# EE359 – Lecture 12 Outline

- Announcements
  - Midterm announcements
  - No HW next week (practice MTs)
  - HW5 posted, due Monday 4pm (no late HWs)
- Transmit Diversity
- Midterm Review
- Introduction to adaptive modulation
- Variable-rate variable-power MQAM
- Optimal power and rate adaptation

# Midterm Announcements

- Midterm: Thursday (11/9), 6-8 pm in (room TBD)
  - Food will be served after the exam!
- Review sessions
  - My midterm review will be during tomorrow's makeup lecture
  - TA review: Monday 11/6 from 4-6 pm in 364 Packard
- 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 next 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
- No HW next week
- 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

# Review of Last Lecture

- Array Structure of a Diversity Combiner
- Performance metrics:
  - Outage probability and average probability of error
  - Array and Diversity gain
- Combining Techniques
  - Selection Combining (SC): Path with highest gain used
  - Maximal Ratio Combining (MRC): Paths cophased and summed with optimal weights to maximize SNR
- SC Performance Analysis
  - Combiner SNR is the maximum of the branch SNRs.
  - CDF easy to obtain ($\Pi_i p(\gamma_i<\gamma_{thr})$), pdf found by differentiating.
  - $P_{out}$ obtained from CDF. Average $P_s$ typically found numerically
  - Diminishing returns with number of antennas.
  - Can get up to about 20 dB of gain.

# Review Continued
# MRC Performance

- With MRC, $\gamma_\Sigma=\Sigma\gamma_i$ for branch SNRs $\gamma_i$
  - Optimal technique to maximize output SNR
  - Yields 20-40 dB performance gains
  - Distribution of $\gamma_\Sigma$ hard to obtain
- Standard average BER calculation

$$\overline{P}_S = \int P_S(\gamma_\Sigma) p(\gamma_\Sigma) d\gamma_\Sigma = \int\int \dots \int P_S(\gamma_\Sigma) p(\gamma_1) * p(\gamma_2) * \dots * p(\gamma_M) d\gamma_1 d\gamma_2 \dots d\gamma_M$$

  - Hard to obtain in closed form
  - Integral often diverges
- MGF Approach

$$\overline{P}_s = \frac{\alpha_M}{\pi} \int_0^{\pi/2} \prod_{i=1}^{M} \mathcal{M}_{\gamma_i} \left[ \frac{-.5\beta_M}{\sin^2 \phi} \right] d\phi.$$

Cover in HW and ppt, not lecture

# Transmit Diversity

- With channel knowledge, similar to receiver diversity, same array/diversity gain
- Without channel knowledge, can obtain diversity gain through Alamouti scheme:
  - 2 TX antenna space-time block code (STBC)
  - Works over 2 consecutive symbols
  - Achieves full diversity gain, no array gain
  - Part of various wireless standards, including LTE
  - Hard to generalize to more than 2 TX antennas
  - Alamouti code not covered in lecture/exams

# Midterm Review

- Overview of Wireless Systems
- Signal Propagation and Channel Models
- Modulation and Performance Metrics
- Impact of Channel on Performance
- Fundamental Capacity Limits
- Diversity Techniques
- Main Points

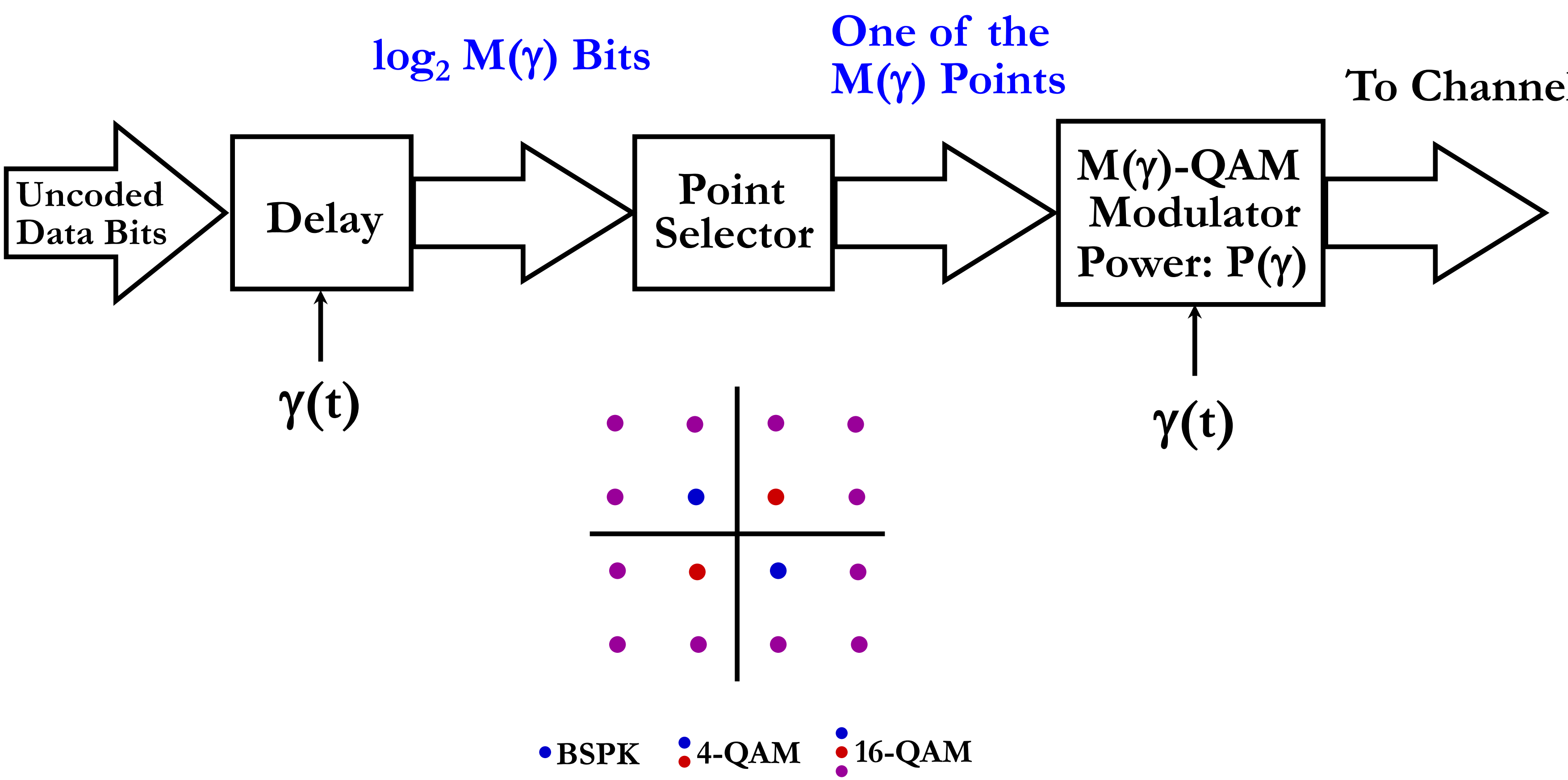
# Adaptive Modulation

- 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**

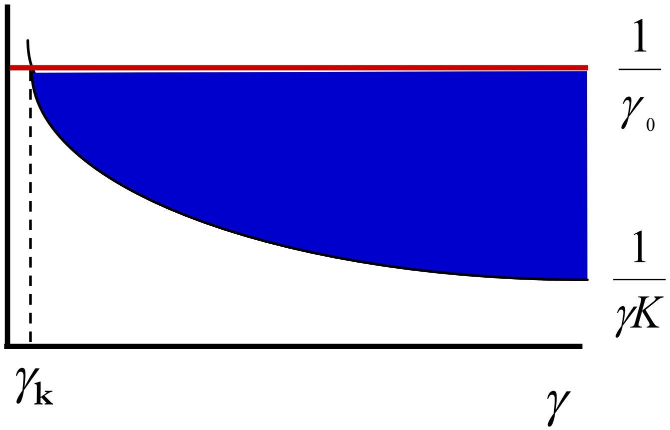
$$\max_{P(\gamma)} E \log_2[M(\gamma)] = \max_{P(\gamma)} E \log_2\left[1 + K\gamma \frac{P(\gamma)}{\overline{P}}\right]$$

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

# Optimal Adaptive Scheme

- **Power Adaptation**

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

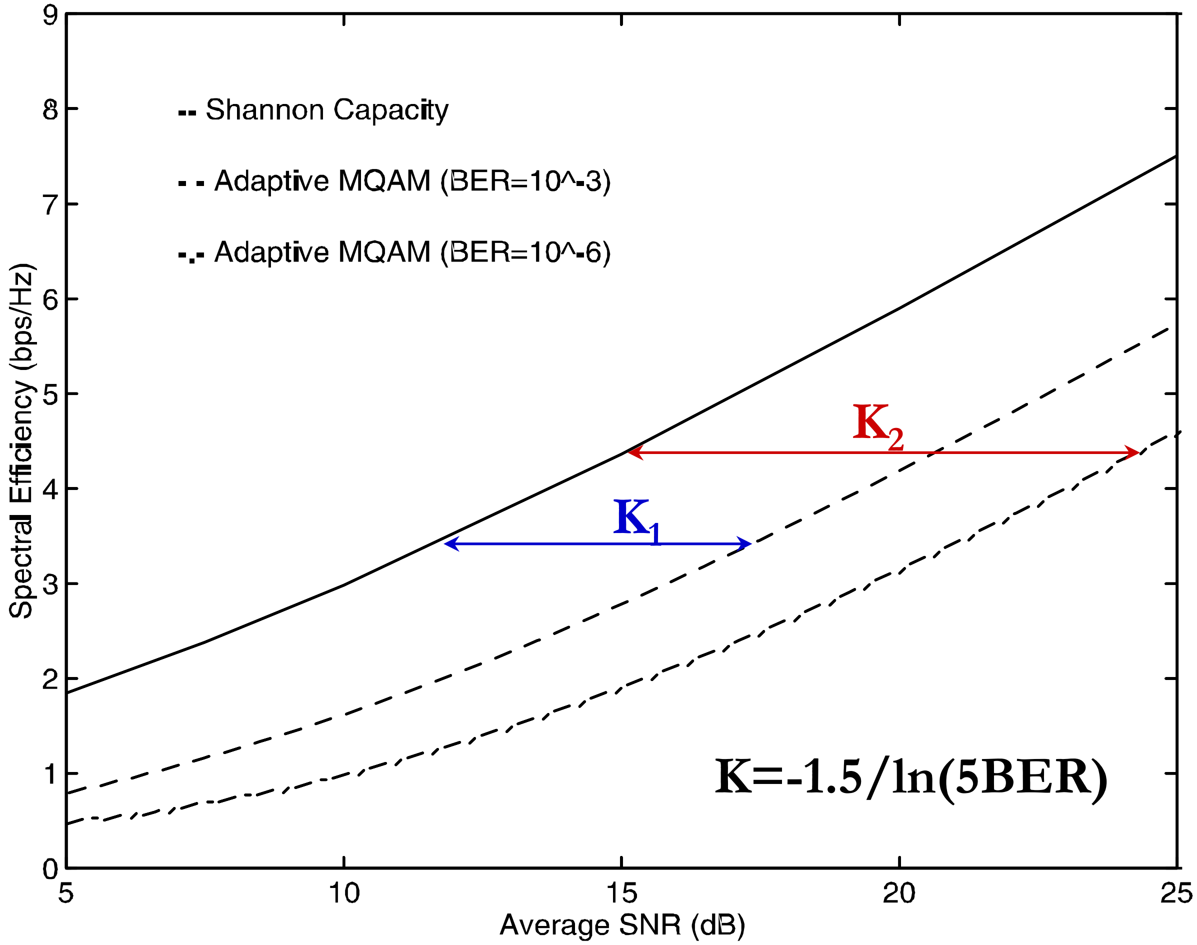



- **Spectral Efficiency**

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

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

# Spectral Efficiency




***Can reduce gap by superimposing a trellis code***

# Main Points

- Transmit diversity with channel state information at the TX is same as RX diversity
  - Can obtain diversity gain even without channel information at transmitter via space-time block codes.
- 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