EE359 – Lecture 11 Outline

- Announcements
  - HW due Friday 5pm, no late HWs
  - Midterm announcements
  - Bonus lecture query: extend last lecture?
- Average Ps with outage
- P_s due to Doppler and ISI
- Introduction to Diversity
- Combining Techniques
- Performance of Diversity in Fading

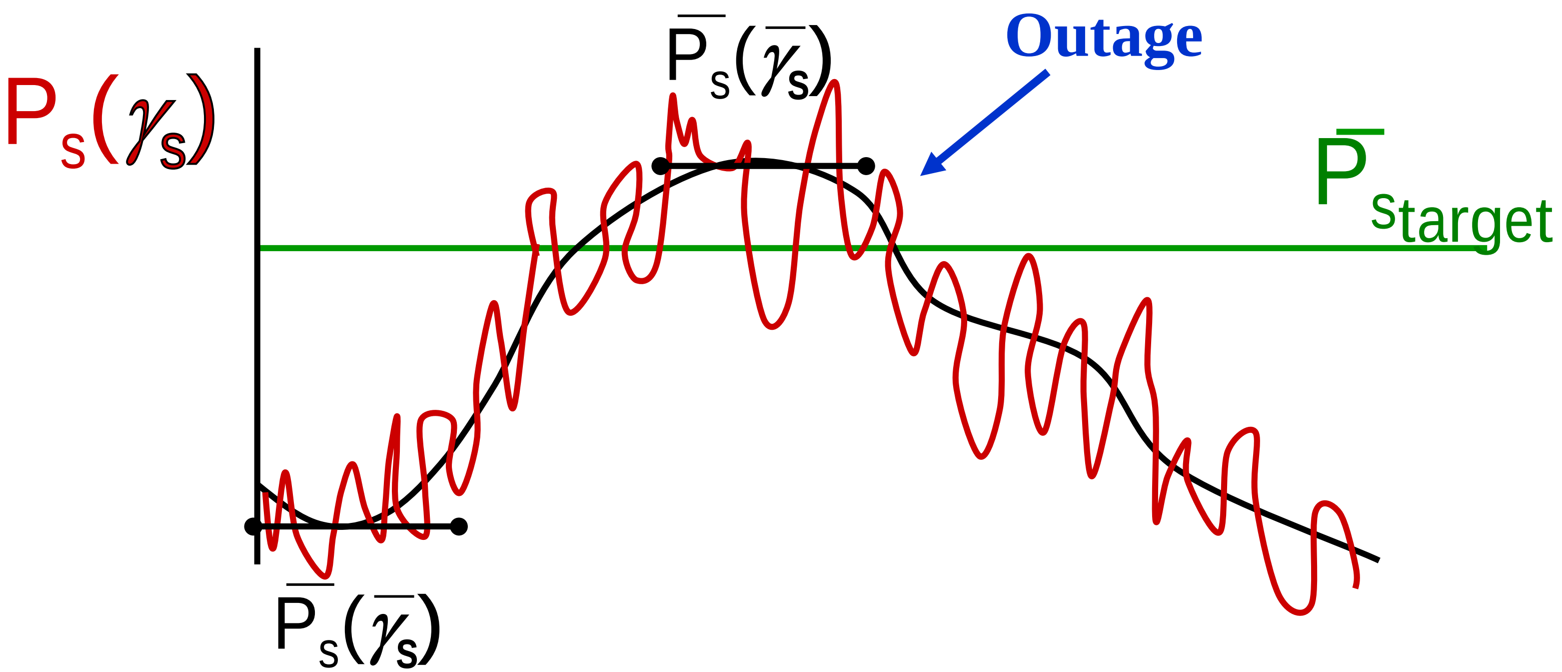
Midterm and Extra Lecture Announcements

- Midterm Wed Nov. 4, 8:45-10:45a in this rm.
  - Open book/notes (bring textbook/calculators)
  - Covers Chapters 1-7
- Review Session Sunday 4-5:30pm, rm TBD
- Extra OHs
  - Me: Friday, Monday, Tuesday 2-3pm, Yao TBD
  - No HW next week
- Midterms from past 3 MTs posted
  - 10 bonus points for "taking" a practice exam
  - Solns for all exams given when you turn in practice exam

Review of Last Lecture

- Outage probability
  - Probability that P_s is above target
  - Equivalently, probability γ_s below target
  - Used when $T_c >> T_s$
- Average P_s in fast fading:
  - Averaged over fast fading distribution
  - Good metric when $T_c \sim T_s$
  - Alternate Q function approach greatly simplifies calculations (switch integral order, becomes Laplace Xfm)
- Fading severely degrades performance

Combined outage and average P_s



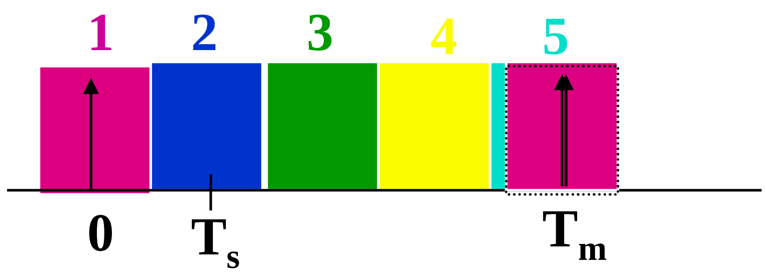
- Used in combined shadowing and flat-fading
- $\bar{P}_s$ varies slowly, locally determined by flat fading
- Declare outage when $\bar{P}_s$ above target value

Doppler Effects

- High doppler causes channel phase to decorrelate between symbols
- Leads to an irreducible error floor for differential modulation
  - Increasing power does not reduce error
- Error floor depends on $B_d T_s$

ISI Effects

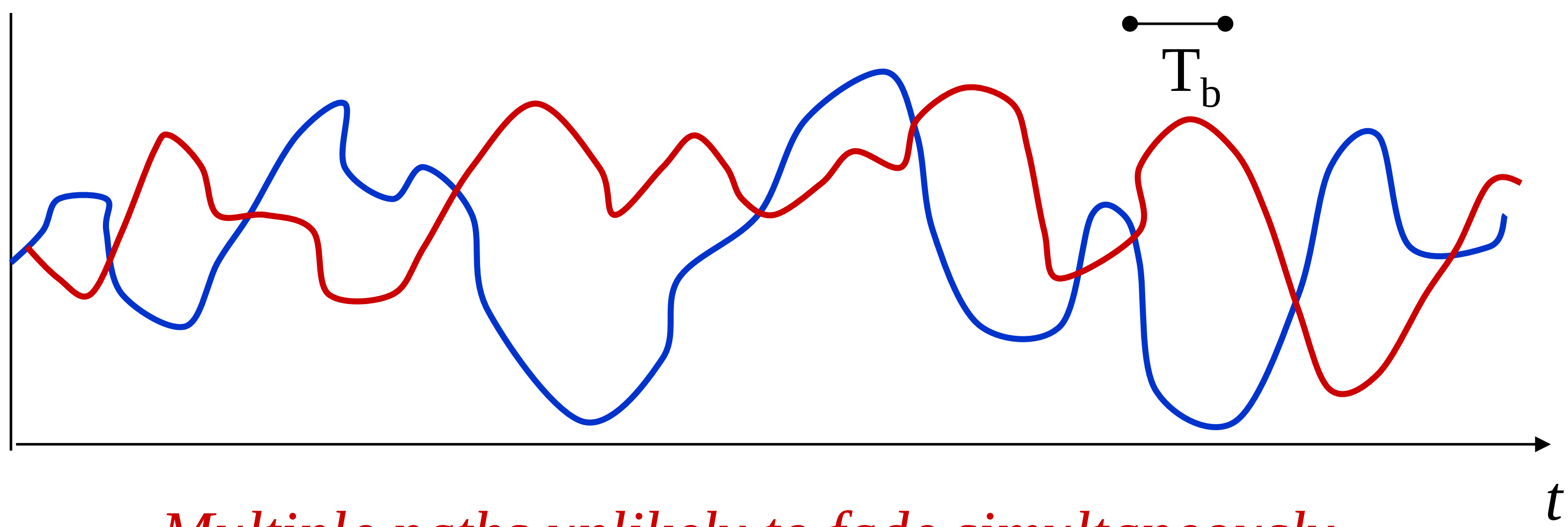
- Delay spread exceeding a symbol time causes ISI (self interference).



- ISI leads to irreducible error floor
  - Increasing signal power increases ISI power
- ISI requires that $T_s >> T_m$ ($R_s << B_c$)

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)

Diversity 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.
- Maximal Ratio Combining (MRC)
  - Optimal technique (maximizes output SNR)
  - Combiner SNR is the sum of the branch SNRs.
  - Distribution of SNR hard to obtain.
  - Can use MGF approach for simplified analysis.
  - Exhibits 10-40 dB gains 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

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

Main Points

- Doppler spread only impacts differential modulation causing an irreducible error floor at low data rates
- Delay spread causes irreducible error floor or imposes rate limits
- Diversity overcomes the effects of fading by combining fading paths
- Diversity typically entails some penalty in terms of rate, bandwidth, complexity, or size.
- Techniques trade complexity for performance.
  - MRC yields 20-40 dB gain, SC around 20 dB.