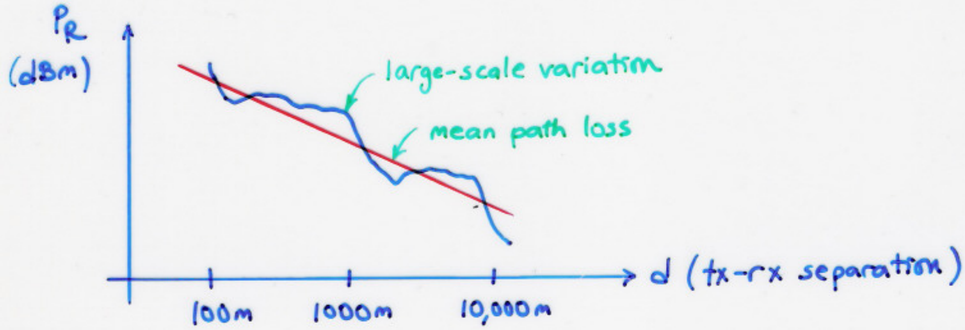
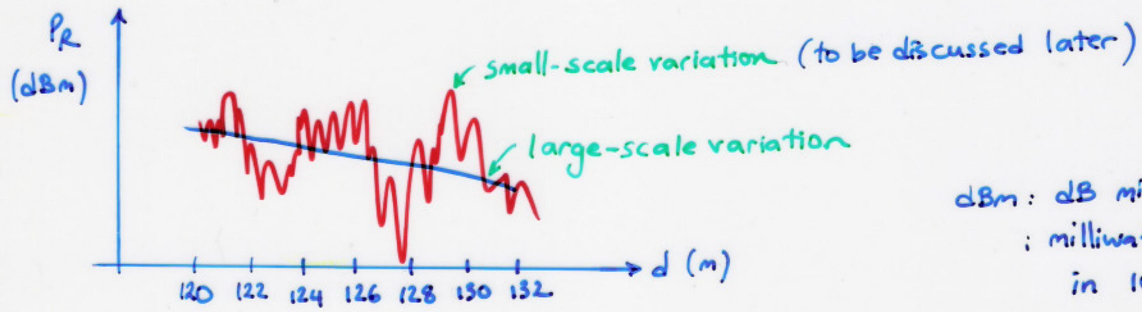
MOBILE RADIO PROPAGATION

Large-Scale Path Loss

* Free-space propagation: discussed ✓
* Terrestrial propagation: mean path loss + large-scale variation → shadowing
  + small-scale variation → multipath fading



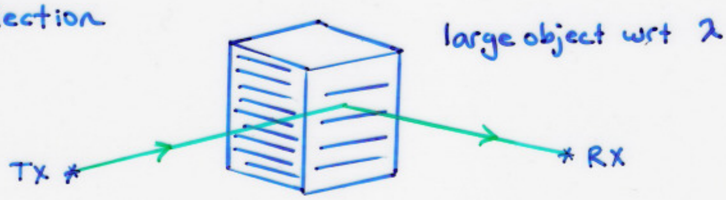


dBm: dB milliwatts
: milliwatts represented in $10\log_{10}()$ scale.

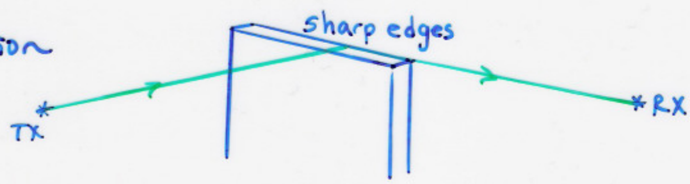
−13 dBm = 50 μW
0 dBm = 1 mW
20 dBm = 100 mW

Basic Propagation Mechanisms

1) Reflection

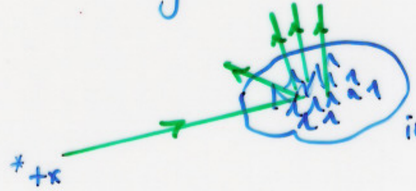


2) Diffraction



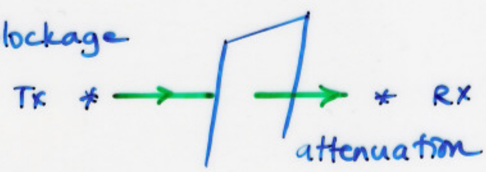
bending of waves around sharp edges

3) Scattering



mobile propagation environment: complex combination of reflection, diffraction, scattering, and blockage phenomena

4) Blockage



Free space propagation exponent:

$$P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi)^2 d^2}$$ (Note: notation changed: $d \leftarrow R$)

$$P_R\Big|_{d=d_0} = P_R(d_0) = \frac{P_T G_T G_R \lambda^2}{(4\pi)^2 d_0^2} \rightarrow P_R(d) = P_R(d_0) \times \left(\frac{d_0}{d}\right)^2$$

↳ seperates the "near-field" and the "far-field"

$P_R \propto \frac{1}{d^2}$ (amplitude [voltage] $\propto \frac{1}{d}$)

* How about mobile communications?

Found experimentally that $P_R \propto \frac{1}{d^n}$ propagation exponent

$2 < n < 6$, with $n=4$ is a typical value.

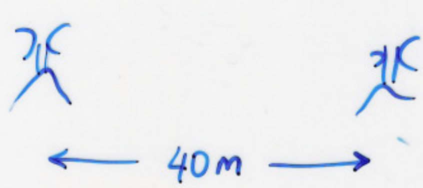
$$\bar{P}_R(d) = P_R(d_0)\left(\frac{d_0}{d}\right)^n$$

↳ an approximate "emprical" formula

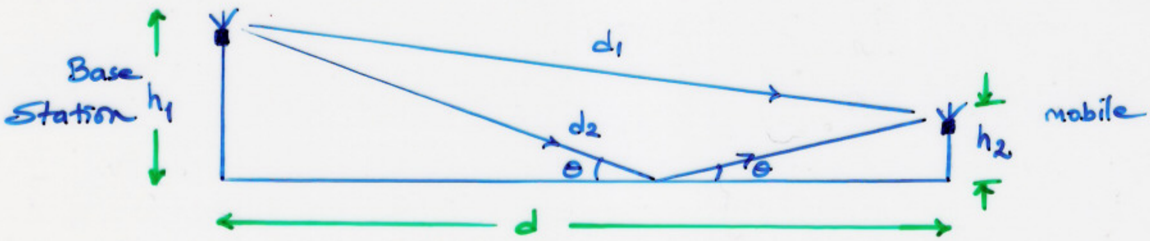
Some Insight

* LOS links: no reflection → almost like free space propagation

$P_R \propto \frac{1}{d^2}$



* Two-path model (Sousa's derivation)



$$P_R = P_o \left(\frac{\lambda}{4\pi d}\right)^2 \left|1 + a e^{j\Delta\phi}\right|^2$$

$P_o \rightarrow P_T G_T G_R$

$a \rightarrow$ reflecting coefficient of ground

$$\Delta\phi = \beta \,\Delta d = \frac{2\pi}{\lambda}\Delta d$$

$$d_1 = \sqrt{(h_1 - h_2)^2 + d^2}$$

$$d_2 = \sqrt{(h_1 + h_2)^2 + d^2}$$

$$\Delta d = d_2 - d_1 = d\left(\sqrt{1 + \left(\frac{h_1 + h_2}{d}\right)^2} - \sqrt{1 + \left(\frac{h_1 - h_2}{d}\right)^2}\right)$$

Binomial expansion:

$$(1+x)^n = 1 + nx + \frac{n(n-1)}{2!}x^2 + \cdots, \quad |nx| < 1$$

$$\frac{1}{2}\left(\frac{h_1 + h_2}{d}\right)^2 < 1 \quad \text{and} \quad \frac{1}{2}\left(\frac{h_1 - h_2}{d}\right)^2 < 1$$

$$\rightarrow \Delta d = d\left(\left[1 + \frac{(h_1 + h_2)^2}{2d^2} + \cdots\right] - \left[1 + \frac{(h_1 - h_2)^2}{2d^2} + \cdots\right]\right)$$

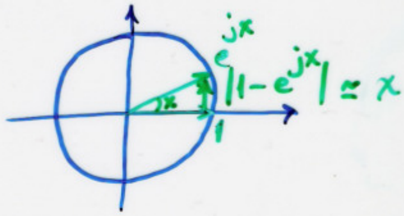
omit higher-order terms since $\frac{h_1 + h_2}{d} \ll 1$

$$\Delta d \cong \frac{2h_1 h_2}{d}$$

assume $a = -1$ (perfect reflection)

$$P_r = P_o \left(\frac{\lambda}{4\pi d}\right)^2 \left|1 - e^{j\Delta\phi}\right|^2 \cong P_o \left(\frac{\lambda}{4\pi d}\right)^2 (\Delta\phi)^2 , \quad \text{for } \Delta\phi \ll 1$$

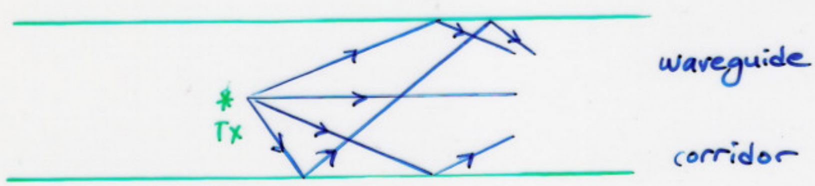
$$\Delta\phi = \frac{2\pi}{\lambda}\Delta d = \frac{4\pi h_1 h_2}{\lambda d}$$



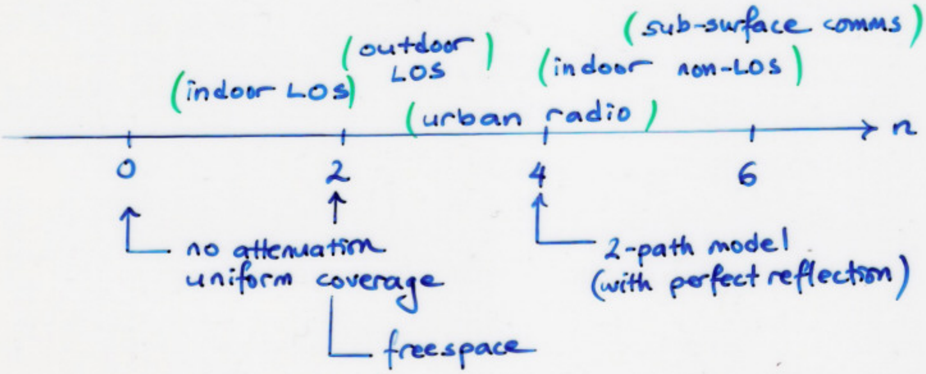
$$\therefore P_r = P_o \left(\frac{h_1 h_2}{d^2}\right)^2$$

$$\rightarrow P_r \propto \frac{1}{d^4} \quad (n=4)$$

* Can n be less than 2 ? Yes $(n > 0)$



n: path loss exponent
propagation exponent



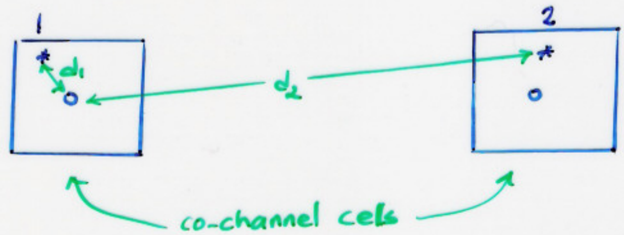
Note that $P_r \propto \frac{1}{d^n}$, so $n \uparrow \Rightarrow P_r \downarrow$

outdoor mobile communications: $n=4$ value is often used in simulations

In reality, n depends on many factors including operating frequency

* Small "n" or large "n" is desirable ?

(i) Capacity-limited systems (assume # cells is given & fixed)



reverse-link SIR (signal-to-interference ratio) for user 1 : $SIR_1 \triangleq \frac{P_{R_1}}{P_{R_2} + \underbrace{N_0 W}_{\text{negligible wrt } P_{R_2}}}$

$P_{R_1} = \frac{P_0}{(d_1)^n}$, $P_{R_2} = \frac{P_0}{(d_2)^n}$ $\rightarrow SIR_1 = \left(\frac{d_2}{d_1}\right)^n$

Since $d_2 > d_1$, $n \uparrow \Rightarrow SIR \uparrow$

$\therefore$ cluster size can be decreased $\rightarrow$ Cap $\uparrow$

(ii) Coverage-limited systems

capacity is not an issue, large area with not too many users

$$SINR = \frac{P_{R_1}}{N_0 W + P_{R_2}} \approx \frac{P_{R_1}}{N_0 W} \propto \frac{1}{d^n}$$

dominated by background noise ($N_0 W \gg P_{R_2}$)

$\rightarrow$ small n desired.