EE359 – Lecture 3 Outline

- Announcements
  - HW posted, due Fri 4pm
  - Discussion section starts Wed, 4-5pm, 364 Packard (tentative)
  - TA OHs start this week
  - Thanks for all the book typos entered into the website!
- Log Normal Shadowing
- Combined Path Loss and Shadowing
- Outage Probability
- Model Parameters from Measurements
- Statistical Multipath Model

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Lecture 2 Review

- Propagation Characteristics
  - Path loss, shadowing, multipath
- Overview of Path Loss Models
- Free Space Path Loss
  - Power falloff proportional to λ and to d^{-2}
- Two Ray Model
  - Power falloff independent of λ; proportional to d^{-4}
- Simplified Model: $P_r=P_tK[d_0/d]^\gamma$, $2\leq\gamma\leq 8$.
  - Captures main characteristics of path loss
- mmWave Path Loss Models:
  - Large attenuation at 60/120/180GHz and from rain
- Empirical Models (not on HW or exams)

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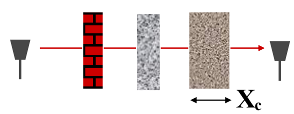
Shadowing



- 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

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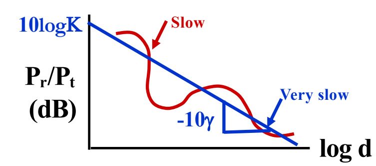
Combined Path Loss and Shadowing

- Linear Model: ψ lognormal

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



- dB Model

$$\frac{P_r}{P_t}(dB) = \underbrace{10\log_{10}K}_{K_{dB}} - 10\gamma\log_{10}\left(\frac{d}{d_0}\right) - \psi_{dB},\quad \psi_{dB}\sim N(\mu_\psi,\sigma_\psi^2)$$

$\mu_\psi=0$ when average shadowing incorporated into K and γ, else $\mu_\psi>0$

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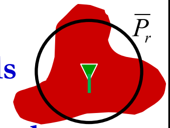
Outage Probability



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

$$P_{out} = \mathrm{p}(P_r < P_{min})$$

- For log-normal shadowing model

$$P_{out} = 1 - \mathrm{Q}\left(\frac{P_{min} - (P_t + 10log_{10}K - 10\gamma log_{10}(d/d_0))}{\sigma_{\psi_{dB}}}\right)$$

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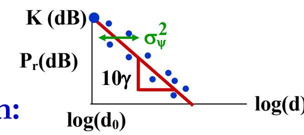
Model Parameters from Empirical Measurements



- Fit model to data
- Path loss (K,γ), d_0 known:
  - "Best fit" line through dB data
  - K obtained from measurements at d_0.
    - Or can solve for (K,γ) 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 γ

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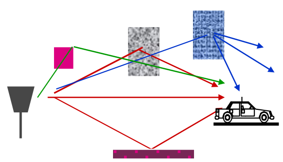
Statistical Multipath Model



- Random # of multipath components, each with
  - Random amplitude
  - Random phase
  - Random Doppler shift
  - Random delay
- Random components change with time
- Leads to time-varying channel impulse response

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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 γ.
- Statistical multipath model leads to a time-varying channel impulse response

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