MODEL BASED SIGNAL ANALYSIS PROJECT

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ABSTRACT

In this project, we will provide an analysis of the performance of maximum likelihood detection (MLD) over flat-fading channels in a wireless multiple input–multiple output (MIMO) antenna system. We will introduce a tight union bound with an asymptotic form on the probability of bit error rate (BER) for MIMO MLD systems with two-dimensional signal constellations (such as QAM and PSK). Using this analytic bound, we will demonstrate the performance of the MIMO antenna system quantitatively with respect to channel estimation, constellation size, and antenna configuration.

PROBLEM STATEMENT

Analysis and Modeling of Maximum Likelihood Detection for a MIMO Antenna System

LIST OF ASSUMPTIONS

- System parameters
  - K = 2 # Number of transmit antennas
  - L = 4 # Number of receive antennas
  - M = 16 # Constellation size (QAM or PSK)
  - Es_avg = 1 # Average symbol energy
  - No = 1e-3 # Noise power spectral density
- Channel estimation parameters
  - sigma_v = 0.1 # Channel estimation accuracy
  - rho_hv = 0.8 # Correlation coefficient

DATASET DESCRIPTION

$$\boldsymbol{H} = \beta_{hv}\boldsymbol{V} + \boldsymbol{E}$$

$$p_{\boldsymbol{y}}(\boldsymbol{y}|\boldsymbol{d}, \boldsymbol{V}) = \frac{1}{(2\pi)^L \left(\sigma_y^2\right)^L} \exp\left(\frac{-\mu}{2\sigma_y^2}\right)$$

where H is the Channel Gain Matrix, V & E is the zero mean Gaussian distributed error matrix with the variance 1- rho_hv^2

SOME EQUATIONS

TO CALCULATE UNION BOUND

$$P_s \leq M^{-K} \sum_m \sum_j \left(\sum_i P_{s_{m,ij}} \right)$$

$$P_{s_{m,ij}} = \frac{1}{(1 + r_{s_{m,ij}})^{2L-1}} \sum_{l=0}^{L-1} \binom{2L-1}{l} r_{s_{m,ij}}^{l}.$$

$$r_s^{m,i,j} = a_s^{m,i,j} \cdot T_s^{m,j} + \sqrt{(a_s^{m,i,j} \cdot T_s^{m,j})^2 + 2 \cdot (a_s^{m,i,j} \cdot T_s^{m,j}) + 1}$$

$$a_s^{m,i,j} = \frac{||d_i - d_j||^2}{2 \cdot E_s}$$

$$T_s^{m,j} = \frac{\gamma_c \cdot |\rho_{hv}|^2}{\left(\frac{\gamma_c \cdot (1 - |\rho_{hv}|^2)}{E_s} \cdot ||d_j||^2\right) + 1}$$

METHODOLOGY

Our investigation begins with a comprehensive definition of key parameters characterizing our MIMO (Multiple Input Multiple Output) system, including the number of transmit antennas (K), receive antennas (L), constellation size (M), and other essential variables such as average symbol energy, noise power spectral density (No), channel estimation accuracy (sigma_v), and the correlation coefficient (rho_hv). This foundational step lays the groundwork for our subsequent analytical endeavors, providing a holistic understanding of the system's configuration and characteristics.

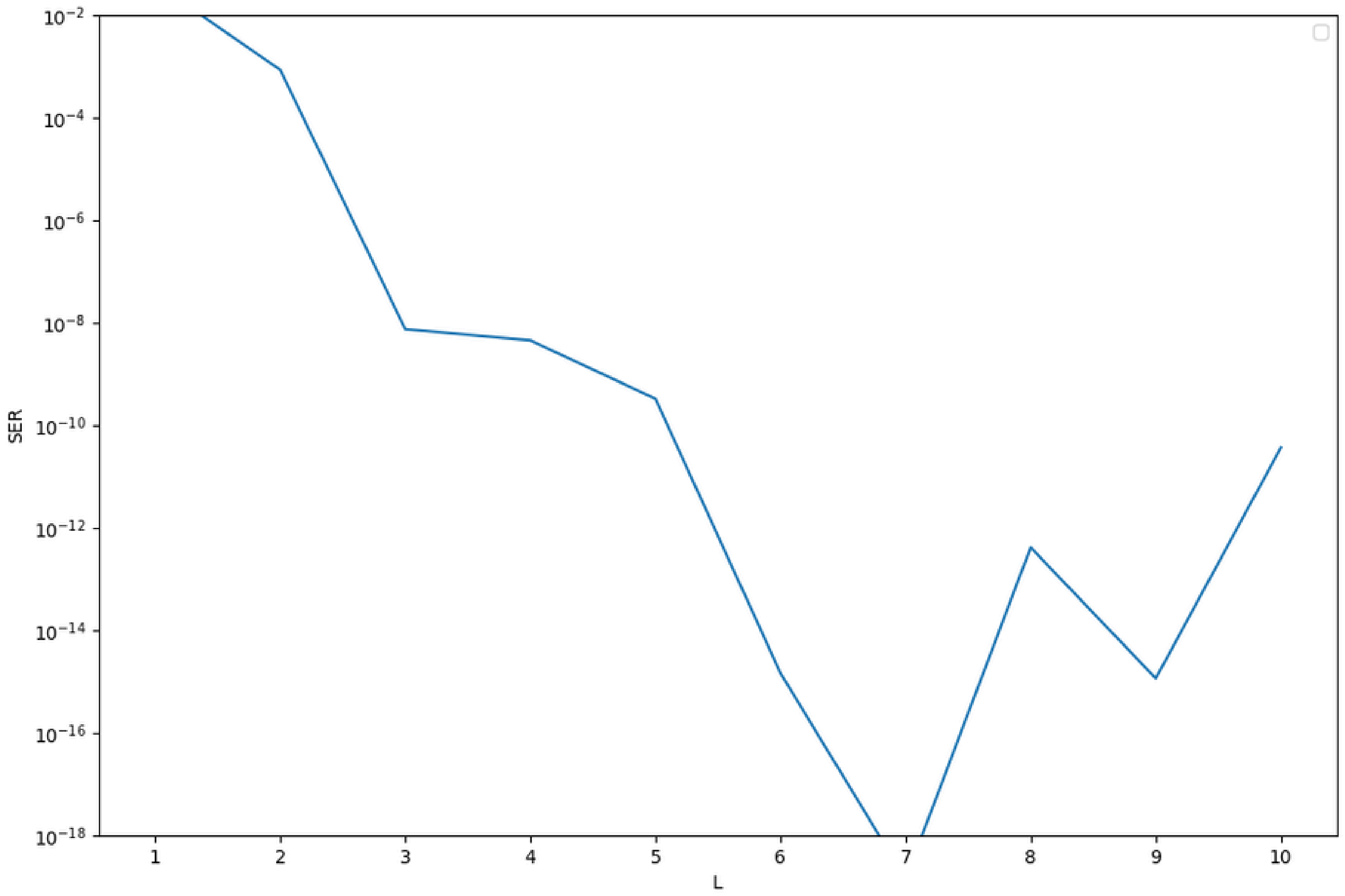
Subsequently, we proceed to simulate the transmission process by generating random channel gain matrices (H) based on the specified transmit and receive antenna configurations (K and L, respectively). These complex Gaussian matrices serve to encapsulate the spatial diversity inherent in MIMO systems, reflecting the intricate propagation characteristics of wireless communication channels.

With the transmission simulated, we embark on computing received signal vectors (y) using the classic model $y = Hd + n$, where 'n' represents the additive white Gaussian noise. This critical step enables us to emulate the reception process, accounting for noise and channel fading effects. Following this, we calculate the Maximum Likelihood (ML) metric (Lambda) using the provided formula, serving as a pivotal performance indicator. Our subsequent implementation of a union bound on the Symbol Error Rate (SER) offers insights into system resilience across varying channel estimation accuracies and antenna configurations, guiding optimization efforts and informing design decisions. Through systematic analysis, we unravel nuanced performance trends, facilitating a comprehensive understanding of the system's behavior and offering valuable insights for further system refinement and optimization.

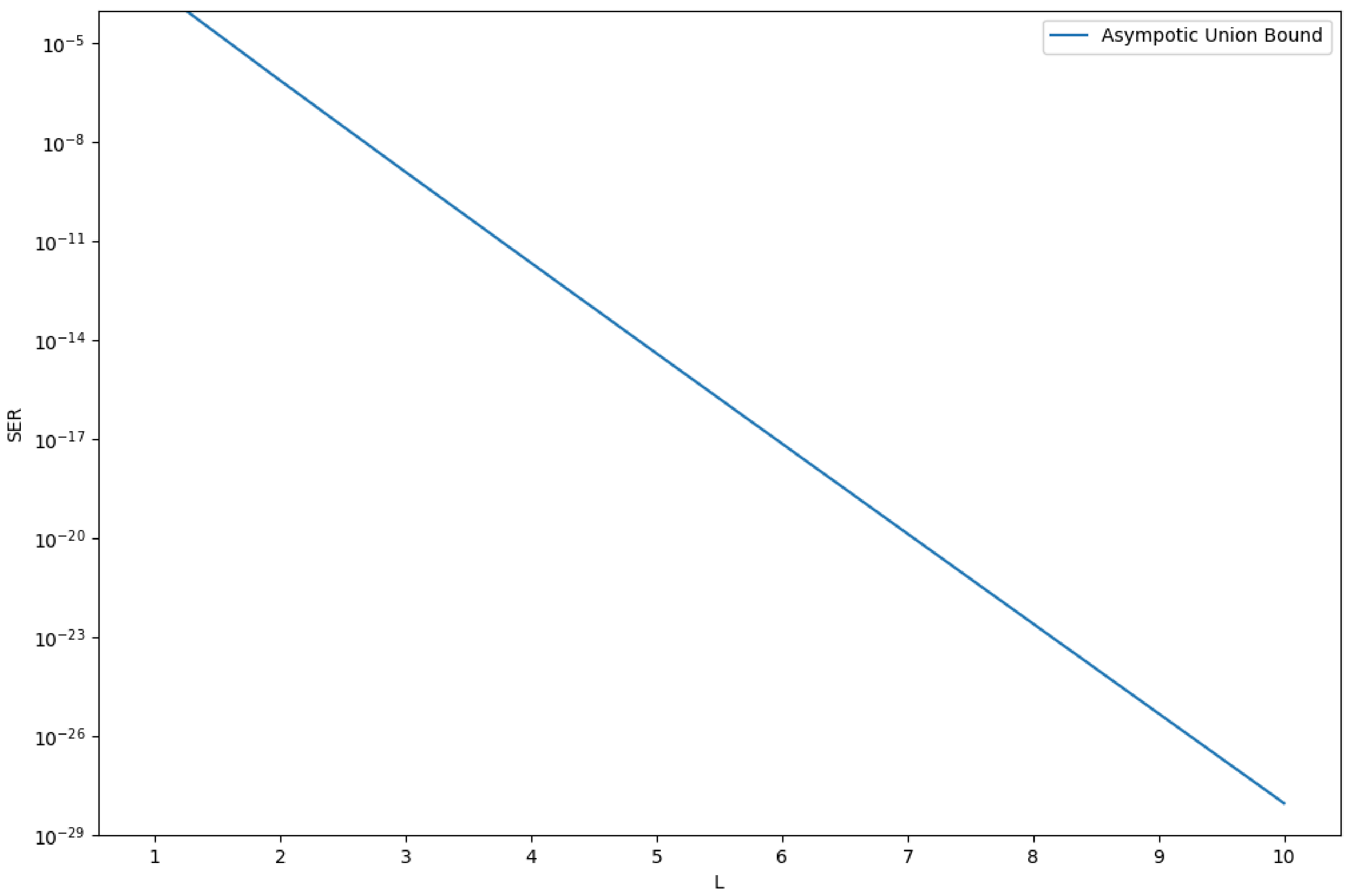
METHOD OF SIMULATION

1. Define MIMO system parameters.
2. Simulate channel gain matrices.
3. Generate candidate data vectors.
4. Compute received signal vectors.
5. Calculate Maximum Likelihood metric.
6. Implement union bound on SER.

ANALYSIS

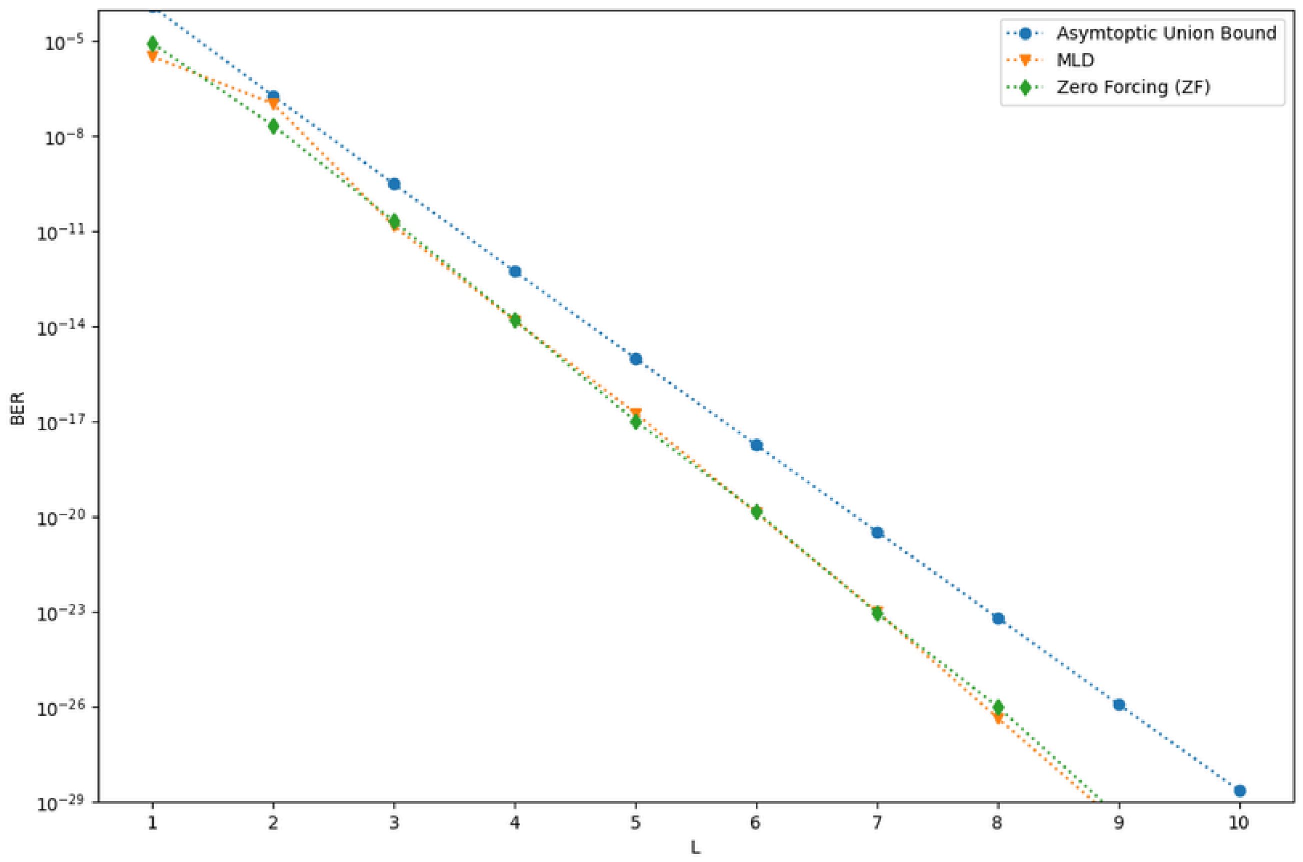


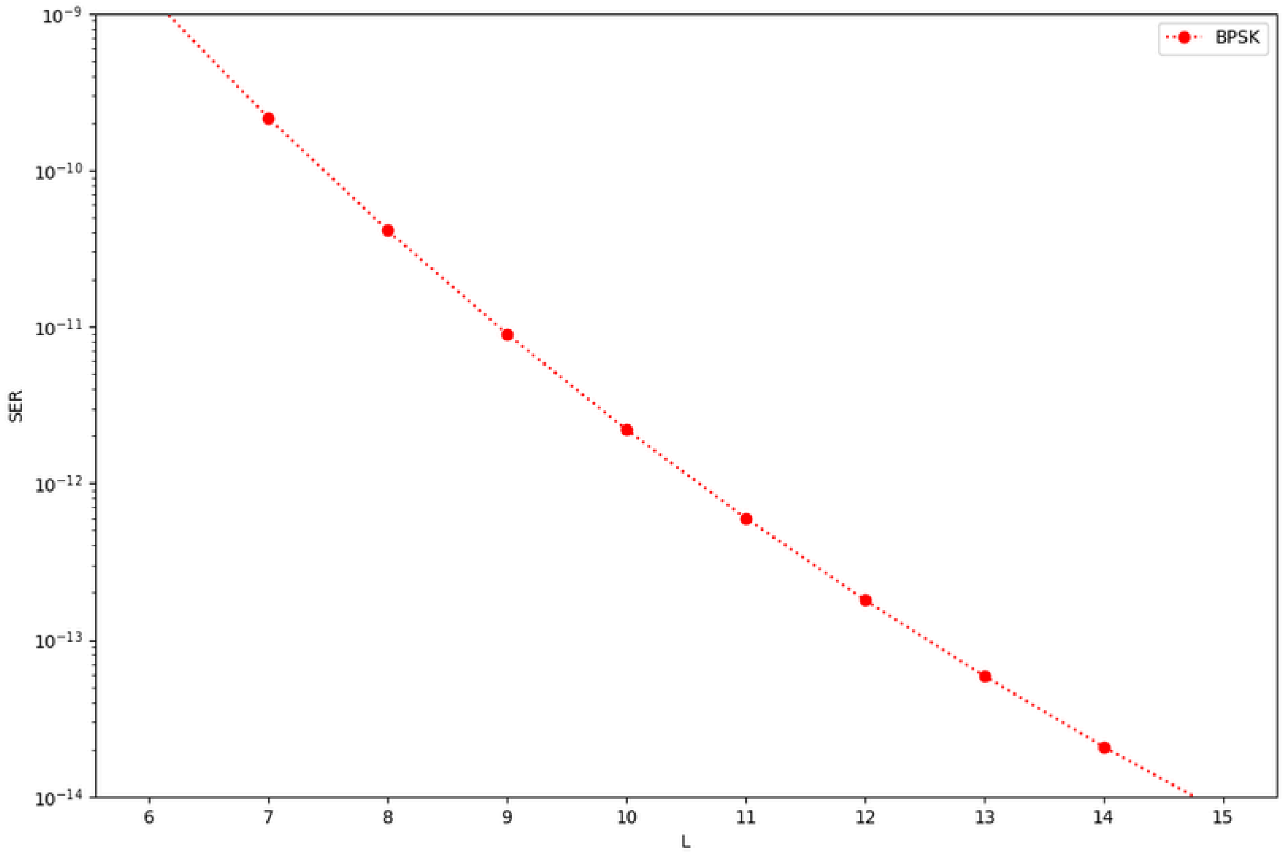
Symbol Error Rate (SER) with varying Number of Recieve Antennas (L)



Asymptotic Union Bound with varying Number of Receive Antennas (L)

ANALYSIS





Deductions

- It can be deduced that with a relatively high SNR (i.e., BER is below a specific level such as 0.01), the error probability is proportional to the inverse of the SNR. This implies that the diversity order of maximum likelihood detection (MLD) is equal to the number of receive antennas, independent of the number of transmit antennas.

- With a large number of receive antennas, the SNR penalty due to increased number of transmit antennas approaches 0 dB.

- This implies that (and without regard to complexity) we can achieve an arbitrary high data rate with a low SNR penalty when the number of receive antennas is sufficiently large.

THANK YOU