

## EE359 – Lecture 13 Outline

- Announcements
  - Midterm announcements
  - No HW due this week (will be usual HW next week)
- Adaptive MQAM: optimal power and rate
- Finite Constellation Sets
- Update rate
- Estimation error
- Estimation delay

## Midterm Announcements

- Midterm Wed Nov. 4, 8:45-10:45a in this rm.
  - Open book/notes (bring textbook/calculators)
  - Covers Chapters 1-7 (through today's lecture)
- Review Session notes posted
- Extra OHs
  - Me: Monday, Tuesday 2-3pm,
  - Yao: Tues, 4-5pm in 380-380w
- Midterms from past 3 MTs posted
  - 10 bonus points for "taking" a practice exam (due at MT)
  - Solns for all exams given when you turn in practice exam

## Review of Last Lecture

- Combining Techniques
- Selection Combining and its Performance
- Maximal Ratio Combining

$$\bar{P}_b = \int \int P_b(\gamma_2) p(\gamma_2) d\gamma_2 = \int \int \dots \int P_b(\gamma_2) p(\gamma_1) \cdot p(\gamma_2) \cdot \dots \cdot p(\gamma_M) d\gamma_1 \cdot d\gamma_2 \cdot \dots \cdot d\gamma_M$$

- MGF Approach for Performance of MRC

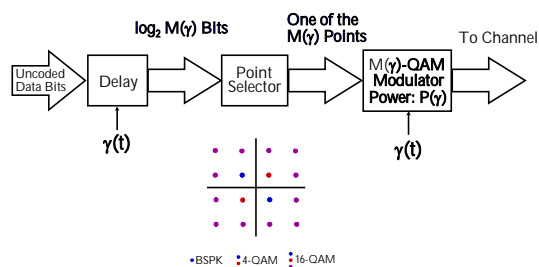
$$\bar{P}_b = \frac{1}{\pi} \int_0^{\pi/2} \prod_{i=1}^M M_i \left[ \frac{-g}{\sin^2 \phi}; \gamma_i \right] d\phi$$

- EGC and Transmit Diversity

## 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



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

## Optimization Formulation

- Adaptive MQAM: Rate for fixed BER

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

- Rate and Power Optimization

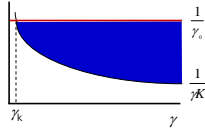
$$\max_{P(\gamma)} E \log_2[M(\gamma)] = \max_{P(\gamma)} E \log_2 \left[ 1 + K\gamma \frac{P(\gamma)}{P} \right]$$

*Same maximization as for capacity, except for  $K = 1.5 \ln(5BER)$ .*

## Optimal Adaptive Scheme

- Power Adaptation

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

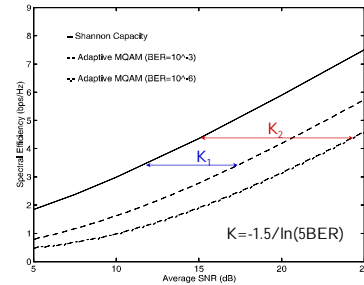


- Spectral Efficiency

$$\frac{R}{B} = \int_{\gamma_K}^{\infty} \log_2 \left( \frac{\gamma}{\gamma_K} \right) p(\gamma) d\gamma$$

Equals capacity with effective power loss  $K = -1.5/\ln(5BER)$ .

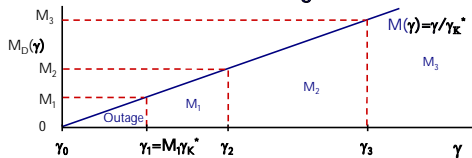
## Spectral Efficiency



Can reduce gap by superimposing a trellis code

## Constellation Restriction

- Restrict  $M_D(\gamma)$  to  $\{M_0=0, \dots, M_N\}$ .
- Let  $M(\gamma) = \gamma/\gamma_K^*$ , where  $\gamma_K^*$  is later optimized.
- Set  $M_D(\gamma)$  to  $\max_j M_j$ ;  $M_j \leq M(\gamma)$ .
- Region boundaries are  $\gamma_j = M_j \gamma_K^*$ ,  $j=0, \dots, N$
- Power control maintains target BER



## Power Adaptation and Average Rate

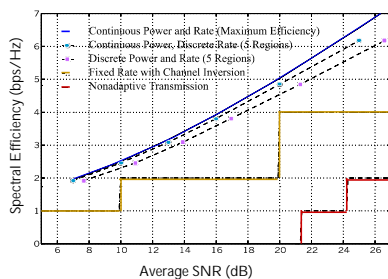
- Power adaptation:
  - Fixed BER within each region
  - $E_s/N_0 = (M_j - 1)/K$
  - Channel inversion within a region
- Requires power increase when increasing  $M(\gamma)$

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

- Average Rate

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

## Efficiency in Rayleigh Fading



## 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.