Analysis of 256-QAM Performance

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***Abstract*—In this report, a 256-QAM (Quadrature Amplitude Modulation) communication system was analyzed and modeled using MATLAB and Simulink to assess its performance under various noise conditions. The study focused on evaluating the system's behavior in the presence of additive white Gaussian noise (AWGN) and phase noise, both of which play a critical role in real-world wireless communication scenarios. To achieve this, the simulation incorporated essential components, including QAM modulation and demodulation blocks, noise channels (AWGN and phase noise), and a bit error rate (BER) calculation module to quantify system performance. The analysis was carried out using key performance metrics such as BER and constellation diagrams, which provided insight into the impact of different noise sources on signal integrity. Additionally, the study explored the effects of integrating an orthogonal frequency-division multiplexing (OFDM) scheme into the system, as well as replacing 256-QAM with alternative modulation techniques like M-PSK (M-ary Phase Shift Keying). It was observed that increasing the signal-to-noise ratio (SNR) led to a reduction in BER, confirming the fundamental relationship between noise power and transmission reliability. Moreover, phase noise introduced significant signal distortion, particularly in high-order QAM schemes. The implementation of OFDM improved the system's resistance to noise by mitigating inter-symbol interference, while M-PSK demonstrated greater robustness against phase noise, albeit at the cost of reduced spectral efficiency. These findings highlight the trade-offs involved in designing resilient communication systems, emphasizing the need for careful modulation scheme selection and noise mitigation strategies to optimize performance in practical applications.**

***Index Terms*—**

I. Introduction

QUadrature Amplitude Modulation (QAM) is a widely utilized digital modulation technique known for its efficiency in transmitting high data rates over bandwidth-constrained channels. Unlike other modulation schemes that vary frequency or phase exclusively, QAM simultaneously alters both the amplitude and phase of the carrier signal by modulating its in-phase (I) and quadrature (Q) components. This dual-dimensional encoding allows for increased spectral efficiency, making QAM a fundamental choice in modern communication systems, including wireless networks, broadband services, and satellite communications.

This experiment specifically examines the performance of a 256-QAM system, a higher-order variant capable of transmitting 8 bits per symbol, under the influence of Additive White Gaussian Noise (AWGN) and phase noise. The study employs MATLAB and Simulink to simulate and analyze system behavior, evaluating key performance metrics such as error rates and signal integrity. By assessing the impact of noise on the received signal, this investigation aims to provide insights into the robustness and reliability of 256-QAM in practical communication environments.

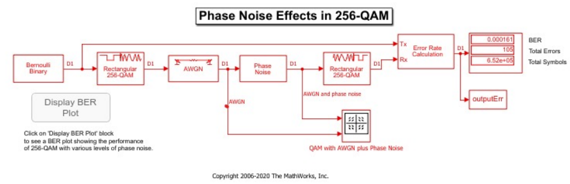

Fig. 1. Phase noise effect in 256-QAM

- The Bernoulli Binary Generator block generates a random signal consisting of a sequence of 8-bit binary values in the range [0, 255].
- The Rectangular QAM Modulator Baseband block modulates the signal using baseband 256-ary QAM.
- The AWGN Channel block models a noisy channel by adding white Gaussian noise to the modulated signal.
- The Phase Noise block introduces noise in the angle of its complex input signal.
- The Rectangular QAM Demodulator Baseband block demodulates the signal.

These additional model blocks can help you interpret the simulation.

- The Constellation Diagram block a displays constellation diagram of the signal with AWGN and phase noise added.
- The Error Rate Calculation block counts bits that differ between the received signal and transmitted signal.
- The To Workspace block, labeled `outputErr`, outputs the results to the workspace for use when plotting the results.
- A Callback Button labeled `Display BER Plot` opens a plot showing the Eb/N0 performance curves for 256-QAM transmission and reception at various levels of phase noise.

QAM is a single-carrier modulation technique that acts effectively as dual carrier modulation. To be specific, the single carrier undergoes a Hilbert transformation creating a 90◦ separation between the initial carrier and the created carrier, which is coincidentally orthogonal1 to the original carrier when demodulation is concerned.

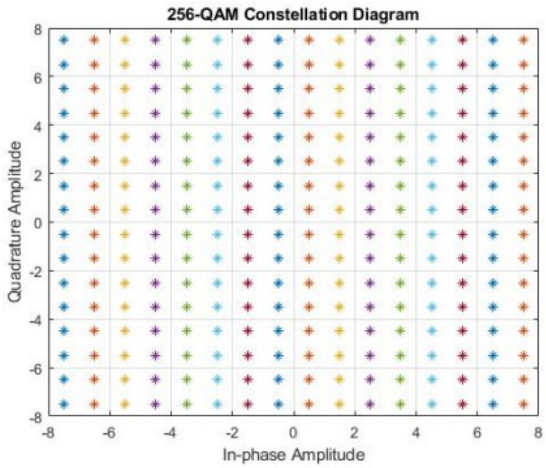

Fig. 2. 256-QAM constellation diagram

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II. Materials and Methods

MATLAB and Simulink softwares were used

Open MATLAB and launch Simulink to create a blank model workspace.

Insert Key Blocks from the Communication Toolbox such as bernulli binary generator, 256 QAM madulator and demodulator, AWGN channel, phase noise, display block etc.

Arrange the blocks and establish connections based on the provided block diagram.Ensure the signal flows sequentially through the generator, modulator, AWGN channel, phase noise, demodulator, and error rate calculator.

Link scopes to monitor constellation diagrams, eye diagrams, and BER plots. Configure Simulation Parameters

Execute the simulation by clicking ”Run.”Record and observe the contellation diagrams, eye diagrams and display output.

Generate and Analyze the BER Plot. Use the BER Plot block to graph the bit error rate for different Eb/No values.

Replace the 256-QAM Modulator and Demodulator blocks with OFDM Modulator and Demodulator blocks.

Connect the OFDM blocks within the existing signal path.Rerun the simulation and observe changes.Save new constellation and eye diagrams.Compare the BER performance of OFDM versus 256-QAM.

Replace the 256-QAM Modulator and Demodulator with M-PSK Modulator and Demodulator blocks.Select a modulation order, such as 16-PSK, for testing.Simulate and compare results with the previous configurations.Observe changes in BER, eye diagrams, and constellation clarity

III. Results

The constellation diagram displayed by the first scatter plot in Fig. 3 is a constellation diagram of 256-QAM for Eb/No=100 dB and without the presence of phase noise.

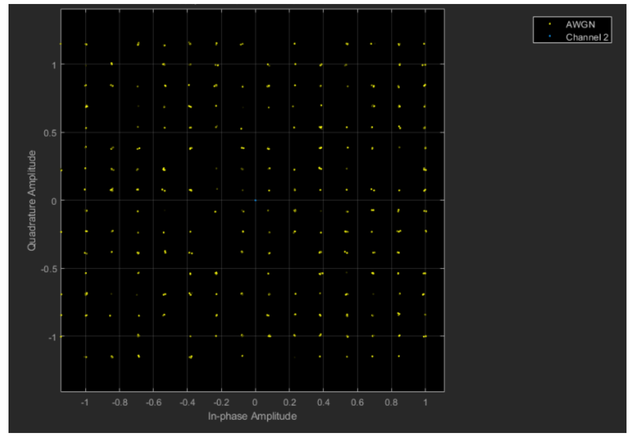

Fig. 3. 256-QAM constellation diagram without phase noise

The Scatter Plot Scope placed after the Phase Noise block gives different result for each Phase Noise Level Density(PNLD). Resulting constellation diagrams for PNLD=-30 dBc/Hz and PNLD=-80 dBc/Hz are displayed in Fig.4 and Fig.5, respectively.

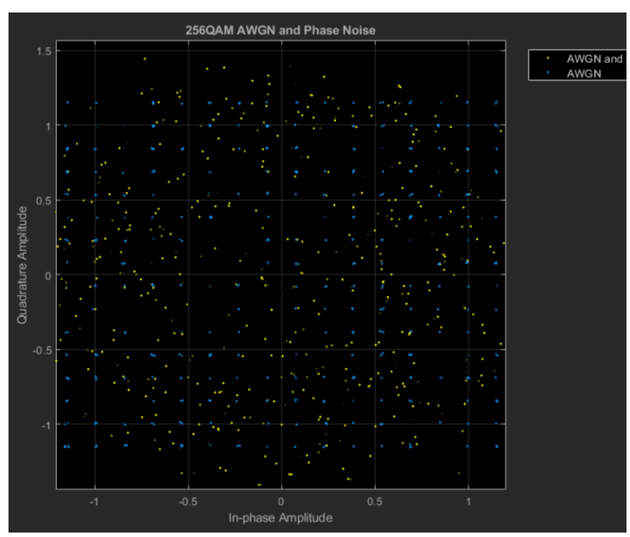

Fig. 4. Constellation diagram of 256-QAM for Eb/No=100 dB and PNLD=-30 dBc/Hz

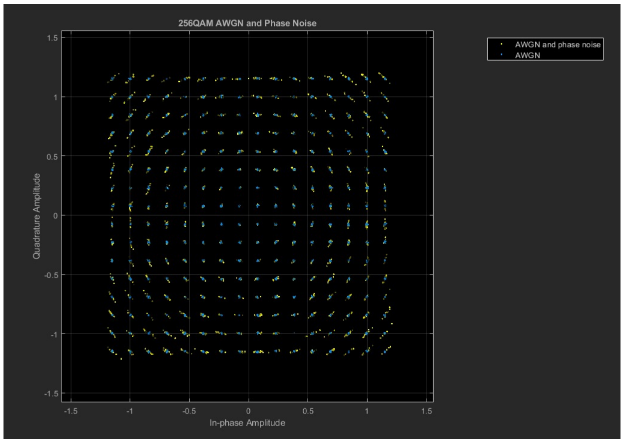

Fig. 5. Constellation diagram of 256-QAM for Eb/No=100 dB and PNLD=-80 dBc/Hz

To study the effect of phase noise on BER performance of 256-QAM modulation technique, the phase noise level density is varied . Simulation of BER curve for each of values [-88 -85 -82 -79 -76] dBc/Hz of a PNLD is performed and the result is shown in Fig.6.

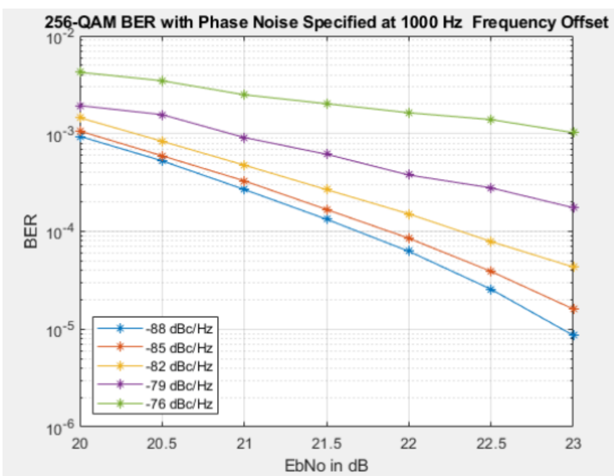

Fig. 6. BER vs. Eb/No for 256-QAM at different phase noise level densities

After adding OFDM blocks ;OFDM modulator and demodulator into the system as shown in the block diagram in Fig.7,we see a contellation diagram with scattered points in Fig 8

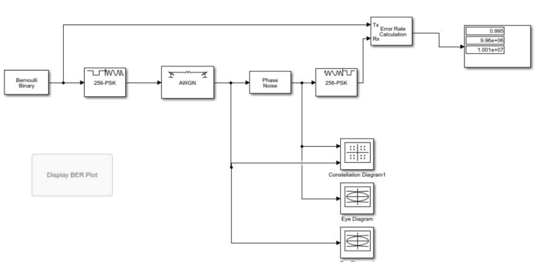

Fig. 7. OFDM block diagram

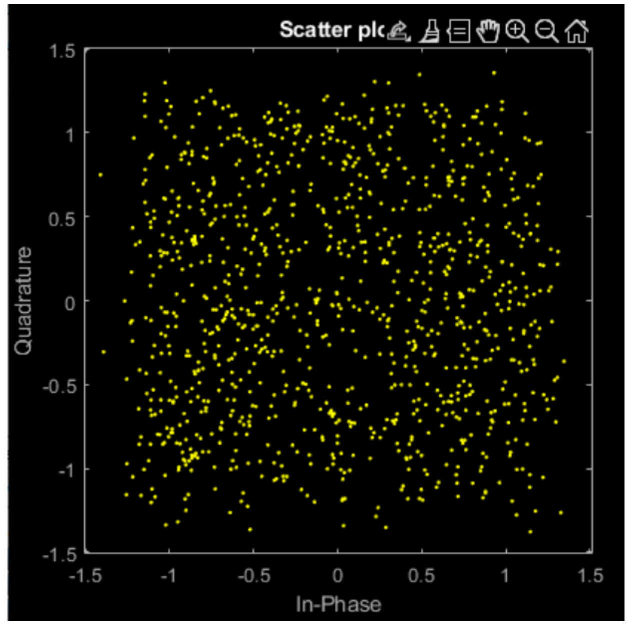

Fig. 8. OFDM scatter plot

To examine how 256-QAM would behave with different modulation schemes, the 256-QAM block was replaced with M-PSK block; M-PSK modulator and demudulator as shown in the block diagram in Fig.9.

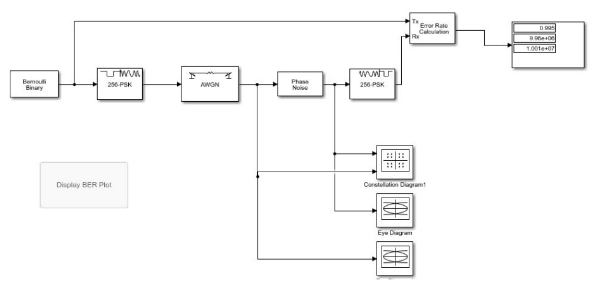

Fig. 9. M-PSK block diagram

The constellation diagram of the M-PSK modeling scheme was ring-shaped with the contellation clusters forming ring as depicted in Fig.10

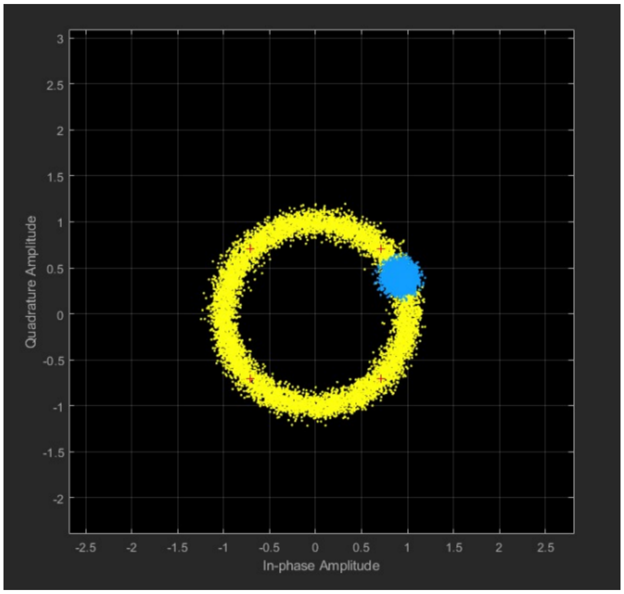

Fig. 10. M-PSK contellation diagram

IV. Discussion

The constellation diagram of 256-QAM in an AWGN channel, as depicted in Fig.3, exhibits well-defined clusters corresponding to distinct modulation states. When there is no phase noise present, these clusters remain tightly centered around their ideal positions with minimal dispersion. The clear separation between states signifies a high SNR environment, ensuring reliable data transmission. This demonstrates the optimal performance of 256-QAM under AWGN-dominated conditions, highlighting its efficiency for high data rate communication.

Figs.4 and 5 illustrate scatter plots obtained after introducing phase noise into the system. It is evident that phase noise introduces significant angular displacement in the clusters when compared to the scenario without phase noise. The resulting constellation diagrams for PNLD values of -30 dBc/Hz and -80 dBc/Hz exhibit noticeable differences: as the phase noise level decreases from -30 dBc/Hz to -80 dBc/Hz, the angular displacement of the clusters is significantly reduced.

Fig.6 presents the BER vs. Eb/No curve for 256-QAM at varying phase noise densities. The graph clearly shows that as the phase noise level decreases, the BER (Bit Error Rate) also declines. This occurs because phase noise induces random phase variations in the transmitted signal, causing constellation points to spread and increasing the likelihood of errors. However, as phase noise diminishes, the points remain more stable and closer to their ideal positions, thereby reducing transmission errors.

In the OFDM block diagram depicted in Fig.7, the transmitted data is divided into multiple orthogonal subcarriers, each carrying a 256-QAM symbol. When phase noise is introduced in an OFDM system, it causes **cumulative distortion** across all subcarriers. Each subcarrier experiences different phase noise effects, leading to random rotations or jitter in the constellation points. The scatter plot in Fig.8 reflects this, as the constellation points appear more dispersed than in a standalone 256-QAM system. The resulting diagram represents the **aggregate effect** of phase noise on all subcarriers after demodulation, where imperfections may further contribute to noise and distortion.

To explore alternative modulation schemes, we replaced the 256-QAM block with an M-PSK model in the simulation. The differences in output are evident in Fig.10. In **256-QAM**, both the amplitude and phase of the carrier signal are modulated, forming a **grid-like constellation**. In contrast, **M-PSK** modulates only the **phase**, keeping the amplitude constant, which results in a **circular or ring-shaped constellation**. Since phase noise directly affects the phase of the signal, it tends to cause rotational distortion or smearing in M-PSK. Additionally, M-PSK typically exhibits a higher error probability than QAM at the same SNR level, as its constellation points have smaller angular separation as the modulation order increases.

Acknowledgment

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