DEMYSTIFYING WAVEFORM DESIGN AND SIGNAL PROCESSING FOR WIRELESS COMMUNICATION

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Introduction

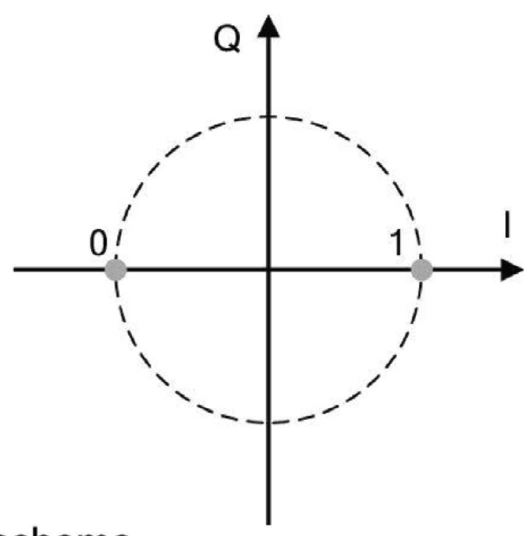
- Digital communication is the bedrock of modern civilisation, facilitating the exchange & proliferation of information & knowledge
- Pivotal role in continued advancement of mankind

Methodology

1. Additive White Gaussian Noise (AWGN)

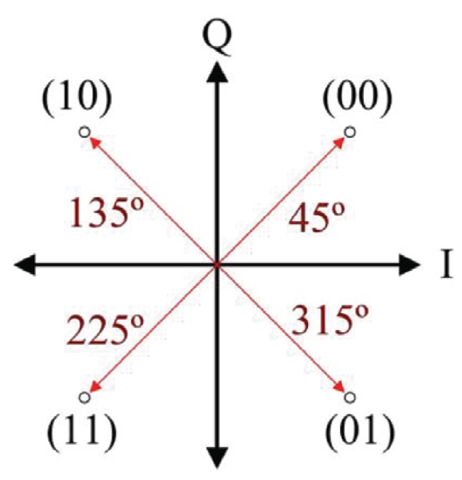
- Monte Carlo simulation
  - Models random disturbances in digital communication systems
  - Modelled as a Gaussian distribution

2. Binary Phase Shift Keying (BPSK)



- Dual phase modulation scheme
  - Modulated by phase change of 180°, 0 & 1 represented by phase shifts of 0° & 180°
- 0 & 1 are converted to symbols -1 & 1 respectively

3. Quadrature Phase Shift Keying (QPSK)

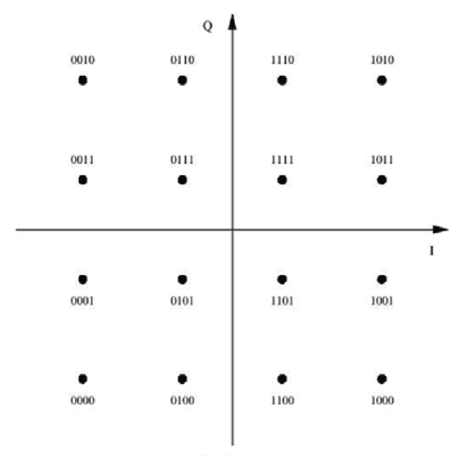


- Modulates 2 bits at once
- Modulated by phase change of 90°
- 00, 01, 10 & 11 are represented by the phase shifts of 45°,135°, 225° & 315°
- 1st bit → symbol on in-phase axis
- 2nd bit → symbol on quadrature axis

Objectives

To understand waveform design and signal processing through investigating:
- Performance of the modulation schemes BPSK, QPSK & 16-QAM over AWGN
- Performance of hamming coded BPSK

4. 16-Quadrature Amplitude Modulation (QAM)

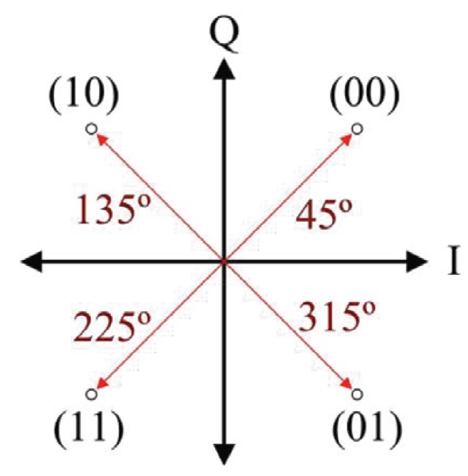


- 2 carrier signals shifted in phase by 90° are modulated & combined
- 16 distinct states, encoding 4 bits per symbol
- Decimal represented by the 4 bits to generate a symbol → constellation that corresponds to decimal on the constellation diagram
- Demodulation: returning symbol w/ minimum Euclidean distance between received symbol vector & points in reference array

$$d(x,y) = \sqrt{(x_1-y_1)^2+(x_2-y_2)^2+...+(x_n-y_n)^2}$$

where $x=(x_1,x_2,...,x_n)$ & $y=(y_1,y_2,...,y_n)$ are 2 points in n-dimensional space.

5. Hamming Code

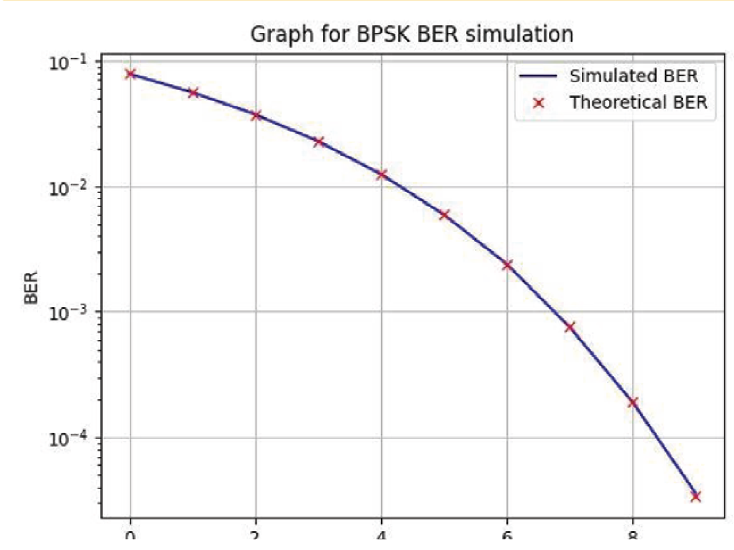


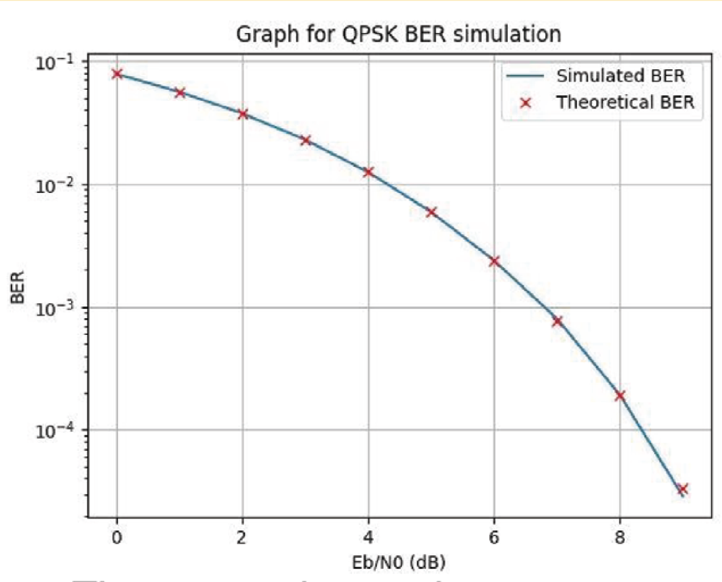
- Type of error correction code
- Encoding of 4 bits into 7 bits by the addition of 3 parity bits

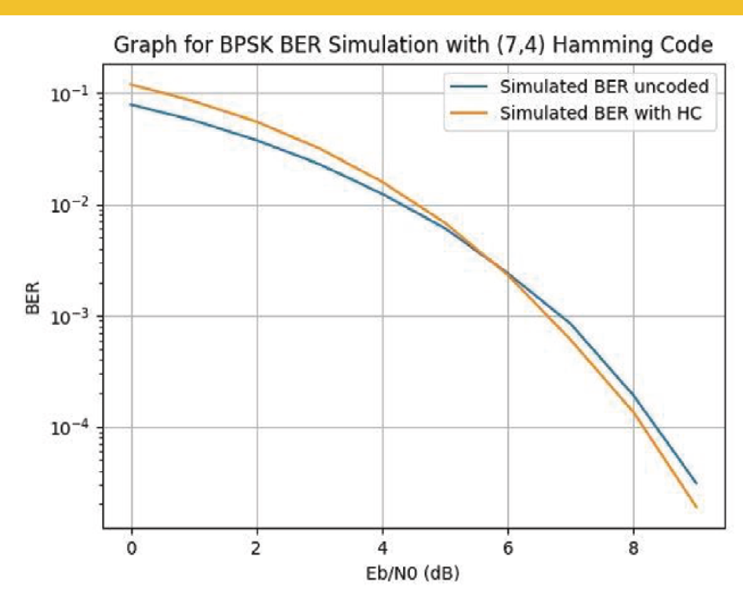
$$G=\begin{bmatrix}1&0&0&0&1&0&1\\0&1&0&0&1&1&0\\0&0&1&0&1&1&1\\0&0&0&1&0&1&1\end{bmatrix}$$

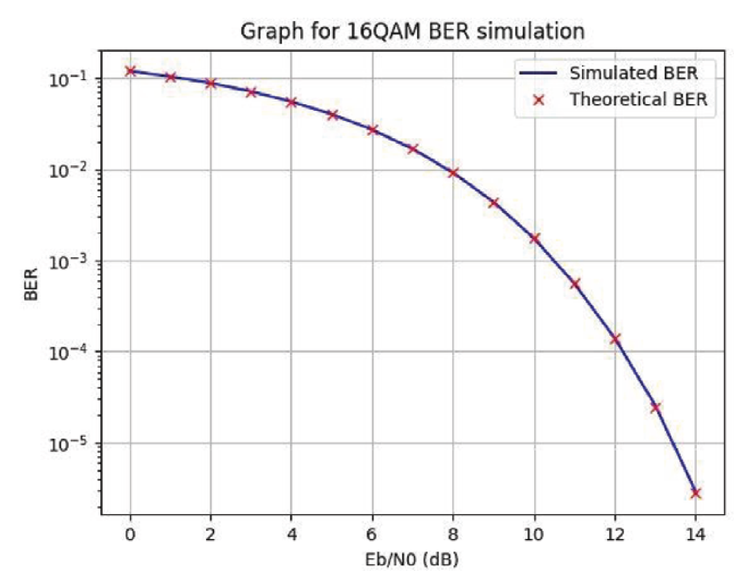
- G x 4 bits = 7 bits that is transmitted
- 16 permutations of binary strings multiplied by G to give the reference array
- Demodulated bits compared w/ reference array → most similar permutation in array is returned

Results & Discussions









- The curves decreasing at an increasing rate
- Energy / bit increases, BER decreases → performance is inversely correlated to energy / bit
- BER for 16-QAM is the highest amongst the 3 while the BER for QPSK & BPSK are identical
- Constellation points are closer together → more susceptible to noise & interference

- Initial BER for BPSK with (7,4) Hamming Code (HC) > BPSK
- Higher energy per bit, BER of BPSK w/ HC < BPSK
- Redundancy in the form of parity bits to enable error correction → initially increases BER since system must handle additional bits
- Inefficient → limited redundancy added → only detect & correct errors when the error rate is low

Conclusion & Applications

- BPSK & QPSK have lower BER than 16- QAM
  - Bandwidth efficiency: 16-QAM > QPSK > BPSK
  - QPSK 2x bandwidth efficiency of BPSK [1]
- Hamming code is far superior at higher energy / bits → better for irl usage
- Framework for BER simulation using Python
  - Uncommon as of now

Limitations & Future Work

- Limited computer power
- Can investigate synchronisation, different channels (e.g. fading), different error correcting codes (e.g. Reed-Solomon codes) to simulate more realistic digital communication networks

References

[1] T. J. Lim, L. K. Rasmussen, and H. Sugimoto, "Relative Performance of BPSK and QPSK in the Presence of Complex Multiuser CDMA Interference," Wireless Personal Communications, vol. 13, no. 3, pp. 237-256, 2000, doi: https://doi.org/10.1023/a:1008974119760.