

EE359 – Lecture 11 Outline

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

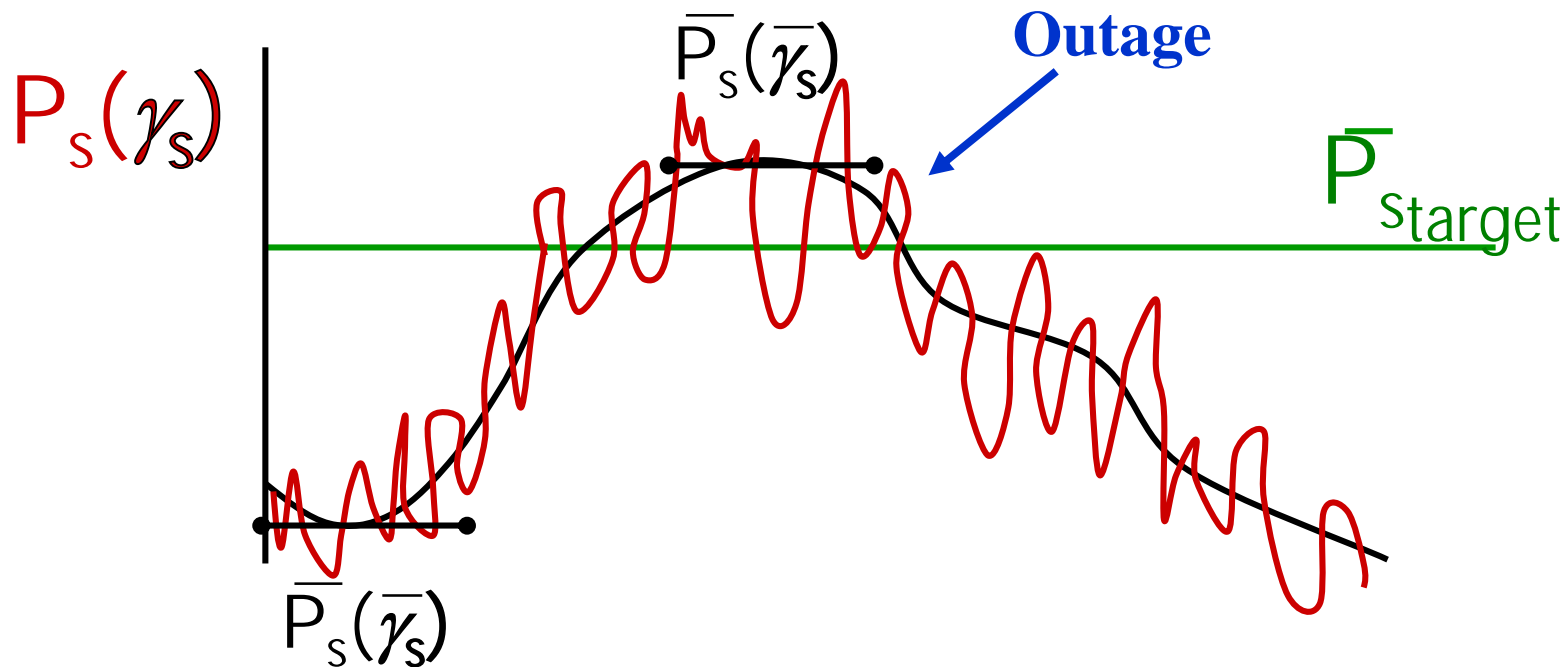
Midterm and Extra Lecture Announcements

- 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 $T_c \gg T_s$
- 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



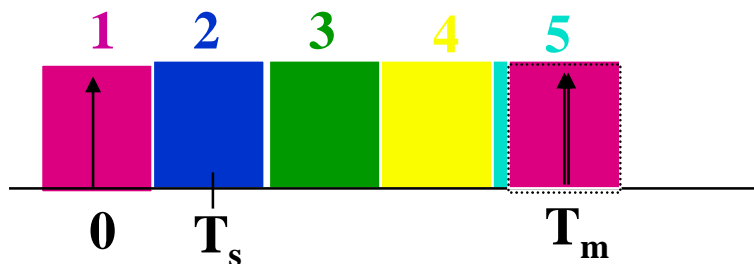
- Used in combined shadowing and flat-fading
- \bar{P}_s varies slowly, locally determined by flat fading
- Declare outage when \bar{P}_s above target value

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).

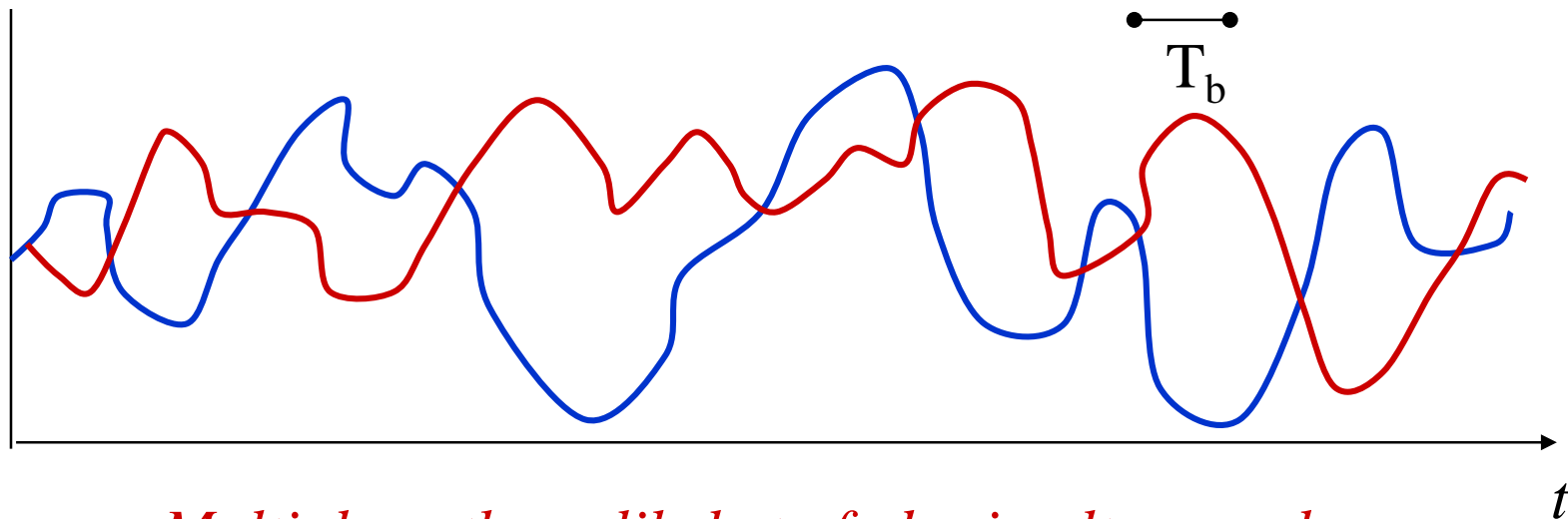


- ISI leads to irreducible error floor
 - Increasing signal power increases ISI power
- ISI requires that $T_s \gg T_m$ ($R_s \ll B_c$)

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, $\gamma_{\Sigma} = \sum \gamma_i$ 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

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

- Hard to obtain in closed form
- Integral often diverges

- MGF Approach

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

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.