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BER Performance of 16-PSK in MIMO Systems under ACI and CCI over Fading Channels

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Abstract

With the growing demand for higher data rates and improved spectral efficiency in modern communication systems, understanding the ability of higher-order modulation schemes such as 16 Phase Shift Keying (16-PSK) to resist interference or fading conditions is essential, particularly under realistic channel impairments. This paper provides a performance analysis of 16-PSK modulation in a wireless system, under the impact of Adjacent Channel Interference (ACI) and Co-Channel Interference (CCI) across fading channel environments. Additionally, it's evaluating the system performance over both Rayleigh and Rician fading channels using various MIMO (Multiple-Input Multiple-Output) configurations, including 2×2, 2×3, and 2×4 setups. The simulation model was built using MATLAB Simulink to evaluate Bit Error Rate (BER) as a function of Signal-to-Interference Ratio (SIR) and Energy per Bit to Noise Power Spectral Density (E_b/N_0).

Keywords: 16-PSK, MIMO, Rayleigh Channel, Rician Channel, Adjacent Channel Interference (ACI), Co-Channel Interference (CCI), Fading Channels, BER.

1. Introduction

Interference occurs due to multiple users sharing the same frequency spectrum in wireless communication systems. Two common types of interference include Adjacent Channel Interference (ACI) and Co-Channel Interference (CCI). As the frequency spectrum gets more crowded, it becomes more important to understand how interference affects modulation methods in wireless systems. As the frequency spectrum gets more congested, it becomes more important to understand how interference affects modulation methods in wireless systems. In digital communications, Phase Shift Keying (PSK) is a commonly used modulation technique that is more sensitive to noise and interference and offers higher spectral efficiency than binary Phase Shift Keying (BPSK), and quadrature Phase Shift Keying (QPSK).

This paper investigates the performance of 16-PSK under ACI and CCI in fading channels, particularly Rayleigh and Rician, which model multipath propagation.

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2. Background and Related Work

Numerous studies have investigated the effects of interference on various modulation schemes. For instance, the impact of Co-Channel Interference (CCI) on Quadrature Amplitude Modulation (QAM) has been analyzed under both Additive White Gaussian Noise (AWGN) and fading channel conditions. It is found that the presence of Co-Channel Interference (CCI) in QAM systems leads to a degradation in Bit Error Rate (BER), particularly under fading conditions and in the absence of Line-of-Sight (LOS) paths. adaptive modulation techniques have been proposed to mitigate the effects of channel variations, which allowing the system to switch between modulation types based on the channel quality and interference levels. It achieves higher bandwidth efficiency. Earlier studies showed that 16-PSK achieves higher bandwidth efficiency conversely more sensitive to noise and interference. Which means the system needs stronger error correction and signal processing. Indicating that the system needs stronger error correction and signal processing. Previous studies have shown that employing multiple antennas in MIMO systems improves performance by reducing the effects of fading. this paper specifically focuses on 16-PSK and evaluates its performance under both Adjacent Channel Interference (ACI) and Co-Channel Interference (CCI) using simulation that closely mimic real-world fading environments.

3. MIMO System

The MIMO system is an essential modern communication system, where many antennas are used on both the transmitter and receiver sides, as shown in Fig. (1), to enhance the data rate, reliability, and spectral efficiency. This system utilizes multipath propagation to send multiple data streams simultaneously over the same frequency band, thereby increasing throughput without requiring extra bandwidth. It enhances signal quality through spatial diversity and beamforming, which makes it more resistant to fading and interference. However, MIMO systems also have some downsides. They cost more, need extra equipment and processing power, and use more energy because of their complexity. This can lead to shorter battery life, especially in mobile devices.

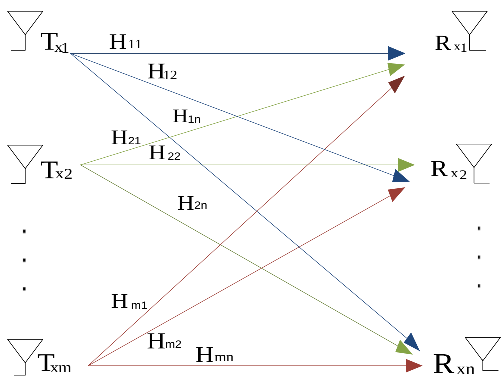

Figure 1: m×n MIMO System

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

Equation (1) in the case of a 2x2 MIMO system can be written as:

$$R_1 = H_{11}S_1 + H_{12}S_2 + N_1 \quad (1)$$

And for a 2x3 MIMO system, equation (1) can be written as:

$$R_1 = H_{11}S_1 + H_{12}S_2 + N_1 \quad (2)$$

As well as a 2x4 MIMO system equation, (1) can be written as:

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

Where :

R is the signal received at the antenna.

H is the channel fading coefficient from the transmit antenna to the receive antenna.

S is the transmitted symbol , and N is the noise component at the receiving antennas.

4. Fading Channel

A **fading channel** is a type of wireless communication channel where the level of the received signal varies randomly due to physical phenomena such as multipath propagation and reflections. Fading occurs when the signal travels from the transmitter to the receiver through multiple different paths caused by reflections, diffraction and scattering from obstacles like buildings, trees, and other structures. These multiple copies of the signal interfere with each other at the receiver, which can either strengthen or weaken the received signal.

Multipath propagation is one of the main causes of fading, where the signal reaches the receiver through multiple paths with different delays. One of the most common types of fading is Rayleigh fading, which occurs when there is no direct line-of-sight **(**LOS**)** between the transmitter and the receiver, and the received signal relies entirely on reflected paths. In contrast, Rician fading occurs when there is a direct LOS path in addition to reflected paths**,** which provides greater signal stability and improved performance compared to Rayleigh fading. Communication reliability is greatly impacted by fading, as it reduces throughput, increases the Bit Error Rate (BER), and introduces inter-symbol interference. One of the most effective solutions to mitigate fading in wireless communication is the use of MIMO systems, which utilize spatial diversity to enhance both performance and reliability. A thorough

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understanding of fading and how to deal with it are essential in the design of robust and efficient wireless systems, including 4G, 5G, Wi-Fi, satellite, and mobile networks.

5. M-Ary Phase Shift Keying

In order to achieve higher bandwidth efficiency, multi-level (M-ary) digital modulation is widely adopted in the design of modern communication systems. M-ary signaling allows digital inputs with more than two modulation levels to be applied at. The data is transmitted in the form of symbols, each symbol is represented by n bits, so there are M=2^n different signal levels in M-ary modulation. In M-ary PSK, n =log2M data bits are represented by a symbol; thus, the bandwidth efficiency is increased by n times. So, the main motivation to use M-ary PSK is to improve bandwidth efficiency in digital communication systems. 16-Phase Shift Keying (16-PSK) is a method of sending digital data by changing the phase of a carrier wave. It uses 16 different phase states, and each state represents 4 bits of information. The signal points in 16-PSK are evenly spaced around a circle, with 22.5 degrees between each point. This technique allows more data to be sent compared to lower-order PSK methods like BPSK and QPSK, meaning it can send more information within the same bandwidth. Having more phase states makes 16-PSK more sensitive to interference, noise, and errors, which leads to a higher error rate at the same signal-to-noise level. Because of this, receivers need advanced methods to accurately decode these signals. Despite its weaknesses, 16-PSK is used in wireless communication systems that need high data rates, such as satellite and cellular communications, where efficient use of bandwidth is important. Overall, 16-PSK helps increase data speed and spectral efficiency but requires advanced signal processing to reduce the effects of channel problems.

6. System Model

The simulation model shown in Fig. (2) is designed to evaluate the performance of 16-PSK (Phase Shift Keying) modulation under the effects of adjacent and co-channel interference in fading channels. The model includes a 16-PSK modulator and demodulator, which transform the input binary data into unique phase symbols for transmission and then decode them back at the receiver. The signal is transmitted through various channel models, such as the Additive White Gaussian Noise (AWGN) channel, the Rayleigh fading channel, and the Rician fading channel. The system is subjected to two forms of interference, Adjacent Channel Interference (ACI) and Co-Channel Interference (CCI). The interference levels are adjusted by modifying the Signal-to-Interference Ratio (SIR) in order to analyze their effect on the overall performance of the system. The main output of the model is the Bit Error Rate (BER), which is measured at the receiver to assess the quality and reliability of communication under

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different interference and fading conditions. This model helps to understand how 16-PSK works in real wireless communication situations.

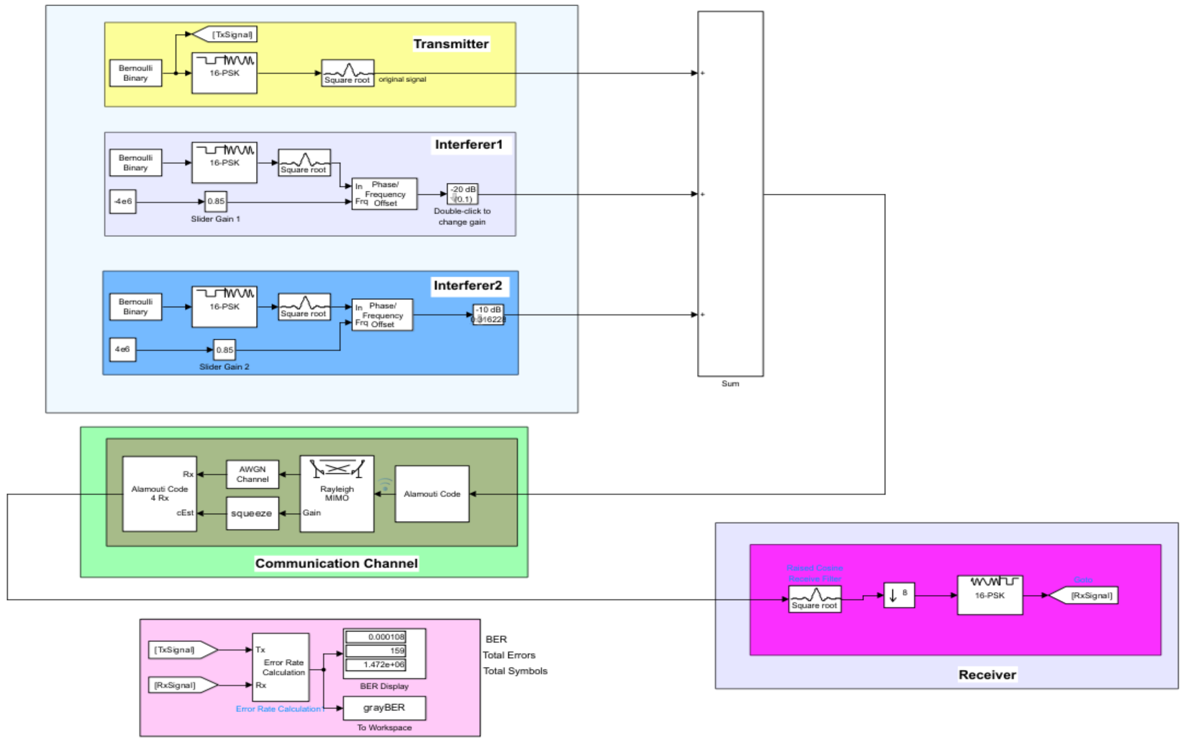

Figure 2: Simulation Model of the Communication System with Interference using 16-PSK

7. Simulation and Results

Simulations were conducted using MATLAB Simulink to evaluate the performance of 16-PSK modulation over AWGN and Rayleigh channels, considering interference from adjacent channels (ACI) and co-channel interference (CCI). The Bit Error Rate (BER) was measured at different Signal-to-Interference Ratios (SIR) and bit energy-to-noise ratios (E_b/N_0). The results showed that BER increases more significantly under CCI compared to ACI. Additionally, BER was higher in the Rayleigh channel due to multipath interference. However, at high SIR values (above 20 dB), 16-PSK performed well even in the presence of interference. BER versus E_b/N_0 graphs were presented at various SIR levels to illustrate the impact of interference and fading under both AWGN and Rayleigh channel conditions. Figures 3–5 illustrate the performance of 16-PSK over Rician and Rayleigh fading channels using 2×2, 2×3, and 2×4 MIMO systems under interference. The curves show BER as a function of E_b/N_0. The results demonstrate that Rician channels achieve better performance than Rayleigh channels due to the presence of a strong Line-of-Sight (LOS) path, while Rayleigh channels

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experience more severe signal fading due to the absence of direct paths. These figures clearly highlight the significant impact of both interference and fading type on system performance.

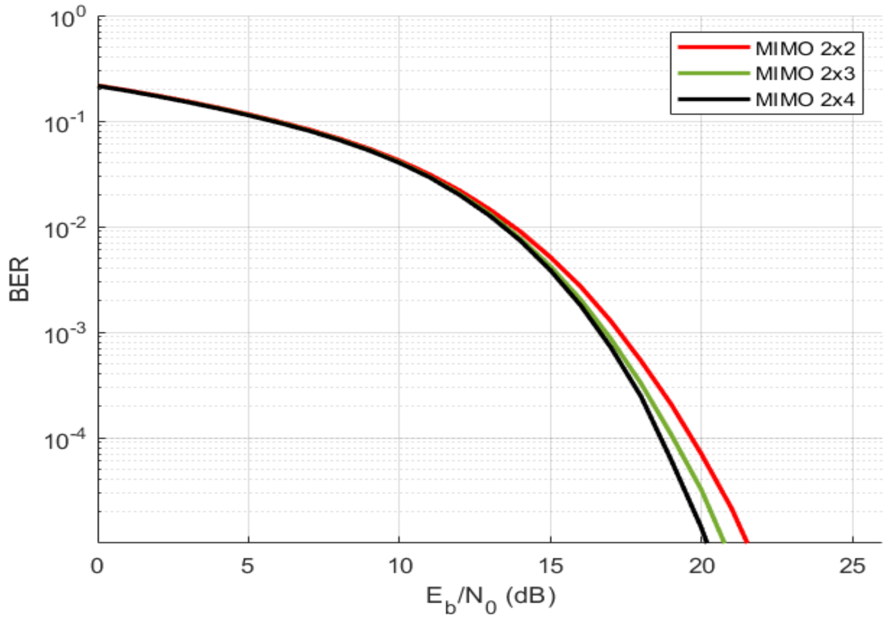

Figure 3: 16 PSK over Rician

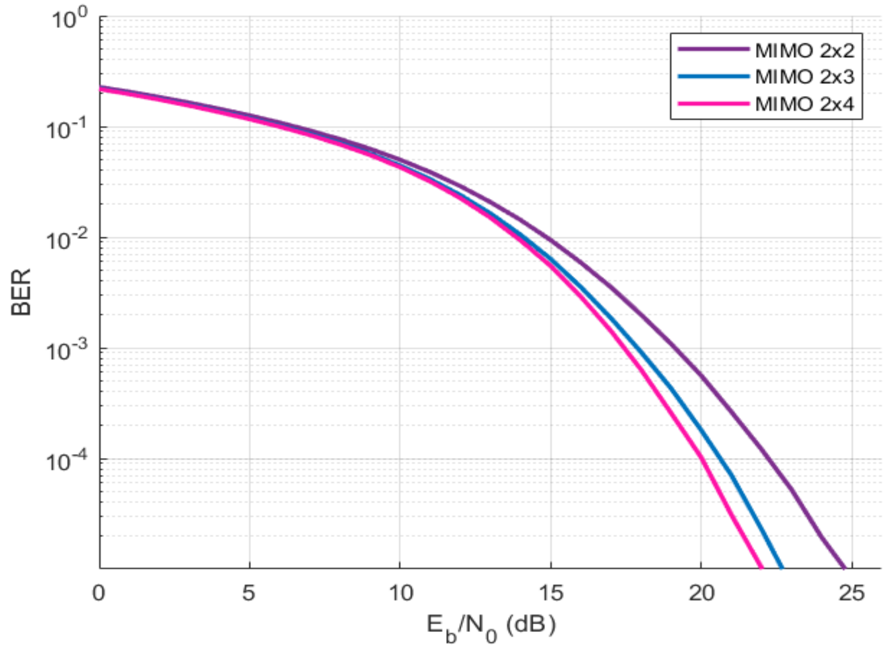

Figure 4: 16 PSK over Rayleih

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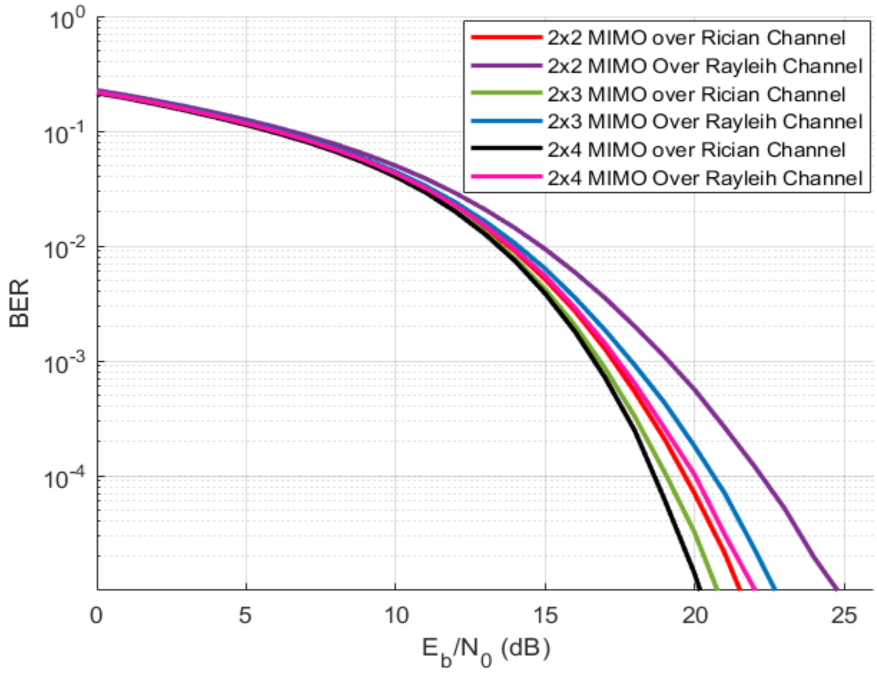

Figure 5: 16 PSK over Rician and Rayleih

Referring to the Table I it is observed that the Rician channel consistently outperforms the Rayleigh channel across all MIMO configurations, requiring a lower Eb/No to achieve the same Bit Error Rate (BER). This advantage is attributed to the presence of a strong Line-of-Sight (LoS) component in the Rician model. Additionally, the performance gain between the two channels decreases as the number of receive antennas increases, highlighting the effect of enhanced spatial diversity in mitigating channel impairments.

Table I Comparative Eb/No Values for 16-PSK MIMO Systems over Rician and Rayleigh Channels under Interference Conditions (BER = 10^{-4})

MIMO Configuration	Eb/No (dB) Rician	Eb/No (dB) Rayleigh	Performance Gain of Rician over Rayleigh
2×2	19.70	22.25	2.55 dB gain
2×3	19.00	20.60	1.60 dB gain
2×4	18.65	20.00	1.35 dB gain

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8. Conclusion

This study highlights the impact of Adjacent Channel Interference (ACI) and Co-Channel Interference (CCI) on the performance of 16-PSK modulation across Rician and Rayleigh fading channels, using various MIMO configurations. The simulation results consistently showed that the Rician channel surpasses the Rayleigh channel in all MIMO setups (2×2, 2×3, and 2×4), due to the presence of a strong Line-of-Sight (LOS) component, which improves signal reliability and minimizes the Negative effects of multipath fading. Alternatively, Rayleigh channels, which lack a Line-of-Sight (LOS) path, were more affected by signal degradation. The Bit Error Rate (BER) was clearly higher in Rayleigh environments at equivalent E_b/N_0 values, showing they are more affected by interference and fading.

With the use of MIMO technology, the system becomes more robust. As the number of receive antennas increases, performance improves even in the challenging Rayleigh environment. In contrast, Rician channels always showed better performance in all cases, due to the presence of a strong Line-of-Sight (LOS) path, and performance improves even more as the number of antennas increases. The results show that using MIMO systems with a reliable communication channel, such as a Rician fading channel, can greatly improve the performance and dependability of 16-PSK modulation, especially in environments affected by interference.

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