

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 ($\bar{P}_s = \int P_s(\gamma)p(\gamma)d\gamma$).
- Combined outage and average P_s .

2. Outage Probability: $p(P_s < P_{starget}) = p(\gamma_s < \gamma_{starget})$.

- 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 : $\bar{P}_s = \int P_s(\gamma_s)p(\gamma_s)d\gamma_s$.

- 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 \bar{P}_s during nonoutage
- \bar{P}_s obtained in small region where $\bar{\gamma}_s$ approximately constant as $\bar{P}_s = \int P_s(\gamma_s)p(\gamma_s|\bar{\gamma}_s)$.
- A target $\bar{\gamma}_s$ is needed to obtain a target \bar{P}_s .
- Outage occurs when shadowing causes $\bar{\gamma}_s$ 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 ($T_s \gg T_m$).

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).