EE359 – Lecture 2 Outline

- Announcements
  - 1st HW posted by tonight, due next Friday at 4pm.
  - Discussion section starts next week, W 4-5 (364 Packard)*
  - TA OHs start next week: Wed 5-6pm, Fri 10-11am (Tom), Thu 4-5pm (Milind). Email: Thu 5-6pm (Milind), Fri 11-12pm (Tom). Packard 3rd floor kitchen area. SCPD via Zoom
- Review of Last Lecture
- TX and RX Signal Models
- Path Loss Models
  - Free-space and 2-Ray Models
  - General Ray Tracing
  - Simplified Path Loss Model
  - Empirical Models
  - mmWave Models

*to be confirmed

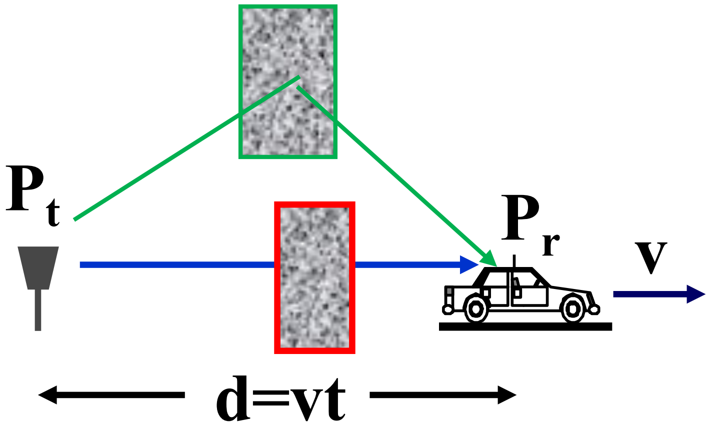
Lecture 1 Review

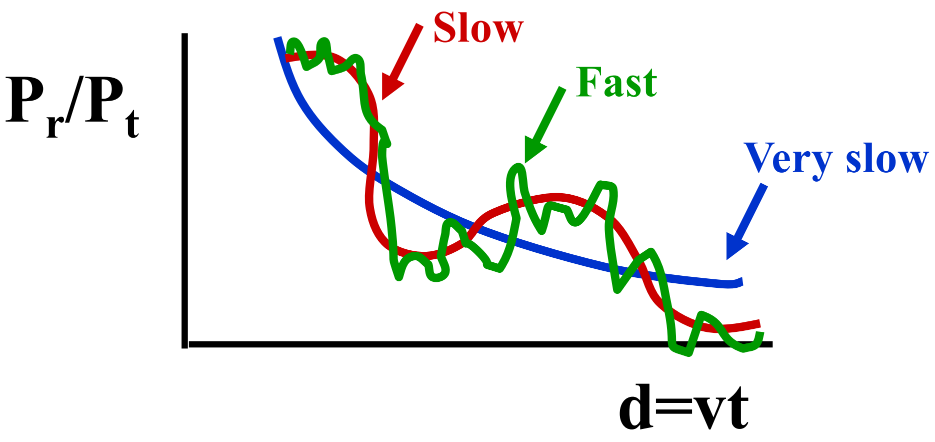
- Course Information
- Wireless Vision
- Technical Challenges
- Current/Next-Gen Wireless Systems
- Spectrum Regulation and Standards
- Emerging Wireless Systems

Emerging systems can be covered in a bonus lecture

Propagation Characteristics

- Path Loss (includes average shadowing)
- Shadowing (due to obstructions)
- Multipath Fading

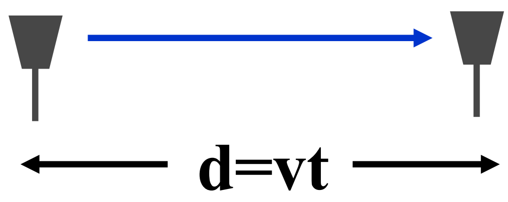




Path Loss Modeling

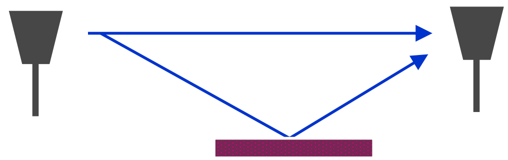
- Maxwell's equations
  - Complex and impractical
- Free space and 2-path models
  - Too simple
- Ray tracing models
  - Requires site-specific information
- Simplified power falloff models
  - Main characteristics: good for high-level analysis
- Empirical and Standards-based Models
  - Not accurate; used to assess different designs

Free Space (LOS) Model



- Path loss for unobstructed LOS path
- Power falls off :
  - Proportional to $1/d^2$
  - Proportional to λ^2 (inversely proportional to f^2)
    - This is due to the effective aperture of the antenna

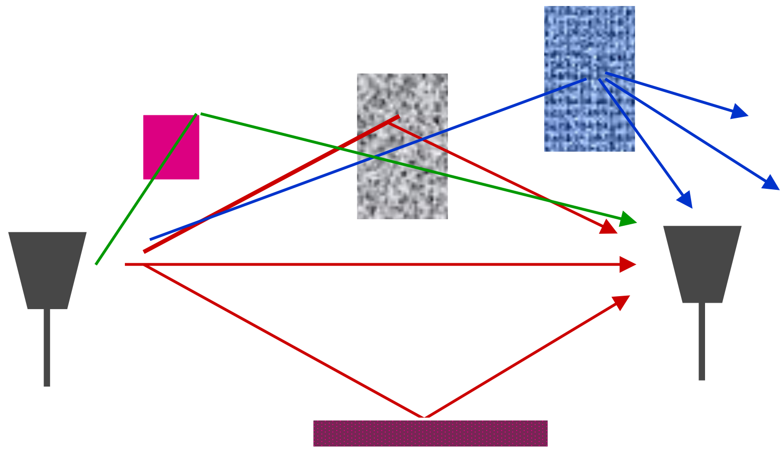
Two Ray Model



- Path loss for one LOS path and 1 ground (or reflected) bounce
- Ground bounce approximately cancels LOS path above critical distance
- Power falls off
  - Proportional to d^2 (small d)
  - Proportional to d^4 ($d>d_c$)
  - Independent of λ (f_c)
    - Two-path cancellation equivalent to 2-element array, i.e. the effective aperature of the receive antenna is changed.

General Ray Tracing

- Models signal components as particles
  - Reflections
  - Scattering
  - Diffraction



Reflections generally dominate

- Requires site geometry and dielectric properties
  - Easier than Maxwell (geometry vs. differential eqns)
- Computer packages often used

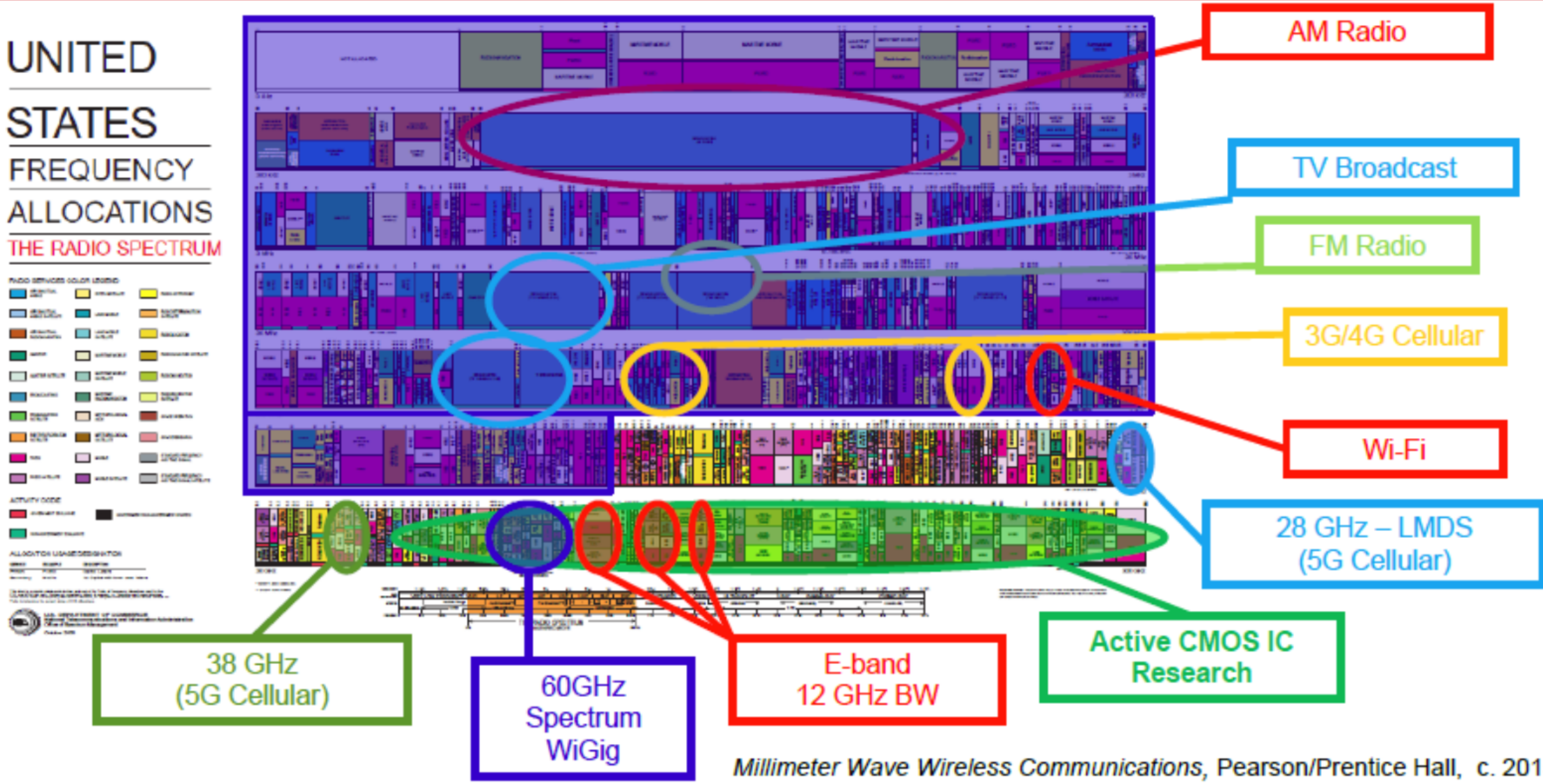
10-ray reflection model explored in HW

Simplified Path Loss Model

- Used when path loss dominated by reflections.
- Most important parameter is the path loss exponent γ, determined empirically.

$$P_r = P_t K \left[\frac{d_0}{d} \right]^{\gamma}, \qquad 2 \le \gamma \le 8$$

mmWave: What's the big deal?



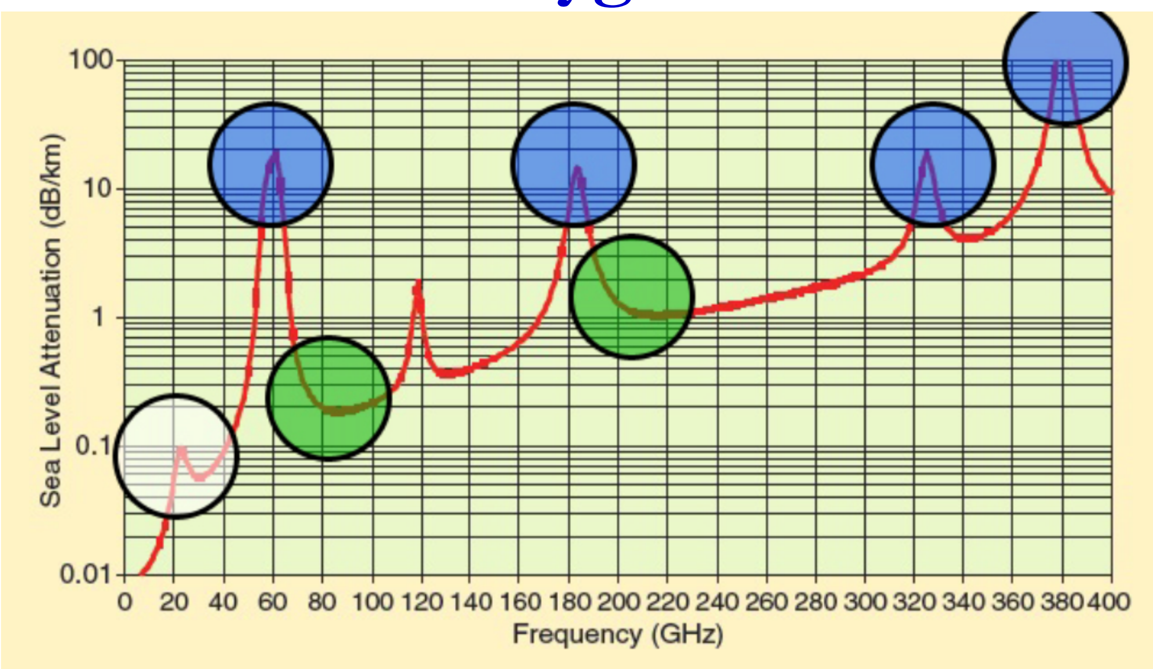
Millimeter Wave Wireless Communications, Pearson/Prentice Hall, c. 2015

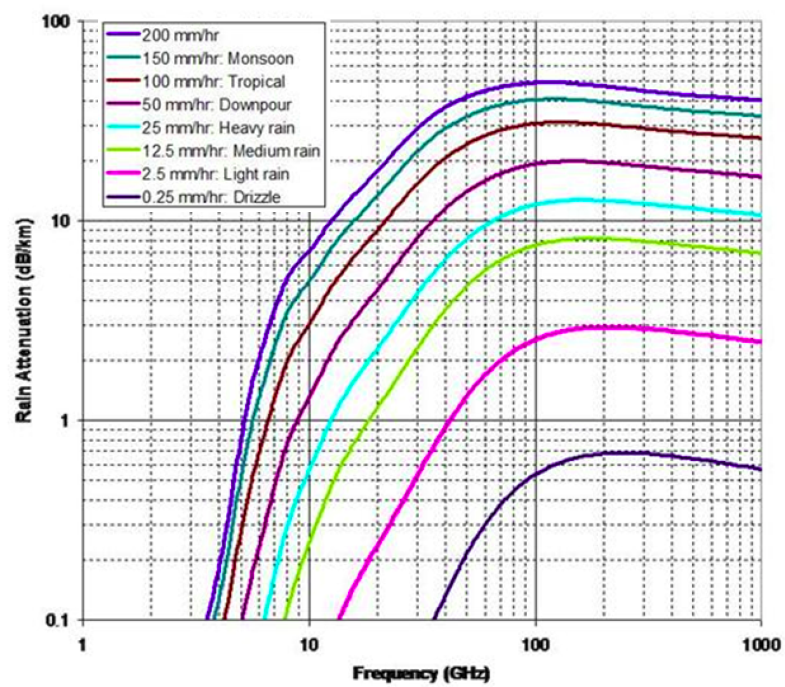
All existing commercial systems fit into a small fraction of the mmWave band

mmWave Propagation (60-100GHz)

mmW Massive MIMO

- Channel models immature
  - Based on measurements, few accurate analytical models
- Path loss proportion to λ^2 (huge)
- Also have oxygen and rain absorbtion





mmWave systems will be short range or require "massive MIMO"

Empirical Channel Models

(not covered in lecture, not on HW/exams)

- **Early cellular empirical models:**
  - **Empirical path loss models for early cellular systems were based on extensive measurements.**
  - **Okumura model: empirically based (site/freq specific), uses graphs**
  - **Hata model: Analytical approximation to Okumura**
  - **Cost 231 Model: extends Hata to higher freq. (2 GHz)**
  - **Multi-slope model**
  - **Walfish/Bertoni: extends Cost 231 to include diffraction**
- **Current cellular models (LTE and 5G):**
  - **Detailed path loss models for UE (3GPP TS 36.101) and base stations (3GPP TS 36.104) for different multipath delay spreads, user speeds and MIMO antenna correlations.**
  - **The 5G model includes higher frequencies (up to 100 GHz).**
- **WiFi channel models: TGn and TGac**
  - **Indoor and outdoor path loss models with MIMO (4x4 & greater), 40 MHz channels (& greater), and different multipath delay spread.**

Commonly used in cellular and WiFi system simulations

Main Points

- Path loss models simplify Maxwell's equations
- Models vary in complexity and accuracy
- Power falloff with distance is proportional to d^2 in free space, d^4 in two path model
- Main characteristics of path loss captured in simple model $P_r=P_tK[d_0/d]^\gamma$
- mmWave propagation models still immature
  - Path loss large due to frequency, rain, and oxygen
- Empirical models used in simulations