Lecture 10 - EE 359: Wireless Communications - Fall 2009

Linear Modulation Performance in Fading

Lecture Outline

- **Performance of Linear Modulation in Fading**
- **Outage Probability**
- **Average Probability of Error**
- **Combined Outage and Average Probability of Error**
- **Doppler Effects on Performance**
- **Delay Spread (ISI) Effects on Performance**

1. **Performance of Linear Modulation in Fading:**
   - In fading γ_s and therefore P_s are random variables.
   - Three performance metrics to characterize the random P_s.
   - Outage: $p(P_s > P_{target} = p(\gamma < \gamma_{target})$
   - Average P_s ($\overline{P}_s = \int P_s(\gamma)p(\gamma)d\gamma$).
   - Combined outage and average P_s.
2. **Outage Probability:** $p(P_s < P_{s_{\text{target}}}) = p(\gamma_s < \gamma_{s_{\text{target}}})$.
   - Outage probability used when fade duration long compared to a symbol time.
   - Obtained directly from fading distribution and target γ_s.
   - Can obtain simple formulas for outage in log-normal shadowing or in Rayleigh fading.
3. **Average P_s:** $\overline{P}_s = \int P_s(\gamma_s)p(\gamma_s)d\gamma_s$.
   - Rarely leads to close form expressions for general $p(\gamma_s)$ distributions.
   - Can be hard to evaluate numerically.
   - Can obtain closed form expressions for general linear modulation in Rayleigh fading (using approximation $P_s \approx \alpha_M Q(\sqrt{\beta_M \gamma_s})$ in AWGN).
   - Using alternate Q function representation, the average P_s becomes the moment generating function of the distribution: easy to calculate for any modulation and any fading distribution using standard Laplace transforms.
4. **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.
5. **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 $P_{b_{\text{floor}}} \approx .5(\pi B_d T_b)^2$.

6. **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 ($T_s >> T_m$).

Main Points

- Outage probability based on target SNR in AWGN.
- Fading greatly increases average P_s. Easy to compute using alternate Q function.
- 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.
- Need to find ways to combat flat and frequency-selective fading (focus of the rest of the course).