EE359 – Lecture 11 Outline

- Announcements
  - Class project links posted (please check). Will have comments back this week.
  - Midterm announcements
  - HW5 posted, due Monday 4pm (no late HWs)
    - Regular OHs this week for TAs, mine are after class
  - No HW next week (practice MTs)
  - Makeup lecture here, tomorrow, at noon
- Diversity Combining Techniques
- Selection Combining
- Maximal Ratio Combining
- Transmit Diversity

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

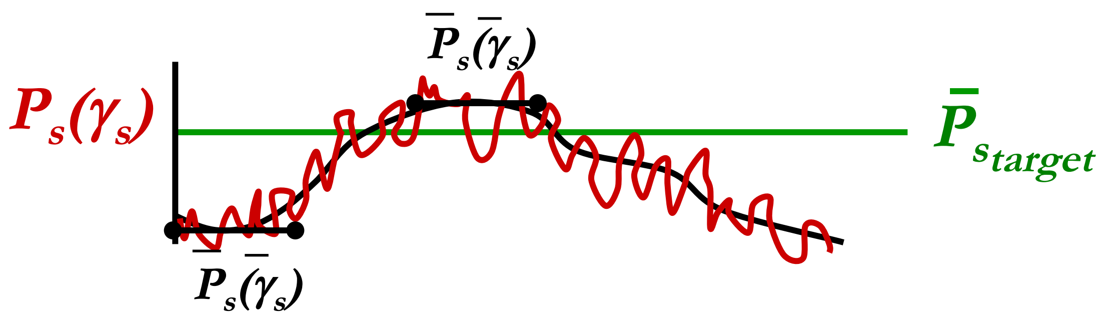
Review of Last Lecture

- Average P_s (P_b): $$\overline{P}_s = \int P_s(\gamma_s)p(\gamma_s)d\gamma_s$$
- MGF approach for average P_s
  - Average P_s becomes a Laplace transform

$$\overline{P}_s = \frac{\alpha_M}{\pi}\int_0^{\pi} M_{\gamma_s}\left(\frac{-.5\beta_M}{\sin^2 x}\right)dx$$

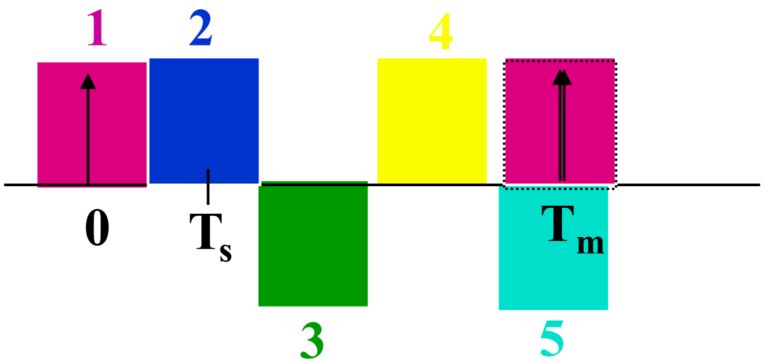
$M_{\gamma s}$ is MGF of fading pdf of SNR
γ_s, α_M,β_M depends on modulation

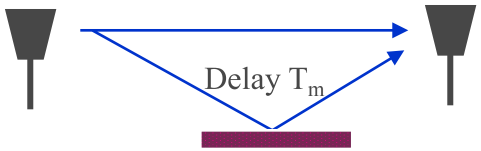
- Combined average and outage P_s



Review Continued:
Delay Spread (ISI) Effects

- Delay spread exceeding a symbol time causes ISI (self interference).





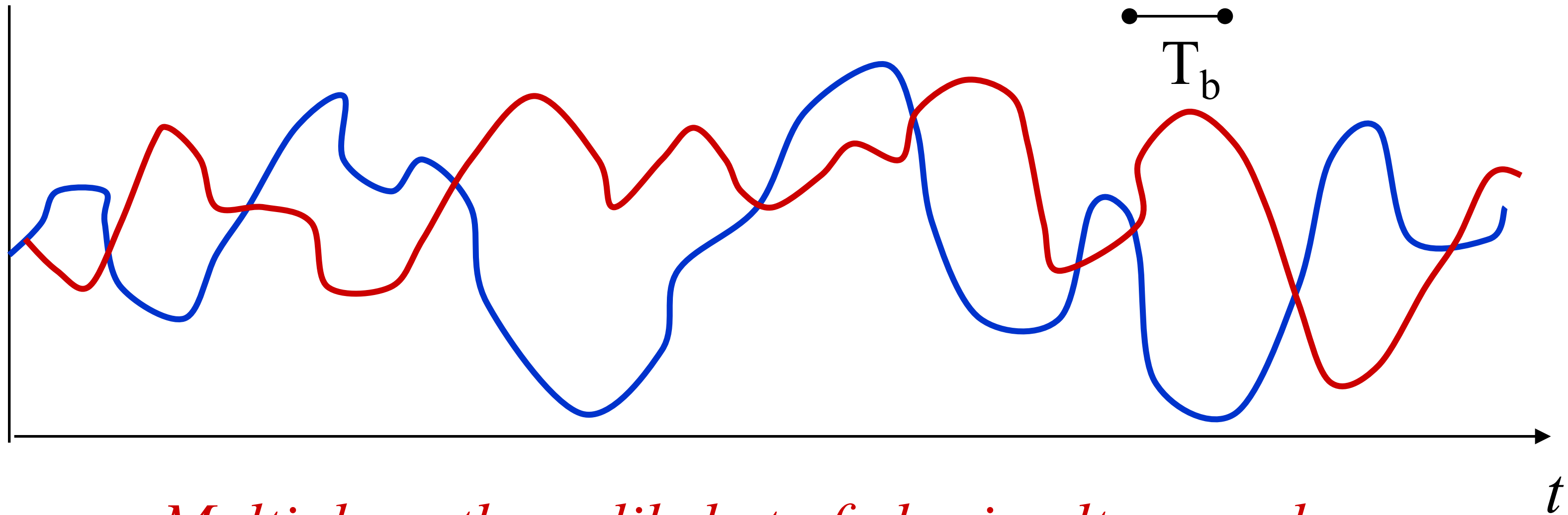
- ISI leads to irreducible error floor: $\overline{P}_{b,floor} \approx (\sigma_{T_m}/T_s)^2$
  - Increasing signal power increases ISI power
- ISI imposes data rate constraint: $T_s >> T_m$ ($R_s << B_c$)

$$R \leq \log_2(M) \times \sqrt{\overline{P}_{b,floor}/\sigma^2_{T_m}}$$

Review Continued:

Introduction to Diversity

- Basic Idea
  - Send same bits over independent fading paths
    - Independent fading paths obtained by time, space, frequency, or polarization diversity
  - Combine paths to mitigate fading effects



Multiple paths unlikely to fade simultaneously

Combining Techniques

- Selection Combining
  - Fading path with highest gain used
- Maximal Ratio Combining
  - All paths cophased and summed with optimal weighting to maximize combiner output SNR
- Equal Gain Combining
  - All paths cophased and summed with equal weighting
- Array/Diversity gain
  - Array gain is from noise averaging (AWGN and fading)
  - Diversity gain is change in BER slope (fading)

Our focus

Selection Combining Analysis and Performance

- Selection Combining (SC)
  - Combiner SNR is the maximum of the branch SNRs.
  - CDF easy to obtain, pdf found by differentiating.
  - Diminishing returns with number of antennas.
  - Can get up to about 20 dB of gain.

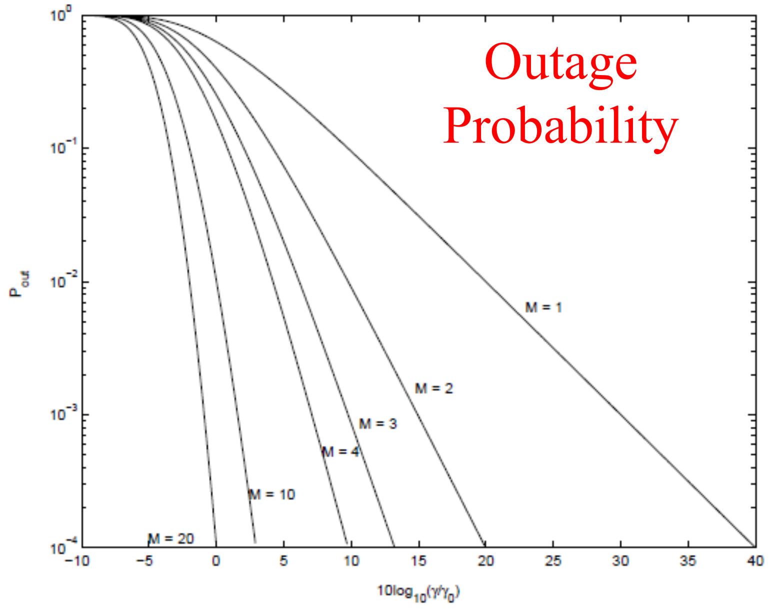


Figure 7.2: Outage Probability of Selection Combining in Rayleigh Fading.

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

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

  - Hard to obtain in closed form
  - Integral often diverges
- MGF Approach (N paths):

Cover in HW and ppt, not lecture

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

M_{γ_i} is MGF of fading pdf of i^{th} branch SNR γ_i, α_M, β_M depend on modulation

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

Main Points

- Selection diversity picks path with highest SNR
  - Diminishing returns with number of fading paths
- MRC optimally combines fading paths to maximize combiner SNR
  - MRC vs SC trade off complexity for performance.
  - MRC yields 20-40 dB gain, SC around 20 dB.
- Analysis of MRC simplified using MGF approach
- 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.