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Multicarrier MIMO in Different Fading Scenarios

[1]Suraj S, [2] Dr.Rajani Katiyar ,[3] Dr. Ravishankar.S
[123]Electronics and communication
R.V College of Engineering
Karnataka, India

Abstract - This paper explores the performance of multicarrier Multiple Input Multiple Output (MIMO) systems in various fading scenarios. To generate an Orthogonal Frequency Division Multiplexing (OFDM) signal and integrate it with MIMO techniques to enhance spectral efficiency and reliability. OFDM is a widely adopted modulation scheme that partitions a wideband signal into multiple orthogonal subcarriers, making it highly effective in mitigating frequency-selective fading and inter-symbol interference. MIMO leverages multiple transmit and receive antennas to provide spatial diversity and multiplexing gains, significantly improving system capacity and robustness

Keywords— Multicarrier MIMO, OFDM, Fadingscenarios, QAM, Diversity schemes

1. Introduction

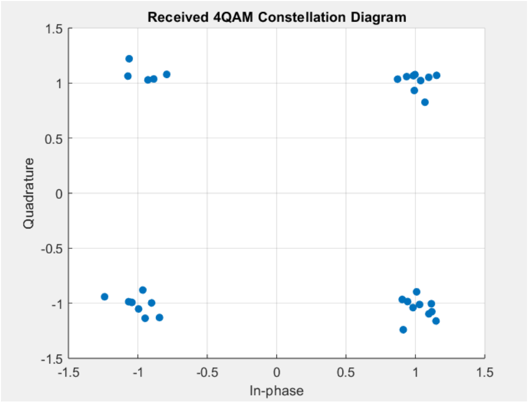
In the realm of modern wireless communication, achieving high data rates and reliable transmission over varying channel conditions is crucial. Orthogonal Frequency Division Multiplexing (OFDM) has emerged as a prominent modulation technique, particularly effective in combating the challenges of frequency selective fading and inter-symbol interference. OFDM divides the available spectrum into multiple orthogonal subcarriers, enabling robust performance in multipath environments.

This paper embarks on a comprehensive exploration of a MIMO technology which further improves the wireless communication systems by leveraging multiple antennas at both the transmitter and receiver ends. MIMO systems exploit spatial diversity and multiplexing to increase system capacity and improve reliability. The integration of MIMO with OFDM, known as MIMO-OFDM, combines the benefits of both technologies, resulting in a potent solution for high-speed and reliable communication.

Fading, a significant factor affecting wireless communication, introduces signal strength and quality variability due to multipath propagation. Various fading scenarios, such as Rayleigh and Rician model different propagation environments and impact system performance in distinct ways. Rayleigh fading represents environments with severe multipath effects, and Rician fading models scenarios with a dominant line-of-sight component.

This paper investigates the performance of MIMO-OFDM systems across different fading scenarios. First by generating an OFDM signal and subsequently applying MIMO techniques to assess the system's capability in enhancing data throughput and resilience against channel impairments. Through simulations under Rayleigh, and Rician, fading conditions, we analyze key performance metrics such as BER, SNR and channel capacity.

The objective of this study is to demonstrate the effectiveness of MIMO-OFDM in diverse fading environments and to provide insights into optimizing wireless communication systems for next-generation applications. By evaluating the interplay between OFDM and MIMO in various channel conditions, this research aimsto contribute valuable knowledge towards advancing the design and deployment of robust and high-capacity wireless networks.



2. Objectives

OFDM (Orthogonal Frequency Division Multiplexing) divides a high-data-rate stream into several parallel low-data-rate streams, modulated over orthogonal subcarriers. Each subcarrier can be modulated using techniques like QAM. The generated signal can then be transmitted over multiple frequency bands to reduce inter-symbol interference.

Rayleigh and Rician fading simulate real-world wireless environments. In Rayleigh fading, there is no direct line-of-sight (LOS), while in Rician fading, a dominant LOS path is present. Simulations analyze how these conditions affect OFDM signal performance, particularly in terms of bit error rate (BER).

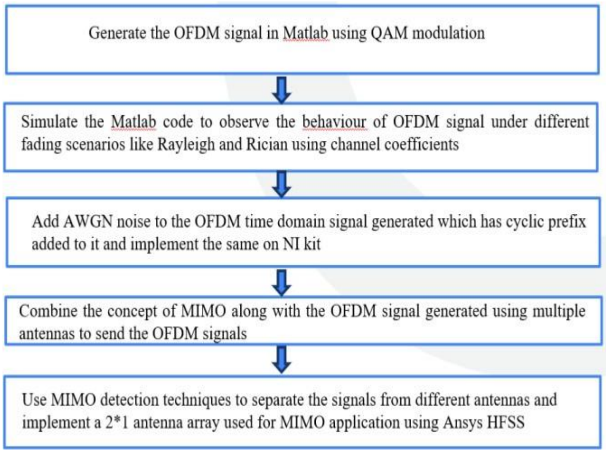
AWGN (Additive White Gaussian Noise) simulates random noise in a communication channel, which affects signal clarity. The cyclic prefix is added to each OFDM symbol (10% of the subcarriers) to mitigate inter-symbol interference, ensuring proper symbol recovery even under multipath effects.

MIMO (Multiple Input Multiple Output) is integrated with OFDM to exploit spatial diversity, increasing data rate and reliability. Each antenna transmits a separate OFDM signal, and the receiver uses advanced signal processing to recover the original data from multiple antennas.

The generated MIMO-OFDM signal is implemented on an NI kit for hardware prototyping and performance testing in real-world environments. Ansys HFSS software simulates electromagnetic fields to analyze antenna design and ensure proper signal propagation.

3. Methodology

The major goal of this work is to study is to evaluate the performance of MIMO-OFDM systems under various fading scenarios, including Rayleigh and Rician By generating and combining OFDM signals with MIMO techniques, the research aims to enhance data throughput and reliability in challenging propagation environments. The study focuses on analyzing key performance metrics such asBit Error Rate (BER), Signal-to-Noise Ratio (SNR), and channel capacity to provide insights into optimizing wireless communication systems for next-generation applications.



The first step is to generate the OFDM signal by modulating data symbols using Quadrature Amplitude Modulation (QAM) and then apply the Inverse Fast Fourier Transform (IFFT) to convert the frequency-domain representation into the time domain. This involves creating a matrix of QAM symbols, performing IFFT on each row, and combining the results to form the complete OFDM signal.

The second step is to Simulate the MATLAB code by applying Rayleigh and Rician fading models to the generated OFDM signal using channel coefficients to observe how these fading conditions affect the signal's performance. This involves convolving the OFDM signal with the fading channel impulse response and analyzing the impact on key metrics such as Bit Error Rate (BER) and Signal-to-Noise Ratio (SNR).

The third step is to add Additive White Gaussian Noise (AWGN) to the OFDM time domain signal, including the cyclic prefix, by generating noise with a specified power level and adding it to the signal. This step simulates the impact of noise on signal integrity and enables the evaluation of system performance under realistic conditions.

The final step is to combine MIMO with the generated OFDM signal by using multiple antennas to transmit parallel OFDM signals, enhancing capacity and reliability by implementing a 2*1 antenna array used for MIMO application using Ansys HFSS.

4. Results

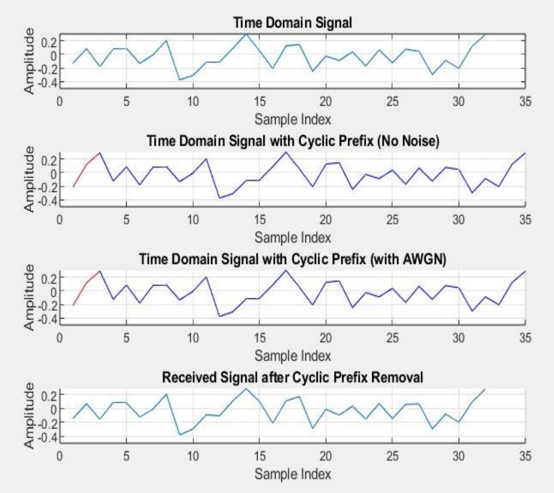


Fig 1:Plots of OFDM signal processing stages

1.)**Time Domain Signal**: Shows the real part of the OFDM signal in the time domain before any modifications, representing the base signal generated by the IFFT.

2.)**Time Domain Signal with Cyclic Prefix (No Noise)**: Displays the time domain signal with the cyclic prefix added, in blue, and the cyclic prefix itself, in red, without any noise, highlighting the prefix's role in mitigating inter-symbol interference.

3.)**Time Domain Signal with Cyclic Prefix (with AWGN)**: Depicts the signal with the cyclic prefix after adding Additive White Gaussian Noise (AWGN). The noise is evident as random fluctuations superimposed on the signal,illustrating its impact on signal quality.

4.)**Received Signal after Cyclic Prefix Removal**: Illustrates the signal after removing the cyclic prefix and processing through the channel. This plot shows the degraded signal quality due to noise and potential distortions introduced during transmission.

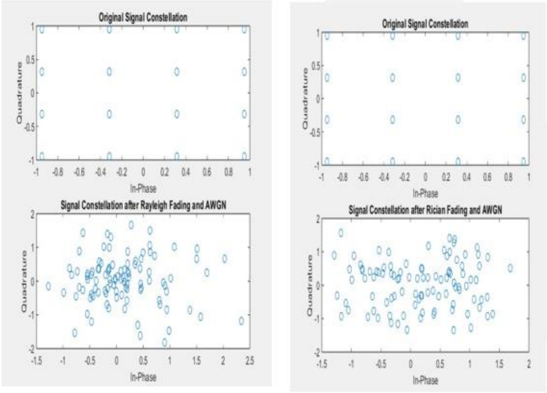


Fig 2: Rayleigh and Rician fading channel behaviour

The simulation's offered signal constellation diagrams show how the OFDM signal is affected by Rician and Rayleigh fading. The original constellation consists of distinct signal states represented by well-defined points. But when noise and fading are added, the spots start to cluster and disperse, which suggests that the signal quality has decreased. This phenomena illustrates the difficulties caused by channel limitations and is typical in wireless communication systems.

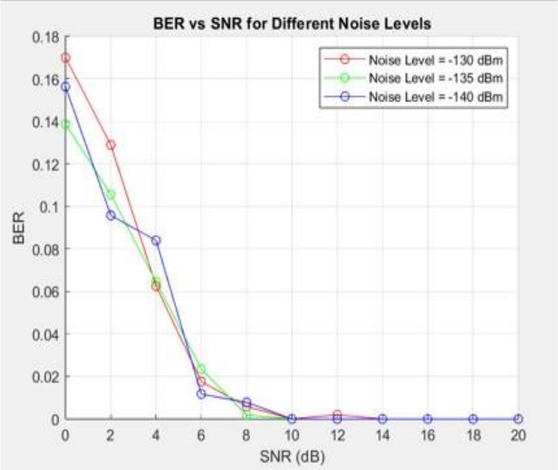


Fig 3: Different values of noise added to the OFDM signal using QAM modulation

The BER against SNR plot for MIMO-OFDM at a 10dB SNR is shown in the above result, which shows how well the system performs at various noise levels. Strong signal strength with little noise interference is shown by the plot's low BER and sharp, well-defined bands at high SNR. Bands become less distinct and mild distortions arise from growing noise as the SNR drops to moderate levels, causing the BER to rise. The plot shows a dramatic increase in BER at low SNR, with overlapping and blurry bands making it difficult to discern the signal from the noise. When the signal-to-noise ratio (SNR) is exceedingly low, noise overwhelms the signal, causing a very high bit-error rate (BER) and making the signal almost undetectable, making in-depth analysis challenging.

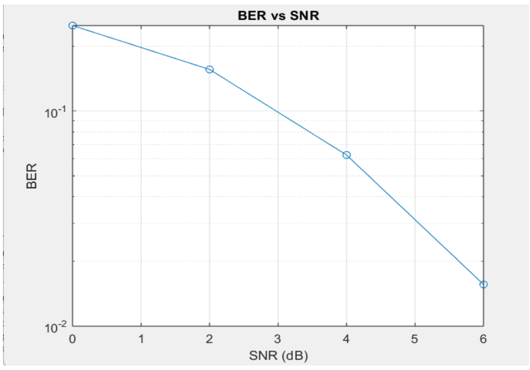


Fig 3: MIMO Performance

This plot shows the Bit Error Rate(BER) as the function of theSignal-to-Noise Ratio (SNR) for a 2*1 Multiple-Input Multiple-Output (MIMO) system. The BER decreases rapidly as the SNR increases, indicating improved communication performance at higher signal powers relative to noise.

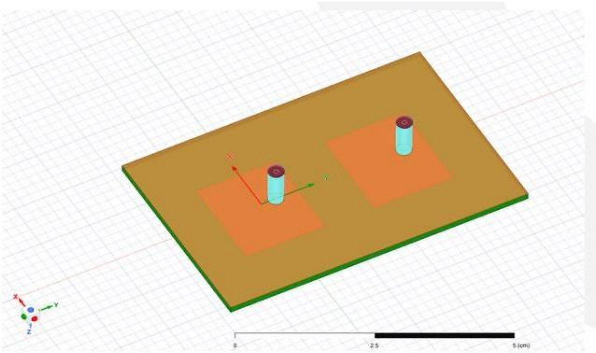


Fig 4: 2*1 Probe feed Antenna Array

This result illustrates the design of a 5.65 GHz antenna, showcasing its layout and dimensions. The antenna ’ s design is optimized for high-frequency performance, ensuring effective signal transmission and reception at the specified frequency.

The result shows the S-parameter dip for the antenna design operating at 5.65 GHz, indicating the frequency at which the antenna achieves optimal impedance matching. The dip corresponds to the resonant frequency where reflection losses are minimized, ensuring efficient signal transmission.

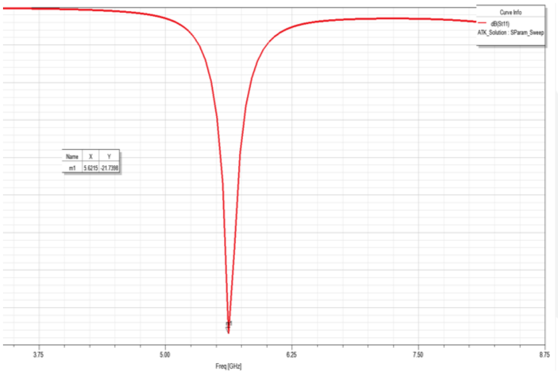


Fig 5: Return Loss

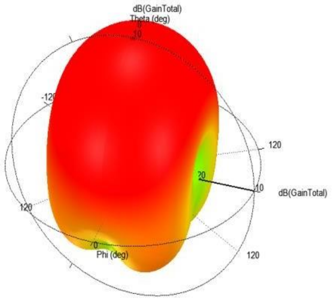


Fig 6: 3D Gain

The result displays a three-dimensional (3D) map that offers a thorough understanding of the radiation pattern of the antenna. It depicts the distribution of radiation in three dimensions and makes nulls, lobes, and other important aspects visible. This visualisation, which shows areas of strong and weak radiation that can affect coverage and signal quality, is essential for comprehending the antenna's performance. In addition, the plot shows the distributions of electric and magnetic fields surrounding the antenna, providing information about near-field properties and the antenna's interaction with its environment.

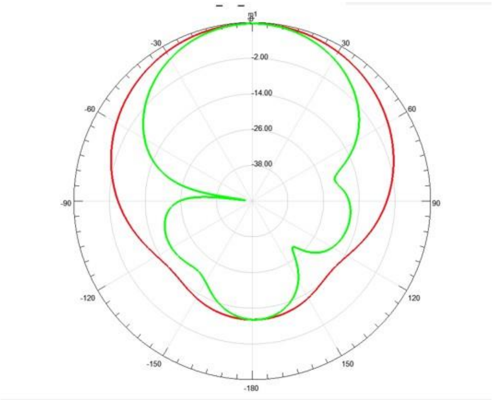


Fig 7: 2D Gain

This outcome displays a 2D plot.They are crucial for displaying radiation patterns in the elevation and azimuth planes, which show the various directions in which the antenna directs electricity. Additionally, they include examples of S-parameters such as the reflection coefficient (S11), which indicate how well the antenna and transmission line match and reduce signal reflections.Furthermore, gain against frequency can be shown in 2D graphs, which shed light on the antenna's bandwidth and efficiency at different frequencies.

5. Conclusion

The Multicarrier MIMO project successfully demonstrates how OFDM signals with M-QAM modulation function in a range of fading circumstances, guaranteeing consistent signal transmission by means of methods like the IFFT and the cyclic prefix addition. Convolution of the signals with various channel models and analysis of the Bit Error Rate (BER) at different Signal-to-Noise Ratio (SNR) levels are part of the thorough examination. The system's capacity to manage channel impairments and improve communication dependability is highlighted in this evaluation, highlighting its potential to advance wireless technologies in the future.

The code creates a 2x1 MIMO system that transmits signals using the OFDM technique. The performance characteristicsare represented in the resulting plot by modeling this arrangement. This plot illustrates how the 2×2 MIMO configuration, combined with OFDM, effectively transmits signals and manages various channel impairments. The observed results demonstrate the system's efficiency and reliability in handling data transmission under different conditions, highlighting the benefits of integrating MIMO with OFDM for enhanced communication performance.

The project also displays the designing of 2*1 antenna array which can be used as an MIMO application as transmitter orthe reciever where the generated OFDM signal is transmittedor received which confirms that when the size of the array is increased,the data throughput and spatial diversity increases in turn increasing the sytem performance.

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