Department of Electrical Engineering
IIT Hyderabad

EE 6340/3801
Wireless Communications

Channel

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Lecture 3 Outline

- Announcements
  - 1st HW will be posted tonight, due next Monday 23rd, 12 pm.
  - Review of Last Lecture
- Wireless Channel
- TX and RX Signal Models
- Path Loss Models
  - Free-space and 2-Ray Models
  - Simplified Path Loss Model
  - General Ray Tracing
  - Empirical Models
  - mmWave Models

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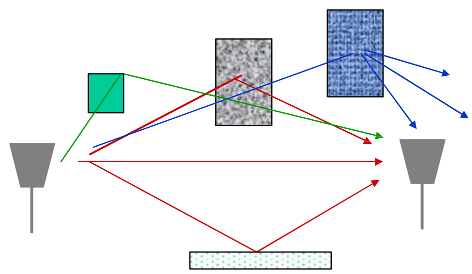
PATHLOSS: RAY-TRACING MODELS

- **Ray-tracing model**
  - Besides LOS, also considers the effects of reflection, diffraction and scattering ➔ considers the effects from each ray



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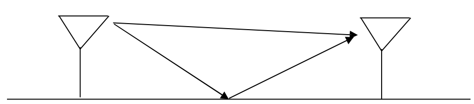
PATH LOSS: RAY TRACING MODEL

- **Example: plane-earth reflection**



Δd :Distance between two paths

Rx signal from LOS: $E_0(t) = A_0 \cos(2\pi ft + \theta)$

Rx signal from reflection: $E_r(t) = \rho A_0 \cos[2\pi f(t + \Delta d / c) + \theta]$
$= \rho A_0 \cos[2\pi ft + \psi + \theta]$

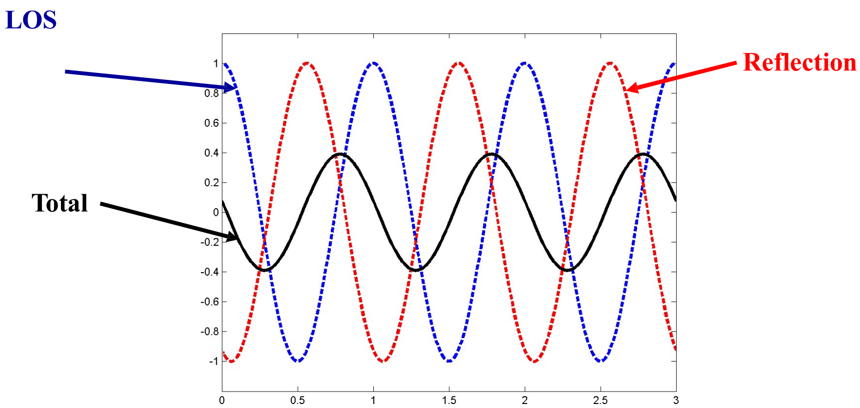
$\psi = 2\pi f \Delta d / c = 2\pi \Delta d / \lambda$: phase difference caused by distance difference

ρ : due to reflection and distance difference

At the receiver: $E_{total}(t) = E_0(t) + E_r(t)$

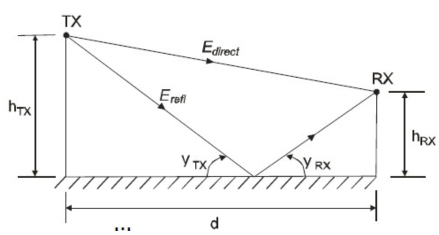
PATH LOSS: RAY TRACING MODEL

- The phase difference between the two rays will result in construction or destruction effects of the Rx signal



Two Ray Model

d^4 Formula



- Path loss for 1 LOS path and 1 ground/reflected path
- Ground path approx. cancels LOS path above critical distance

$$P_{RX}(d) = P_{TX} G_{TX} G_{RX} \left(\frac{\lambda}{4\pi d} \right)^2$$

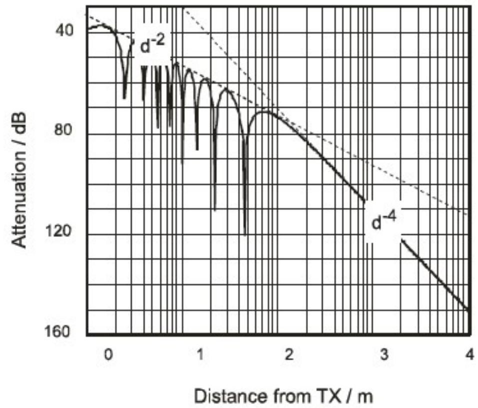
$$P_{RX}(d) \approx P_{TX} G_{TX} G_{RX} \left(\frac{h_{TX} h_{RX}}{d^2} \right)^2$$

$$d_c \approx 4 \frac{h_{TX} h_{RX}}{\lambda}$$

- Power falls off
  - Proportional to d^2 $(d < d_c)$
  - Proportional to d^4 $(d > dc)$
  - Independent of λ (fc)

Simplified Path Loss Model

- Typically exponent varies based on surroundings with $d \in [1.5, 8]$
- Used when path loss dominated by reflections.
- Most important parameter is the path loss exponent γ, determined empirically.



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

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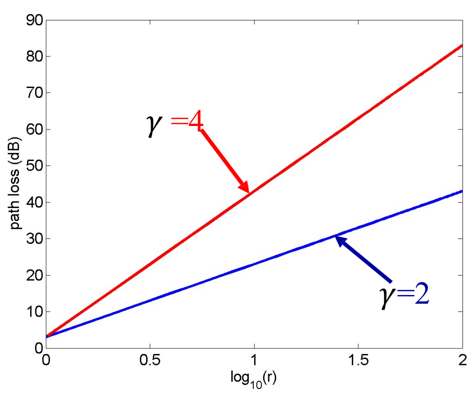
PATH LOSS: GENERAL MODEL

- **Usually represented in the unit of dB**



Fix P_T

$L_p \uparrow \Rightarrow P_R \downarrow$

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PATH LOSS: GENERAL MODEL

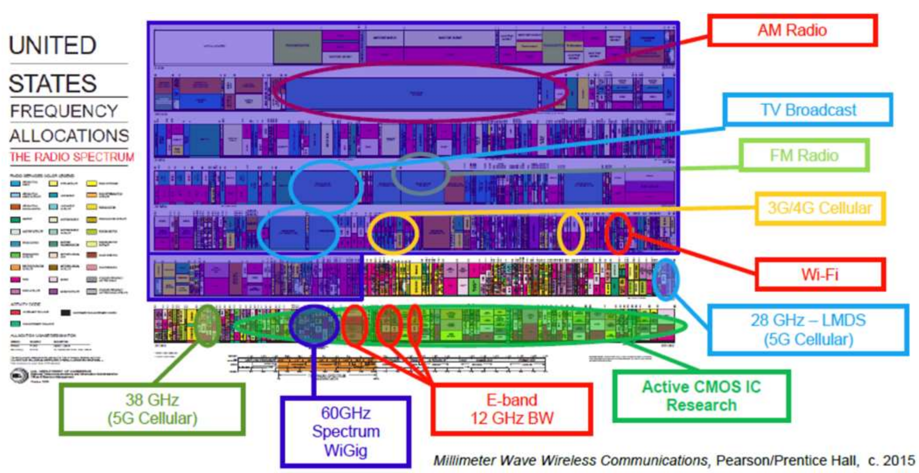
- **Example:**
  - At a distance $r_0 = 10$ meter from Tx, the measured power is $P_T / K = 2mW$. The path loss exponent is γ = 2.9. The appropriate operation of the receiver requires the signal power at receiver must be at lease -90mW. What is the service radius? (using the general/simplified path loss model)

Sol.

$$P_R(dBm) = 10\log_{10}\frac{P_R(mW)}{1(mW)} => P_R(mW) = 10^{P_R(dBm)/10} = 10^{-9}(mW)$$

$$r = r_0 \sqrt[n]{\frac{(P_T/\beta_0)}{P_R}} = 10 \sqrt[2.9]{\frac{2mW}{10^{-9}\,mW}} = 16.1km$$

mmWave: What’s the big deal?



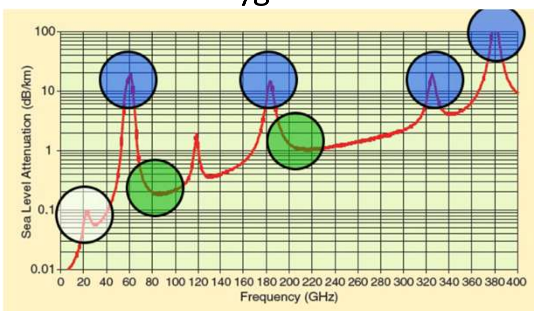
Millimeter Wave Wireless Communications, Pearson/Prentice Hall, c. 2015

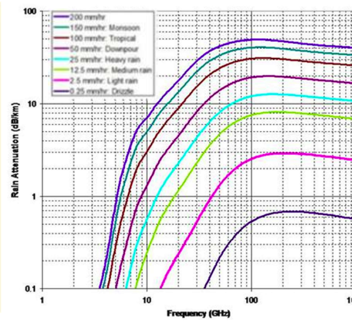
All existing commercial systems fit into a small fraction of the mmWave band

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 are short range or require “massive MIMO”

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OUTLINE

- **Wireless channel**
- **Path loss**
- **Shadowing**
- **Small scale fading**
- **Channel classifications**
- **Noise and interference**
- **Simulation model**

SHADOWING

- **Shadowing:**
  - Caused by large obstructions that are distant from MS
  - Analogy: the shadow of light due to mountain.
  - Effects of shadowing is random due to random # and type of obstructions.
  - The existence of shadowing is verified through field measurement.
- **Consider the effects of path loss and shadowing**

$$\underbrace{P_R = P_T \times \frac{1}{K}\left(\frac{d_0}{d}\right)^{\gamma}}_{\text{path loss}} \times \underbrace{S}_{\text{shadowing}}$$

S : models the effects of shadowing. Random variable.

SHADOWING

- **dB representation**

$$\boxed{10\log_{10} P_R = 10\log_{10}\frac{P_T}{\beta_0} + n \times 10\log_{10}\left(\frac{r_0}{r}\right) + 10\log_{10} S}$$

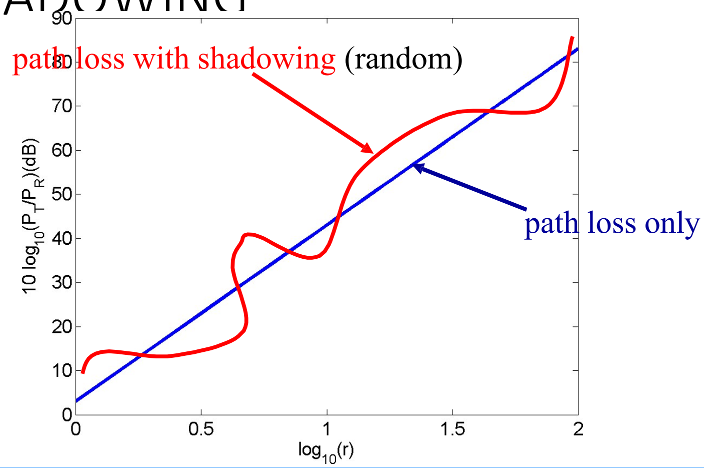
- $S(dB) = 10\log_{10} S$ **: follows Gaussian distribution (normal distribution)**

$$f_{S(dB)}(x) = \frac{1}{\sqrt{2\pi}\sigma_{dB}} \exp\left(-\frac{(x-m_{dB})^2}{2\sigma_{dB}^2}\right)$$

S(dB) follows normal distribution ➔ the log of S follows normal distribution
➔ The distribution of S is called lognormal distribution

Shadowing is called lognormal shadowing

SHADOWING



combined effects of path loss and shadowing (red curve)