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

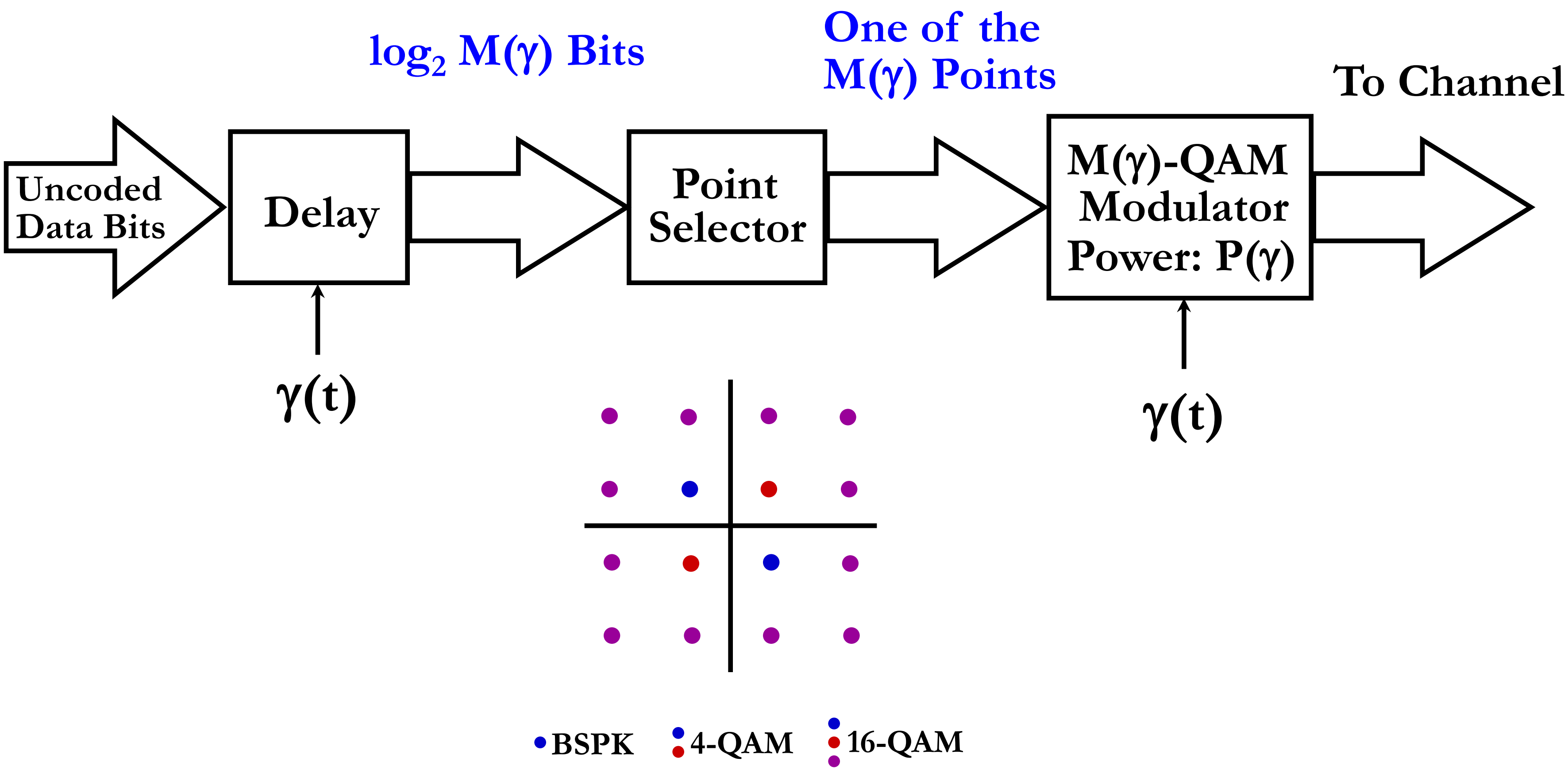
Adaptive Modulation

- 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



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

Optimization Formulation

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

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

- **Rate and Power Optimization**

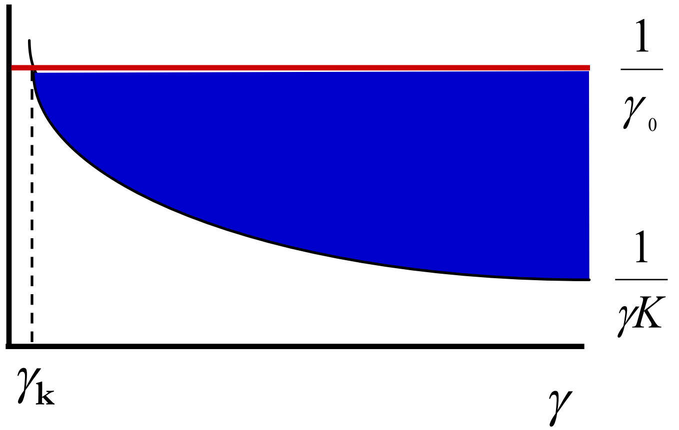
$$\max_{P(\gamma)} E \log_2[M(\gamma)] = \max_{P(\gamma)} E \log_2\left[1 + K\gamma \frac{P(\gamma)}{\overline{P}}\right]$$

Same maximization as for capacity, except for K=-1.5/ln(5BER).

Optimal Adaptive Scheme

- **Power Adaptation**

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

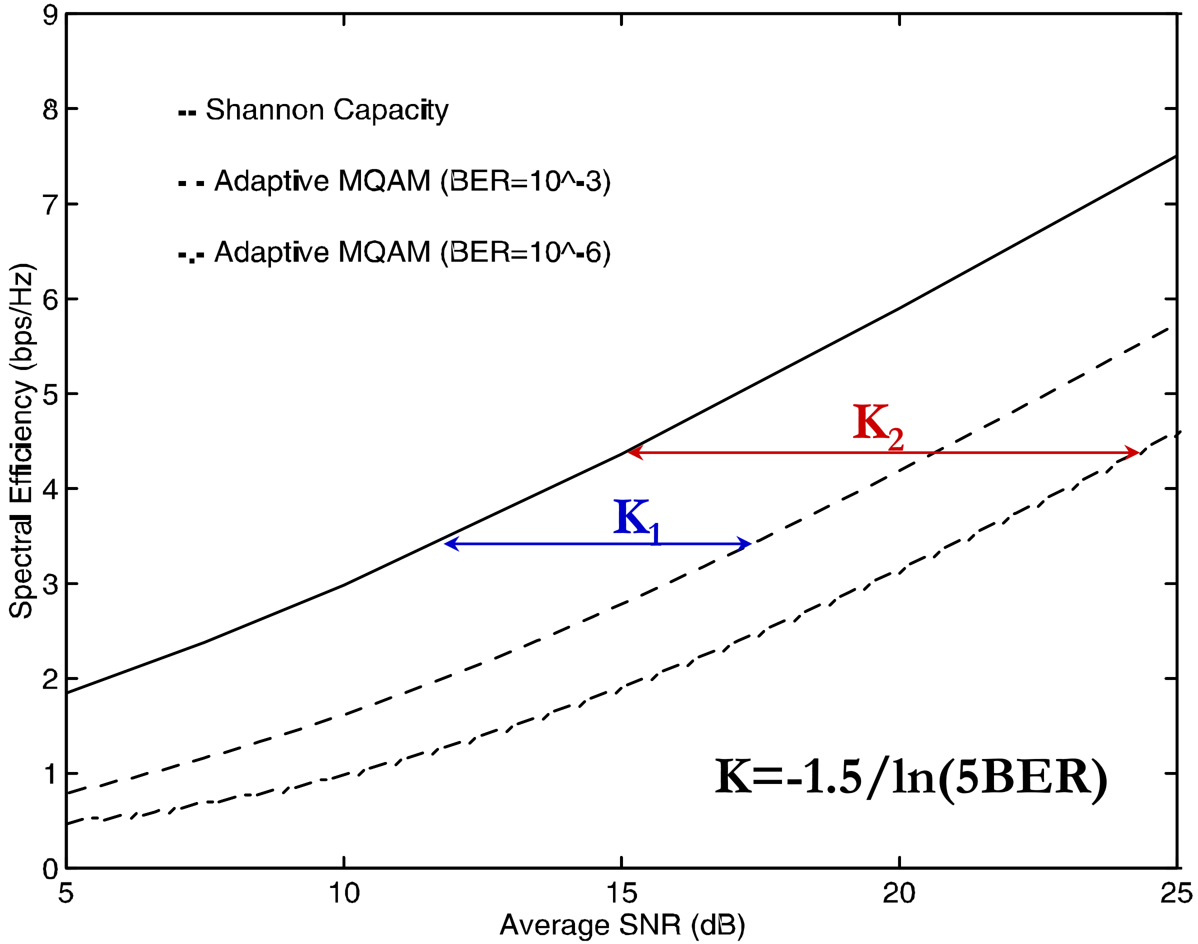


- **Spectral Efficiency**

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

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

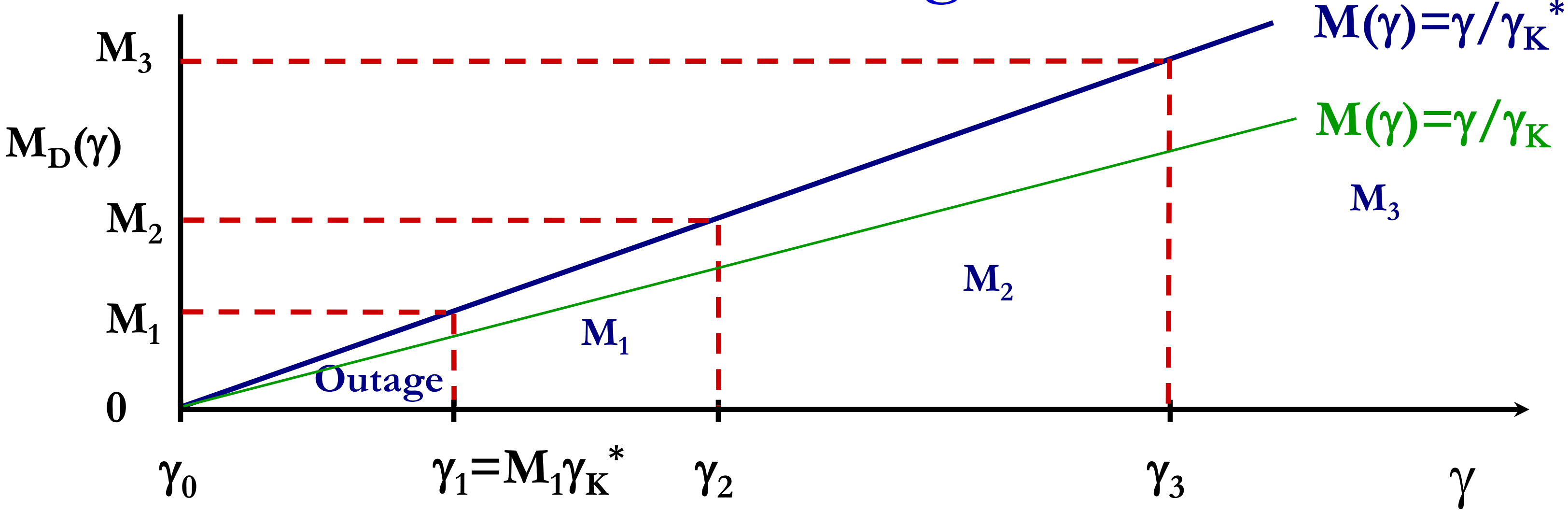
Spectral Efficiency



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 γ_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,…,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(γ)

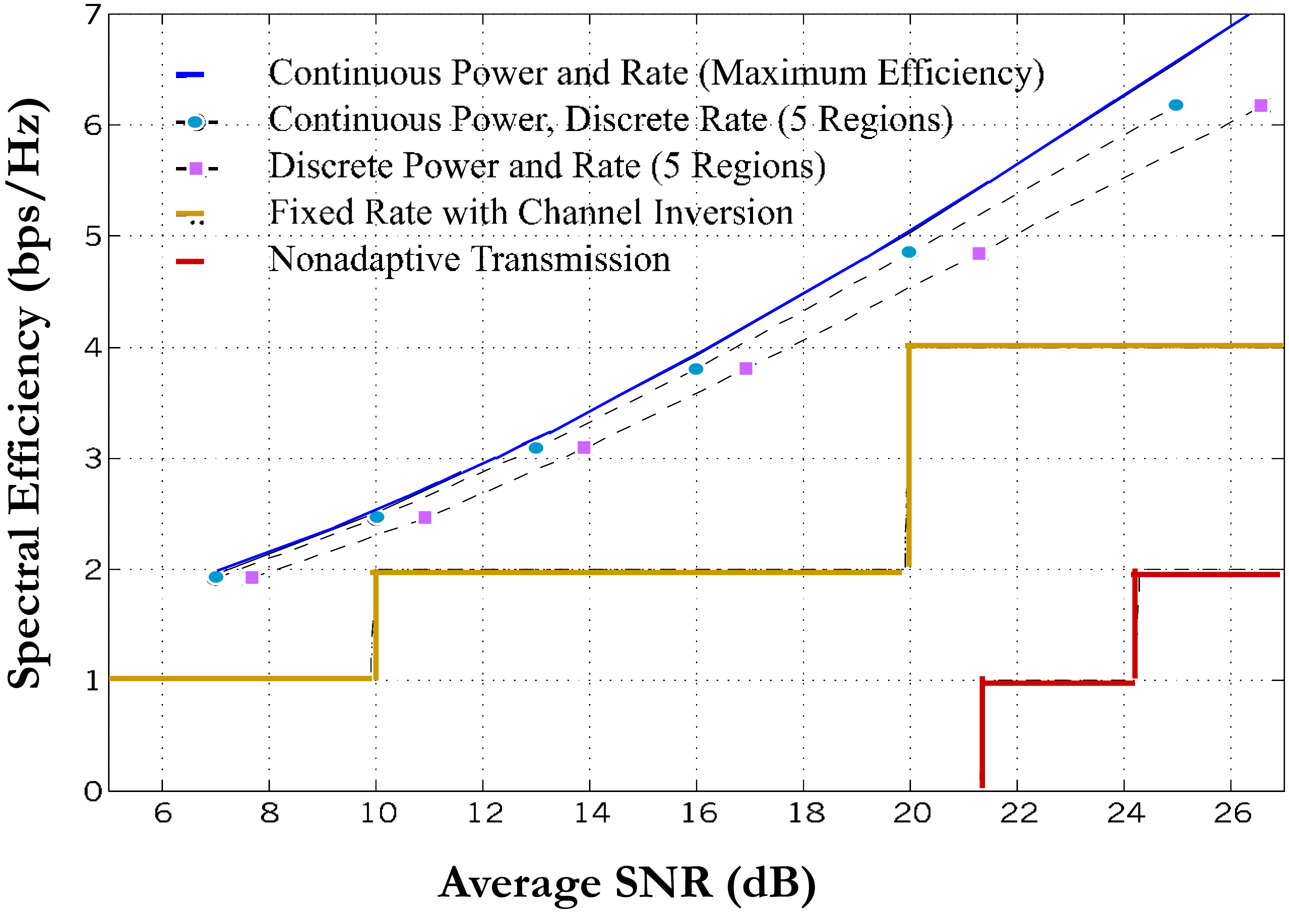
$$\frac{P_j(\gamma)}{P}=\begin{cases}(M_j-1)/(\gamma K) & \gamma_j \le \gamma < \gamma_{j+1}, j>0 \\ 0 & \gamma < \gamma_1\end{cases}$$

- Average Rate

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

- Practical Considerations:
  - Update rate/estimation error and delay

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.
- Estimation error/delay causes error floor