EE359 – Lecture 12 Outline

- Announcements
  - Midterm announcements
  - No HW next week (practice MTs)
  - HW5 posted, due Tuesday 5pm (no late HWs)
- MGF Approach to MRC
- Generalized Combining
- Transmit Diversity
- Midterm Review
- Introduction to adaptive modulation
- Variable-rate variable-power MQAM

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Midterm Announcements

- Midterm: Friday (2/21), 2-4 pm in (Hewlett 103)
  - Food will be served after the exam!
- Review sessions
  - My midterm review will be during today's lecture
  - TA review (+OHs): Wednesday 2/19 from 4-6 pm in 364 Packard
- Midterm logistics:
  - Open book/notes; Bring reader/calculators. Disconnected electronic devices OK.
  - Covers Chapters 1-7 (sections covered in lecture and/or HW)
- OHs next week:
  - Me: Tue 2/18: 3-4:45pm, Thu 6-7pm, Fri 10:30-11:30am all in 371 Packard
  - Tom: Wed ~5-6pm, Thu 1:30-2:50pm, Fri 11:30-12:30pm
- 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

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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.

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Review continued
MRC and its Performance

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

$$\bar{P}_b=\int P_b(\gamma_\Sigma)p(\gamma_\Sigma)d\gamma_\Sigma=\int\int\ldots\int P_b(\gamma_\Sigma)p(\gamma_1)*p(\gamma_2)*\ldots*p(\gamma_M)d\gamma_1 d\gamma_2\ldots d\gamma_M$$

  - Hard to obtain in closed form
  - Integral often diverges
- MGF Approach: For P_s in AWGN of $P_s = \alpha Q(\sqrt{\beta\gamma})$

$$\bar{P}_s=\frac{\alpha}{\pi}\int_0^{\pi/2}\prod_{i=1}^{M}\int_0^{\infty}\exp\left[\frac{-.5\beta}{\sin^2\phi}\gamma_i\right]p_{\gamma_i}(\gamma_i)d\gamma_i dx=\frac{\alpha}{\pi}\int_0^{\pi/2}\prod_{i=1}^{M}\mathcal{M}_{\gamma_i}\left(\frac{-.5\beta}{\sin^2\phi}\right)d\phi.$$

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Generalized Combining

- For a diversity system with M branches:
  - Selects L branches, 1<L<M, with the highest SNR
  - Combined the L branches with MRC or EGC
- Complexity/performance tradeoffs
  - Better performance than L-branch MRC/EGC with higher complexity
  - Worse performance than M-branch MRC/EGC with lower complexity
- Performance analysis requires order statistics to characterize the L branches with the best SNR
  - MGF approach with order statistics can be used to obtain the distribution of the output SNR, P_s, P_{out}

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Transmit Diversity

Not covered in lecture/HW/exams

- With channel knowledge, similar to receiver diversity, same array/diversity gain
- <u>Without</u> 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

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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

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Adaptive Modulation (not on MT)

- 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

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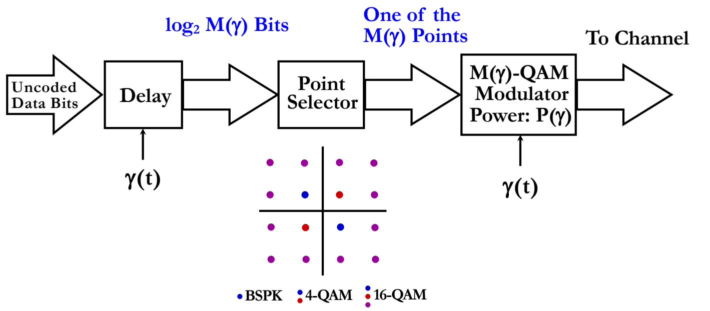
Variable-Rate Variable-Power MQAM



Goal: Optimize P(γ) and M(γ) to maximize R=Elog[M(γ)] subject to error probability target: $P_b \leq .2e^{-1.5\gamma/(M-1)}$

Problem formulation and solution similar to flat-fading capacity

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Main Points

- Analysis of MRC simplified using MGF approach
- GC combines benefits of SC and MRC
- TX diversity with CSI at TX 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 adapts instantaneous power and data rate to maximize average data rate
  - Optimization very similar to flat-fading channel capacity

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