Announcements
- HW posted, due Friday 4pm
- Discussion section starts tomorrow, 4-5pm, 364 Packard
- TA OHs start this week
- We will have to reschedule 1 more class, on election day (Nov. 8), MT is also that week. Options are M am, W or F. Will send Piazza poll.

Log Normal Shadowing

Combined Path Loss and Shadowing

Outage Probability

Model Parameters from Measurements
Lecture 2 Review

- Signal Propagation Overview
- Ray Tracing Models
- Free Space Model
  - Power falloff with distance proportional to $d^{-2}$
- Two Ray Model
  - Power falloff with distance proportional to $d^{-4}$
- Simplified Model: $P_r = P_t K [d_0/d]^{\gamma}$, $2 \leq \gamma \leq 8$.
  - Captures main characteristics of path loss
- mmWave propagation
- Empirical Models
• Models attenuation from obstructions
• Random due to random # and type of obstructions
• Typically follows a log-normal distribution
  • dB value of power is normally distributed
  • $\mu=0$ (mean captured in path loss), $4<\sigma<12$ (empirical)
  • CLT used to explain this model
  • Decorrelates over decorrelation distance $X_c$
Combined Path Loss and Shadowing

- **Linear Model:** $\psi$ lognormal

\[
\frac{P_r}{P_t} = K \left( \frac{d_0}{d} \right) ^{\gamma} \psi
\]

- **dB Model**

\[
\frac{P_r}{P_t} (dB) = 10 \log_{10} K - 10^{\gamma} \log_{10} \left( \frac{d}{d_0} \right) + \psi_{dB}, \quad \psi_{dB} \sim N(0, \sigma_{\psi}^2)
\]
Outage Probability

- Path loss only: circular “cells”; Path loss+shadowing: amoeba-shaped cells
- Outage probability: probability received power falls below given minimum:

\[ p_{out} = p(P_r < P_{min}) \]

- For log-normal shadowing model

\[ p_{out} = 1 - Q\left( \frac{P_{min} - (P_t + 10\log_{10}K - 10\gamma\log_{10}(d/d_0))}{\sigma_{\Psi d_B}} \right) \]
Model Parameters from Empirical Measurements

- **Fit model to data**

- **Path loss \((K, \gamma), d_0\) known:**
  - "Best fit" line through dB data
  - \(K\) obtained from measurements at \(d_0\).
  - Or can solve for \((K, \gamma)\) simultaneously (least squares fit)
  - Exponent is MMSE estimate based on data
  - Captures mean due to shadowing

- **Shadowing variance**
  - Variance of data relative to path loss model (straight line) with MMSE estimate for \(\gamma\)
Main Points

- Random attenuation due to shadowing modeled as log-normal (empirical parameters)

- Shadowing decorrelates over decorrelation distance

- Combined path loss and shadowing leads to outage and non-circular coverage areas for WiFi/cellular

- Path loss and shadowing parameters obtained from empirical measurements through a least-squares fit
  - Matches environment in which measurements are taken.
  - Can do a 1D fit with $K$ fixed or a 2D fit over $K$ and $\gamma$. 