EC307: Mobile Communication and Networks

Module 8: Radio Propagation Model

Introduction

Radio propagation describes how electromagnetic waves travel from a transmitter (Tx) to a receiver (Rx). In wireless communication, three primary propagation mechanisms dominate:

- Free Space Propagation (Line-of-Sight)
- Reflection (Ground Reflection / Two-Ray Model)
- Diffraction (Knife-Edge Diffraction)

These mechanisms are the basis for all large-scale wireless channel models.

1. Free Space Propagation Model

This model applies when there is a clear **Line-of-Sight (LOS)** between Tx and Rx with no obstacles.

Friis Transmission Equation

$$P_r(d) = P_t\, G_t\, G_r \left(\frac{\lambda}{4\pi d}\right)^2$$

Path Loss:

$$L_p(d) = \left(\frac{4\pi d}{\lambda}\right)^2, \qquad L_p(d)_{\mathrm{dB}} = 20\log_{10}\!\left(\frac{4\pi d}{\lambda}\right)$$

Numerical Examples (Free Space)

$$P_t = 1\ \mathrm{W}, \quad f = 2\ \mathrm{GHz} \Rightarrow \lambda = \frac{3\times10^8}{2\times10^9} = 0.15\ \mathrm{m}, \quad d = 100\ \mathrm{m}.$$

$$P_r = 1\cdot\left(\frac{0.15}{4\pi\cdot100}\right)^2 = \left(\frac{0.15}{1256.637}\right)^2 \approx (1.193\times10^{-4})^2 \approx 1.42\times10^{-8}\ \mathrm{W}.$$

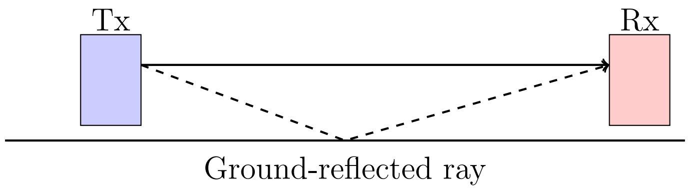
$$P_r(\mathrm{dBm}) = 10\log_{10}(1.42\times10^{-8}\times1000) \approx -48.5\ \mathrm{dBm}.$$

2. Reflection Model (Two-Ray Ground Reflection)

When a signal encounters the ground or a large smooth surface, it reflects. The received signal is the vector sum of the direct (LOS) component and the ground-reflected component. For sufficiently large distance and typical heights, the two-ray approximation gives:

$$P_r(d) \approx P_t\, G_t\, G_r\, \frac{h_t^2 h_r^2}{d^4}$$

which implies a $1/d^4$ dependence (for the envelope).



Numerical Examples (Two-Ray)

$$P_t = 1 \text{ W}, \quad h_t = 30 \text{ m}, \quad h_r = 2 \text{ m}, \quad d = 1000 \text{ m}.$$

$$P_r = 1 \cdot \frac{30^2 \cdot 2^2}{1000^4} = \frac{(900)(4)}{10^{12}} = \frac{3600}{10^{12}} = 3.6 \times 10^{-9} \text{ W}.$$

$$P_r(\text{dBm}) = 10 \log_{10}(3.6 \times 10^{-9} \times 1000) = 10 \log_{10}(3.6 \times 10^{-6}) \approx -54.4 \text{ dBm}.$$

3. Diffraction Model (Knife-Edge)

Diffraction allows waves to reach shadowed regions by bending around sharp obstacles. The knife-edge model approximates an obstacle by a sharp edge and uses the diffraction parameter v.

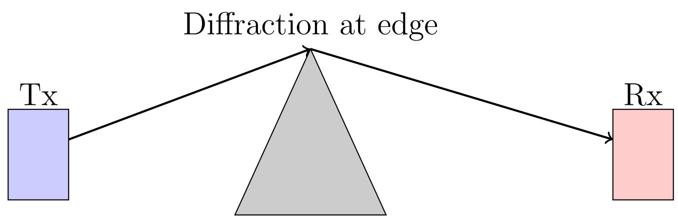
Diffraction parameter

$$v = h\sqrt{\frac{2(d_1 + d_2)}{\lambda d_1 d_2}}$$

where h is the height of the obstacle above the LOS, d_1, d_2 are distances from Tx and Rx to the obstacle, and λ is wavelength.

Diffraction loss (approximation)

$$L_d(v) \approx 6.9 + 20 \log_{10}\left(\sqrt{(v - 0.1)^2 + 1} + v - 0.1\right) \text{ dB}$$



Numerical Examples (Diffraction)

$$h = 10 \text{ m}, \quad d_1 = d_2 = 100 \text{ m}, \quad f = 1 \text{ GHz} \Rightarrow \lambda = 0.3 \text{ m}.$$

Compute v:

$$v = 10\sqrt{\frac{2(100+100)}{0.3 \cdot 100 \cdot 100}} = 10\sqrt{\frac{400}{3000}} = 10\sqrt{0.133333} \approx 10 \times 0.365 = 3.65.$$

Then diffraction loss:

$$L_d = 6.9 + 20\log_{10}\Big(\sqrt{(3.65-0.1)^2+1} + 3.65 - 0.1\Big).$$

Compute inner term:

$$3.65 - 0.1 = 3.55; \quad (3.55)^2 = 12.6025; \quad +1 = 13.6025; \quad \sqrt{13.6025} \approx 3.689.$$

So bracket $= 3.689 + 3.55 = 7.239$. Then

$$L_d \approx 6.9 + 20\log_{10}(7.239) \approx 6.9 + 20 \times 0.859 = 6.9 + 17.18 = 24.08 \text{ dB}.$$

Summary

Model	Key Idea	Representative Formula	Decay
Free Space	Pure LOS, no reflections	$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2$	$1/d^2$
Two-Ray Reflection	Direct + ground-reflected ray (interference possible)	$P_r \approx P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}$	$1/d^4$
Knife-Edge Diffraction	Bending around sharp obstacles	$L_d(v) = 6.9 + 20\log_{10}(\cdots)$ with $v = h\sqrt{\frac{2(d_1+d_2)}{\lambda d_1 d_2}}$	additional dB loss depending on v

Notes

- Use free-space for unobstructed LOS (satellite, short microwave links). Use two-ray for terrestrial links where ground reflection is strong (base station to mobile); use diffraction where obstacles block LOS (urban streets, hills).
- Higher frequency (smaller λ) increases free-space loss for same distance.