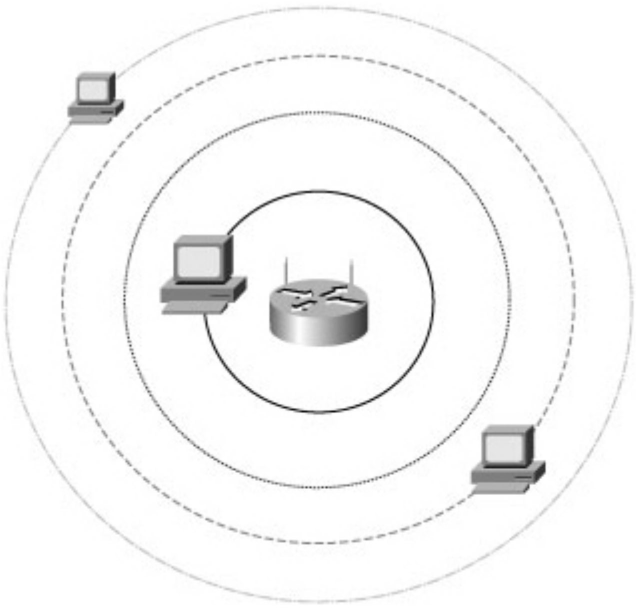
Lecture 2 Outline

- Signal Propagation Overview
- TX and RX Signal Models
  - Complex baseband models
- Path Loss Models
  - Free-space Path Loss
  - Ray Tracing Models
  - Simplified Path Loss Model
  - Empirical Models
- Log Normal Shadowing
- Combined Path Loss and Shadowing
- Model Parameters from Measurements

Pass Loss

- Pass loss: degradation of receive power with respect to the increasing transmitter-receiver distance

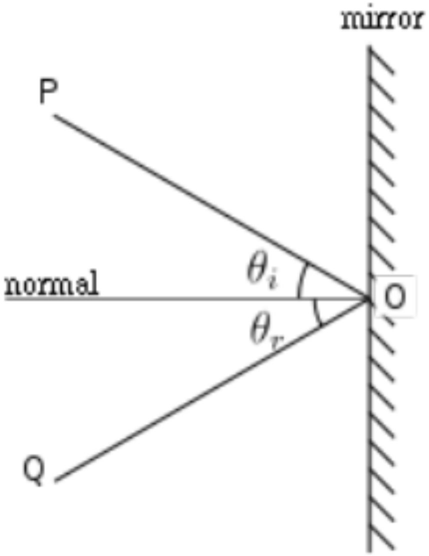


EM wave encounters an obstacle

- Reflection
- Diffraction
- Scattering
- Absorption

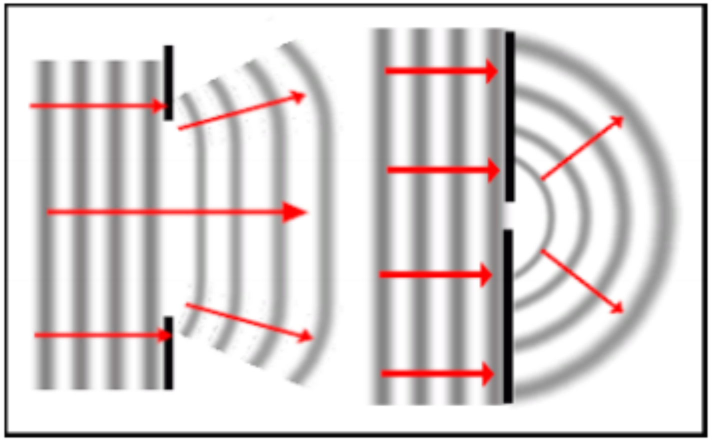
Reflection

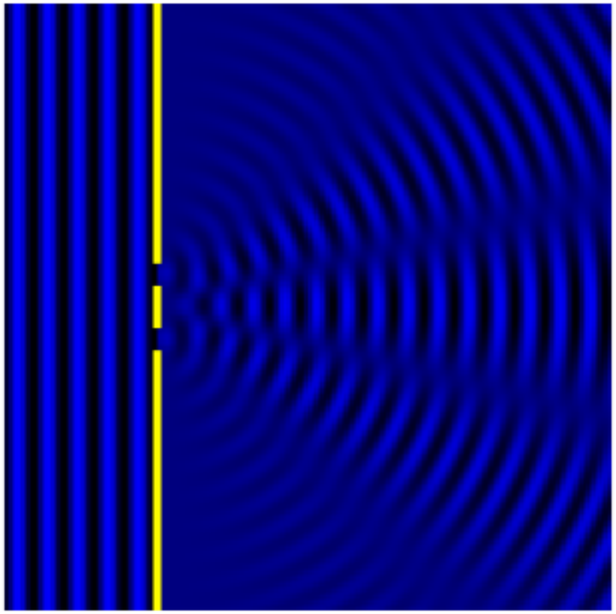
- Wave hits an object with dimension much larger than the radio wavelength will be partially reflected off the surface of the object



Diffraction

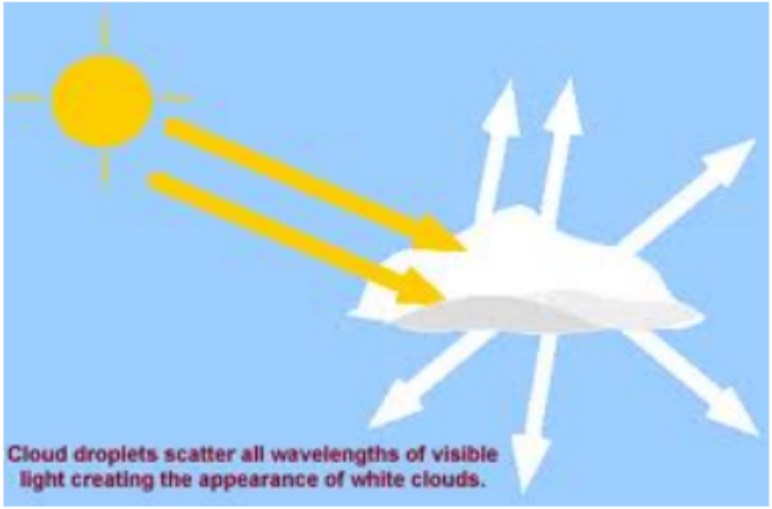
- Apparent bending of waves around small obstacles and the spreading out of waves past small openings

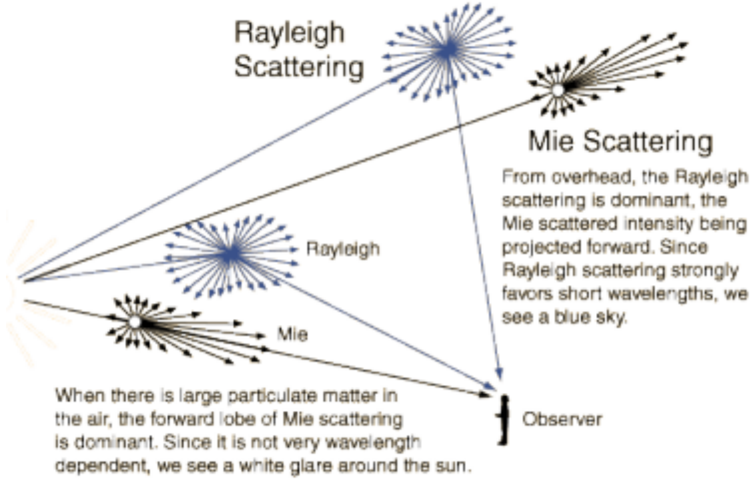




Scattering

- EM wave scattered by particles that are much smaller in diameter than the wavelength



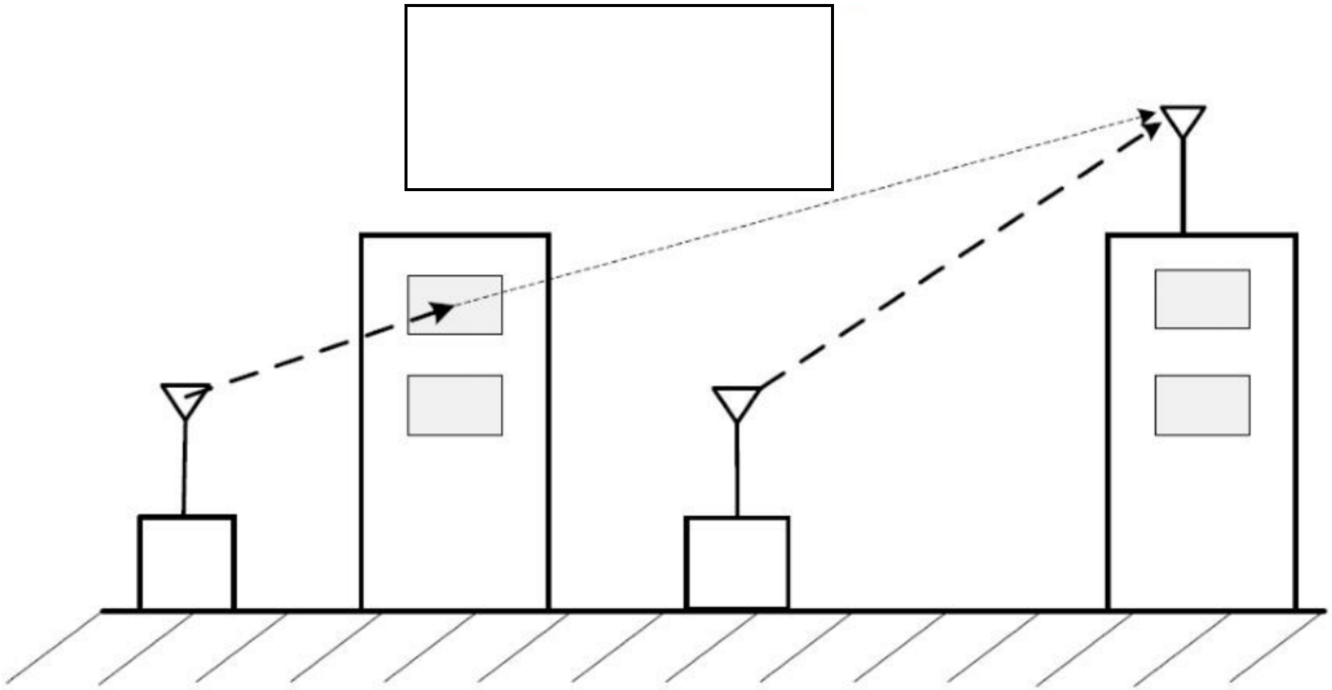


Absorption

- The absorption of EM wave is often called attenuation
- The energy of EM wave is taken up by some matter and transformed to other forms of energy, e.g., heat

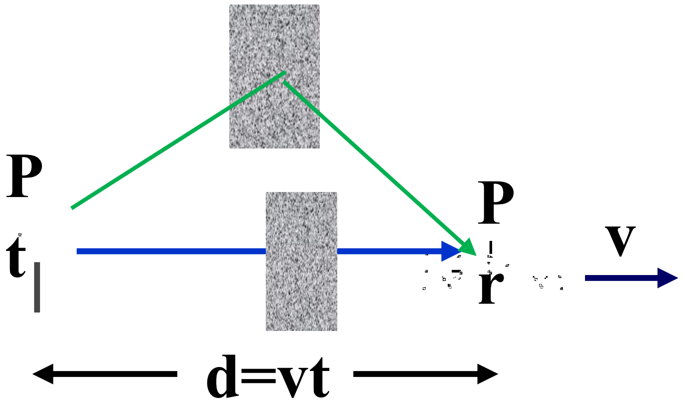
Shadowing

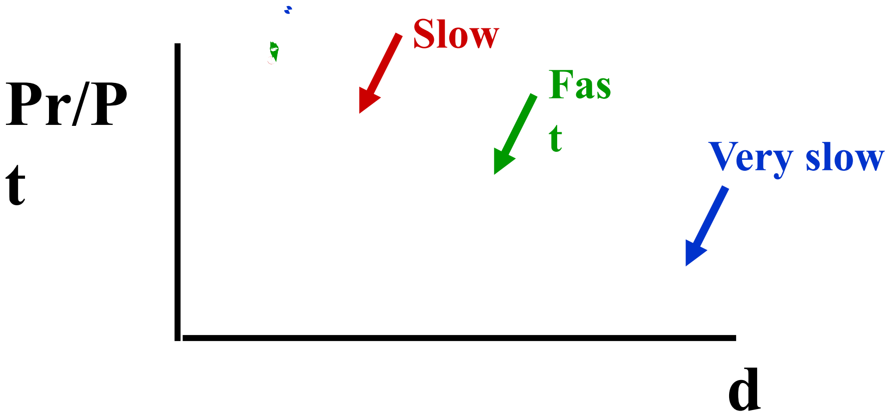
- Shadowing: variation of receive signal power due to obstacles



Propagation Characteristics

- Path Loss (includes average shadowing)
- Shadowing (due to obstructions)
- Multipath Fading -- small-scale propagation effect





Path Loss Modeling

- Maxwell's equations
  - Complex and impractical
- Free space path loss model
  - Too simple
- Ray tracing models
  - Requires site-specific information
- Simplified power falloff models
  - Main characteristics: good for high-level analysis
- Empirical Models
  - Don't always generalize to other environments

Representation of Bandpass Signals

- **Bandpass signal:**

$$s(t) = s_I(t)\cos(2\pi f_c t) - s_Q(t)\sin(2\pi f_c t)$$

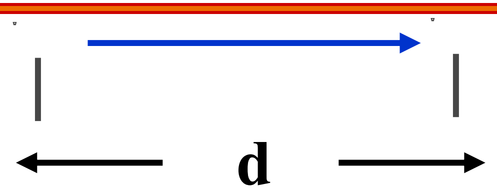
  - **sI(t) is in-phase component, sQ(t) is quadrature component**

- **Define a complex signal:** $u(t) = s_I(t) + js_Q(t)$

$$s(t) = \mathrm{Re}\{u(t)\}\cos(2\pi f_c t) - \mathrm{Im}\{u(t)\}\sin(2\pi f_c t) = \mathrm{Re}\{u(t)e^{j2\pi f_c t}\}$$

- **u(t) is called equivalent lowpass signal for s(t)**

Free Space (LOS) Model



- Path loss and path gain:
  - Path loss:

$$P_L = \quad P_L\, dB = 10\,l$$

  - Path gain:

$$P_G = \quad P_G\, dB = -P_L\, dB =$$

- Power falls off:

$$s(t) = \mathrm{Re}\{u(t)e^{j2\pi f_c t}\} \qquad r(t) = \mathrm{Re}\left\{\frac{\lambda\sqrt{G_l}e^{-j2\pi d/\lambda}}{4\pi d}u(t)e^{j2\pi f_c t}\right\}$$

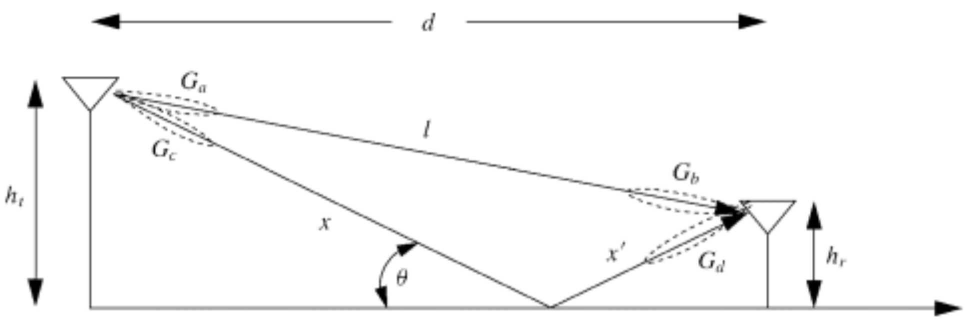
$$\frac{P_r}{P_t} = \left[\frac{\sqrt{G_l}\lambda}{4\pi d}\right]^2$$

  - Gl is the product of tx and rx antenna field radiation pattern in the LOS direction
  - Proportional to 1/d2,l2

Ray Tracing Approximation

- Rx contains multipath signal components
- Ray tracing:
  - Assume a finite number of reflectors with known location and dielectric property
  - Then, the received signal from each signal component can be calculated
  - Typically includes reflected rays, can also include scattered and diffracted rays.
- Accurate for rural area, city street and indoor environment

Two Path Model



- Path loss for one LOS path and one ground (or reflected) bounce
- Delay spread: (x+x'-l)/c

$$P_r = P_t\left[\frac{\lambda}{4\pi}\right]^2\left|\frac{\sqrt{G_l}}{l}+\frac{R\sqrt{G_r}e^{-j\Delta\phi}}{x+x'}\right|^2, \qquad \Delta\phi=\frac{2\pi(x+x'-l)}{\lambda}\approx\frac{4\pi h_t h_r}{\lambda d}$$

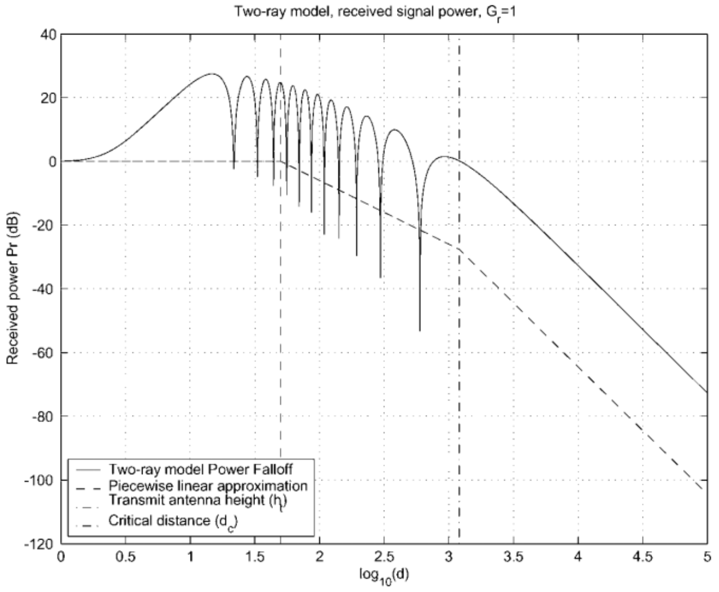
$$P_r \approx \left[\frac{\lambda\sqrt{G_l}}{4\pi d}\right]^2\left[\frac{4\pi h_t h_r}{\lambda d}\right]^2 P_t = \left[\frac{\sqrt{G_l}h_t h_r}{d^2}\right]^2 P_t$$

Two Path Model

- Ground bounce approximately cancels LOS path above critical distance

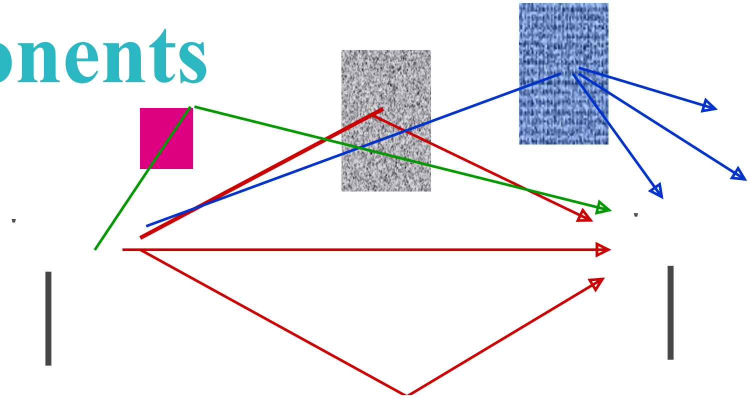
$$P_r \approx \left[\frac{\sqrt{G_l}h_t h_r}{d^2}\right]^2 P_t$$

- Power falls off
  - Proportional to d2 (small d
  - Proportional to d4 (d>dc)
  - Independent of l (f)



General Ray Tracing

- Models all signal components
  - Reflections
  - Scattering
  - Diffraction



- Requires detailed geometry and dielectric properties of site
  - Similar to Maxwell, but easier math.
- Computer packages often used

Simplified Path Loss Model

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

$$P_r = P_t K \left[\frac{d_0}{}\right]^{\gamma}$$

where $K \text{ dB} = 20 \log_{10} \frac{\lambda}{4\pi d_0}$, is achieved from free-space model

Indoor Propagation Model

- Indoor model differ widely in the materials used for walls and floors, the layout of rooms, windows and obstructing objects
- Difficult to find generic models

$$P_r \text{ dBm} = P_t \text{ dBm} - P_L(d) - \sum_{i=1}^{N_f} \text{FAF}_i - \sum_{i=1}^{N_p} \text{PAF}_i$$

FAF: floor attenuation factor (8-20dB)

PAF: partition attenuation factor

Table 2.1: Typical partition losses

Partition type	Partition loss (dB)
Cloth partition	1.4
Double plasterboard wall	3.4
Foil insulation	3.9
Concrete wall	13
Aluminum siding	20.4
All metal	26

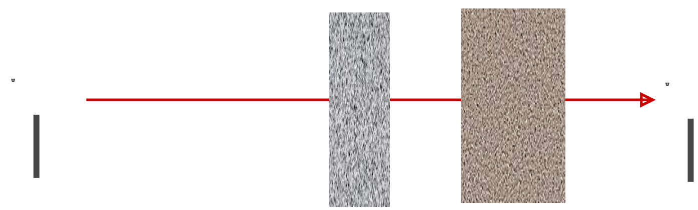
Empirical Channel Models

- Cellular Models: Okumura model and extensions:
  - Empirically based (site/freq specific)
  - Awkward (uses graphs)
  - Hata model: Analytical approximation to Okumura
  - Cost 231 Model: extends Hata to higher freq. (2 GHz)
  - Walfish/Bertoni: extends Cost 231 to include diffraction

- WiFi channel models: TGn
  - Empirical model for 802.11n developed within the IEEE standards committee. Free space loss up to a breakpoint, then slope of 3.5. Breakpoint is empirically-based.

Commonly used in cellular and WiFi system simulations

Shadowing



- **Models attenuation from obstructions**
- **Random due to random # and type of obstructions**

$$p(\psi_{\mathrm{dB}}) = \frac{1}{\sqrt{2\pi}\sigma_{\psi_{\mathrm{dB}}}} \exp\left[-\frac{(\psi_{\mathrm{dB}} - \mu_{\psi_{\mathrm{dB}}})^2}{2\sigma^2_{\psi_{\mathrm{dB}}}}\right]$$

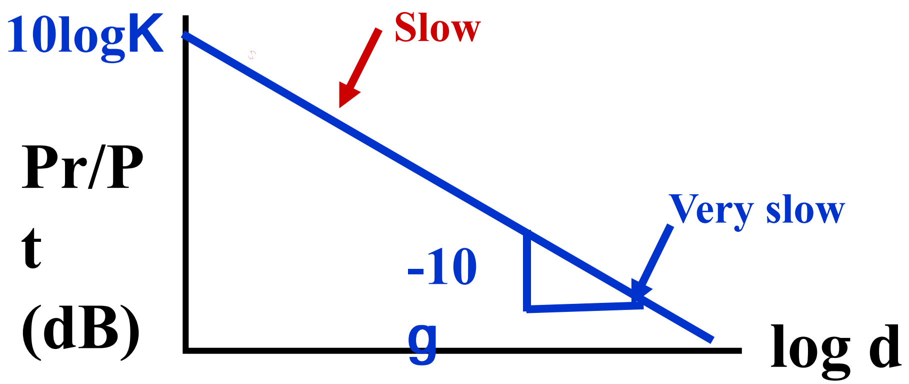
$$p(\psi) = \frac{\xi}{\sqrt{2\pi}\sigma_{\psi_{\mathrm{dB}}}\psi} \exp\left[-\frac{(10\log_{10}\psi - \mu_{\psi_{\mathrm{dB}}})^2}{2\sigma^2_{\psi_{\mathrm{dB}}}}\right], \quad \psi > 0,$$

- **Typically follows a log-normal distribution**
  - **dB value of power is normally distributed**
  - **m=0 (mean captured in path loss), 4 dB<s<13 dB (empirical)**
  - **Central limit theorem can be used to explain this model**

Combined Path Loss and Shadowing

- **Linear Model: *y* lognormal**

$$\frac{P_r}{} = K \Big/ \Big(\ldots$$



- **dB Model**

$$\frac{P_r}{P_t}(dB) = 10\log_{10} K - 1\ldots$$

Outage Probability

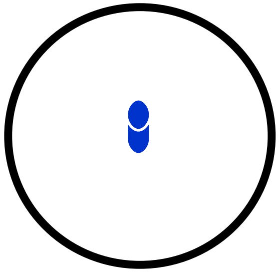
- Path loss: circular cells
- Path loss + shadowing: amoeba cells
  - Tradeoff between coverage and interference
- Outage probability
  - Probability received power below given minimum

$$P_{\text{out}}(P_{\min}, d) = p(P_r(d) < P_{\min})$$

$$p(P_r(d) \leq P_{\min}) = 1 - Q\left(\frac{P_{\min} - (P_t + 10\log_{10} K - 10\gamma \log_{10}(d/d_0))}{\sigma_{\psi_{\text{dB}}}}\right)$$

$$Q(z) \triangleq p(X > z) = \int_z^\infty \frac{1}{\sqrt{2\pi}} e^{-y^2/2}\, dy.$$

Cell Coverage Area



- Cell coverage area
  - % of cell locations at desired power
  - Increases as shadowing variance decreases
  - Large % indicates interference to other cells

Main Points

- Path loss models simplify Maxwell’s equations
- Models vary in complexity and accuracy
- Power falloff with distance is proportional to d2 in free space, d4 in two path model
- Main characteristics of path loss captured in simple model Pr=PtK[d0/d]g
- Empirical models used in simulations
  - Low accuracy (15-20 dB std)
  - Capture phenomena missing from formulas
  - Can be awkward to use in analysis

Main Points

- Random attenuation due to shadowing modeled as log-normal (empirical parameters)
- Combined path loss and shadowing leads to outage and amoeba-like cell shapes
- Cellular coverage area dictates the percentage of locations within a cell that are not in outage

Assignment

- Read Chapter 2
- Homework: 2-2, 2-13, 2-17, 2-19