Reading: Radio Propagation Model

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Mandatory Reading

- Mandatory reading
  - 4.2.1
  - 4.2.2
  - 4.2.3
  - 4.2.4

  - 4.4.1
  - 4.4.2
  - 4.4.3.7
    - Several models

4.2.3 Free-Space Loss

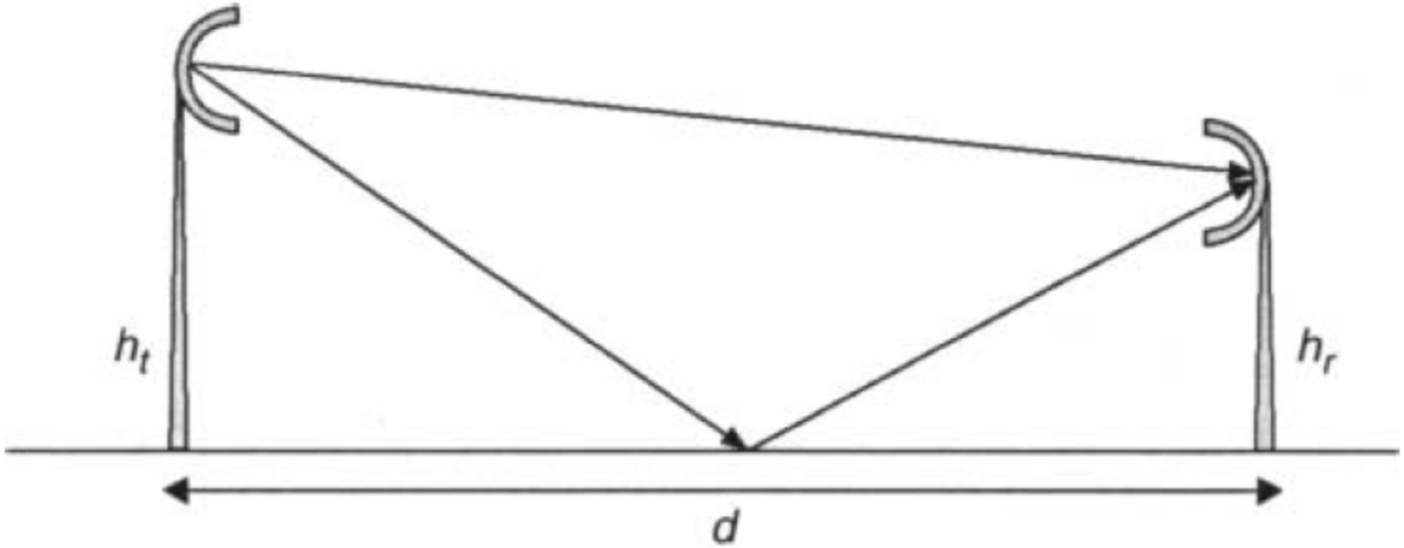
$$l_{\text{free}} = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2$$

$$L_{\text{free}}(\text{dB}) = 32.45 + 20\log f(\text{MHz}) + 20\log d(\text{Km})$$

$$P_r(d) = [P_t G_t G_r \lambda^2] / [(4\pi)^2 d^2]$$

- EIRP (effective isotropic radiated power)
  - PtGt
- ERP

4.2.4 Reflection



$$\frac{P_r}{P_t} = G_t G_r \left(\frac{h_t h_r}{d^2} \right)^2$$

4.4.2 Link Budget Analysis

Figure 4-9: The Satellite Link Can Be Characterized by *EIRP* and *G*

For example, consider a downlink satellite link as in Figure 4-9.

$$P_r[\text{dB}] = P_t + G_t + G_r - Losses = EIRP_{satellite} + G_{r\,earth} - Losses \quad (27)$$

The noise at the receiver is taken to be

$$N = \text{k}T_e B \quad (28)$$

where k is Boltzmann's constant (1.38×10^{-23} Joules/Kelvin), B is the noise bandwidth in Hz, and T_e is the equivalent receiver noise temperature in °K. Alternatively, noise power per Hz is defined as

$$N_0 = \text{k}T_e \quad (29)$$

Now, the expression for the received signal power per noise power per Hz can be written as

$$(P_r / N_0)_{\text{dB}} = EIRP_{satellite} + (G_{r\,earth} / T_e)_{\text{dB}} - Losses + 10\log \text{k} \quad (30)$$

4.4.3.7 Statistical fading models

4.4.3.7 log-distance path-loss model

$$\overline{PL}(d) \propto \left(\frac{d}{d_0}\right)^n$$

$$\overline{PL}(d)[dB] = \overline{PL}(d_0) + 10n\log_{10} \frac{d}{d_0}$$

4.4.3.7.2 Log-normal shadowing

$$PL(d)[dB] = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10n\log_{10}\frac{d}{d_0} + X_\sigma$$

Egli Model

$$L_{50} = G_t G_r \left[\frac{h_t h_r}{d^2} \right]^2 \beta$$

Okumura Model

The median attenuation equation is represented as

$$L_{50}(dB) = L_F + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA}$$

$$G(h_{te}) = 20\log_{10}\left(\frac{h_{te}}{200}\right) \quad 30\,\mathrm{m} < h_{te} < 100\,\mathrm{m}$$

$$G(h_{re}) = \begin{cases} 10\log_{10}\left(\frac{h_{re}}{3}\right) & h_{re} < 3\,\mathrm{m} \\ 20\log_{10}\left(\frac{h_{re}}{3}\right) & 3\,\mathrm{m} < h_{re} < 10\,\mathrm{m} \end{cases}$$

Hata model

$$L_{50,urban} = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(f_c)$$
$$-13.82\log_{10}(h_{te}) - a(h_{re}) + 44.9 - 6.55\log_{10}(h_{te}) + 10\log_{10}(d)$$

Hata provides mobile antenna correction factors in dB for small and medium cities as [Hat90]

$$a(h_{re}) = (1.11\log_{10} f_c - 0.7) - (1.56\log_{10} f_c - 0.8)$$

for large cities as

$$a(h_{re}) = \begin{cases} 8.29\left(\log_{10}(1.54h_{re})\right)^2 - 1.1 & f_c \le 300 \text{ MHz} \\ 3.2\left(\log_{10}(11.75h_{re})\right)^2 - 4.98 & f_c > 300 \text{ MHz} \end{cases}$$

Hata also modified this last equation for suburban and open rural areas. These equations are

$$L_{50}(dB) = \begin{cases} L_{50,urban} - 2\left[\log_{10}(f_c/28)\right]^2 - 5.4 & Surburban \\ L_{50,urban} - 4.78\left[\log_{10}(f_c)\right]^2 + 18.33\log_{10}(f_c) - 40.94 & Open\ \&\ Rural \end{cases}$$

Cost-231 model

$$L_{50}(\text{Urban}) = 46.3 + 33.9\log_{10}(f_c) - 13.82\log_{10}(h_{te}) - a(h_{re})$$
$$+[44.9 - 6.55\log_{10}(h_{te})]\log_{10} d + C$$

$$1{,}500\ \text{MHz} \le f_c \le 2{,}000\ \text{MHz}$$
$$30\,\text{m} \le h_{te} \le 20\ \text{m}$$
$$1\ \text{m} \le h_{re} \le 10\ \text{m}$$
$$1\ \text{km} \le d \le 20\ \text{km}$$

4.4.3.7.5 Indoor structures

- Walls
- Partition losses between floors
- Partition losses on the same floor

- 4.4.3.7.6 coverage calculation
  - Several examples

Optional Reading

- 4.3 Antennas
  - 4.3.2.3 field and power patterns
  - 4.3.2.4 beamwidth
  - 4.3.2.5 directivity, gain, aperature

  - 4.3.5 beamforming and smart antenna

- 4.4.3 RF engineering