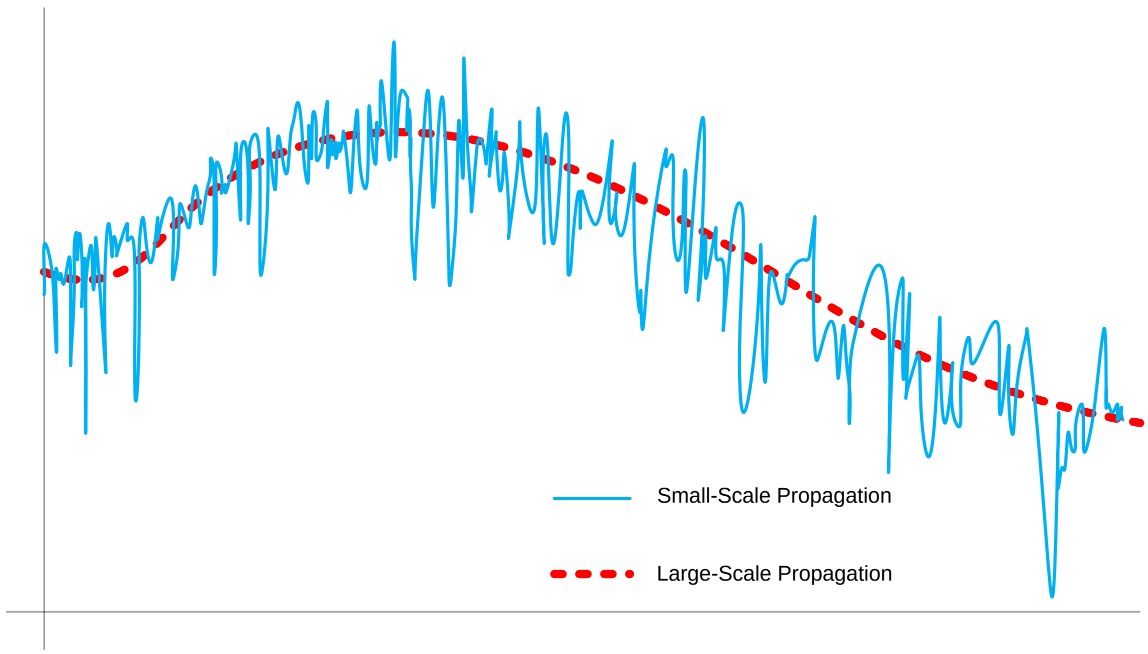
Mobile Radio Propagation: Large Scale Propagation Modeling

Radio Wave Propagation

Radio waves suffer from several channel problems as they travel through the air. Some of these cause very rapid variations in the envelope of the signal (resulting from small-scale movements of the mobile unit or the surroundings) while some of them result in relatively slow envelope variations (resulting from large-scale movement of the mobile unit or the surroundings). The following figure illustrates combination of both rapid (small-scale) and slow (large-scale) signal envelope variations as illustrated by the blue signal. The local average of this signal is indicated by the dashed line which illustrates the slow variations in the envelope only. In this chapter we talk about the slow large-scale variations only.



It is worth mentioning that small-scale propagation variations occur as a result of fractional wavelength movements of the mobile phone or its surroundings on the order of a wavelength (0.1 λ - 1 λ). For mobile phones with frequencies in the range of 800 MHz to 2000 MHz, this corresponds to movements on the order of 1cm – 10 cm. Large-scale propagation variations occur as a result of multiple wavelength movements in the range of (5 λ to 50 λ) which corresponds to movements on the order of 1m to 10m.

Free Space Propagation Model

Power Received at a Distance from a Transmitter

As a transmitted signal travels through vacuum or air, its power gets distributed over a larger and larger sphere and therefore attenuates as the square of the distance from the transmitter to the receiver. In fact, the power received at distance *d* from a transmitter is

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2} \quad \text{W}$$

where

P_t is transmitted power (W)

G_t is gain of transmitting antenna (Linear not dB)

G_r is gain of receiving antenna (Linear not dB)

λ is wavelength of transmitted signal (m)

d is horizontal distance between transmitter and receiver (m)

In dB, the same relation can be written as

$$P_r(d)\ [\text{dBW}] = P_t\ [\text{dBW}] + G_t\ [\text{dB}] + G_r\ [\text{dB}] + 20\log_{10}\lambda - 20\log_{10}4\pi - 20\log_{10}d$$

Gain of an Antenna

Given the effective area of an antenna and the frequency or wavelength of the signal it is transmitting/receiving, we can find the gain of that antenna. The gain of an antenna is basically the ability of an antenna to concentrate its transmitted power at a specific direction. That is, compared to an isotropic antenna which radiates equally in all directions, a transmitting antenna with a gain of G that is fed with the same amount of power as an isotropic antenna radiates G times as much as an isotropic antenna in the direction of its highest radiation direction. An antenna with a transmitting gain of G will have a receiving gain of G. The gain of an antenna is given by

$$G = \frac{4\pi A_e}{\lambda^2}$$

where

A_e is effective area of antenna in m^2 (related to its surface exposed to radiation) and

$$\lambda = \frac{c}{f} = \frac{2\pi c}{\omega}$$

Path Loss

As the EM wave travels, its power drops as it is spread over a larger sphere. This drop in power is known as path loss which is given by

$$PL(d) = \frac{\lambda^2}{(4\pi)^2 d^2}$$

Relating Electric Field Intensity to Received Power (Power Flux Density)

Often, we need to relate the strength of an electric field at a specific distance away from a transmitting antenna to the power received by another antenna at that same point. In this case, we need to understand the concept of the Power Flux Density (PFD).

The Power Flux Density (PFD) is defined as the amount of power that passes through an area of 1 m^2 that is located on a sphere of radius d (the 1 m^2 is part of the surface of the sphere). The PFD is defined as

$$P_d = \frac{EIRP}{4\pi d^2} = \frac{P_t G_t}{4\pi d^2} = \frac{|E|^2}{R_{fs}} = \frac{|E|^2}{\eta} \quad \text{W/m}^2$$

$EIRP$	is Effective Isotropic Radiated Power (W) which is equal to power fed to a transmitting antenna times its gain $P_t G_t$. This means that an isotropic antenna would have to be fed with $P_t G_t$ Watts of power to radiate the same amount of power as that specific antenna
$\|E\|$	is magnitude of electric filed intensity (V/m)
$R_{fs} = \eta$	is intrinsic impedance of **free space** (in Ω) which is equal to $120\pi\ \Omega = 377\ \Omega$

So,

$$P_r(d) = P_d \cdot A_e = \frac{|E|^2}{120\pi} A_e = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2} = \frac{|E|^2 G_r \lambda^2}{480 \cdot \pi^2} \quad \text{W}$$

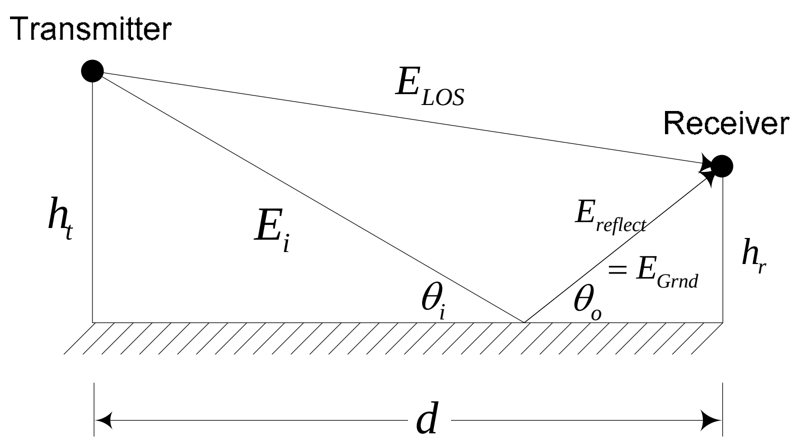
Large-Scale Propagation Mechanisms

There are 3 basic large-scale propagation mechanisms that affect the envelope of a transmitted electromagnetic signal:

1. Reflection
2. Diffraction
3. Scattering

Reflection (Reflection from Dielectrics)

Ground Reflection (Two-Ray) Model



If the condition,

$$d > \frac{20 h_t h_r}{\lambda}$$

is satisfied, then the total electric field at the receiver antenna in terms of some field strength E_0 at some distance d_0 is

$$E_{TOT}(d) = \frac{2E_0 d_0}{d}\frac{2\pi h_t h_r}{\lambda d} \quad \text{V/m}$$

This allows us to use the above equation (which is illustrated next)

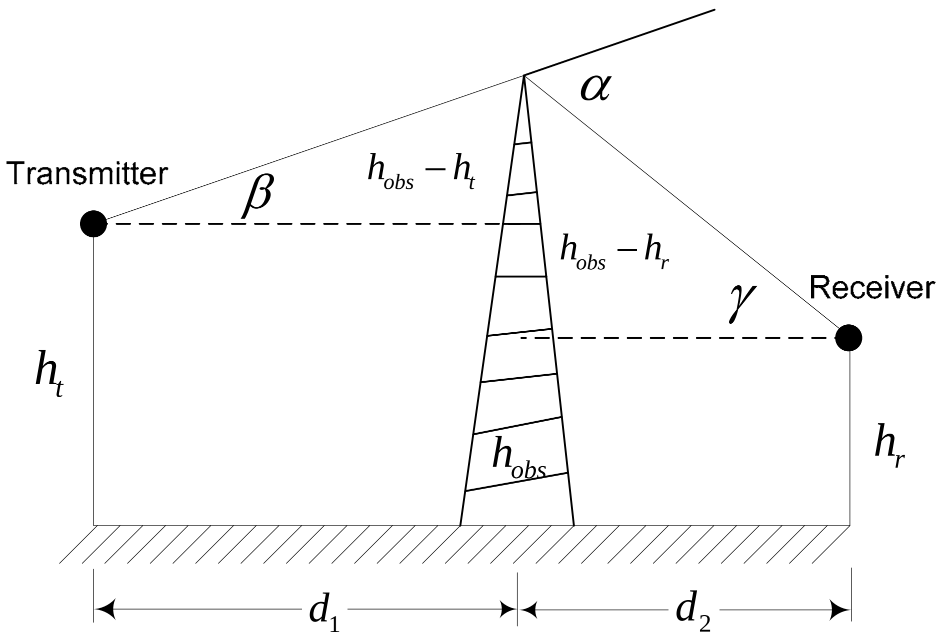
$$P_r(d) = P_d \cdot A_e = \frac{\left|E_{TOT}(d)\right|^2}{120\pi} A_e = \frac{\left|E_{TOT}(d)\right|^2 G_r \lambda^2}{480 \cdot \pi^2} \quad \text{W}$$

to obtain a relation of the received power in the two-ray model that is related only to antenna heights given by

$$P_r(d) = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4} \quad \text{W}$$

Diffraction (Fresnel Zones)

This configuration is called the (Single) Knife-edge Diffraction Model



Clearly,

$$\alpha = \beta + \gamma$$

and it is clear that

$$\beta = \tan^{-1}\left(\frac{h_{obs} - h_t}{d_1}\right)$$

$$\gamma = \tan^{-1}\left(\frac{h_{obs} - h_r}{d_2}\right)$$

Using the above, we obtain a relation to find the parameter ν given by

$$v = \alpha \sqrt{\frac{2(d_1 + d_2)}{\lambda d_1 d_2}} \qquad (\alpha \quad \text{must be in } \underline{\text{radians}} \text{ not degrees})$$

Note that α can be positive or negative. It is positive if the obstacle is higher than the line of sight between the transmitter and receiver, zero if it just touches the line of sight, and negative if it is lower than the line of sight between transmitter and the receiver.

Once v is determined from the above equation, a sketch (given in the book) gives the corresponding additional gain of the signal. This means, you may compute the power received by the receiving antenna assuming no obstacle exists, the actual power received with the presence of the obstacle is higher by a dB value that is equal to the value given in the sketch. (Understand this process)

Scattering

A surface is considered to be smooth (not rough) if the peak-to-peak variations in its surface h_c is less than

$$h_c = \frac{\lambda}{8 \sin \theta_i}$$

θ_i = incident angle

The following equations are not required

Scattering loss factor ρ_S is

$$\rho_S = e^{-8\left(\frac{\pi \sigma_h \sin \theta_i}{\lambda}\right)^2}$$

σ_h = standard deviation of surface height about average

Reflection coefficient is

$$\Gamma_{rough} = \rho_S \Gamma$$