Combined Outage/Average P_s. Doppler and ISI. Diversity.

Lecture Outline

- **Combined Outage and Average Probability of Error**
- **Doppler Effects on Performance**
- **Delay Spread (ISI) Effects on Performance**
- **Introduction to Diversity**
- **Realization of Independent Fading Paths**
- **Diversity Combining Techniques**
- **Performance of Diversity Combining in Fading**
- **MRC Diversity and its Performance**

1. **Combined outage and average error probability:**
   - Shadowing causes outage and flat-fading determines $\overline{P}_s$ during nonoutage
   - $\overline{P}_s$ obtained in small region where $\overline{\gamma}_s$ approximately constant as $\overline{P}_s = \int P_s(\gamma_s)p(\gamma_s|\overline{\gamma}_s)$.
   - A target $\overline{\gamma}_s$ is needed to obtain a target $\overline{P}_s$.
   - Outage occurs when shadowing causes $\overline{\gamma}_s$ to fall below its target value.

2. **Doppler Effects on Performance**
   - Doppler has little impact on coherent modulation (small bandwidth expansion).
   - High doppler can cause channel phase to decorrelate between symbols.
   - Leads to an irreducible error floor for differential modulation.
   - Error floor approximated by $P_{b_{\text{floor}}} \approx .5(\pi B_d T_b)^2$.

3. **Delay Spread (ISI) Effects on Performance.**
   - Delay spread exceeding a symbol time causes ISI (self-interference).
   - ISI leads to an irreducible error floor.
   - Without ISI compensation, avoid error floor by reducing data rate ($T_s >> T_m$).

4. **Introduction to Diversity**
   - Basic concept is to send same information over independent fading paths.
   - Paths are combined to mitigate the effects of fading.

5. **Realization of Independent Fading Paths**
   - Space Diversity: Multiple antenna elements spaced apart by decorrelation distance.
   - Polarization Diversity: Two antennas, one horizontally polarized and one vertically polarized.

- Frequency diversity: Multiple narrowband channels separated by channel ooherence bandwidth.
- Time diversity: Multiple timeslots separated by channel coherence time.

6. **Array and Diversity Gain**
   - Array gain is the gain in SNR from noise averaging over the multiple antennas. Gain in both AWGN and fading channels.
   - Diversity gain is the change in slope of the probability of error due to diversity. Only applies to fading channels.

7. **Techniques for Combining Independent Fading Paths**
   - Selection Combining: largest fading path chosen.
   - Maximal Ratio Combining: all paths cophased and summed with optimal weighting to maximize SNR at combiner output.
   - Equal Gain Combining: all paths cophased and summed with equal weighting.

8. **Selection Combining and its Performance**
   - Combiner SNR γ_Σ is the maximum of the branch SNRs.
   - This gives diminishing returns, in terms of power gain, as the number of antennas increases.
   - CDF of γ_Σ easy to obtain, then pdf found by differentiating.
   - Typically get 10-15 dB of gain for 2-3 antennas.

9. **Maximal Ratio Combining (MRC)**
   - Branch weights optimized to maximize output SNR of combiner.
   - Optimal weights are proportional to branch SNR.
   - Resulting combiner SNR γ_Σ is sum of branch SNRs.
   - Distribution obtained by characteristic function analysis (can be hard).

10. **Performance of MRC with i.i.d. Rayleigh fading**
    - For M branch diversity with i.i.d. Rayleigh fading on each branch, γ_Σ is chi-squared with $2M$ degrees of freedom.
    - Can obtain P_{out} and $\overline{P}_s$ from this distribution.
    - For BPSK, get 15 dB gain at 10^{-3} BER. Larger gains obtained at lower BERs.

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 is a powerful technique to overcome the effects of flat fading by combining multiple independent fading paths
- Diversity typically entails some penalty in terms of rate, bandwidth, complexity, or size.
- Both selection combining and MRC significantly reduce the impact of fading.
- The different combining techniques offer different levels of complexity and performance.