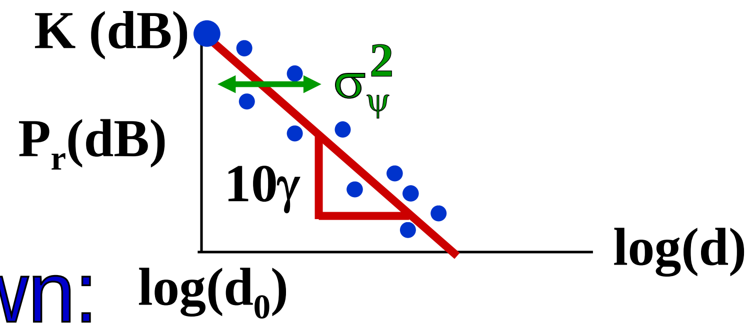
# EE359 – Lecture 4 Outline

- Announcements:
  - 1st HW due tomorrow.
  - Makeup lecture Friday, 12pm-1:10, 102 Hewlitt, wth pizza at 11:45 (also 10/9, these are makeups for Oct. 12-14)
  - Discussion T 4-4:50 in 380-380W (Math dept. basement)
- Review of Last Lecture
- Model Parameters from Empirical Data
- Random Multipath Model
- Time Varying Channel Impulse Response
- Narrowband Approximation for RX Signal
- In-phase and Quadrature RX Signal Components

# Review of Last Lecture

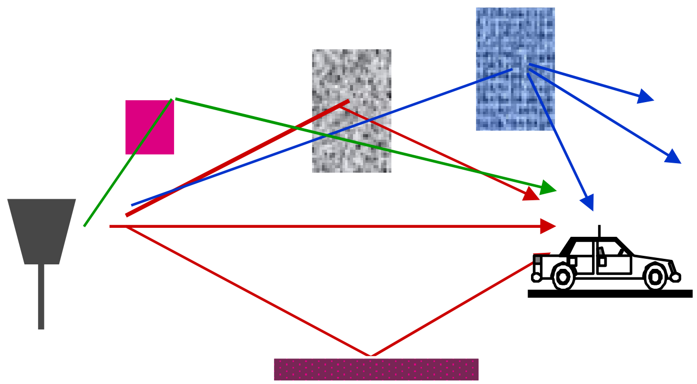
- Log Normal Shadowing
- Combined Path Loss and Shadowing
- Cell Coverage Area

# 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 $d_0$.
  - 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

# 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

# Time Varying Impulse Response

- Response of channel at t to impulse at t-τ:

$$c(\tau,t)=\sum_{n=1}^{N}\alpha_n(t)e^{-j\varphi_n(t)}\delta(\tau-\tau_n(t))$$

  - t is time when impulse response is observed
  - t-τ is time when impulse put into the channel
  - τ is how long ago impulse was put into the channel for the current observation
    - path delay for MP component currently observed

# Received Signal Characteristics

- Received signal consists of many multipath components
- Amplitudes change slowly
- Phases change rapidly
  - Constructive and destructive addition of signal components
  - Amplitude fading of received signal (both wideband and narrowband signals)

# Narrowband Model

- Assume delay spread $\max_{m,n}|\tau_n(t)-\tau_m(t)| << 1/B$
- Then $u(t) \approx u(t-\tau)$.
- Received signal given by

$$r(t) = \Re\left\{ u(t) e^{j2\pi f_c t} \left[ \sum_{n=0}^{N(t)} \alpha_n(t) e^{j\phi_n(t)} \right] \right\}$$

- No signal distortion (spreading in time)
- Multipath affects complex scale factor in brackets.
- Characterize scale factor by setting $u(t)=\delta(t)$

# In-Phase and Quadrature under CLT Approximation

- In phase and quadrature signal components:

$$r_I(t) = \sum_{n=0}^{N(t)} \alpha_n(t) e^{j\phi_n(t)} \cos(2\pi f_c t),$$

$$r_Q(t) = \sum_{n=0}^{N(t)} \alpha_n(t) e^{j\phi_n(t)} \sin(2\pi f_c t)$$

- For N(t) large, $r_I(t)$ and $r_Q(t)$ jointly Gaussian (sum of large # of random vars).
- Received signal characterized by its mean, autocorrelation, and cross correlation.
- If $\varphi_n(t)$ uniform, the in-phase/quad components are mean zero, indep., and stationary.

# Main Points

- Statistical multipath model leads to a time-varying channel impulse response
- Received signal has random amplitude fluctuations
- Narrowband model and CLT lead to in-phase/quad components that are stationary Gaussian processes
  - Processes completely characterized by their mean, autocorrelation, and cross correlation.
- Assuming uniform phase offsets, process is zero mean with joint expectation also zero.