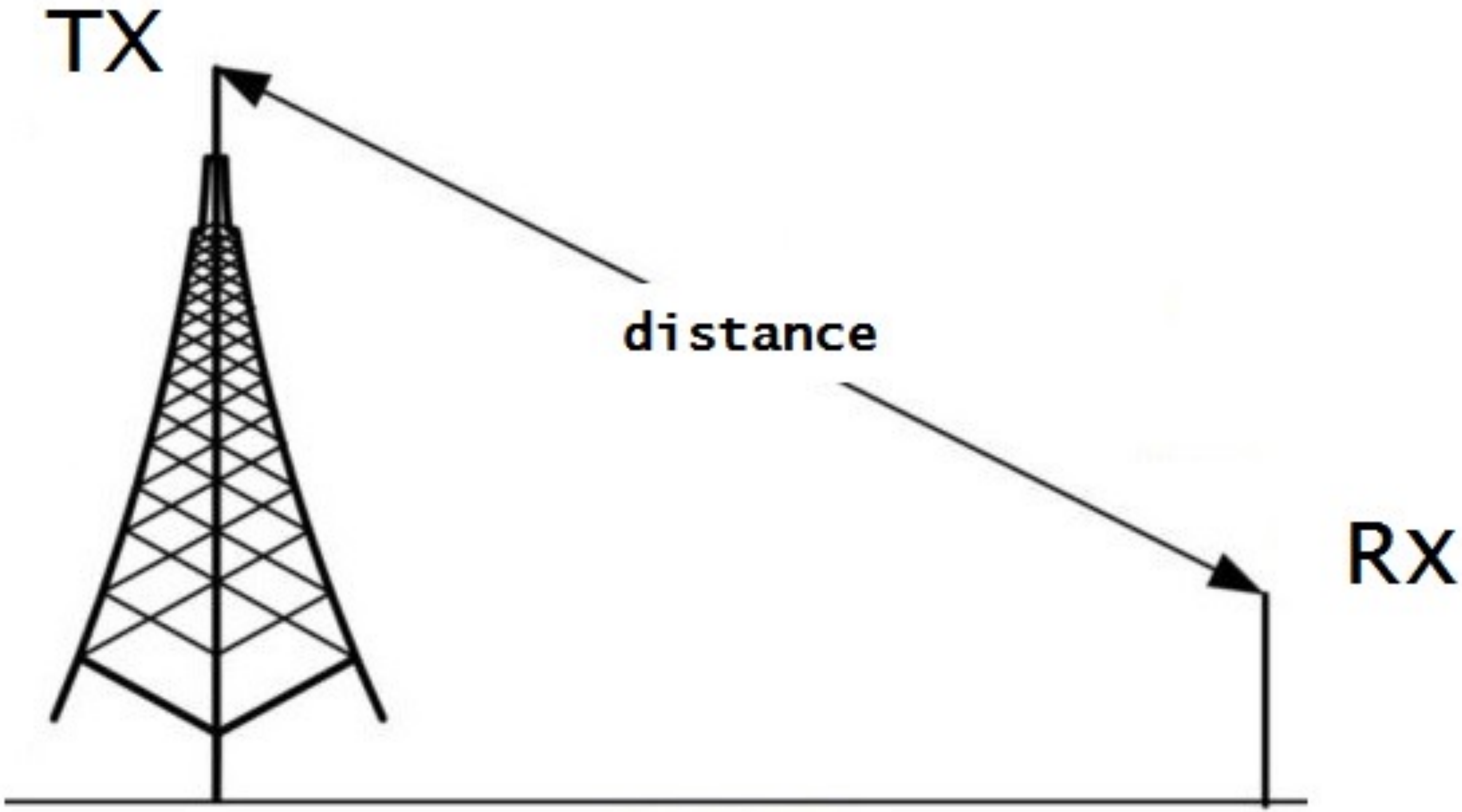
Unit 2 – Large Scale Fading

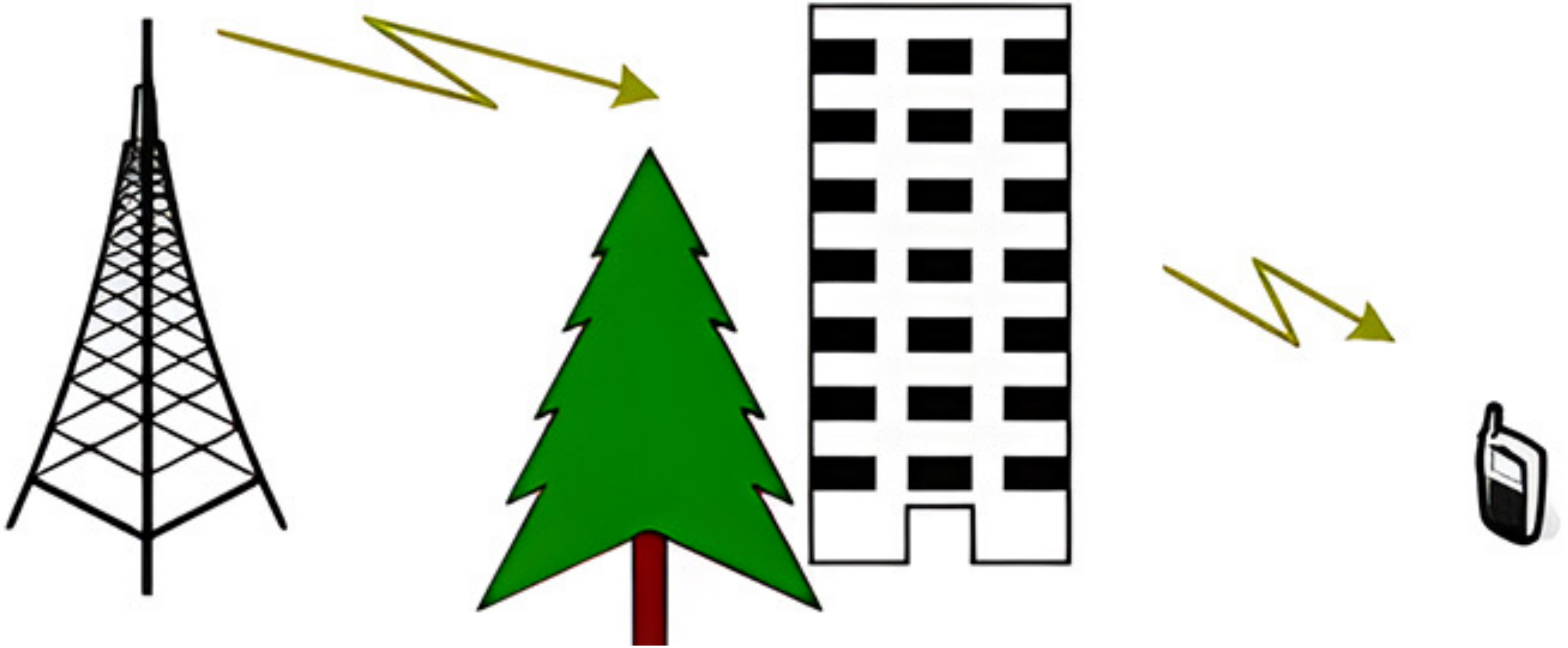
Free Space Path Loss



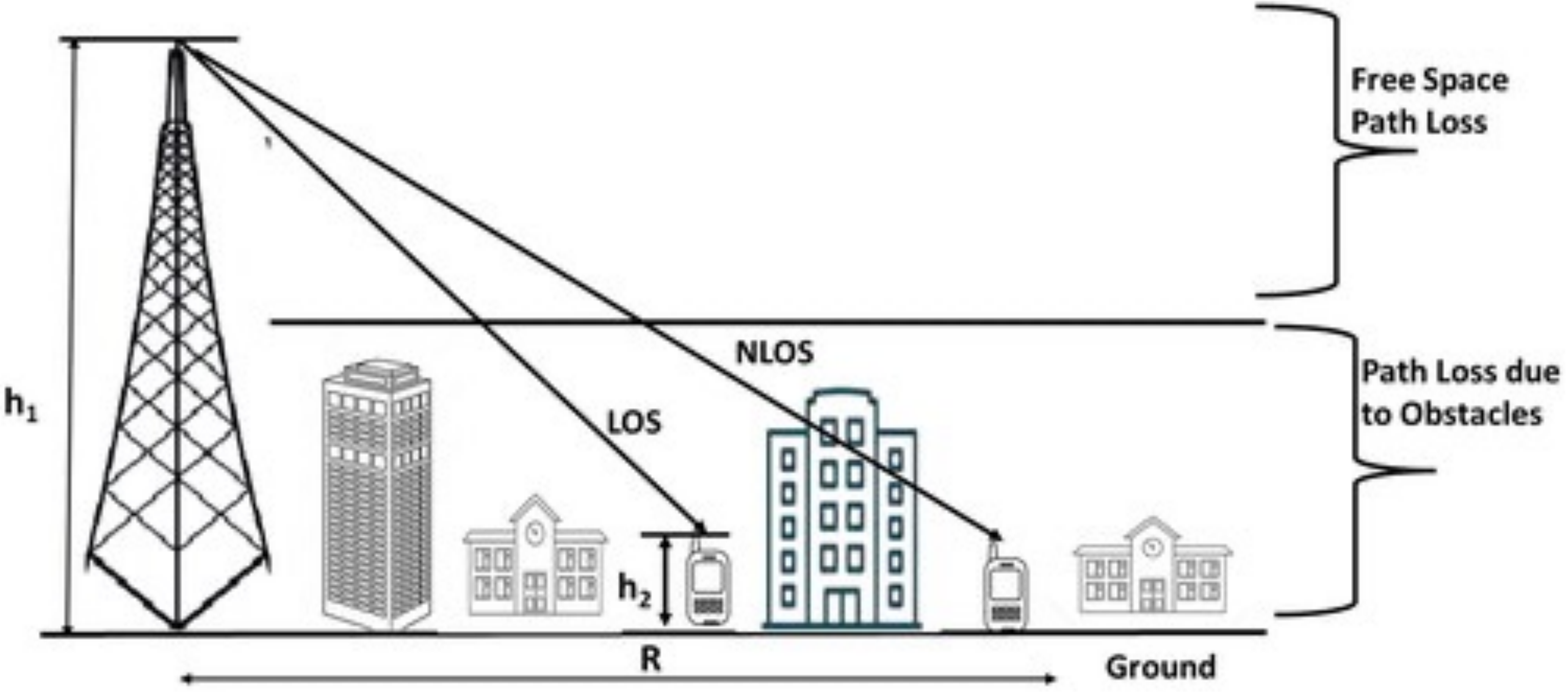
- **Path loss** characterizes how a signal's received power decreases with transmit-receive distance.

- It is caused by dissipation of the power radiated by the transmitter as well as by effects of the propagation channel.

Shadowing



Path Loss and Shadowing



- **Shadowing** is the attenuation caused by **obstacles** between the transmitter and receiver that absorb the transmitted signal.

- When the attenuation is strong, the signal is blocked.

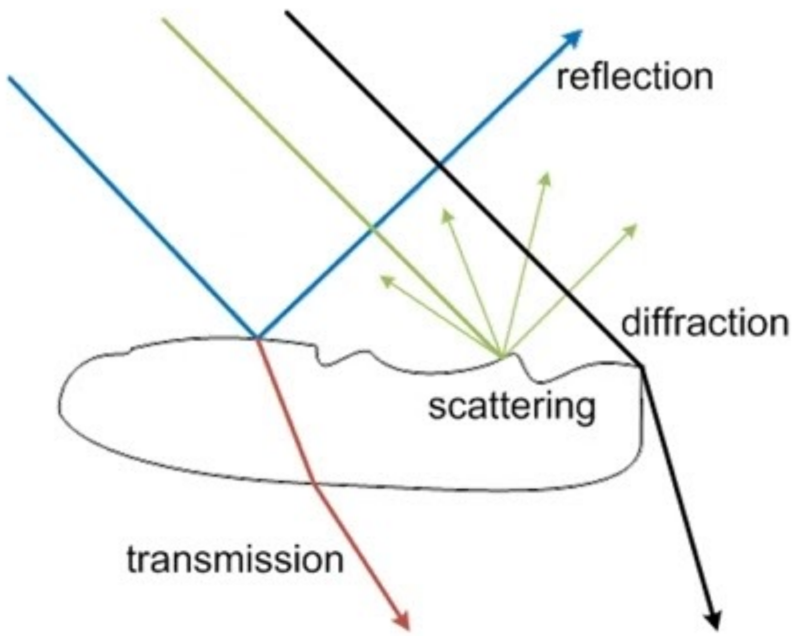
- The number and type of objects that cause shadowing at any given receiver location is typically unknown.

- Hence attenuation due to shadowing is modeled as a random parameter.

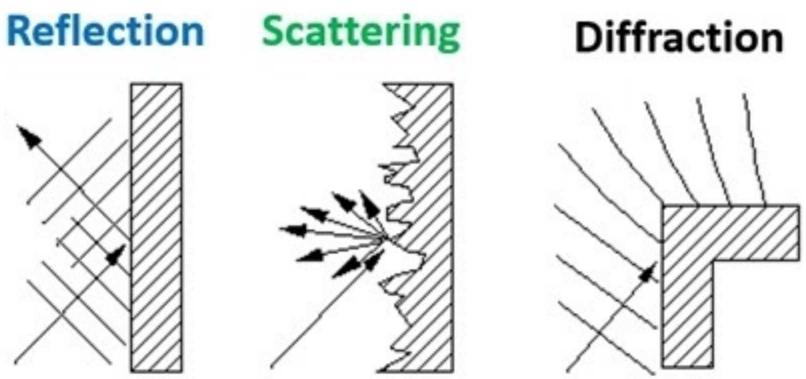
- Unlike path loss, shadowing does not depend on the transmit-receive distance itself but rather on the objects between the transmitter and receiver.

Radio wave propagation

- In practice: obstacles



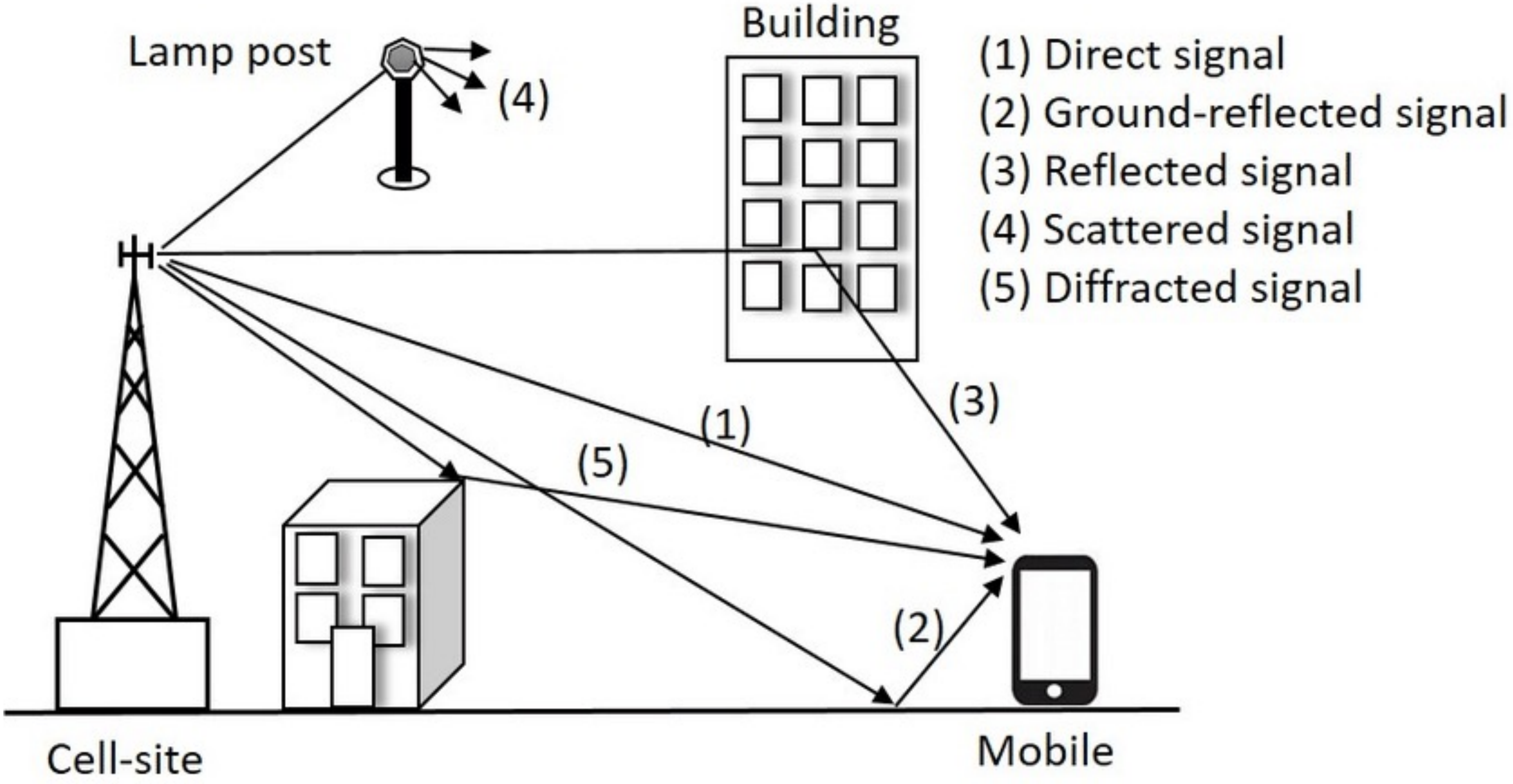
LOS: Line-of-sight
NLOS: Non-line-of-sight



http://interface.cipic.ucdavis.edu/images/research/waves2.gif

- **Reflection** on smooth surfaces
- **Transmission** through objects
- **Scattering** on rough surfaces
- **Diffraction** around sharp edges
- Smooth/rough, large/small are relative to the *wavelength*
- *Line-of-sight* is not necessarily needed for communication
- Increasing frequency gives
  - more "optical" propagation
  - smaller antennas
  - higher path loss

Multipath


Lamp post
(4)
Building
(1) Direct signal
(2) Ground-reflected signal
(3) Reflected signal
(4) Scattered signal
(5) Diffracted signal
(3)
(1)
(5)
(2)
Cell-site
Mobile

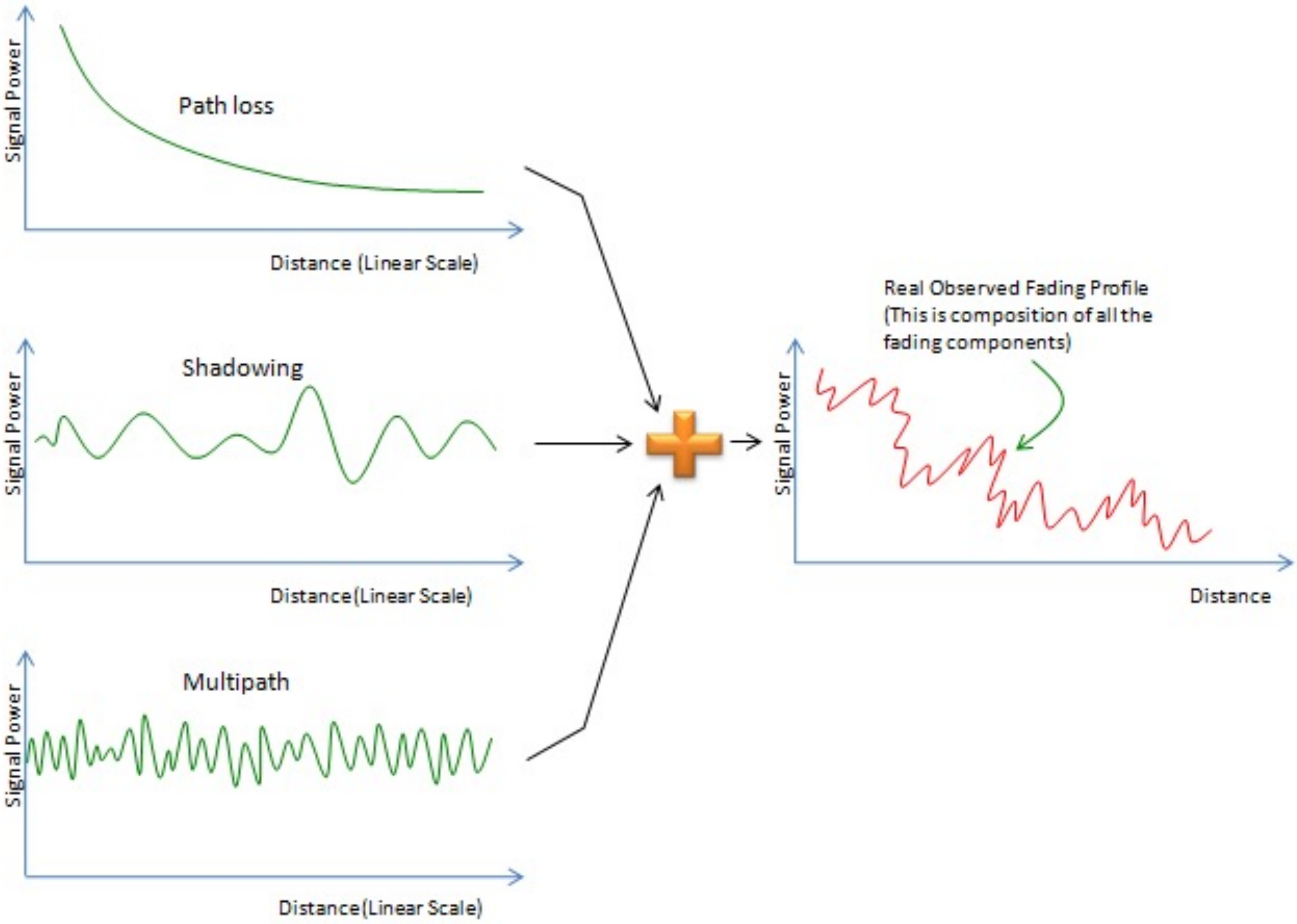
- **Reflection, diffraction, and scattering** are caused by a transmitted signal interacting with objects in the environment around the transmitter or receiver.

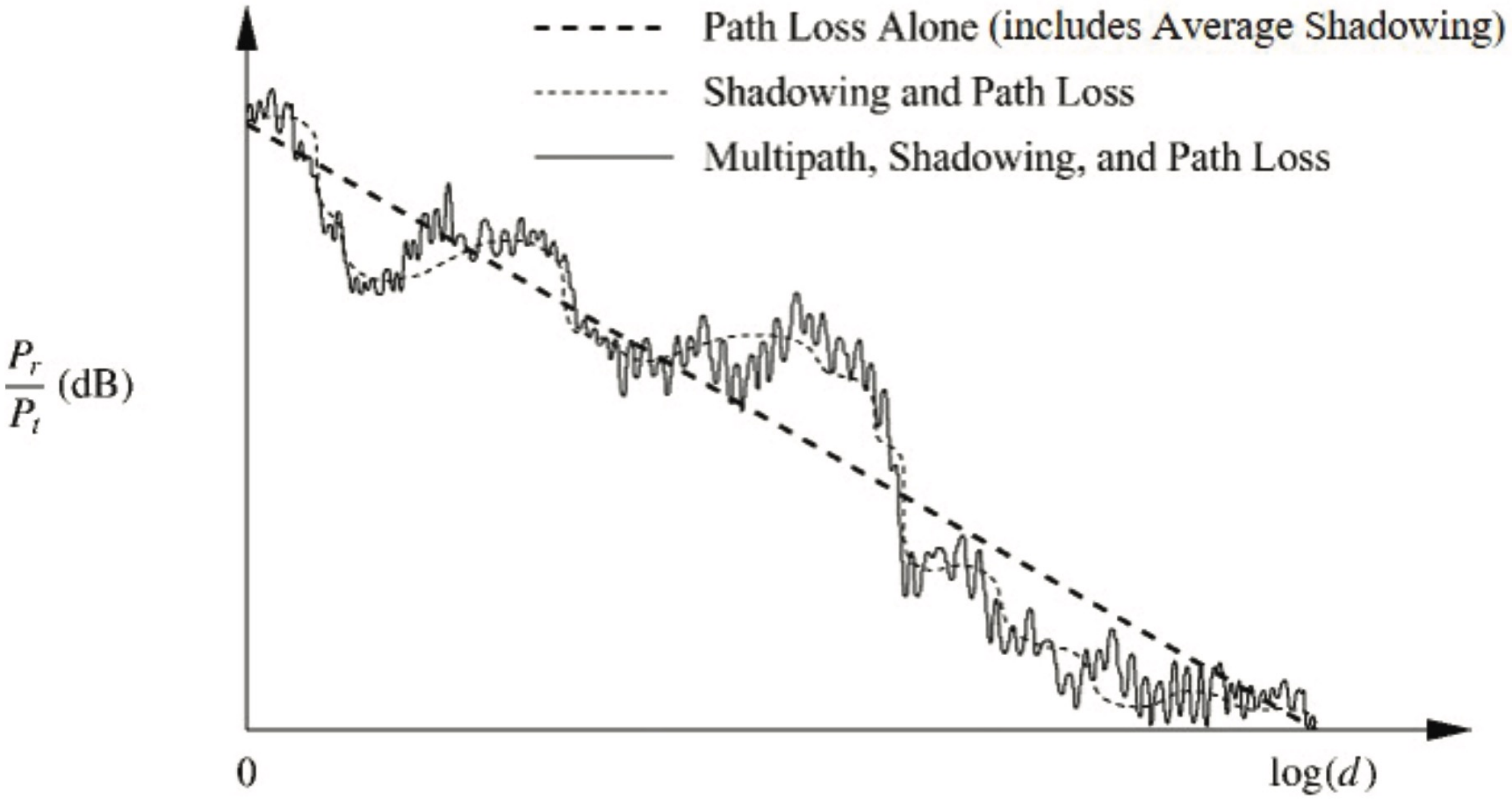
- The signal components that arise due to these objects are called **multipath components.**

- Different multipath components arrive at the receiver with different time delays and phase shifts.

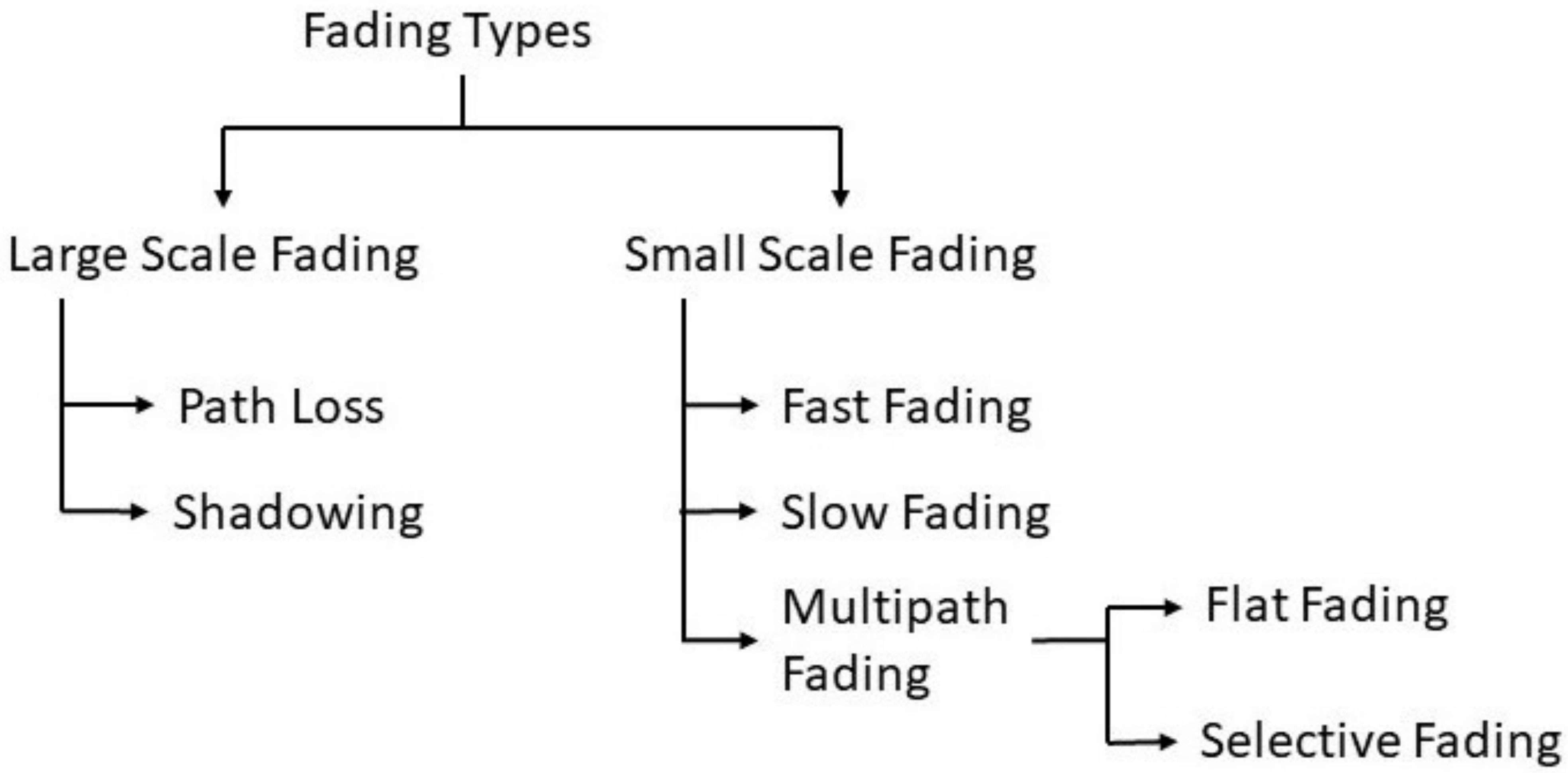
- When the **phase shifts are aligned**, the multipath components add constructively; when **they are not aligned**, they add destructively.

- This constructive and destructive addition of multipath components leads to significant variations in the received signal power.


Path loss
Signal Power
Distance (Linear Scale)
Shadowing
Signal Power
Distance(Linear Scale)
Multipath
Signal Power
Distance(Linear Scale)
Real Observed Fading Profile
(This is composition of all the
fading components)
Signal Power
Distance



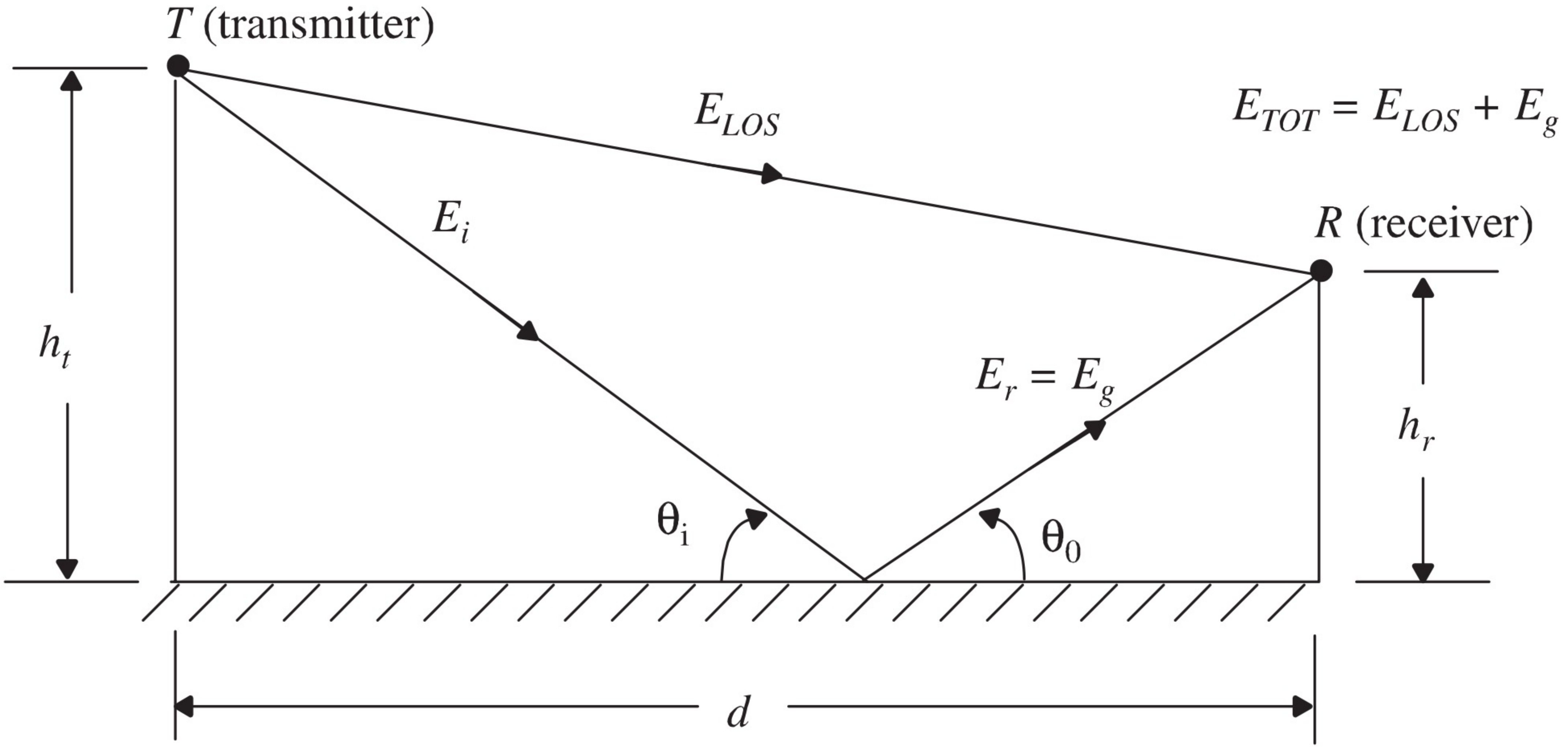
l: Effects of path loss, shadowing, and multipath on received power as a function of distance.


Fading Types
Large Scale Fading
Small Scale Fading
Path Loss
Shadowing
Fast Fading
Slow Fading
Multipath Fading
Flat Fading
Selective Fading

Since variations in received power due to path loss and shadowing occur over relatively large distances, these variations are sometimes referred to as **large-scale propagation effects**.

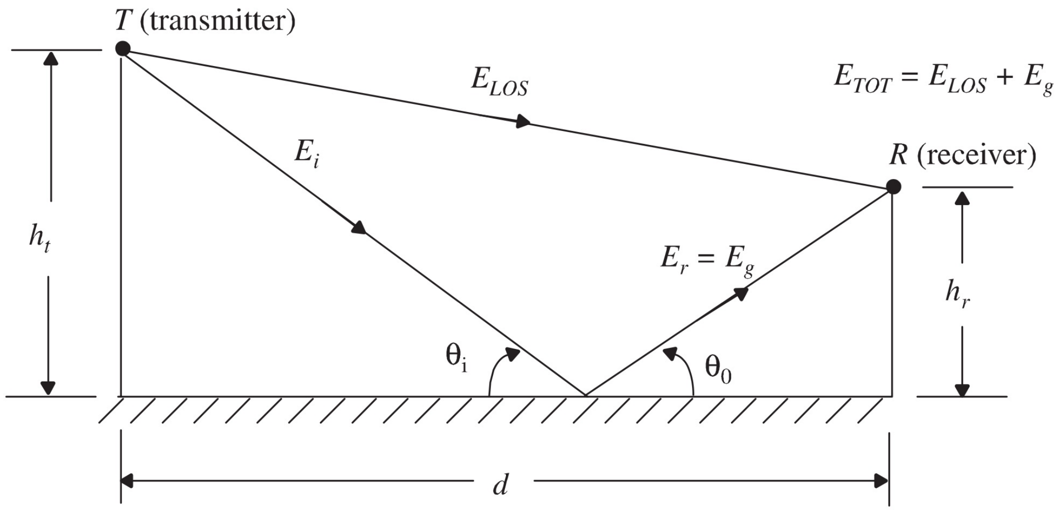
The received power variations due to constructive and destructive addition of multipath components occur over very short distances, on the order of the signal wavelength, since each component's phase rotates 360 degrees over that distance. Hence, power variations due to multipath are sometimes referred to as **small-scale propagation effects**.

Ground Reflection (Two-Ray) Model



Two-ray ground reflection model.

Ground Reflection (Two-Ray) Model



Two-ray ground reflection model.

The free space propagating E-field is given by

$$E(d,t) = \frac{E_0 d_0}{d}\cos\left(\omega_c\left(t - \frac{d}{c}\right)\right) \qquad (d > d_0)$$

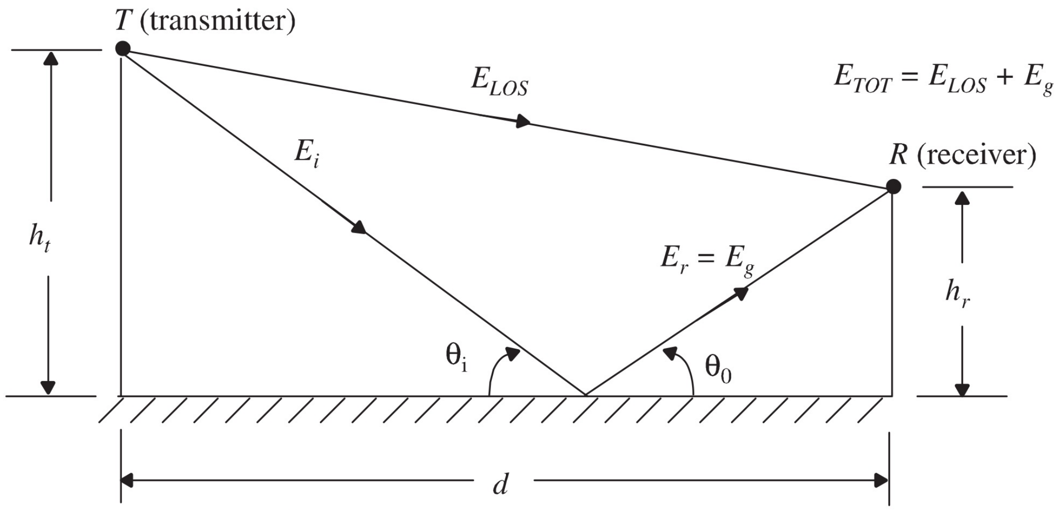
The E-field due to the line-of-sight component at the receiver can be expressed as

$$E_{LOS}(d',t) = \frac{E_0 d_0}{d'}\cos\left(\omega_c\left(t - \frac{d'}{c}\right)\right)$$

The E-field for the ground reflected wave, which has a propagation distance of *d″,* can be expressed as

$$E_g(d'',t) = \Gamma\frac{E_0 d_0}{d''}\cos\left(\omega_c\left(t - \frac{d''}{c}\right)\right)$$

Ground Reflection (Two-Ray) Model



Two-ray ground reflection model.

According to laws of reflection in dielectrics

$$\theta_i = \theta_0$$

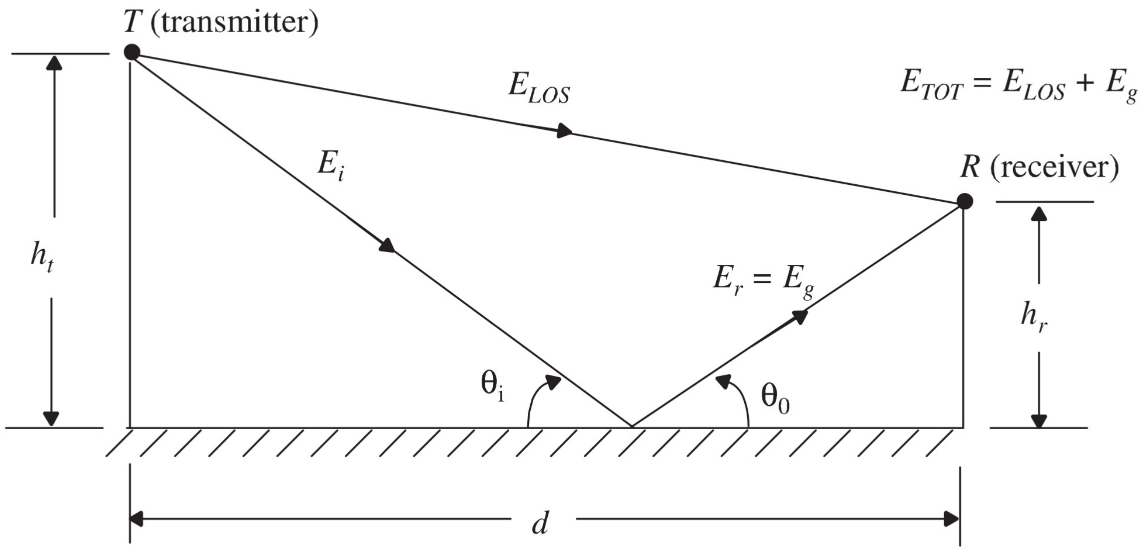
$$E_g = \Gamma E_i$$

$$E_t = (1+\Gamma)E_i$$

Γ is the reflection coefficient for ground.

For small values of θ_i (i.e., grazing incidence), the reflected wave is equal in magnitude and 180° out of phase with the incident wave

Ground Reflection (Two-Ray) Model

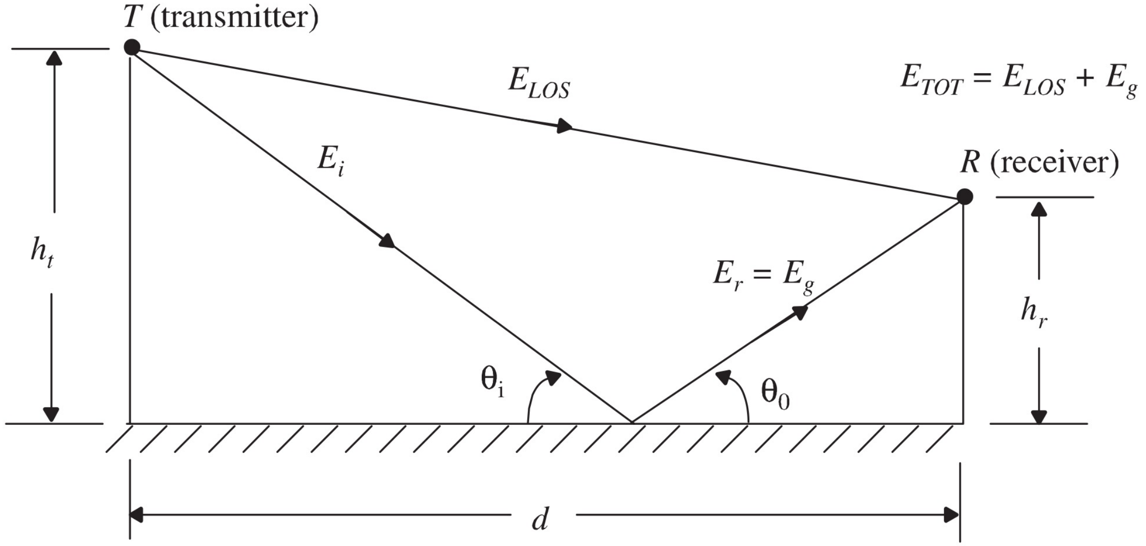


Two-ray ground reflection model.

$$|E_{TOT}| = |E_{LOS} + E_g|$$

$$E_{TOT}(d,t) = \frac{E_0 d_0}{d}\cos\left(\omega_c\left(t - \frac{d}{c}\right)\right) + (-1)\frac{E_0 d_0}{d}\cos\left(\omega_c\left(t - \frac{d}{c}\right)\right)$$

Ground Reflection (Two-Ray) Model



Two-ray ground reflection model.

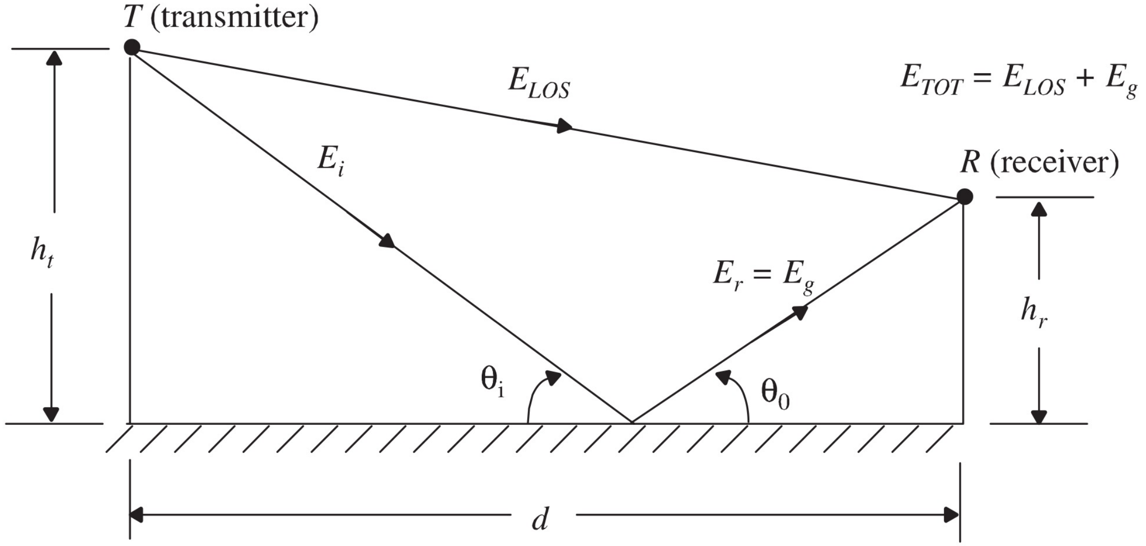
The received E-field can be approximated as

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

The received power at a distance *d* from the transmitter for the two-ray ground bounce model can be expressed as

$$P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}$$

Ground Reflection (Two-Ray) Model



Two-ray ground reflection model.

The received power at a distance *d* from the transmitter for the two-ray ground bounce model can be expressed as

$$P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}$$

The path loss for the two-ray model (with antenna gains) can be expressed in dB as

$$PL(\mathrm{dB}) = 40\log d - (10\log G_t + 10\log G_r + 20\log h_t + 20\log h_r)$$

Ground Reflection (Two-Ray) Model

Example 4.6

A mobile is located 5 km away from a base station and uses a vertical $\lambda/4$ monopole antenna with a gain of 2.55 dB to receive cellular radio signals. The E-field at 1 km from the transmitter is measured to be 10^{-3} V/m. The carrier frequency used for this system is 900 MHz.

(a) Find the length and the effective aperture of the receiving antenna.

(b) Find the received power at the mobile using the two-ray ground reflection model assuming the height of the transmitting antenna is 50 m and the receiving antenna is 1.5 m above ground.

$$P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}$$

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

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

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

Outdoor Propagation Models

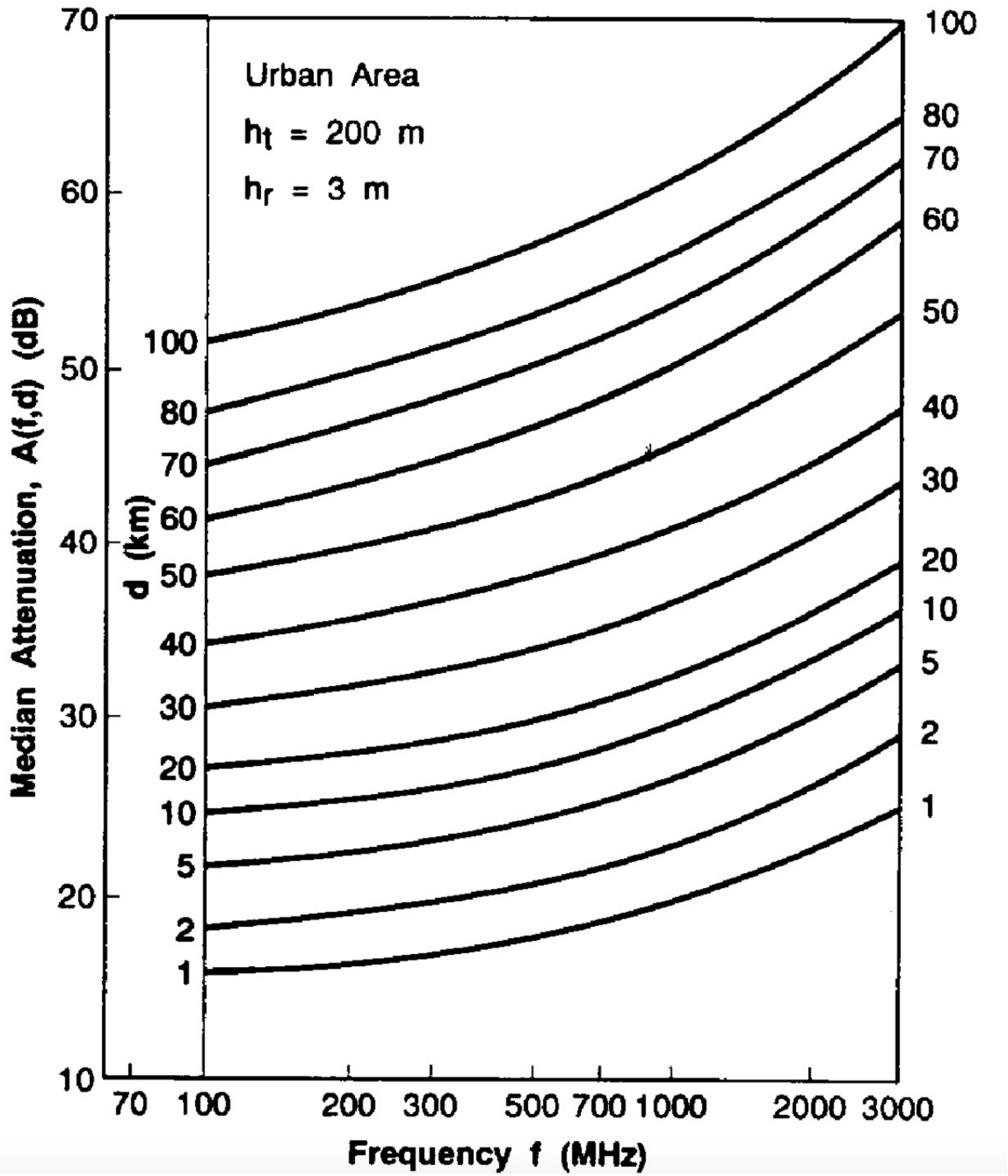
Okumura Model

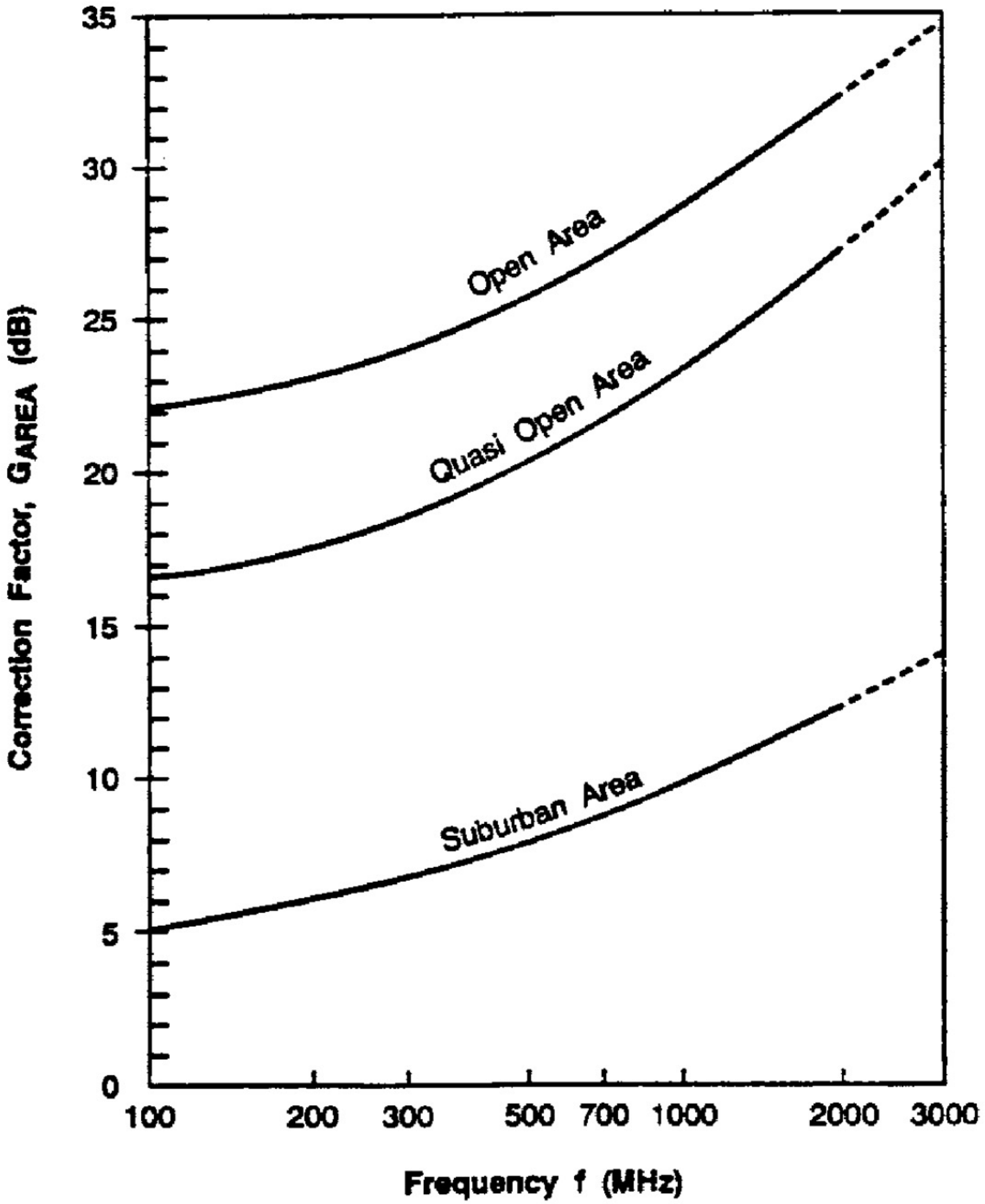
Widely used models for signal prediction in urban areas

This model is applicable for

- frequencies in the range 150 MHz to 1920 MHz
- distances of 1 km to 100 km
- base station antenna heights ranging from 30 m to 1000 m

Okumura Model





Outdoor Propagation Models

Okumura Model

The model can be expressed as

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

$$G(h_{te}) = 20\log\left(\frac{h_{te}}{200}\right) \qquad 1000\ \mathrm{m} > h_{te} > 30\ \mathrm{m}$$

$$G(h_{re}) = 10\log\left(\frac{h_{re}}{3}\right) \qquad h_{re} \le 3\ \mathrm{m}$$

$$G(h_{re}) = 20\log\left(\frac{h_{re}}{3}\right) \qquad 10\ \mathrm{m} > h_{re} > 3\ \mathrm{m}$$

Outdoor Propagation Models

Okumura Model

Okumura's model is wholly based on measured data and does not provide any analytical explanation.

Okumura's model is considered to be among the simplest and best in terms of accuracy in path loss prediction for mature cellular and land mobile radio systems in cluttered environments.

It is very practical and has become a standard for system planning in modem land mobile radio systems in Japan.

The major disadvantage with the model is its slow response to rapid changes in terrain, therefore the model is fairly good in urban and suburban areas, but not as good in rural areas.

Common standard deviations between predicted and measured path loss values are around 10 dB to 14 dB

Outdoor Propagation Models

Okumura Model

Example 4.10

Find the median path loss using Okumura's model for d = 50 km, h_{te} = 100 m, h_{re} = 10 m in a suburban environment. If the base station transmitter radiates an EIRP of 1 kW at a carrier frequency of 900 MHz, find the power at the receiver (assume a unity gain receiving antenna).

Solution

The free space path loss L_F can be calculated using Equation (4.6) as

$$L_F = 10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] = 10\log\left[\frac{(3\times10^8/900\times10^6)^2}{(4\pi)^2\times(50\times10^3)^2}\right] = 125.5\,\text{dB}.$$

From the Okumura curves

$$A_{mu}(900\text{ MHz}(50\text{ km})) = 43\,\text{dB}$$

and

$$G_{AREA} = 9\,\text{dB}.$$

Using Equation (4.81.a) and (4.81.c), we have

$$G(h_{te}) = 20\log\left(\frac{h_{te}}{200}\right) = 20\log\left(\frac{100}{200}\right) = -6\,\text{dB}.$$

$$G(h_{re}) = 20\log\left(\frac{h_{re}}{3}\right) = 20\log\left(\frac{10}{3}\right) = 10.46\,\text{dB}.$$

Using Equation (4.80), the total mean path loss is

$$\begin{aligned} L_{50}(\text{dB}) &= L_F + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA} \\ &= 125.5\text{ dB} + 43\text{ dB} - (-6)\text{ dB} - 10.46\text{ dB} - 9\text{ dB} \\ &= 155.04\text{ dB}. \end{aligned}$$

Therefore, the median received power is

$$\begin{aligned} P_r(d) &= EIRP(\text{dBm}) - L_{50}(\text{dB}) + G_r(\text{dB}) \\ &= 60\text{ dBm} - 155.04\text{ dB} + 0\text{ dB} = -95.04\text{ dBm}. \end{aligned}$$

Outdoor Propagation Models

Walfisch and Bertoni Model

Considers the impact of rooftops and building height by using diffraction to predict average signal strength at street level

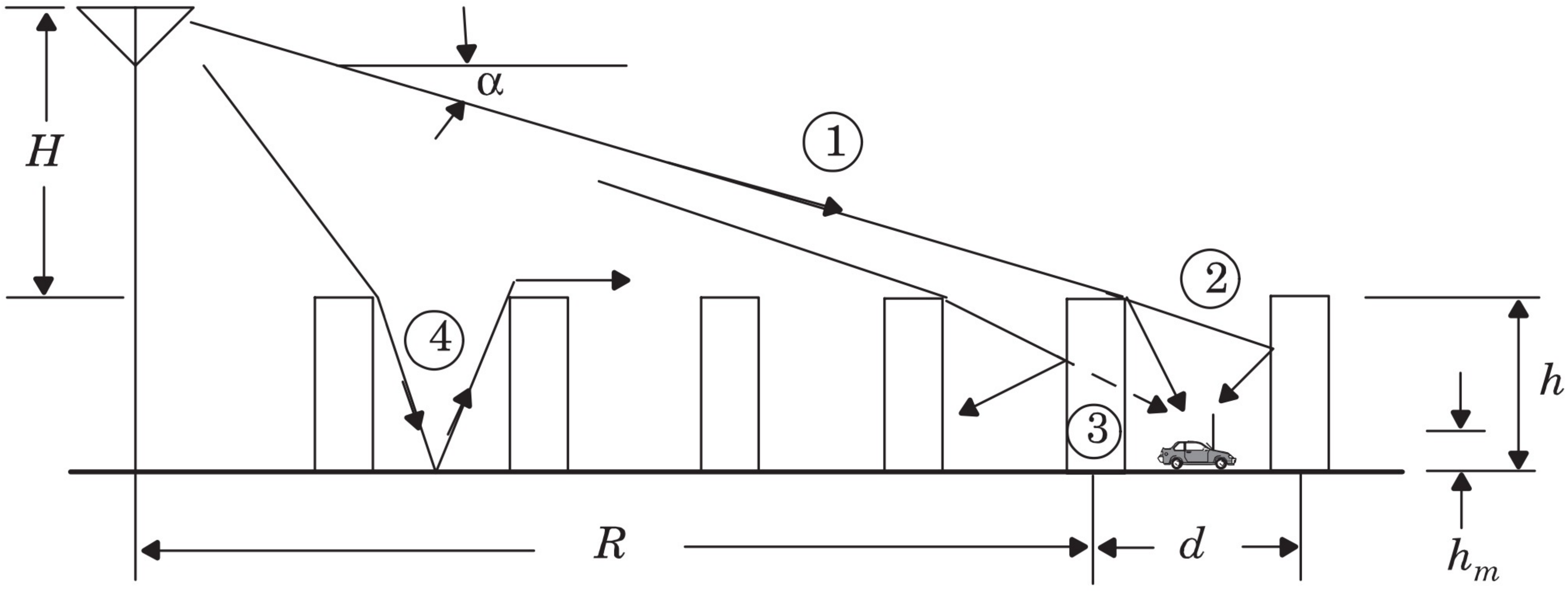


Figure 4.25 Propagation geometry for model proposed by Walfisch and Bertoni [from [Wal88]

Walfisch and Bertoni Model

In dB, the path loss is given by

$$S(\mathrm{dB}) = L_0 + L_{rts} + L_{ms}$$

where L_0 represents free space loss, L_{rts} represents the “rooftop-to-street diffraction and scatter loss,” and L_{ms} denotes multiscreen diffraction loss due to the rows of buildings [Xia92].

Log-distance Path Loss Model

The average large-scale path loss for an arbitrary T-R separation is expressed as a function of distance by using a path loss exponent, *n*

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

$$\overline{PL}(\mathrm{dB}) = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right)$$

Log-distance Path Loss Model

Table 4.2 Path Loss Exponents for Different Environments

Environment	Path Loss Exponent, *n*
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Log-normal Shadowing Model

Measurements have shown that at any value of *d,* the path loss *PL(d)* at a particular location is random and distributed log-normally (normal in **dB)** about the mean distance-dependent value

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

and

$$P_r(d)[dBm] = P_t[dBm] - PL(d)[dB] \quad \text{(antenna gains included in } PL(d)\text{)}$$

where X_σ is a zero-mean Gaussian distributed random variable (in dB) with standard deviation σ (also in dB).

Q-function or error function *(erf)*

Q-function or error function *(erf)* may be used to determine the probability that the received signal level will exceed (or fall below) a particular level

The Q-function is defined as

$$Q(z) = \frac{1}{\sqrt{2\pi}}\int_{z}^{\infty} \exp\left(-\frac{x^2}{2}\right)dx = \frac{1}{2}\left[1 - erf\left(\frac{z}{\sqrt{2}}\right)\right]$$

where

$$Q(z) = 1 - Q(-z)$$

Q-function or error function *(erf)*

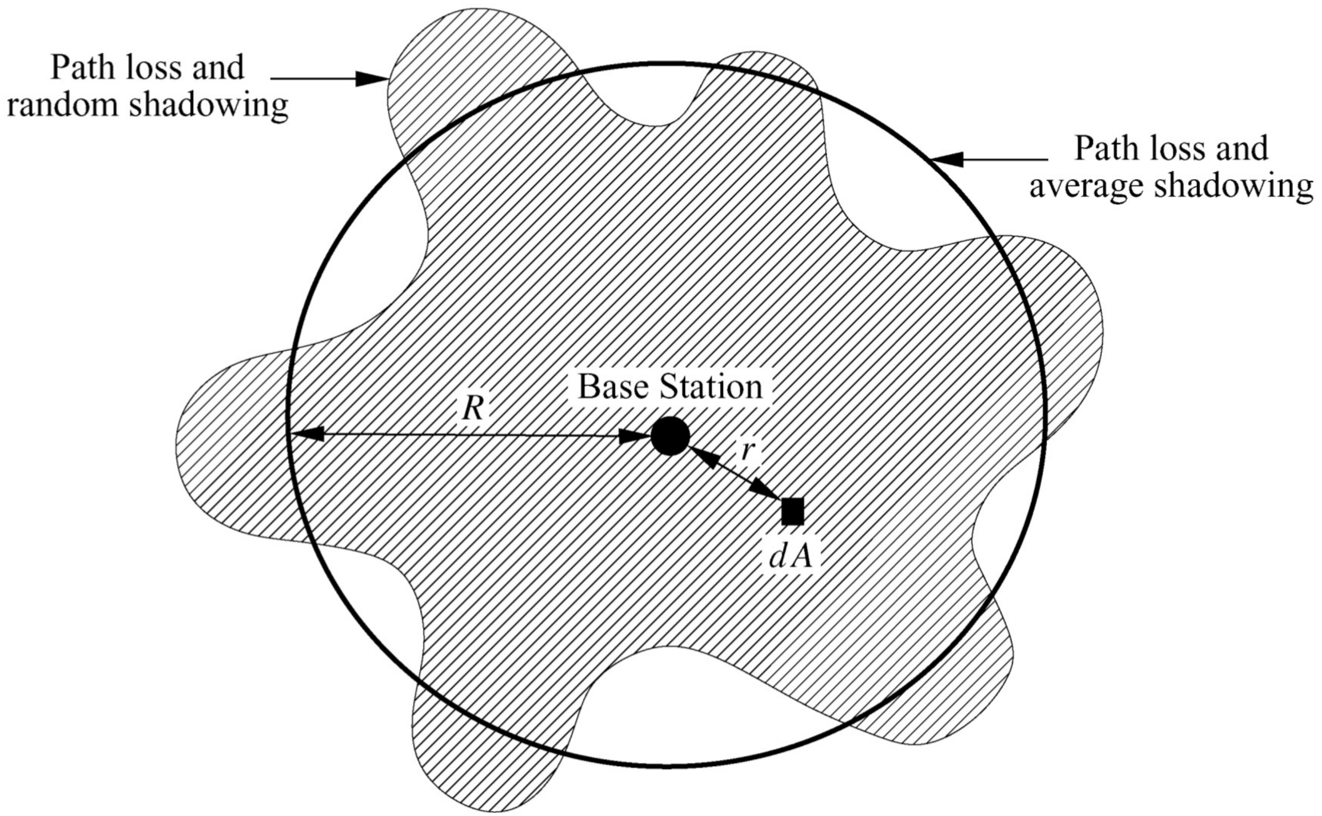
The probability that the received signal level (in dB power units) will exceed a certain value γ can be calculated from the cumulative density function as

$$Pr[P_r(d) > \gamma] = Q\left(\frac{\gamma - \overline{P_r(d)}}{\sigma}\right)$$

Similarly, the probability that the received signal level will be below γ is given by

$$Pr[P_r(d) < \gamma] = Q\left(\frac{\overline{P_r(d)} - \gamma}{\sigma}\right)$$

Determination of Percentage of Coverage Area



$$U(\gamma) = \frac{1}{\pi R^2}\int Pr[P_r(r) > \gamma]dA = \frac{1}{\pi R^2}\int_0^{2\pi}\int_0^{R} Pr[P_r(r) > \gamma]r\ dr d\theta$$

Determination of Percentage of Coverage Area

$$U(\gamma) = \frac{1}{2}\left(1 - erf(a) + \exp\left(\frac{1-2ab}{b^2}\right)\left[1 - erf\left(\frac{1-ab}{b}\right)\right]\right)$$

$$a = (\gamma - P_t + \overline{PL}(d_0) + 10n\log(R/d_0))/\sigma\sqrt{2} \text{ and } b = (10n\log e)/\sigma\sqrt{2}$$

By choosing the signal level such that $\overline{P_r}(R) = \gamma$ (i.e. $a = 0$), $U(\gamma)$ can be shown to be

$$U(\gamma) = \frac{1}{2}\left[1 + \exp\left(\frac{1}{b^2}\right)\left(1 - erf\left(\frac{1}{b}\right)\right)\right]$$