EE359 – Lecture 2 Outline

- Announcements
  - 1st HW posted, due next Friday at 4pm.
  - Discussion section and TA OHs starts next week
  - Will finalize makeup lecture schedule today
- Review of Last Lecture
- TX and RX Signal Models
- Path Loss Models
  - Free-space and 2-Ray Models
  - General Ray Tracing
  - Single-Slope Path Loss Exponent Model
  - Empirical Models
  - mmWave Models

1

Makeup lecture options

- Next Thursday
  - Monday (1/13): 11:30-12:50pm w/lunch
  - Tuesday (1/14): 3:00-4:20 or 4:30-5:50pm (+lecture 1:30-2:50)
  - Wednesday (1/15): 9:00-10:20am or 11:30-12:50pm*
  - Regular Time Thu 1:30-2:50pm with Tom giving lecture
  - Friday (1/17): 9:00-10:20am* or 3:30-4:50pm
    - Following Monday is MLK 3-day weekend
- Thu 2/20 moved to Fri 2/21 from 3:30-4:50pm
  - MT week, could do Fri 9am instead
- Tue 2/4 moved to Wed 2/5 11:30-12:50pm w/lunch
- Thu 3/5 moved to Wed 3/4 11:30-12:50pm w/lunch
  - Could do Wed am or Friday 9am or 3:30 instead

Regular time with Tom

*Pending availability

2

Lecture 1 Review

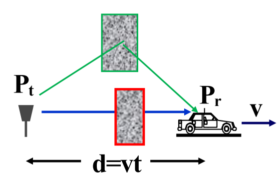
- Course Information
- Wireless Vision
- Technical Challenges
- Current/Next-Gen Wireless Systems
- Spectrum Regulation and Standards
- Emerging Wireless Systems

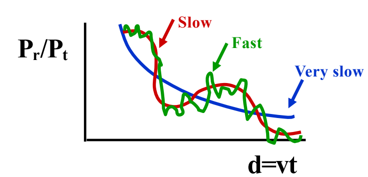
Emerging systems can be covered in a bonus lecture

3

Propagation Characteristics

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





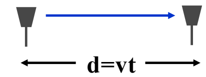
4

Path Loss Modeling

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

5

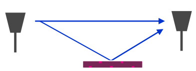
Free Space (LOS) Model



- 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

6

Two Ray Model

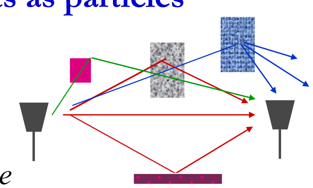


- Path loss for one LOS path and 1 ground (or reflected) bounce
- Ground bounce approximately cancels LOS path above critical distance
- Power falls off
  - Proportional to d^2 (small d)
  - Proportional to d^4 ($d>d_c$)
  - Independent of λ (f_c)
    - Two-path cancellation equivalent to 2-element array,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

7

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

8

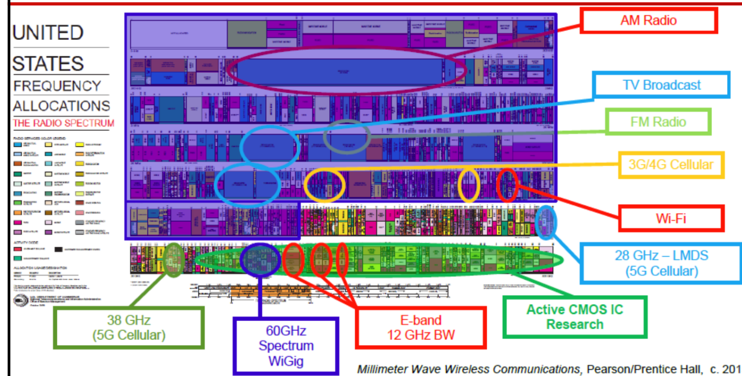
Simplified Path Loss Model

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

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

9

mmWave: What's the big deal?



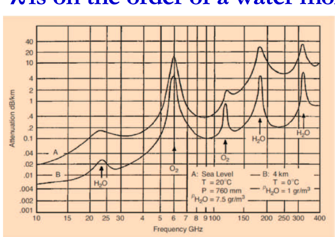
All existing commercial systems fit into a small fraction of the mmWave band

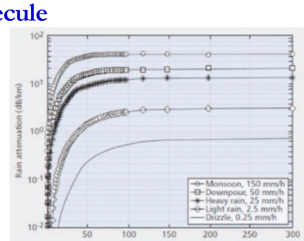
10

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
  - λ is on the order of a water molecule





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

11

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

12

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 single-slope exponent model $P_r=P_tK[d_r/d]^\gamma$
- mmWave propagation models still immature
  - Path loss large due to frequency, rain, and oxygen
- Empirical models used in simulations

13