Assignment-6 Report

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Introduction

This report explores two digital modulation techniques—**16-QAM (Quadrature Amplitude Modulation)** and **16-FSK (Frequency Shift Keying)**—commonly used in wireless and digital communication systems. The primary aim of the simulation is to **compare the symbol error rate (SER)** performance of these schemes under varying levels of noise, represented by the **energy-per-bit to noise power spectral density ratio (Eb/N0)**.

16-PAM (Pulse Amplitude Modulation)

In **16-PAM**, each symbol conveys **4 bits** by varying only the **amplitude** of the signal. The 16 symbols are arranged as distinct amplitude levels along a **1D line** (real axis), with each level representing a unique 4-bit binary pattern.

- **Transmission**:

  The transmitter maps each 4-bit data group to one of **16 equally spaced amplitude levels**, such as -15, -13, ..., +13, +15. These pulses are then sent over the channel as real-valued signals.

- **Detection**:

  The receiver uses **MAP (Maximum A Posteriori)** detection by comparing the **received amplitude** (distorted by noise) to the set of possible 16-PAM levels. The closest amplitude level is selected as the detected symbol.

- **Performance**:

  As **Eb/N0** increases, the signal becomes less affected by noise, and the received amplitudes stay closer to their ideal values—resulting in fewer detection errors.

  However, because the **amplitude levels are closely spaced**, 16-PAM is **more sensitive to noise**, especially at **low Eb/N0**, which leads to a higher symbol error rate.

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2. 16-QAM (Quadrature Amplitude Modulation)

In **16-QAM**, each symbol conveys 4 bits by combining both amplitude and phase modulation. The 16 symbols are arranged in a 4×4 grid (constellation diagram), with each grid point representing a unique combination of amplitude and phase.

- **Transmission**: The transmitter sends symbols formed from both in-phase (I) and quadrature (Q) components, which define the symbol's position in the 2D complex plane.
- **Detection**: The receiver performs **MAP (Maximum A Posteriori)** detection by matching the noisy received signal to the nearest constellation point.
- **Performance**: As Eb/N0 increases, noise effects decrease, causing received symbols to cluster closer to their original transmitted positions and reducing the SER. However, due to tight constellation point spacing, 16-QAM is more susceptible to noise at **low Eb/N0**, resulting in higher error rates.
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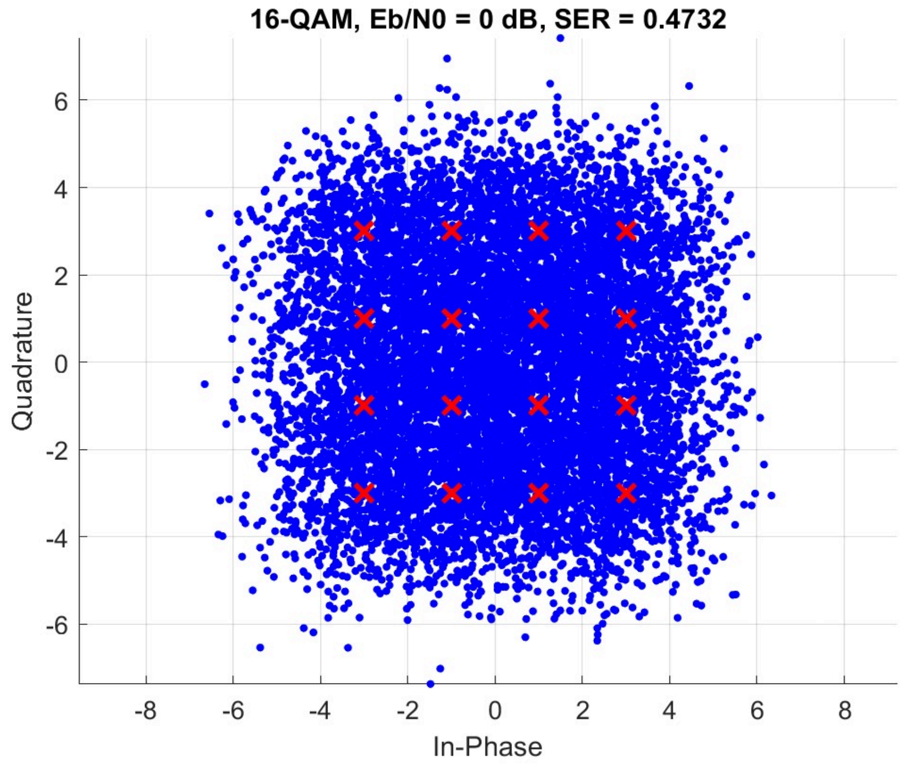
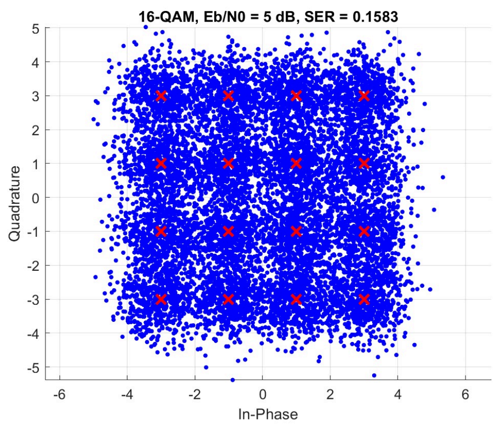
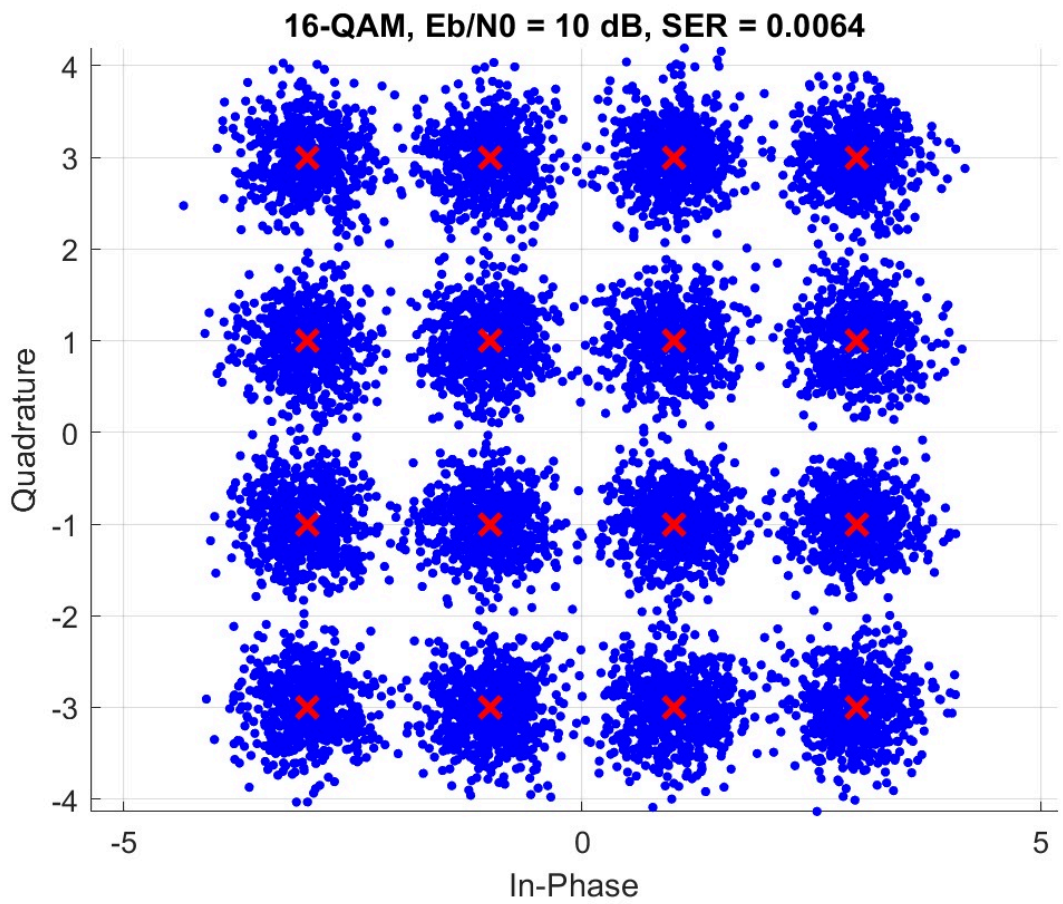
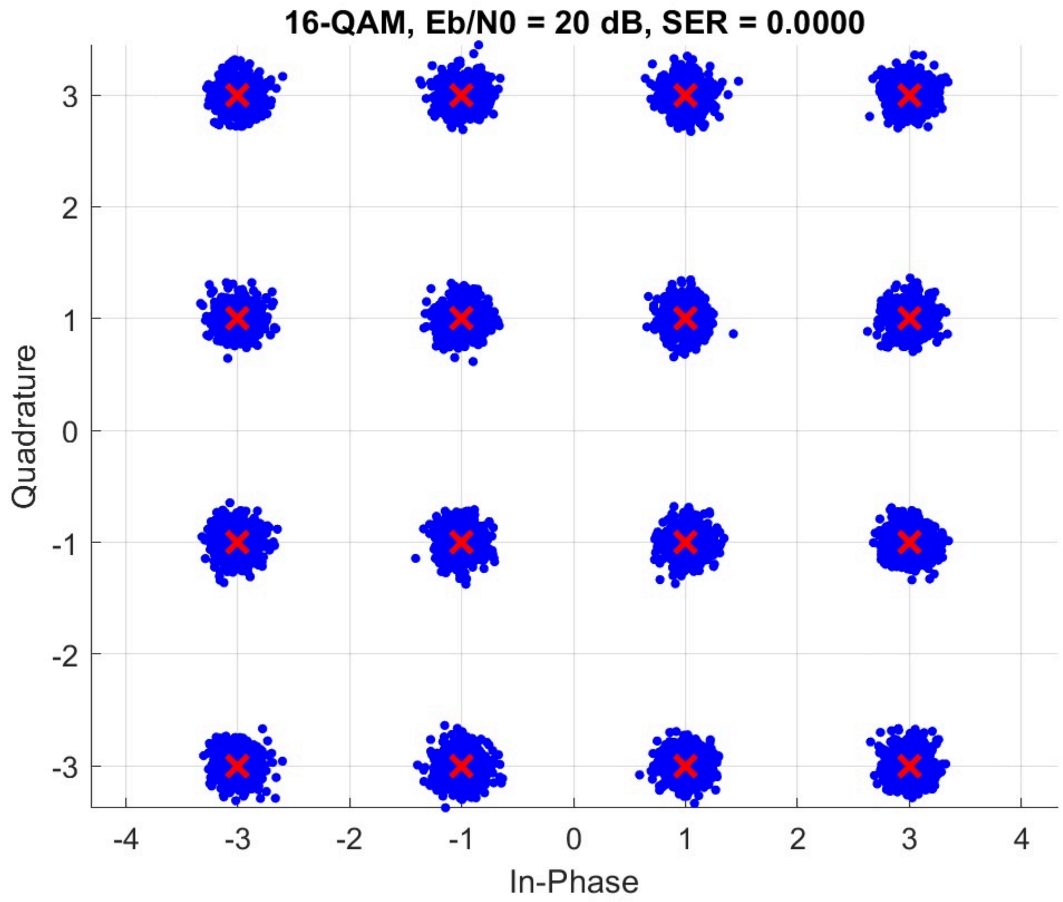

16-QAM, Eb/N0 = 0 dB, SER = 0.4732
Quadrature
In-Phase


16-QAM, Eb/N0 = 5 dB, SER = 0.1583
Quadrature
In-Phase


16-QAM, Eb/N0 = 10 dB, SER = 0.0064
Quadrature
In-Phase



3. 16-FSK (Frequency Shift Keying)

In **16-FSK**, each symbol is represented by one of 16 distinct frequencies. Unlike QAM, this modulation relies solely on frequency changes rather than amplitude or phase.

- **Transmission**: The system assigns a unique frequency to each 4-bit symbol, with the transmitter switching to the corresponding frequency during each symbol period.
- **Detection**: The receiver uses correlators or matched filters to identify the frequency that best matches the received signal. The frequency with the highest correlation determines the detected symbol.
- **Performance**: FSK shows greater resilience to noise than QAM, particularly in low SNR conditions. Because frequencies are well-separated, the receiver can detect symbols correctly even with distortion. This results in **better performance at low Eb/N0** compared to 16-QAM, though its SER improvement with increasing Eb/N0 is more gradual.

4. Simulation Results

Both modulation schemes were simulated using **1000 randomly generated symbols** and tested across various Eb/N0 levels:

0,5,10,20 dB

Observations:

- **16-QAM:**
  - SER decreases significantly as Eb/N0 increases.
  - Performance improves rapidly with increasing SNR, but errors are common at low Eb/N0 due to close constellation spacing.

$$P_e \approx 3Q\left(\sqrt{\frac{4E_b}{5N_0}}\right)$$

- **16-FSK:**

- More robust at low Eb/N0 values due to wider spacing between symbol frequencies.
- The SER improves with Eb/N0 but at a slower rate compared to QAM.

$$P_e = (M-1)Q\left(\sqrt{\frac{E_b \log_2 M}{N_0}}\right)$$ Inc

5. Conclusion

- **16-QAM** offers higher **spectral efficiency** (more bits per second per Hz) but shows greater vulnerability to noise, especially at low SNR.
- **16-FSK** demonstrates better **noise tolerance**, particularly in challenging environments, but requires more bandwidth for the same data rate.
- The simulation confirms that **no single modulation scheme is best in all conditions**—the choice depends on balancing bandwidth efficiency against noise robustness.