Fundamentals of Digital Communications
Class 4: Communication Signals in Signal Spaces

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**Schedule — to master Digital Communications**

Demodulation and Detection Theory

- Class 8
- Class 7

Signal Spaces

- Class 2
- Class 1

Signals and Systems

- Class 4
- Class 3

Stochastic

- Class 6
- Class 5
Class 4 – Communication Signals in Signal Spaces

Goals:

- understand how modulation signals can be represented in signal spaces
- understand the concept of "distance"
Problem 4.1

Given:

- fixed energy per bit $E_b$

Questions:
Compute and compare the minimum distance for the following digital modulation schemes:

- binary phase shift keying (BPSK) (= 2-PAM, = 2-PSK)
- on-off-keying (OOK)
- binary orthogonal signaling
- quarternary phase shift keying (QPSK) (= 4-PSK, = 4-QAM)
- 4-ary pulse amplitude modulation (4-PAM)
**Problem 4.1 - continued**

**Given:**
- fixed energy per bit $E_b$

**Questions:**
Compute and compare the minimum distance for the following digital modulation schemes:
- $M$-PAM for $M = 2^k, k \in \mathbb{N}$
- $M$-ary phase shift keying ($M$-PSK) for $M = 2^k, k \in \mathbb{N}$
- $M$-ary orthogonal signaling for $M = 2^k, k \in \mathbb{N}$
Problem 4.1 - continued

Minimum Distance of M-ary Modulation Schemes

- M-orth
- M-PSK
- M-PAM

Bits/Symbol $k; M = 2^k$

$d_{\text{min}} / (E_b)^{1/2}$
**Problem 4.1**

**Given:**
- 8-ary QAM in 2-dimensional space

**Questions:**
- find \( r_1 \) and \( r_2 \) which maximize \( d_{min} \) as a function of \( E_{av} \)
- find (?) and assign optimum mapping
Questions

- How is the distance defined in a vector space?
- Draw the vectorial signal representation for a 4-ary symmetric PAM?
- Which coding scheme presents an optimal mapping with respect to bit errors?
- Why is the previous coding scheme optimal?
- Which digital modulation scheme is better, QPSK or on-off-keying?
**Questions**

- How is the distance defined in a vector space?
  \[ d = \sqrt{\|s_m - s_n\|^2} \]

- Draw the vectorial signal representation for a 4-ary symmetric PAM?

- Which coding scheme presents an optimal mapping with respect to bit errors? **Grey Coding**

- Why is the previous coding scheme optimal?
  because for the most likely error only one bit changes → probability to recover with error correcting codes highest

- Which digital modulation scheme is better, QPSK or on-off-keying? **QPSK because of higher distance**