signal from n^{th} receive antenna, H_{ij} is the channel from m^{th} transmit antenna to n^{th} receive antenna, S_j is the symbols transmitted m^{th} , and N_j is the noise on the n^{th}receive antenna.

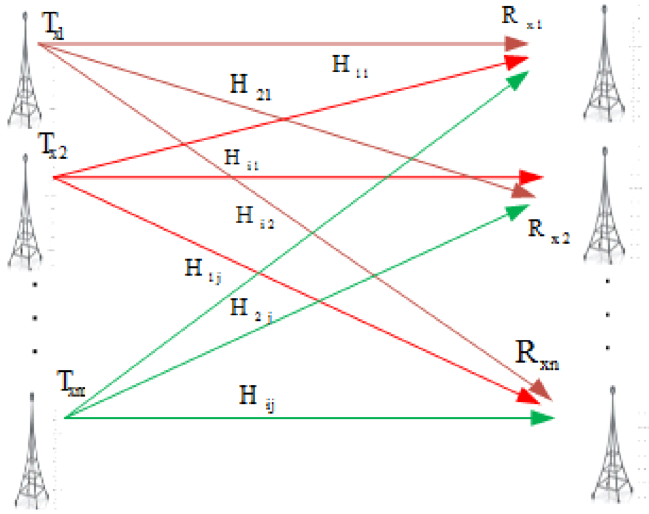

Figure.1. MIMO System ($m_t \times n_r$)

Equation (1) can be represented in matrix form as follows:

$$\begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ \vdots \\ R_{nr} \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} & \cdots & H_{1mt} \\ H_{21} & H_{22} & \cdots & H_{2mt} \\ H_{31} & H_{32} & \cdots & H_{3mt} \\ \vdots & \vdots & \vdots & \vdots \\ H_{nr1} & H_{nr2} & \cdots & H_{nrmt} \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ \vdots \\ S_{mt} \end{bmatrix} + \begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ \vdots \\ N_{nr} \end{bmatrix} \quad (2)$$

This work focuses on a MIMO system configured with two transmit and two receive antennas, denoted as (2x2), as depicted in Figure 2.

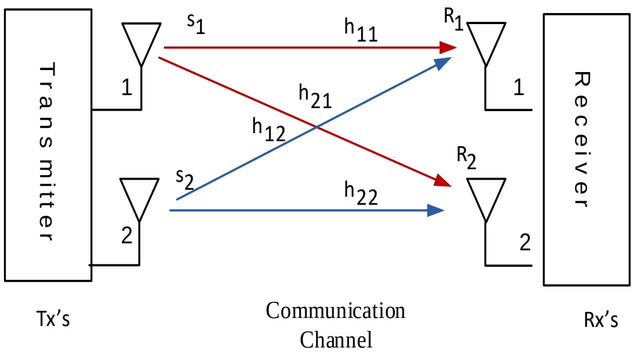

Figure. 2 2x2 MIMO System

The signals received by the first and second receiving antennas can be represented as follows:

$$R_1 = H_{11}S_1 + H_{12}S_2 + N_1 \quad (3)$$

$$R_2 = H_{21}S_1 + H_{22}S_2 + N_2 \qquad (4)$$

Where:

R_1 and R_2 represent the signals received by the first and second antennas, respectively.

H_{11}denotes the channel fading coefficient from the first transmit antenna to the first receive antenna.

H_{21} represents the channel fading coefficient from the second transmit antenna to the first receive antenna,
H_{12} denotes the channel fading coefficient from the first transmit antenna to the second receive antenna,

H_{22} represents the channel fading coefficient from the second transmit antenna to the second receive antenna.

S_1 and S_2 represent the transmitted symbols, while N_1 and N_2 denote the noise components at the first and second receive antennas, respectively.

These two equations can be written in matrix form as follows:

$$\begin{bmatrix} R_1 \\ R_2 \end{bmatrix} = \begin{bmatrix} H_{11} & \mathrm{H}_{12} \\ H_{21} & \mathrm{H}_{22} \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} N_1 \\ S_2 \end{bmatrix} \qquad (5)$$

III. Communication Wireless Channel

A communication channel serves as the medium through which information is transmitted between transmitters and receivers. These channels can be broadly categorized into two types: physical media and free space media. Physical media, also known as guided media, include transmission mediums such as coaxial cables and optical fibers. On the other hand, free space media, referred to as unguided media, operate through open space. Free space channels are further divided into two primary types: the Additive White Gaussian Noise (AWGN) channel and fading channels. Fading channels can be classified into two main categories: Rician and Rayleigh channels. The following points provide a brief overview of these channels. [1, 2, 4, 7].

III.I Additive White Gaussian Noise (AWGN) Channel

"AWGN" stands for Additive White Gaussian Noise, characterizing the noise in a communication system. "Additive" implies that the received signal is the sum of the transmitted signal and the noise. "White" signifies that the noise has a flat power spectral density across the frequency spectrum. "Gaussian" indicates that the noise follows a Gaussian distribution, making it suitable for modeling real-world noise. Finally, "Noise" means it introduces distortion to the received signal. The AWGN channel usually has a wider bandwidth compared to the signal being transmitted. In essence, "Noise" refers to any unwanted signal present in a communication system that interferes with the desired signal. The AWGN channel model involves adding White Gaussian noise to the transmitted signal, as mathematically represented by:

$$R(t) = T(t) + N(t) \qquad (6)$$

Where $T(t)$ the transmitted signal, $N(t)$ the additive noise., and $R(t)$ the received signal.

III.II Rayleigh Fading Channel

The Rayleigh channel is a type of fading channel often referred to as a Non-Line of Sight (NLOS) channel in wireless communication systems. In this channel, the envelope of the carrier signal follows a Rayleigh distribution, which arises due to multipath propagation, with or without the Doppler effect.

In multipath scenarios, particularly under NLOS conditions, the received signal is a combination of multiple components reflected from nearby obstacles such as trees and buildings. This channel supports multiple propagation paths, allowing the signal to reach the receiver through various routes. When these signals arrive at the receiver, they combine to form the overall signal. This fading channel includes both Line of Sight (LOS) and NLOS components, and the reflections can positively impact the performance of the communication system.

III. III Rician Fading Channel

The Rician fading channel, also known as the Line of Sight (LOS) channel, is a variation of the Rayleigh model. Unlike the Rayleigh channel, the Rician fading channel includes a strong dominant signal component in addition to the random multipath components. This dominant component is typically a stationary signal.

In this channel, the amplitude of the signal follows a Rician distribution. When a dominant LOS propagation path is present, the distribution of the small-scale fading envelope becomes Rician. The random multipath components arriving from different angles combine with the stationary dominant signal, adding a DC component to the random multipath at the output of an envelope detector. If the nonzero mean is Rician distributed, the channel is classified as a Rician fading channel.

VI. M-ARY APSK Modulation Technique

M-ary Amplitude M-ary Amplitude Phase Shift Keying (M-ary APSK) is a digital modulation scheme that combines both amplitude and phase modulation to transmit data. It is an advanced form of modulation that allows for higher data rates and improved spectral efficiency compared to traditional modulation schemes like Phase Shift Keying (PSK) or Quadrature Amplitude Modulation (QAM). M-ary APSK is widely used in modern communication systems, including satellite communications, digital video broadcasting, and wireless networks. [4, 6, 7].

M - Ary APSK offers several significant advantages that make it a preferred choice for modern communication systems. One of its primary benefits is high spectral efficiency, as it transmits multiple bits per symbol, enabling higher data rates without requiring additional bandwidth. This makes it ideal for applications where bandwidth is limited. Additionally, M-ary APSK is robust to nonlinear distortions, such as those caused by high-power amplifiers in satellite communications, ensuring reliable performance in systems where signal integrity is critical. The flexibility in its constellation design allows for optimization based on specific channel conditions, improving overall system performance. Furthermore, M-ary APSK performs well in noisy environments due to its ability to control the signal-to-noise ratio (SNR) through multiple amplitude rings. It is also compatible with advanced error correction techniques like LDPC and Turbo codes, enhancing its error resilience. These advantages make M-ary APSK suitable for a wide range of applications, including satellite communications, digital broadcasting, and wireless networks. [10, 1, 14].

Despite its many advantages, M-ary Amplitude Phase Shift Keying (M-ary APSK) has several disadvantages that can limit its effectiveness in certain scenarios. One major drawback is its complexity, as the demodulation and decoding processes are more intricate compared to simpler modulation schemes like PSK or QAM, requiring advanced signal processing techniques. Additionally, M-ary APSK is sensitive to phase noise and frequency offsets, which can degrade performance, especially in systems with imperfect oscillators. Another challenge is its higher peak-to-average power ratio (PAPR), resulting from the varying amplitude levels. This reduces the efficiency of power amplifiers and increases the risk of signal distortion. Designing an optimal constellation for M-ary APSK also poses challenges, as it requires careful optimization of parameters like ring ratios and phase spacing to minimize errors. Moreover, M-ary APSK performs best in moderate to high signal-to-noise ratio (SNR) environments and may not be as reliable in low-SNR conditions compared to simpler schemes like QPSK. These disadvantages must be carefully managed to fully leverage the benefits of M-ary APSK in communication systems. [13, 14].

The mathematical representation of an M-ary APSK signal can be expressed as:

$$v(t) = A_i \cos(\omega t + \theta_i), \quad 0 \le t < T_s \qquad (6)$$

Where:

$V(t)$ is the transmitted signal.

A_i is the amplitude of the i^{th} symbol, where $i=1,2,\ldots,M$.

ω is the carrier frequency.

θ_i is the phase of the i^{th} symbol.

T_s is the symbol duration

The main parameters of M-ary APSK are summarized in the following points

IV.I Bandwidth

The bandwidth (BW) of an M-ary APSK signal is given by $BW = R_s (1+\alpha)$

Where;

R_s is the symbol rate (symbols/sec)

A *is the* roll-off factor (typically between 0 and 1)

If $\alpha=0$, the BW is equal to the symbol rate ($BW=R_s$) which is the minimum theoretical BW

In practical systems, $\alpha > 0$ to reduce inter-symbol interference (ISI), resulting in slightly higher BW.

IV.II Spectral Efficiency

The spectral efficiency (η) of M-ary APSK is the ratio of the bit rate (R_b) to the BW is given by

$$\eta = \frac{R_b}{BW} \tag{7}$$

The bit rate (R_b) is related to the symbol rate (R_s) which is given by

$R_b = R_s \log_2(M) = n R_s$

For 8- the $R_b=3\,R_s$ Therefore, η the can be expressed as:

$$\eta = \frac{\log_2 M}{1+\alpha} = \frac{n}{1+\alpha}$$

Where n is the number of symbol and is equal $\log_2(M)$

For 8- the $R_b=3\,R_s$,

$$\eta = \frac{3}{1+\alpha} \tag{8}$$

IV.III Constellation Diagram

In M-ary APSK, the constellation points are typically arranged in concentric circles, with each circle representing a different amplitude level. The phases are evenly distributed around each circle. The number of amplitude levels and the number of phases per amplitude level determine the total number of symbols M*M*.

For example, in a 8-APSK modulation scheme, there might be two amplitude levels (rings) with 4 phases each, resulting in a total of 8 symbols as shown in figure 3.

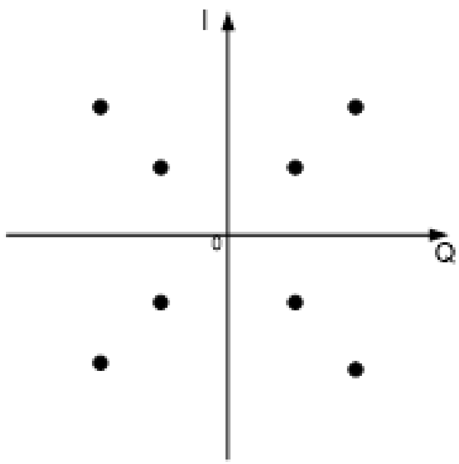

Figure 3. Constellation diagram of the 8-APSK modulation scheme.

IV.IV Error Probability

In M-ary APSK modulation, the probability of error P(e) can be derived based on the specific arrangement of the constellation points and the decision regions in the receiver.

For M-ary APSK, the probability of error for a given symbol can be approximated written in the following formula:

$$P(e) = \frac{1}{M}\sum_{i=0}^{M-1} Q\left(\sqrt{\frac{2E_o}{N_o}}\sin\left(\frac{\pi}{M}i\right)\right) \quad (9)$$

Where

Q(x) is the Q-function, defined as $Q(z) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} e^{-\frac{t^2}{2}}dt$

E_b is the energy per bit.

N_o is the noise power spectral density.

M is the number of constellation points.

VII. Simulation of 8-APSK

The 8-APSK transceiver is implemented using Simulink over AWGN, Rayleigh, and Rician communication channels, as shown in figure.4. This simulation model of the 8-APSK transceiver system includes three main parts such as the transmitter, the communication channel, and the receiver. The main function of these parts sre described brefily in the following points:

- The transmitter include Bernoulli Binary Generator block which generates random binary numbers using a Bernoulli distribution. It is used for generating random data bits to simulate digital communication systems and obtain performance metrics such as bit error rate. Aldo include the M-APSK Modulator Baseband block which modulates the input signal using M-ary APSK modulation. The output is a baseband representation of the modulated signal. This block accepts a scalar, a vector or a matrix input signal. The input signal can be either bits or integers.
- The communication channel includes the following blocks:
- OSTBC Encoder (Alamouti): This block encodes an input symbol sequence using space-time orthogonal space-time block coding (OSTBC). It charts the input symbols block-wise and concatenates the output codeword matrices in the time domain.
- MIMO Fading Channel: This block filters an input signal using a MIMO multipath fading channel, modeling Rayleigh fading and using the Kronecker model for spatial correlation between the links.
- AWGN Channel: This block models a noisy channel by adding white Gaussian noise to the modulated signal.
- Squeeze: This block eliminates singleton dimensions from its multidimensional input signal. A singleton dimension is any dimension whose size is one. This block operates only on signals with more than two dimensions.
- OSTBC Combiner (Alamouti Code 3Rx): This block combines the input signal from all receiving antennas and the channel estimation signal to extract the soft information of the symbols encoded using OSTBC.
- The receiver include the M-APSK Demodulator Baseband block which demodulates a baseband representation of an M-ary APSK. This block accepts a scalar, a vector or a matrix input signal.

In addition to that the simulation model include constellation diagram, calculates the error rate and to workspace blocks used as measurement equipment

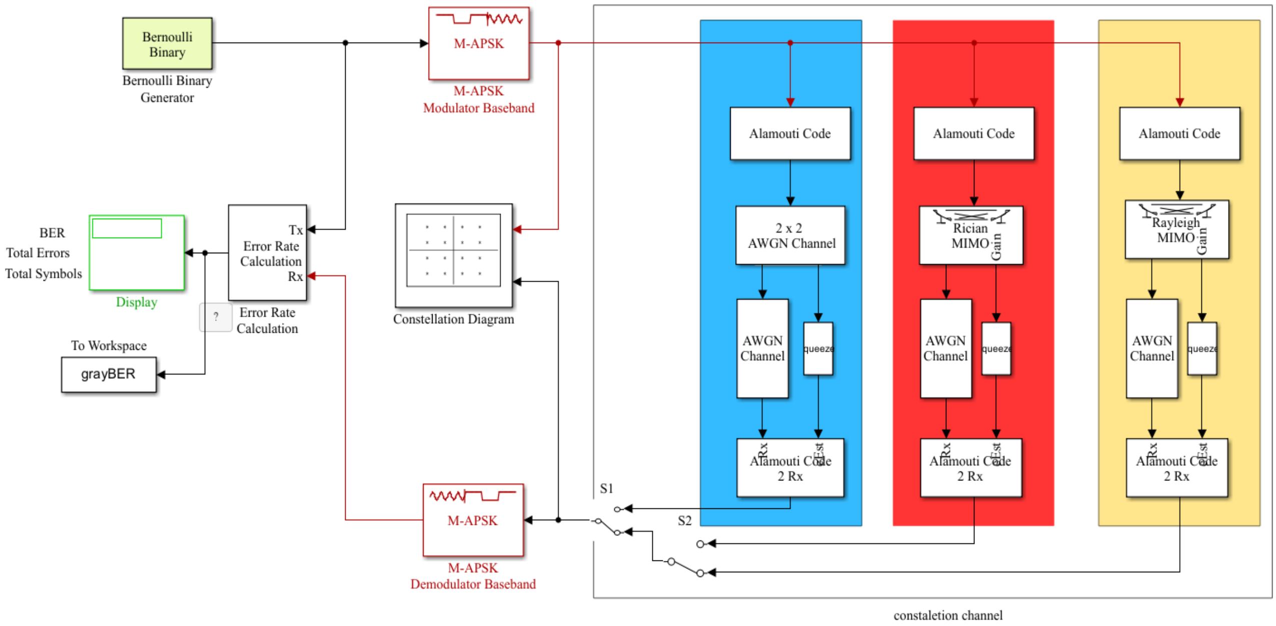

Figure 4. Simulation model of APSK Modulation, 2x2 MIMO system over AWGN and Fading Channel

VIII. Results

After implementing and setting the simulation model parameters for the 8- APSK transceiver for 2x2 MIMO with two transmit and two receive antennas, the 8-APSK modulation is investigated for BER performance over a AWGN and fading channel.

Figure 5 show the BER vs. E_b/N_o performance, for 8-APSK modulation over a AWGN, Rician and Rayleigh channels. The results indicate that as the case of using AWGN channel BER results for the system model displayed in Fig.4 at a BER equal to 10^{-7} dB the E_b/N_0 is 15.27 dB, while in the cases of Rician and Rayleigh channels E_b/N_0 is equal to 23.2, and 28dB respectively. .Therefore for the same BER it can be noticed that the AWGN channel case requires less Eb/N0 compared to the wireless fading channels (Rician and Rayleigh).

Additionally, Figures 6a, 6b, and 6c display the constellation diagrams before and after transmission through the AWGN, Rician, and Rayleigh channels, respectively, with E_b/N_o set to 15.9 dB, since AWGN is taken as there reference rate. These constellation diagrams confirm the achieved BER performance, further illustrating the impact of channel conditions on signal integrity

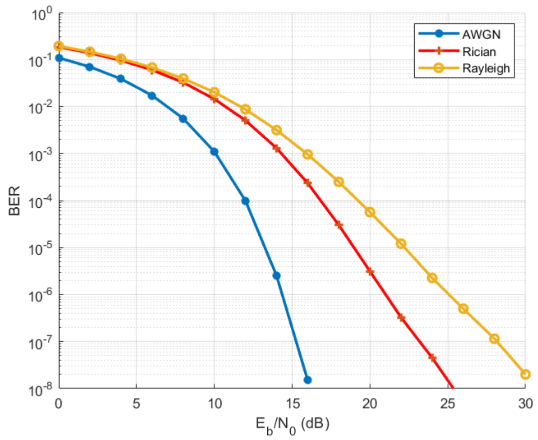

Figure 5. BER Performance for 8-APSK MIMO 2x2 over AWGN, Rician and Rayleigh Channel.

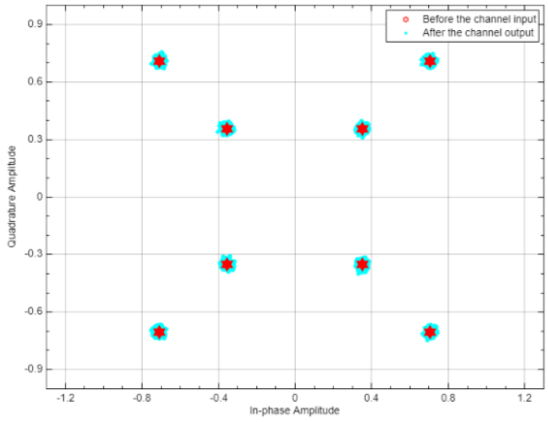

Figure 6 a. Constellation diagrams of the communication system model using 8-APSK over AWGN channel , for E_b/N_o=15.9dB

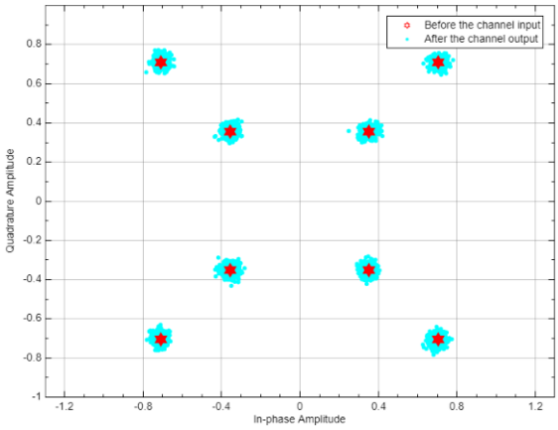

Figure .6 b. Constellation diagrams of the communication system model using 8-APSK over Rician channel , for E_b/N_o=15.9dB

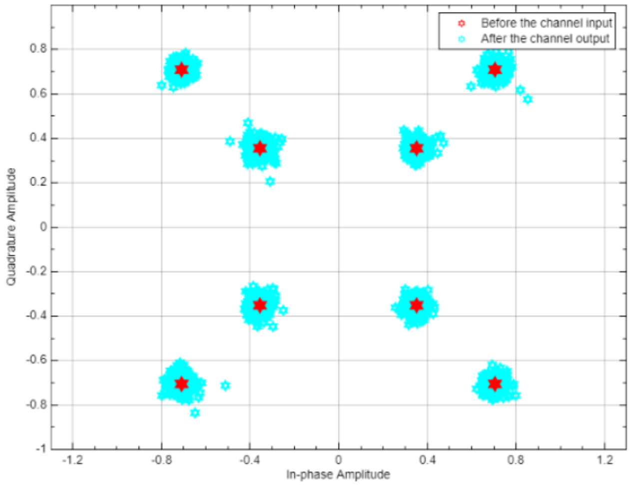

Figure 6 c. Constellation diagrams of the communication system model using 8-APSK over Rayleigh channel, for E_b/N_o=15.9dB

IX. Conclusion

This paper conducted a thorough performance evaluation of a 2×2 MIMO system using 8-APSK modulation over AWGN, Rician, and Rayleigh fading channels. The simulation results revealed significant disparities in performance across channel types. Specifically, the AWGN channel outperformed fading scenarios, achieving a bit error rate (BER) of 10^{-7} at an E_b/N_0 of 15.27 dB. In contrast, the Rician and Rayleigh channels required substantially higher E_b/N_0 values of 23.2 dB and 28 dB, respectively, to reach the same BER threshold. These results underscore the severe degradation caused by multipath fading in wireless environments and emphasize the critical need for resilient modulation techniques to mitigate such effects.

Moreover, the constellation diagrams provided visual corroboration of these findings. While the AWGN channel exhibited minimal signal scattering—consistent with its superior BER performance—the Rician and Rayleigh channels displayed pronounced dispersion due to multipath interference. This distortion aligns directly with the observed increase in Eb/N0$Eb/N0$ requirements, reinforcing the relationship between channel-induced impairments and error rate performance.

Finally, it recommended to Investigate the performance of higher-order modulation schemes, such as 16-APSK or 64-QAM, to assess their effects on system efficiency and performance. Also Investigating the effects of massive MIMO technology on the performance of the 2x2 MIMO system could provide insights into scalability and efficiency, especially in dense urban environmentsIn this part of the article the authors can express their gratitude to projects from the results of which the article has been written, or to people who have contributed to the results published in the article. It is not allowed to insert any figures or logos here.

References

[1] W. Tomasi, “Advanced Electronic Communications Systems”, Pearson Education Limited, 6th Edition, 2014.

[2] W. Liu et al., "Low-Complexity Detection for 8-APSK in MIMO-OFDM SystemsUnder Time-Varying Fading," *IEEE Trans. Broadcast.*, vol. 68, no. 3, pp. 654–667, 2022.

[3] *M. Kasiselvanathan and N. Sathish Kumar,* ” BER Performance Comparison of Large Scale MIMO Receiver Using Q-ary APSK”, Middle-East Journal of Scientific Research 24 (11): 3395-3399, 2016,

[4] D. Adionel Guimar, ” Two-radii 8APSK and Two-radii 16APSK Modulations as Alternatives to 8PSK and 16QAM”, JOURNAL OF COMMUNICATION AND INFORMATION SYSTEMS, VOL. 33, NO. 1, 2018.

[5] W. Liu et al., "Low-Complexity Detection for 8-APSK in MIMO-OFDM SystemsUnder Time-Varying Fading," *IEEE Trans. Broadcast.*, vol. 68, no. 3, pp. 654–667, 2022.

[6] P. Sen, V. Ariyarathna and G. M. Jornet ,” An Optimized M-ary Amplitude Phase Shift Keying Scheme for Ultrabroadband Terahertz Communication”, 2022 IEEE 19th Annual Consumer Communications & Networking Conference (CCNC), 2022.

[7] S. Abdaljlil, and A. Zerek, “A Comparison Study of BER Performance for 8-PSK and 8-QAM Trellis Coded Modulations in a 2x2 OSTBC-MIMO System”, IEEE 11th International Conference on Systems and Control (ICSC).December 18-20 ,2023,Sousse, Tunisia, 2023.

[8] S. Abdaljlil, A. Zerek, H. Almqadim and H. Eissa. “Performance Analysis of 2x2 MIMO 16-PSK with and without Applying TCM Coding Over Different Communication Channels” , 3rd International Conference of Electrical Engineering and Information Technology ICEEIT 2022, 30-32 Oct Benghazi, Libya, 2022.

[9] Y. Zhang et al., "Performance Analysis of APSK Modulation in 5G Millimeter- Wave Systems," *IEEE Trans. Wireless Commun.*, vol. 20, no. 5, pp. 2987–3002, 2021.

[10] A. Alkhateeb et al., "Deep Learning for Massive MIMO Channel Estimation: Recent Advances and Challenges," *IEEE Wireless Commun.*, vol. 28, no. 2, pp. 126–133, 2021.

[11] C. Wang et al., "Energy-Efficient MIMO Systems Using Hybrid APSK-QAM Modulation," *IEEE Access*, vol. 10, pp. 45678–45689, 2022.

[12] S. Abdaljlil, H. Almqadim ,A. R. Zerek and O. Boiprav, “A Comparison Study of BER Performance for 8-PSK and 8-QAM Trellis Coded Modulations in a 2x2 OSTBC-MIMO System”, First International Conference on Advances in Electrical and Computer Engineering Tebessa, Algeria, May 15-16th, 2023.

[13] M. Lau Christopher, “Performance of MIMO Systems Using Space Time Block Codes (STBC)”, Open Journal of Applied Sciences. Vol.11 No.3, March 2021.

[14] Y. Nagy Samir, F. ZAki and H. B. Nafea,” Performance Evaluation of MIMO system in mm wave based on Space Time Block Code and Different Modulation techniques”, MEJ. Mansoura Engineering Journal, Article 9, Volume 47, Issue 4, August 2022.