EE359 – Lecture 13 Outline

- **Announcements**
  - Midterm announcements
  - No HW this week

- Introduction to adaptive modulation
- Variable-rate variable-power MQAM
- Optimal power and rate adaptation
- Finite constellation sets
Midterm Announcements

- **Midterm: Thursday (11/9), 6-8 pm in Thornton 102**
  - Food will be served after the exam!

- **Review sessions completed**

- **Midterm logistics:**
  - Open book/notes; Bring textbook/calculators (have extras; adv. notice reqd)
  - Covers Chapters 1-7 (sections covered in lecture and/or HW)

- **Special OHs this week:**
  - Me: Wed 11/8: 9-11am, Thu 11/9: 12-2pm all in 371 Packard
  - Milind: Tues 11/7, 4-6pm, 3rd Floor Packard Kitchen Area + email
  - Tom: Wed 11/8: 5-7pm, Thu 11/9 2-4pm, 3rd Floor Packard Kitchen Area + email

- **Midterms from past 3 MTs posted:**
  - 10 bonus points for “taking” a practice exam
  - Solutions for all exams given when you turn in practice exam
Adaptive Modulation

- Change modulation relative to fading

- Parameters to adapt:
  - Constellation size
  - Transmit power
  - Instantaneous BER
  - Symbol time
  - Coding rate/scheme

*Only 1-2 degrees of freedom needed for good performance*

- Optimization criterion:
  - Maximize throughput
  - Minimize average power
  - Minimize average BER
Variable-Rate Variable-Power MQAM

Uncoded Data Bits

Delay

$\log_2 M(\gamma)$ Bits

Point Selector

One of the $M(\gamma)$ Points

$M(\gamma)$-QAM Modulator

Power: $P(\gamma)$

To Channel

$\gamma(t)$

$\gamma(t)$

$\gamma(t)$

Goal: Optimize $P(\gamma)$ and $M(\gamma)$ to maximize $R = E \log[M(\gamma)]$
Optimization Formulation

- **Adaptive MQAM: Rate for fixed BER**

\[
M(\gamma) = 1 + \frac{1.5\gamma}{-\ln(5\text{BER})} \frac{P(\gamma)}{P} = 1 + K\gamma \frac{P(\gamma)}{P}
\]

- **Rate and Power Optimization**

\[
\max_{P(\gamma)} E \log_2[M(\gamma)] = \max_{P(\gamma)} E \log_2\left[1 + K\gamma \frac{P(\gamma)}{P}\right]
\]

Same maximization as for capacity, except for \(K=-1.5/\ln(5\text{BER})\).
Optimal Adaptive Scheme

- **Power Adaptation**

\[
P(\gamma) = \begin{cases} \frac{1}{\gamma_0} - \frac{1}{\gamma K} & \gamma \geq \frac{\gamma_0}{K} = \gamma_K \\ 0 & \text{else} \end{cases}
\]

- **Spectral Efficiency**

\[
\frac{R}{B} = \int_{\gamma_k}^{\infty} \log_2 \left( \frac{\gamma}{\gamma_k} \right) p(\gamma) d\gamma.
\]

*Equals capacity with effective power loss* \(K = -1.5 / \ln(5 \text{BER})\).*
Spectral Efficiency

\[ K = -\frac{1.5}{\ln(5 \text{BER})} \]

Can reduce gap by superimposing a trellis code.
Constellation Restriction

- Restrict \( M_D(\gamma) \) to \( \{M_0=0,\ldots,M_N\} \).
- Let \( M(\gamma)=\gamma/\gamma_K^* \), where \( \gamma_K^* \) is optimized for max rate.
- Set \( M_D(\gamma) \) to \( \max_j M_j: M_j \leq M(\gamma) \) (conservative).
- Region boundaries are \( \gamma_j=M_j\gamma_K^* \), \( j=0,\ldots,N \).
- Power control maintains target BER.
Power Adaptation and Average Rate

Power adaptation:

- Fixed BER within each region
  - $E_s/N_0 = (M_j - 1)/K$
- Channel inversion within a region
- Requires power increase when increasing $M(\gamma)$

\[
\frac{P_j(\gamma)}{P} = \begin{cases} 
(M_j - 1)/(\gamma K) & \gamma_j \leq \gamma < \gamma_{j+1}, j > 0 \\
0 & \gamma < \gamma_1 
\end{cases}
\]

Average Rate

\[
\frac{R}{B} = \sum_{j=1}^{N} \log_2 M_j p(\gamma_j \leq \gamma < \gamma_{j+1})
\]

Practical Considerations:

- Update rate/estimation error and delay
Efficiency in Rayleigh Fading

![Graph showing spectral efficiency versus average SNR](image-url)
Main Points

- Adaptive modulation leverages fast fading to improve performance (throughput, BER, etc.)
- Adaptive MQAM uses capacity-achieving power and rate adaptation, with power penalty $K$.
  - Comes within 5-6 dB of capacity
- Discretizing the constellation size results in negligible performance loss.
- Constellations cannot be updated faster than 10s to 100s of symbol times: OK for most dopplers.
- Estimation error/delay causes error floor