

# Signal Propagation. Path Loss Models.

## Lecture Outline

- Overview of Signal Propagation
- Free Space Path Loss Model
- Ray Tracing Path Loss Models
- Simplified Path Loss Model
- Empirical Path Loss Models

### 1. Signal Propagation Characteristics:

- Path loss: power falloff relative to distance
- Shadowing: random fluctuations due to obstructions
- Flat and frequency selective fading: caused by multipath

### 2. Transmitted and received signals:

- **Transmitted Signal:**, with power  $P_t$ , is  $s(t) = \Re\{u(t)e^{j(2\pi f_c t)}\} = s_I(t) \cos(2\pi f_c t + \phi_0) - s_Q(t) \sin(2\pi f_c t + \phi_0)$ , where  $u(t) = s_I(t) + js_Q(t)$  is the complex baseband signal with bandwidth  $B$ ,  $f_c$  is the carrier frequency, and  $\phi_0$  is the initial phase. For simplicity we assume  $u(t)$  real for propagation model analysis.
- **Received signal:**  $r(t) = \Re\{v(t)e^{j(2\pi f_c t)}\}$ , where  $v(t) = u(t)*c(t)$  for  $c(t)$  the baseband channel model.
- Doppler frequency shift  $f_D = (v/\lambda) \cos(\theta)$  may also be introduced in the received signal

### 3. Free space path loss model:

- Typically used for unobstructed LOS signal path.
- Received signal is

$$r(t) = \Re\left\{\frac{u(t)\sqrt{G_l}\lambda e^{j2\pi d/\lambda}}{4\pi d} e^{j(2\pi f_c t + \phi_0)}\right\}$$

with received power

$$P_r = P_t \left[ \frac{\sqrt{G_l}\lambda}{4\pi d} \right]^2.$$

- Power falls off proportional to the ratio of wavelength over distance squared. The inverse frequency dependence is due to the effective aperture of the receiver.
- Power falls off proportional to net antenna gain  $G_l$ .
- *Model not accurate for general environments.*

#### 4. Ray tracing approximation:

- Represent wavefronts as simple particles.
- Simplest models only determine reflections.
- Scattering and defraction can also be included.

#### 5. Two path model:

- One LOS path, one reflected path.
- At small distances, power falls off proportional to  $d^2$  (free space loss on both paths).
- Above some critical distance  $d_c$ , received power given by

$$P_r \approx P_t \left[ \frac{\sqrt{G_l} h_t h_r}{d^2} \right]^2.$$

- Above  $d_c$ , power falls off proportional to  $d^4$  and is independent of signal wavelength (frequency)
- *Model not generally accurate for cities or indoors.*

#### 6. General Ray Tracing:

- Incorporates all signal components: reflections, scattering, and diffraction.
- Reflected rays have power falloff proportional to  $d^2$  by free space path loss model. Scattered and refracted rays have power falloff that depends on exact distance of scattering or refractive object from transmitter and receiver.
- If objects are more than a few wavelengths from receiver, typically neglect scattering and refraction.
- Most computer packages for channel simulation in indoor/outdoor environments use general ray tracing for path loss.
- *Model requires detailed site information.*

#### 7. Simplified path loss model:

- Capture main characteristics of ray tracing using simplified model  $P_r = P_t K \left[ \frac{d_0}{d} \right]^\gamma$ , where  $K$  is a constant factor ( $P_r(d_0)/P_t$ ),  $d_0$  is a reference distance, and  $\gamma$  is the path loss exponent.
- Path loss exponent is function of carrier frequency, environment, obstructions, etc. Typically ranges from 2 to 8 (at around 1 GHz).
- *Model captures main characteristics of ray tracing: good for high-level analysis.*

#### 8. Empirical Models:

- Irregular terrain, like in cities, doesn't lend itself to simple analytical path loss models.
- Empirical path loss models based on extensive measurements.
- Local mean attenuation: empirical measurements of local received power.
- Okumura Model: Empirical model for irregular terrain.

- Hata Model: Analytical approximation to Okumura model.
- Cost 231 Extension to Hata Model: Extends Hata model to 2 GHz and to lower mobile antenna heights. Widely used in 2G simulations.
- Piecewise linear models capture multiple slopes associated with path loss.
- *Models not accurate and don't generalize well to other environments.*

## Main Points

- Path loss models simplify Maxwell's equations. The models vary in complexity and accuracy.
- Power falloff with distance is proportional to  $d^2$  in free space model,  $d^4$  in two path model.
- General ray tracing requires detailed site specific information. Typically generated with computer packages.
- Main characteristics of ray tracing models captured in simplified path loss model.
- Empirical models widely used to study cellular system performance via simulation. Typically awkward for analysis.