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 1
- Class 2

Signals and Systems

- Class 3
- Class 4

Stochastic

- Class 5
- Class 6
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

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

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

Bits/Symbol $k; M = 2^k$
**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 \( E_{av} \)
- assign optimum mapping if possible
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