EEG473 Mobile Communications
lecture # (13)

Mobile Radio Propagation:
Large-Scale Path Loss

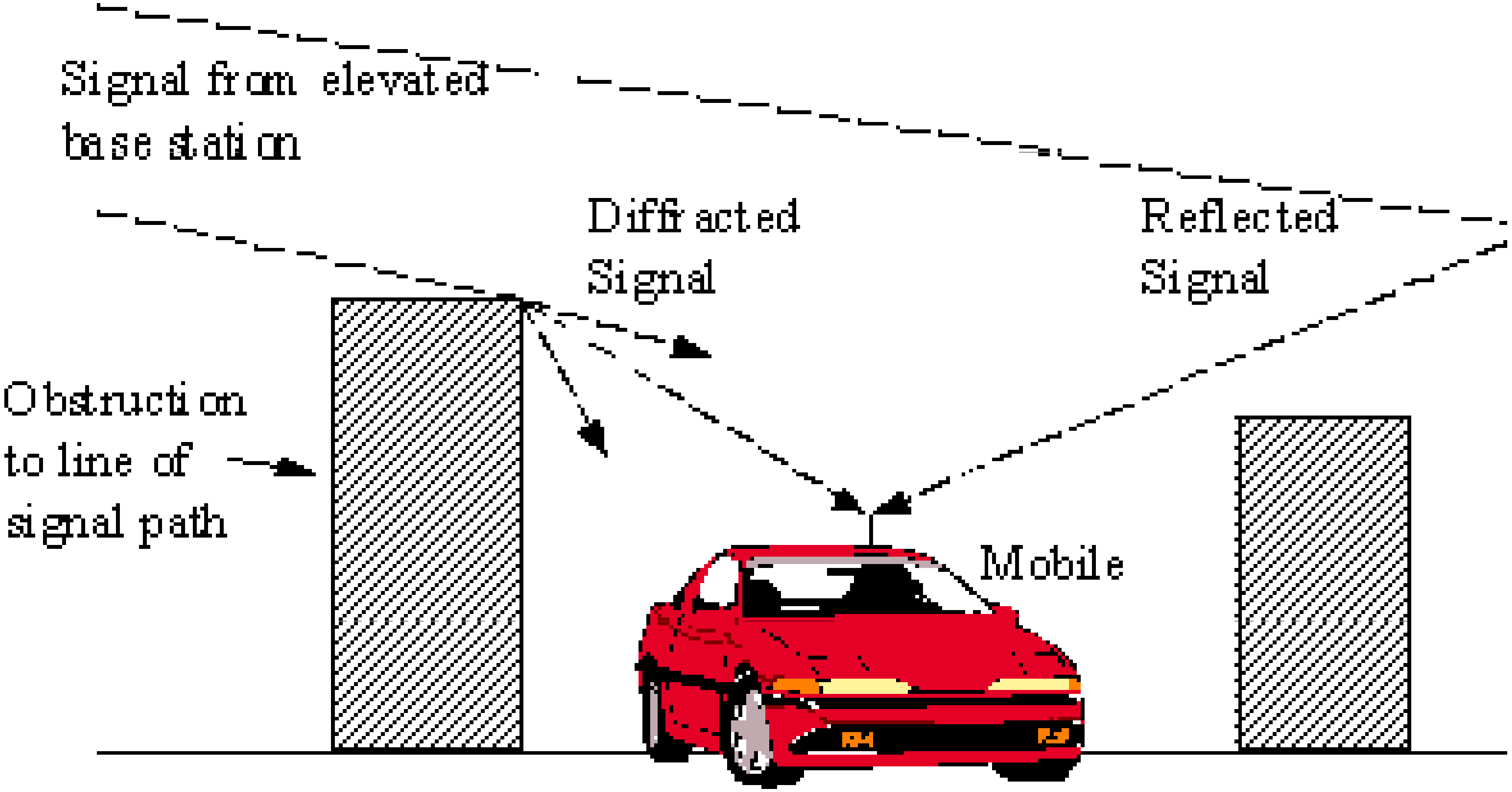

Figure 2 Radio Propagation Effects

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Introduction to Radio Wave Propagation

Electromagnetic wave propagation are attributed to **reflection, diffraction, and scattering.**

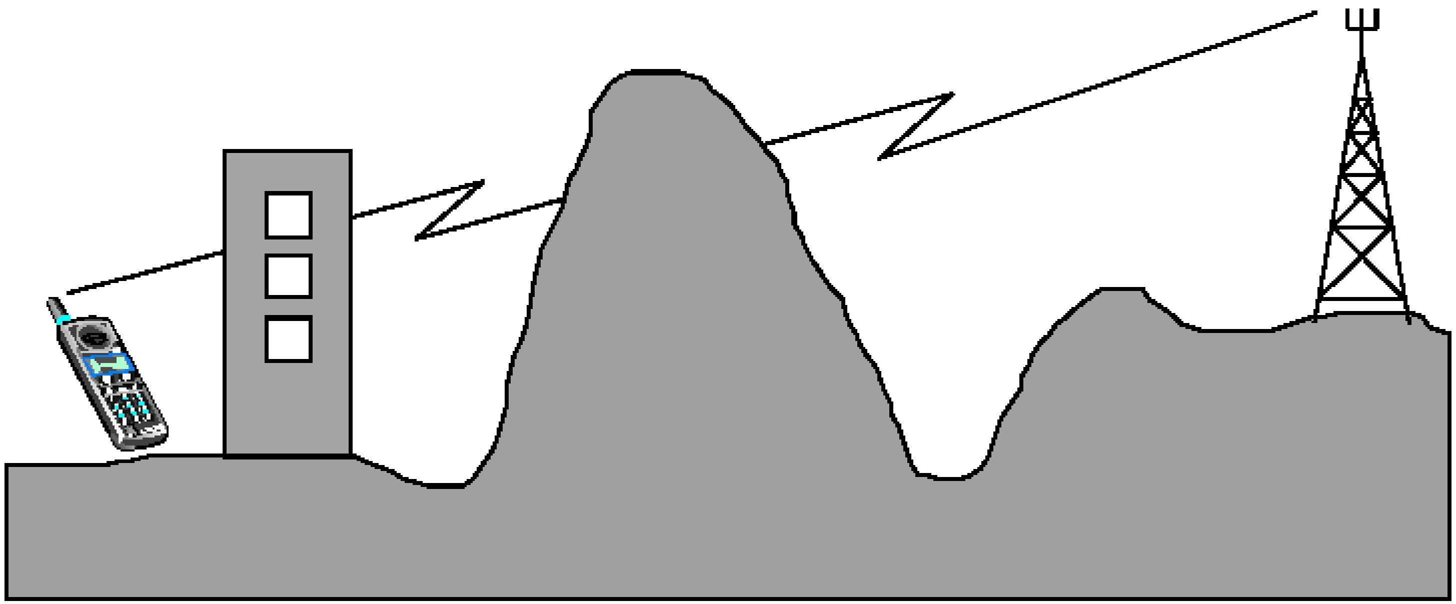
Most cellular radio systems operate in urban areas where there is no direct line-of-sight path between the transmitter and the receiver, and where the presence of high- rise buildings **causes severe diffraction loss.**

Propagation models have traditionally focused on **predicting the average received signal strength** at a given distance from the transmitter, as well as the variability of the signal strength in close spatial proximity to a particular location.

Fading Problems

1. Shadowing (Normal fading):

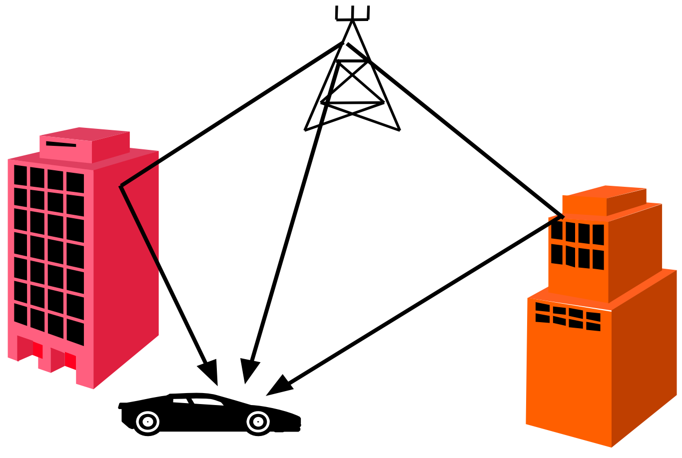
The reason for shadowing is the presence of obstacles like large hills or buildings in the path between the site and the mobile.
The signal strength received fluctuates around a mean value while changing the mobile position resulting in undesirable beats in the speech signal.



Fading Problems

2. Rayleigh Fading (Multi-path Fading)

The received signal is coming from different paths due to a series of reflection on many obstacles. The difference in paths leads to a difference in paths of the received components.



propagation models

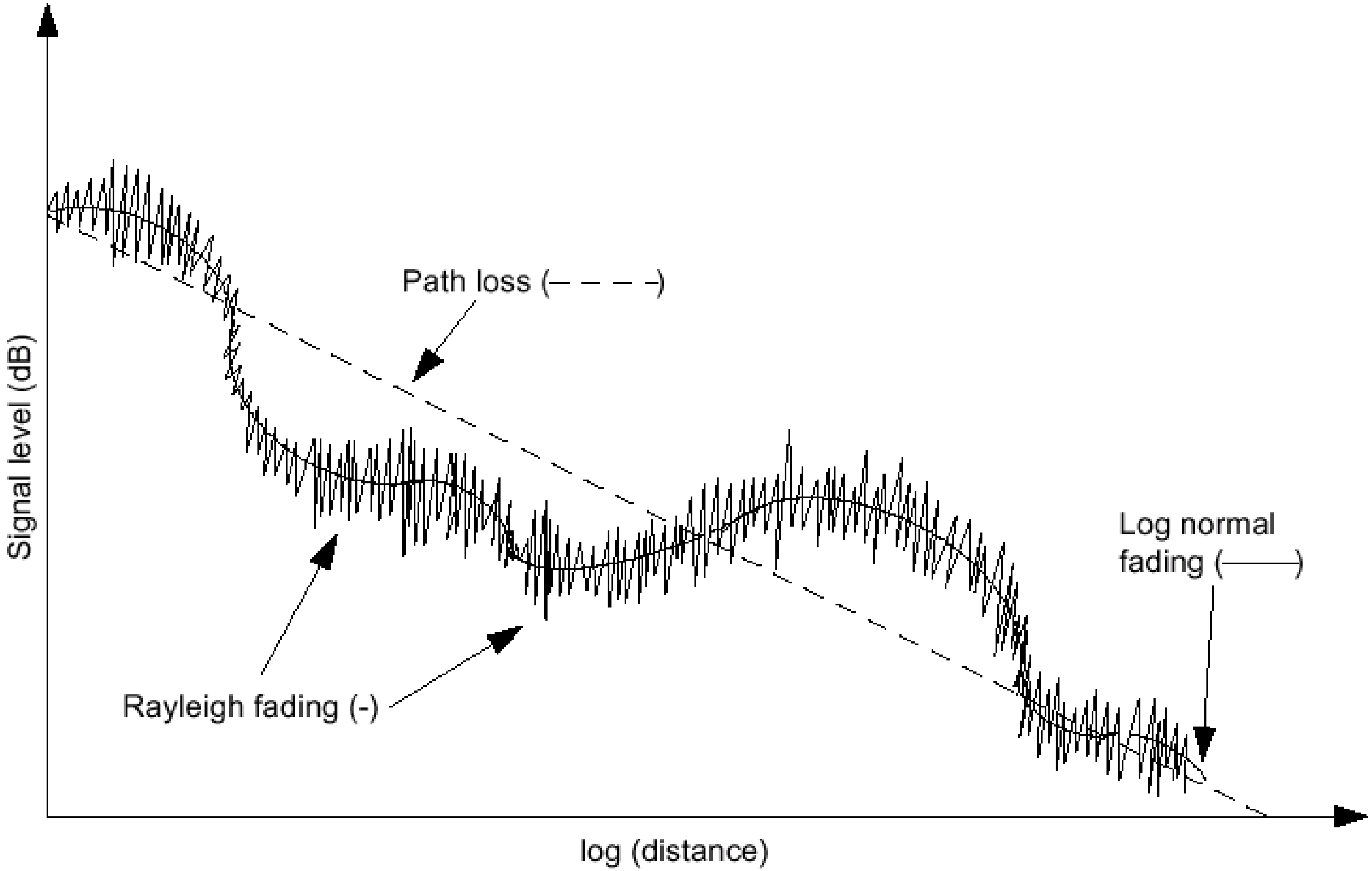
- Propagation models that predict the mean signal strength for an arbitrary transmitter-receiver (T-R) separation distance are useful in estimating the radio coverage area of a transmitter and are called **large-scale propagation models,** since they characterize signal strength over large T-R separation distances (several hundreds or thousands of meters).

- On the other hand, propagation models that characterize the rapid fluctuations of the received signal strength over very short travel distances (a few wavelengths) or short time durations (on the order of seconds) are called **small-scale or fading models.**

In small-scale fading, the received signal power may vary by as much as three or four orders of magnitude **(30 or 40 dB)** when the receiver is moved by only a fraction of a wavelength.

As the mobile moves away from the transmitter over much larger distances, the local average received signal will gradually decrease, and it is this local average signal level that is predicted by **large-scale propagation models.**

Fading Problems



Small-scale and large-scale fading

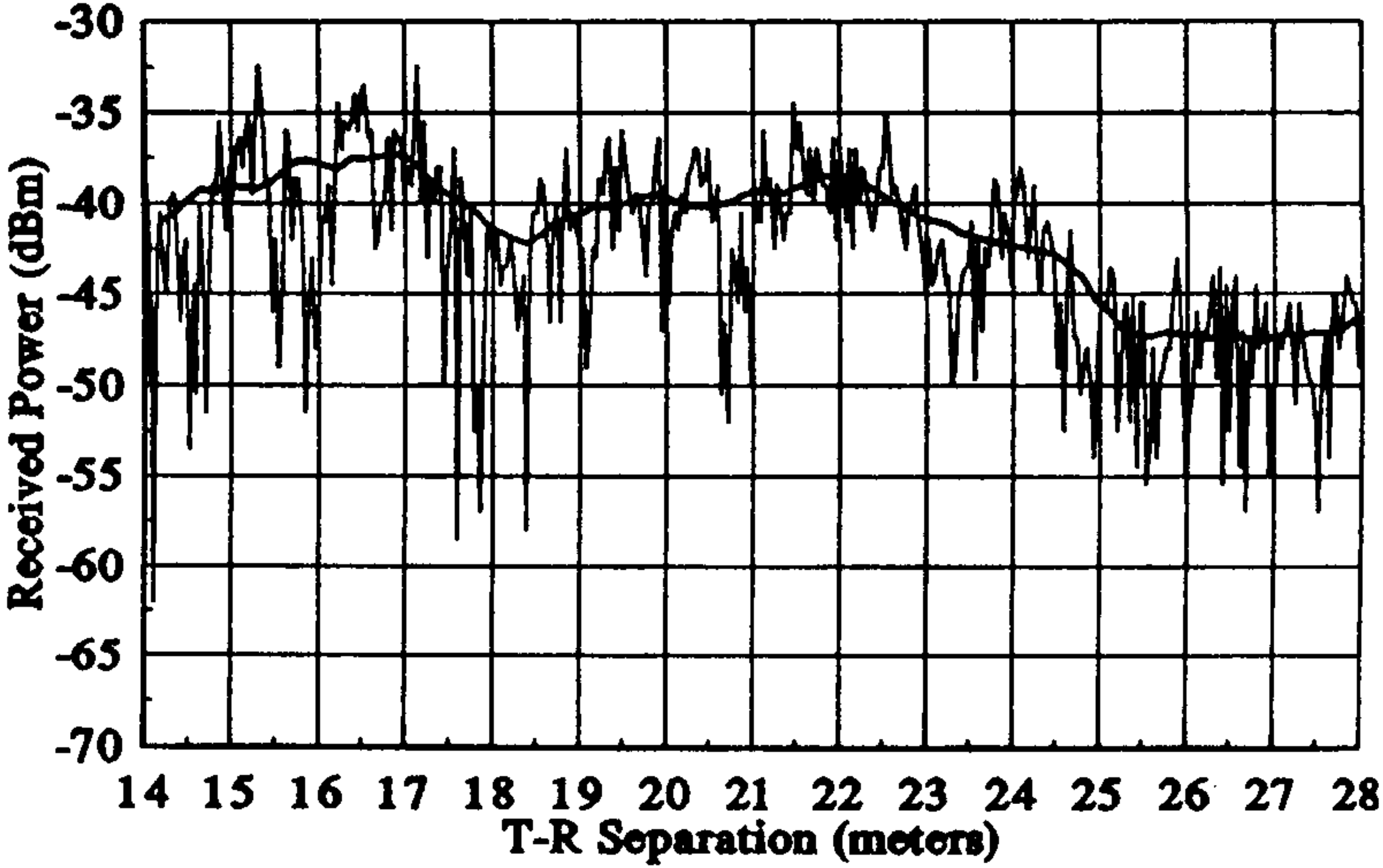
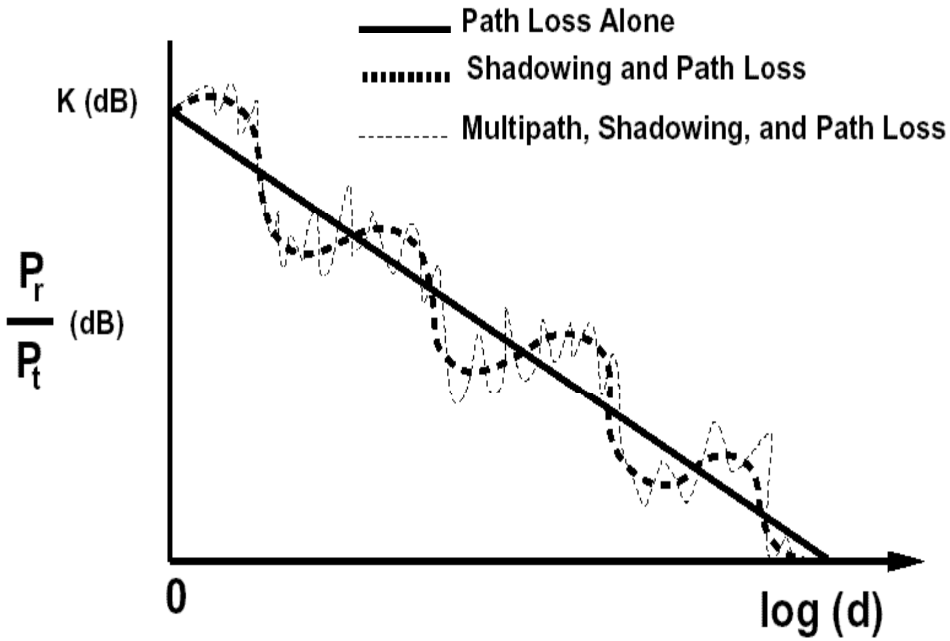


Figure 4.1 Small-scale and large-scale fading.

Basic Ideas: Path Loss, Shadowing, Fading

- Variable decay of signal due to environment, multipaths, mobility



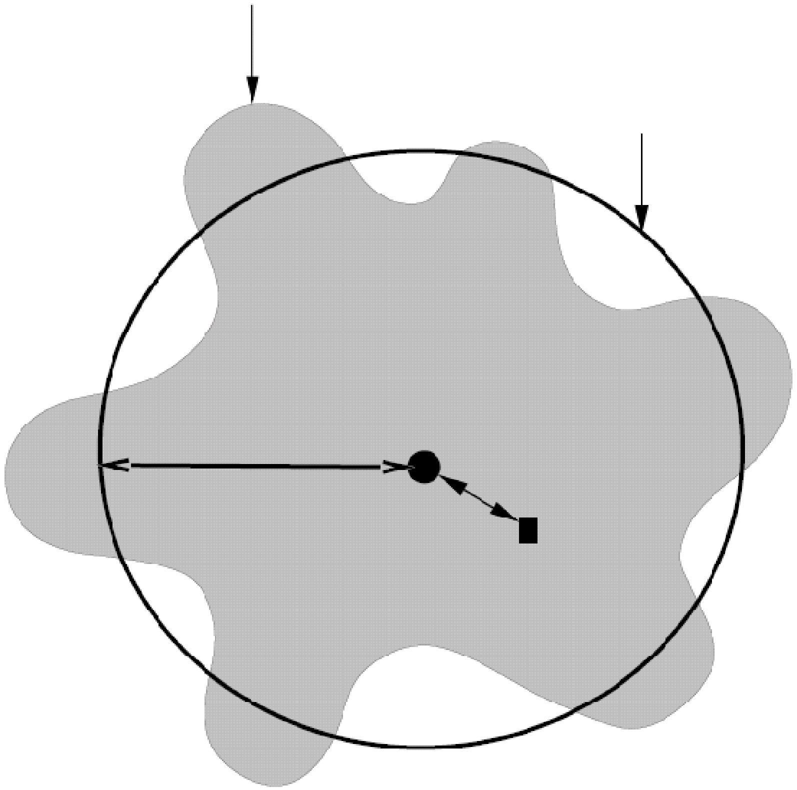
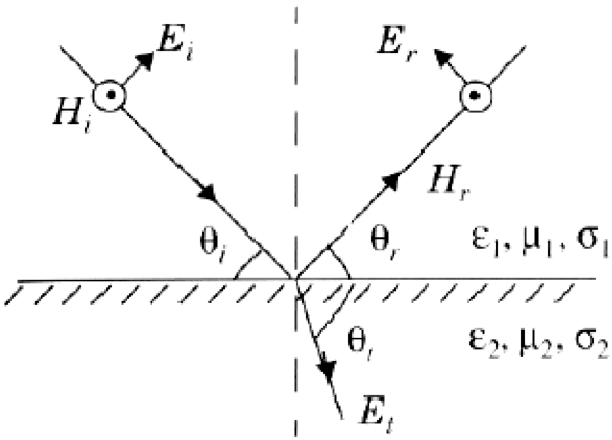


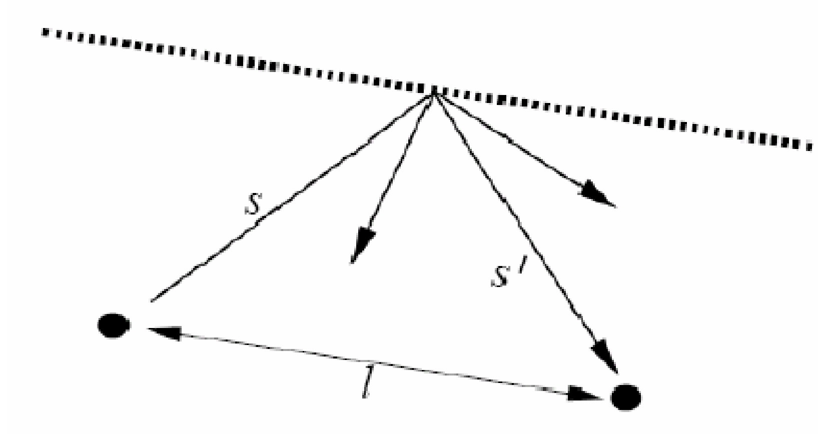
Figure 2.10: Contours of Constant Received Power.

Source: A. Goldsmith book

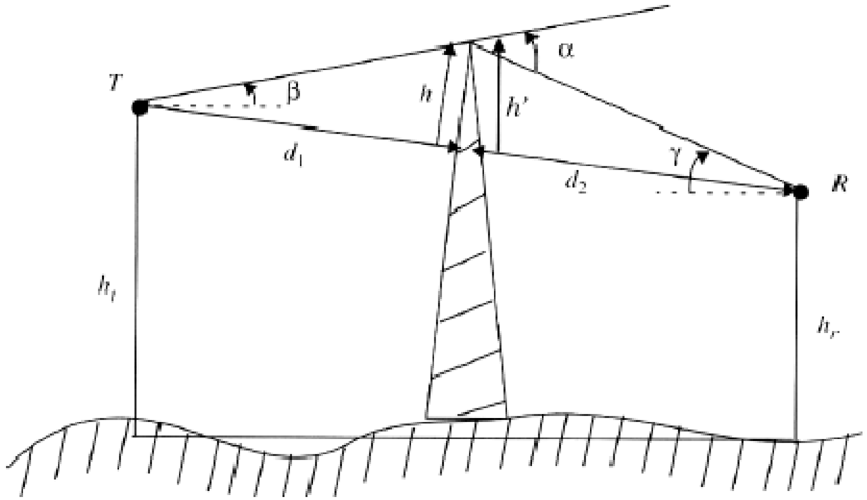
Reflection, Diffraction, Scattering



Reflection/Refraction: large objects (>>λ)



Scattering: small objects, rough surfaces (<λ): foilage, lamposts, street signs



Diffraction/Shadowing: "bending" around sharp edges,

- 900Mhz: λ ~ 30 cm
- 2.4Ghz: λ ~ 13.9 cm
- 5.8Ghz: λ ~ 5.75 cm

Large-scale Fading:
Path Loss, Shadowing

3.2 **Free Space** Propagation Model

The free space propagation model is used to predict received signal strength **when the transmitter and receiver have a clear, unobstructed line-of-sight path between them.**

the free space model predicts that received power decays as a function of the T-R separation distance raised to some power (i.e. a power law function).

Free-Space-Propagation

- The EM radiation field that decays as 1/d (power decays as $1/d^2$)
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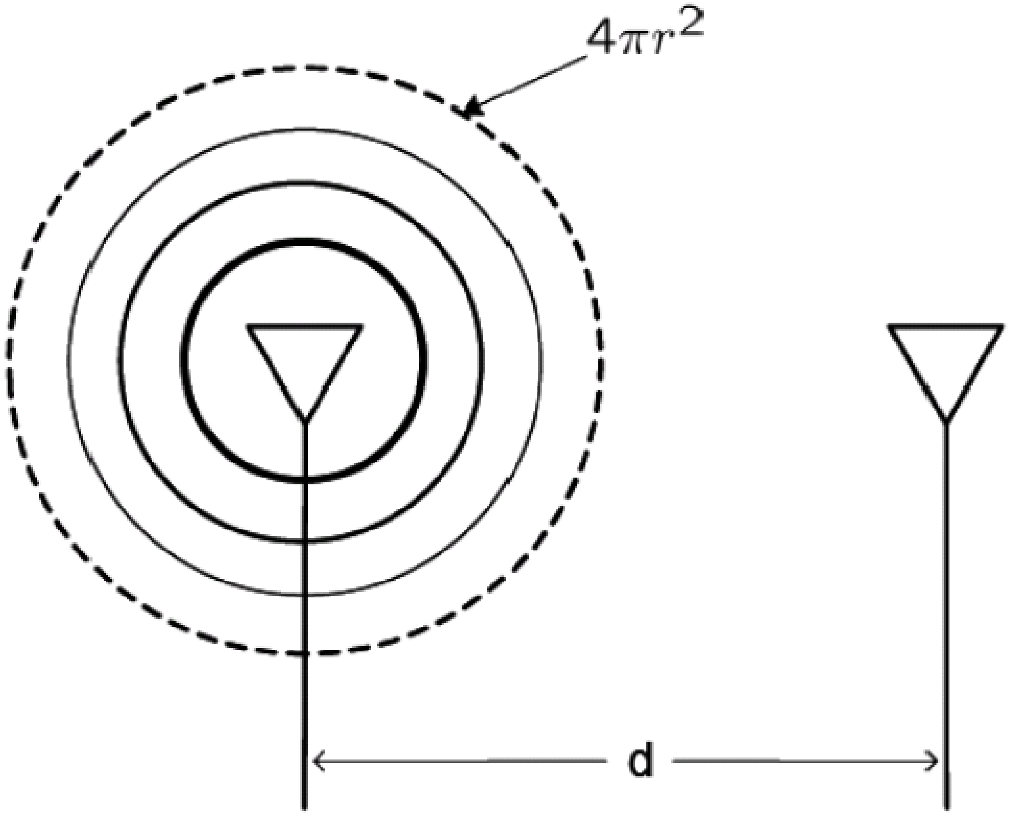

The free space power received by a receiver antenna which is separated from a radiating transmitter antenna by a distance **d**, is given by the **Friis free space equation,**

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \qquad (3.1)$$

Where

P_t is the transmitted power,

$P_r(d)$ is the received power which is a of the T-R separation,

G_t is the transmitter antenna gain,

G_r is the receiver antenna gain,

d is the T-R separation distance in meters,

L is the system loss factor not related to propagation **($L \geq 1$),** and

λ is the wavelength in meters.

The gain of an antenna is related to its **effective aperture**, ***Ae*** by

$$G = \frac{4\pi A_e}{\lambda^2} \quad (3.2)$$

The effective aperture A_e is related to the physical size of the antenna, and λ is related to the carrier frequency by

$$\lambda = \frac{c}{f} = \frac{2\pi c}{\omega_c} \quad (3.3)$$

where f is the carrier frequency in Hertz, ω_c is the carrier frequency in radians per second, and c is the speed of light given in meters/s

1. The values for $\mathbf{P_t}$ **and** $\mathbf{P_r}$ must be expressed in the same units,
2. and $\mathbf{G_t}$ **and** $\mathbf{G_r}$ are dimensionless quantities.
3. The miscellaneous losses **L** $(\mathbf{L \geq I})$ are usually due to transmission line attenuation, filter losses, and antenna losses in the communication system. A value of **L = 1** indicates no loss in the system hardware.
4. The Friis free space equation of (3.1) shows that the **received power** falls off as the **square of the T-R separation distance**. This implies that the received power decays with distance at a rate of 20 dB/decade.

An *isotropic* radiator is an ideal antenna which radiates power with unit gain uniformly in all directions, and is often used to reference antenna gains in wireless systems. The *effective isotropic radiated power (EIRP)* is defined as

$$EIRP = P_t G_t \tag{3.4}$$

and represents the maximum radiated power available from a transmitter in the direction of maximum antenna gain, as compared to an isotropic radiator.

In practice, effective radiated power (ERP) is used instead of EIRP to denote the maximum radiated power as compared to a half-wave dipole antenna (instead of an isotropic antenna).

Since a dipole antenna has a gain of **1.64** (2.15 dB above an isotropic), the ERP will be **2.15 dB** smaller than the EIRP for the same transmission system.

In practice, antenna gains are given in units of **dBi** (dB gain with respect to an isotropic source) or **dBd** (dB gain with respect to a half-wave dipole)

Decibels: dB, dBm, dBi

- **dB** (Decibel) = 10 $\log_{10}$ (Pr/Pt)
  Log-ratio of two signal levels. Named after Alexander Graham Bell. For example, a cable has 6 dB loss or an amplifier has 15 dB of gain. System gains and losses can be added/subtracted, especially when changes are in several orders of magnitude.

- **dBm (dB milliWatt)**
  Relative to 1mW, i.e. 0 dBm is 1 mW (milliWatt). Small signals are -ve (e.g. -83dBm).

  Typical 802.11b WLAN cards have +15 dBm (32mW) of output power. They also spec a -83 dBm RX sensitivity (minimum RX signal level required for 11Mbps reception).

  For example, 125 mW is 21 dBm and 250 mW is 24 dBm. (commonly used numbers)

- **dBi (dB isotropic) for EIRP (Effective Isotropic Radiated Power)**

  The gain a given antenna has over a theoretical isotropic (point source) antenna. The gain of microwave antennas (above 1 GHz) is generally given in dBi.

- **dBd (dB dipole)**
  The gain an antenna has over a dipole antenna at the same frequency. A dipole antenna is the smallest, least gain practical antenna that can be made. A dipole antenna has 2.14 dB gain over a 0 dBi isotropic antenna. Thus, a simple dipole antenna has a gain of 2.14 dBi or 0 dBd and is used as a standard for calibration.

  The term dBd (or sometimes just called dB) generally is used to describe antenna gain for antennas that operate under 1GHz (1000Mhz).

The *path loss*, which represents signal attenuation as a positive quantity measured in dB, is defined as the difference (in dB) between the effective transmitted power and the received power, and may or may not include the effect of the antenna gains. The path loss for the free space model when antenna gains are included is given by

$$PL\,(\mathrm{dB}) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right] \tag{3.5}$$

When antenna gains are excluded, the antennas are assumed to have unity gain, and path loss is given by

$$PL\,(\mathrm{dB}) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] \tag{3.6}$$

The Friis free space model is only a valid predictor for P_r for values of d which are in the far-field of the transmitting antenna. The far-field, or *Fraunhofer region*, of a transmitting antenna is defined as the region beyond the far-field distance d_f, which is related to the largest linear dimension of the transmitter antenna aperture and the carrier wavelength.

mitter antenna aperture and the carrier wavelength. The Fraunhofer distance is given by

$$d_f = \frac{2D^2}{\lambda} \tag{3.7.a}$$

where D is the largest physical linear dimension of the antenna. Additionally, to be in the far-field region, d_f must satisfy

$$d_f \gg D \tag{3.7.b}$$

and

$$d_f \gg \lambda \tag{3.7.c}$$

a close-in distance, d0, as a known received power reference point.

The received power, $P_r(d)$. at any distance $d > d_0$,

The reference distance must be chosen such that it lies in the

far-field region, that is, $d_0 > d_f$, and d_0 is chosen to be smaller than any practical distance used in the mobile communication system.

$$P_r(d) = P_r(d_0)\left(\frac{d_0}{d}\right)^2 \qquad d \geq d_0 \geq d_f$$

may be expressed in units of **dBm** or **dBW** by simply taking the logarithm of both sides and multiplying by 10.

For example, if *Pr* is in units of dBm, the received power is given by

$$P_r(d)\ \text{dBm} = 10\log\left[\frac{P_r(d_0)}{0.001\ \text{W}}\right] + 20\log\left(\frac{d_0}{d}\right) \qquad d \geq d_0 \geq d_f$$

Example 3.1

Find the far-field distance for an antenna with maximum dimension of 1 m and operating frequency of 900 MHz.

Solution to Example 3.1

Given:

Largest dimension of antenna, $D = 1$ m

Operating frequency $f = 900$ MHz, $\lambda = c/f = \dfrac{3 \times 10^8 \text{ m/s}}{900 \times 10^6 \text{ Hz}}$ m

Using equation (3.7.a), far-field distance is obtained as

$$d_f = \frac{2(1)^2}{0.33} = 6 \text{ m}$$

Example 3.2

If a transmitter produces 50 watts of power, express the transmit power in units of (a) dBm, and (b) dBW. If 50 watts is applied to a unity gain antenna with a 900 MHz carrier frequency, find the received power in dBm at a free space distance of 100 m from the antenna. What is P_r (10 km) ? Assume unity gain for the receiver antenna.

Solution to Example 3.2

Given:

Transmitter power, $P_t = 50$ W.

Carrier frequency, $f_c = 900$ MHz

Using equation (3.9),

(a) Transmitter power,

$$P_t(\text{dBm}) = 10\log\left[P_t(\text{mW})/(1\ \text{mW})\right]$$
$$= 10\log\left[50 \times 10^3\right] = 47.0\ \text{dBm}.$$

(b) Transmitter power,

$$P_t(\text{dBW}) = 10\log\left[P_t(\text{W})/(1\ \text{W})\right]$$
$$= 10\log\left[50\right] = 17.0\ \text{dBW}.$$

The received power can be determined using equation (3.1).

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} = \frac{50\,(1)\,(1)\,(1/3)^2}{(4\pi)^2 (100)^2 (1)} = 3.5 \times 10^{-6}\ \text{W} = 3.5 \times 10^{-3}\ \text{mW}$$

$$P_r(\text{dBm}) = 10\log P_r(\text{mW}) = 10\log\left(3.5 \times 10^{-3}\ \text{mW}\right) = -24.5\ \text{dBm}.$$

The received power at 10 km can be expressed in terms of dBm using equation (3.9), where $d_0 = 100$ m and $d = 10$ km

$$P_r(10\ \text{km}) = P_r(100) + 20\log\left[\frac{100}{10000}\right] = -24.5\ \text{dBm} - 40\ \text{dB}$$
$$= -64.5\ \text{dBm}.$$