Introduction

- The mobile radio channel places fundamental limitations on the performance of a wireless communication system
- The wireless transmission path may be
  - Line of Sight (LOS)
  - Non line of Sight (NLOS)
- Radio channels are random and time varying
- Modeling radio channels have been one of the difficult parts of mobile radio design and is done in statistical manner
- When electrons move, they create EM waves that can propagate through space.
- By using antennas we can transmit and receive these EM wave
- Microwave ,Infrared visible light and radio waves can be used.

Properties of Radio Waves

- Are easy to generate
- Can travel long distances
- Can penetrate buildings
- May be used for both indoor and outdoor coverage
- Are omni-directional-can travel in all directions
- Can be narrowly focused at high frequencies(>100MHz) using parabolic antenna

Properties of Radio Waves

- Frequency dependence
  - Behave more like light at high frequencies
    - Difficulty in passing obstacle
    - Follow direct paths
    - Absorbed by rain
  - Behave more like radio at lower frequencies
    - Can pass obstacles
    - Power falls off sharply with distance from source
- Subject to interference from other radio waves

Propagation Models

- The statistical modeling is usually done based on data measurements made specifically for
  - the intended communication system
  - the intended spectrum

- They are tools used for:
  - Predicting the average signal strength at a given distance from the transmitter
  - Estimating the variability of the signal strength in close spatial proximity to a particular locations

Propagation Models

- Large Scale Propagation Model:
  - Predict the mean signal strength for an arbitrary transmitter-receiver(T-R) separation
  - Estimate radio coverage of a transmitter
  - Characterize signal strength over large T-R separation distances(several 100's to 1000's meters)

Free Space Propagation Model

- For clear LOS between T-R
  - Ex: satellite & microwave communications
- Assumes that received power decays as a function of T-R distance separation raised to some power.
- Given by Friis free space eqn:

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

'L' is the system loss factor

L >1 indicates loss due to transmission line attenuation, filter losses & antenna losses

L = 1 indicates no loss in the system hardware

- Gain of antenna is related to its effective aperture A_e by

$$G = 4\pi A_e / \lambda^2$$

Free Space Propagation Model

- Effective Aperture A_e is related to physical size of antenna.

$$\lambda = c/f.$$

- c is speed of light,
- P_t and P_r must be in same units
- G_t ad G_r are dimensionless

- An isotropic radiator, an ideal radiator which radiates power with unit gain uniformly in all directions, and is often used as reference

- Effective Isotropic Radiated Power (EIRP) is defined as

$$EIRP = P_t G_t$$

- Represents the max radiated power available from a transmitter in direction of maximum antenna gain, as compared to an isotropic radiator

Free Space Propagation Model

- In practice Effective Radiated Power (ERP) is used instead of (EIRP)
- Effective Radiated Power (ERP) is radiated power compared to half wave dipole antennas
- Since dipole antenna has gain of 1.64(2.15 dB)

$$ERP = EIRP - 2.15(dB)$$

- the ERP will be 2.15dB smaller than the EIRP for same Transmission medium

Free Space Propagation Model

- Path Loss (PL) represents signal attenuation and is defined as difference between the effective transmitted power and received power

$$Path\ loss\ PL(dB) = 10 \log [Pt/Pr]$$

$$= -10 \log \{GtGr\, \lambda^2/(4\pi)^2 d^2\}$$

- Without antenna gains (with unit antenna gains)

$$PL = -\ 10 \log \{\ \lambda^2/(4\pi)^2 d^2\}$$

- Friis free space model is valid predictor for P_r for values of d which are in the far-field of transmitting antenna

Free Space Propagation Model

- The far field or Fraunhofer region that is beyond far field distance d_f given as : $d_f=2D^2/\lambda$
- D is the largest physical linear dimension of the transmitter antenna
- Additionally, $d_f>>D$ and $d_f>>\lambda$
- The Friis free space equation does not hold for d=0
- Large Scale Propagation models use a close-in distance, d_o, as received power reference point, chosen such that $d_o>= d_f$
- Received power in free space at a distance greater then do

$$Pr(d)=Pr(do)(do/d)^2 \quad d>d_o>d_f$$

Pr with reference to 1 mW is represented as

$$Pr(d)=10\log(Pr(do)/0.001W)+20\log(do/d)$$

Electrostatic,inductive and radiated fields are launched, due to flow of current from anntena.

Regions far away from transmitter electrostatic and inductive fields become negligible and only radiated field components are considered.

Example

- What will be the far-field distance for a Base station antenna with
- Largest dimension D=0.5m
- Frequency of operation fc=900MHz,1800MHz

- For 900MHz
- λ =3*10^8/900*10^6)=0.33m
- df= 2D^2/ λ =2(0.5)^2/0.33=1.5m

Example

- 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

Given:
Transmitter power, $P_t = 50$ W.
Carrier frequency, $f_c = 900$ MHz

Using equation (3.9),
(a) Transmitter power,

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

(b) Transmitter power,

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

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

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

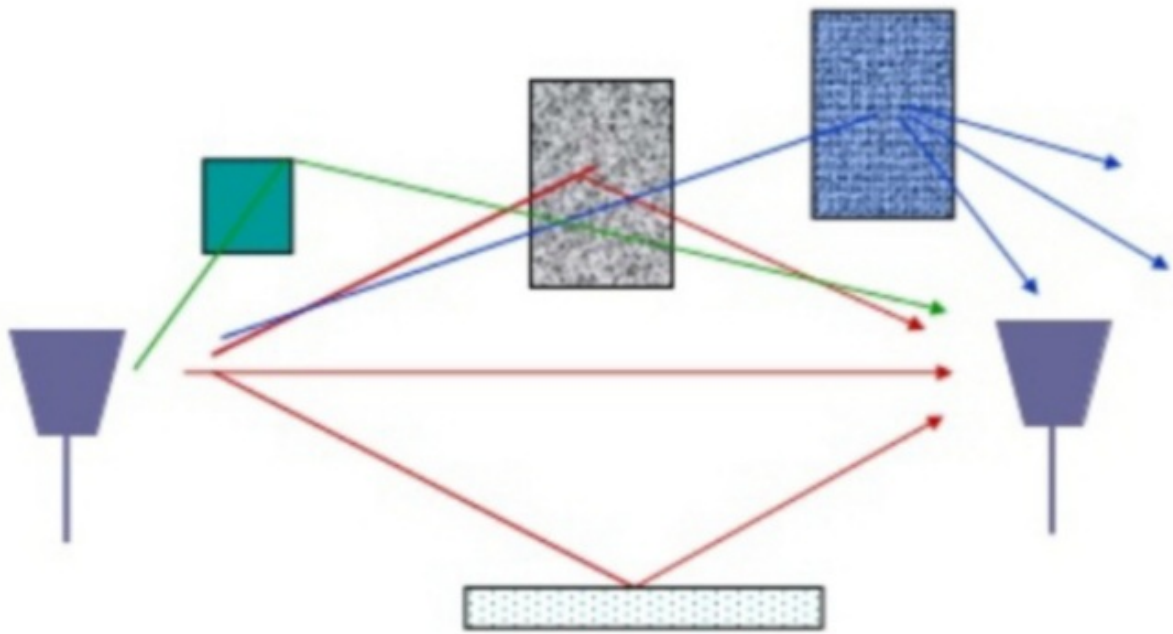
$$P_r(\text{dBm}) = 10\log P_r(\text{mW}) = 10\log\left(3.5 \times 10^{-3}\text{ mW}\right) = -24.5\text{ dBm}.$$

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

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

Propagation Mechanisms

- Three basic propagation mechanism which impact propagation in mobile radio communication system are:
  - Reflection
  - Diffraction
  - Scattering



Propagation Mechanisms

- Reflection occurs when a propagating electromagnetic wave impinges on an object which has very large dimensions as compared to wavelength e.g. surface of earth , buildings, walls

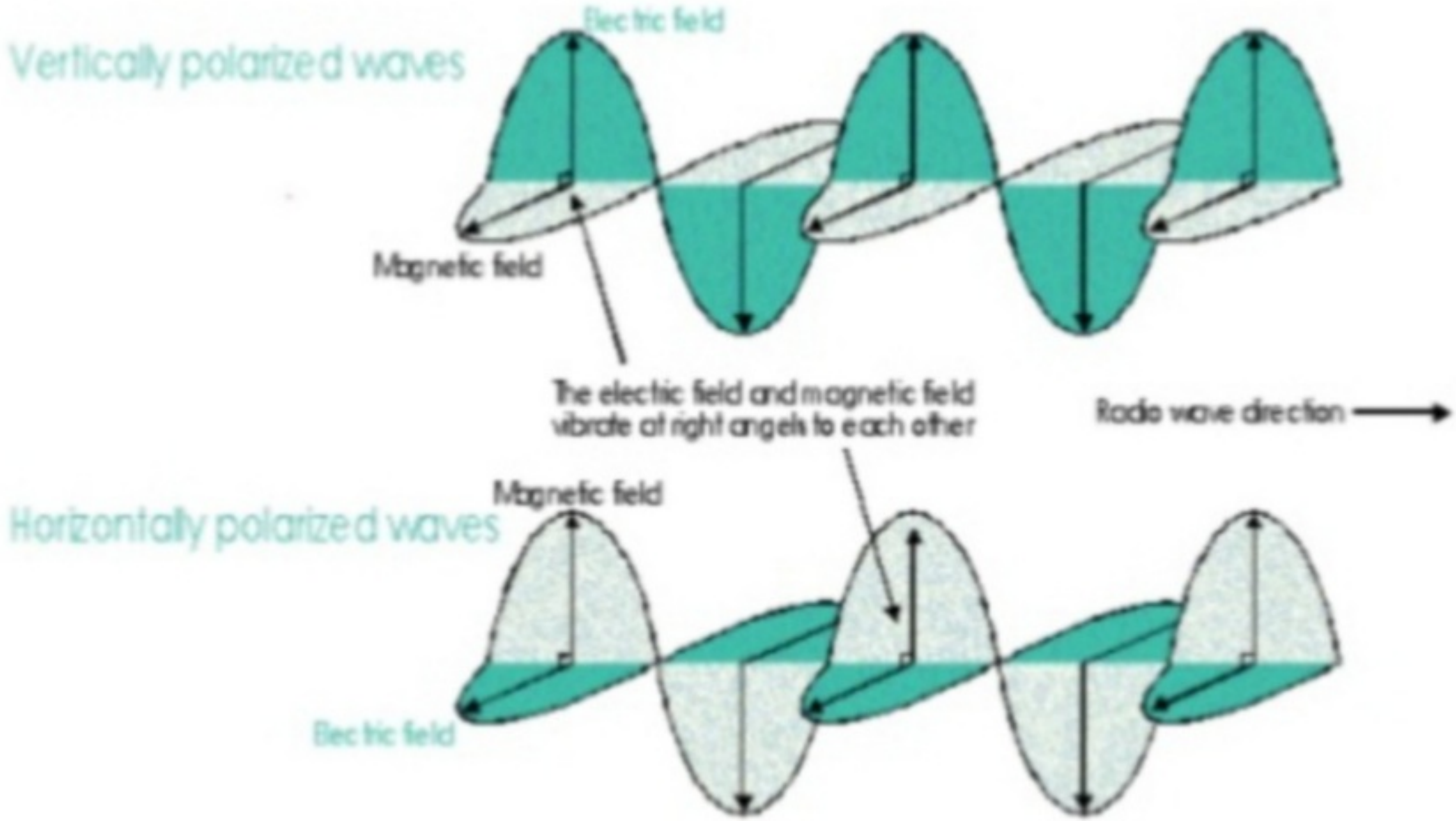
- Diffraction occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp irregularities(edges)
  - Explains how radio signals can travel urban and rural environments without a line of sight path

- Scattering occurs when medium has objects that are smaller or comparable to the wavelength (small objects, irregularities on channel, foliage, street signs etc)

Reflection

- Occurs when a radio wave propagating in one medium impinges upon another medium having different electrical properties
- If radio wave is incident on a perfect dielectric
  - Part of energy is reflected back
  - Part of energy is transmitted
- In addition to the change of direction, the interaction between the wave and boundary causes the energy to be split between reflected and transmitted waves
- The amplitudes of the reflected and transmitted waves are given relative to the incident wave amplitude by Fresnel reflection coefficients

Vertical and Horizontal polarization



Reflection- Dielectrics

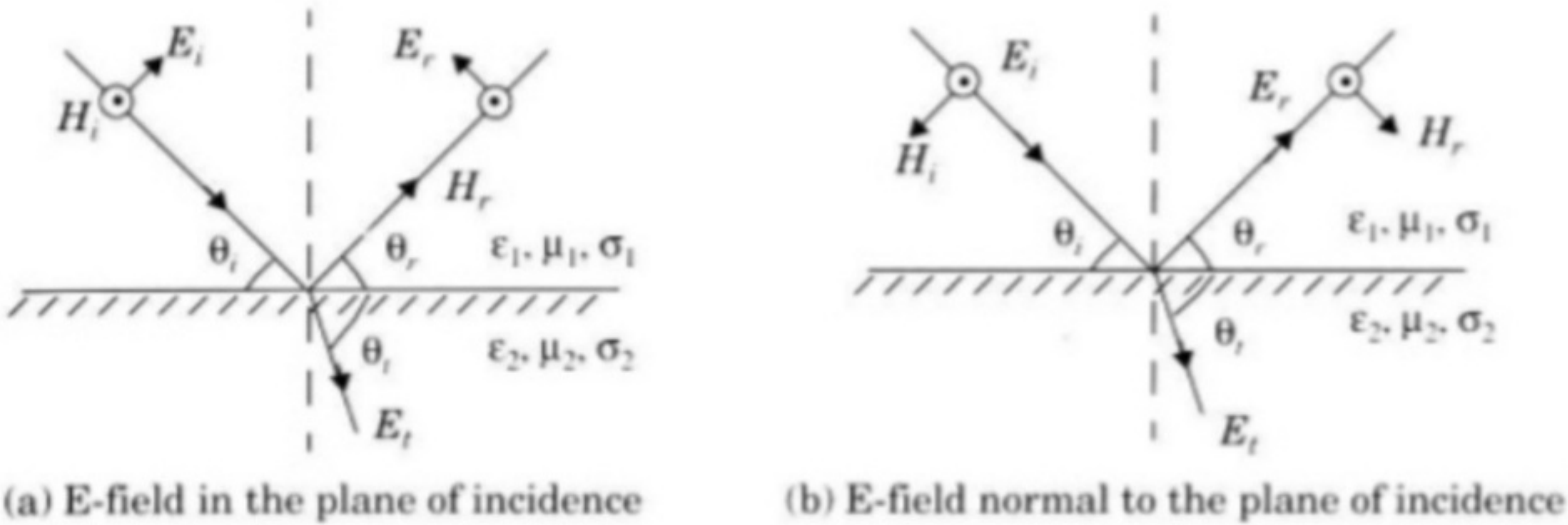


Figure 4.4 Geometry for calculating the reflection coefficients between two dielectrics.

Reflection

-
- $\Gamma(\parallel) = \frac{E_r}{E_i} = \frac{\eta_2 \sin\theta_t - \eta_1 \sin\theta_i}{\eta_1 \sin\theta_t + \eta_1 \sin\theta_i}$ (Paralell E-field polarization)

- $\Gamma(\perp) = \frac{E_r}{E_i} = \frac{\eta_2 \sin\theta_i - \eta_1 \sin\theta_t}{\eta_1 \sin\theta_i + \eta_1 \sin\theta_t}$ (Perpendicular E-field polarization)

- These expressions express ratio of reflected electric fields to the incident electric field and depend on impedance of media and on angles

- η is the intrinsic impedance given by $\sqrt{(\mu/\varepsilon)}$

- μ=permeability,ε=permittivity

Reflection-Perfect Conductor

- If incident on a perfect conductor the entire EM energy is reflected back
- Here we have $\theta_r = \theta_i$
- $E_i = E_r$ (E-field in plane of incidence)
- $E_i = -E_r$ (E field normal to plane of incidence)
- Γ(parallel)= 1
- Γ(perpendicular)= -1

Reflection - Brewster Angle

- It is the angle at which no reflection occur in the medium of origin. It occurs when the incident angle θ_B is such that the reflection coefficient Γ(parallel) is equal to zero.
- It is given in terms of θ_B as given below

$$Sin(\theta_B) = \sqrt{\frac{\varepsilon_1}{\varepsilon_1+\varepsilon_2}}$$

- When first medium is a free space and second medium has an relative permittivity of ε_r *then*

$$Sin(\theta_B) = \frac{\sqrt{\varepsilon_{r-1}}}{\sqrt{e_r^2 - 1}}$$

- Brewster angle only occur for parallel polarization

Ground Reflection(Two Ray) Model

- In mobile radio channel, single direct path between base station and mobile and is seldom only physical means for propagation
- Free space model as a stand alone is inaccurate
- Two ray ground reflection model is useful
  - Based on geometric optics
  - Considers both direct and ground reflected path
- Reasonably accurate for predicting large scale signal strength over several kms that use tall tower height
- Assumption: The height of Transmitter >50 meters

Ground Reflection(Two Ray) Model

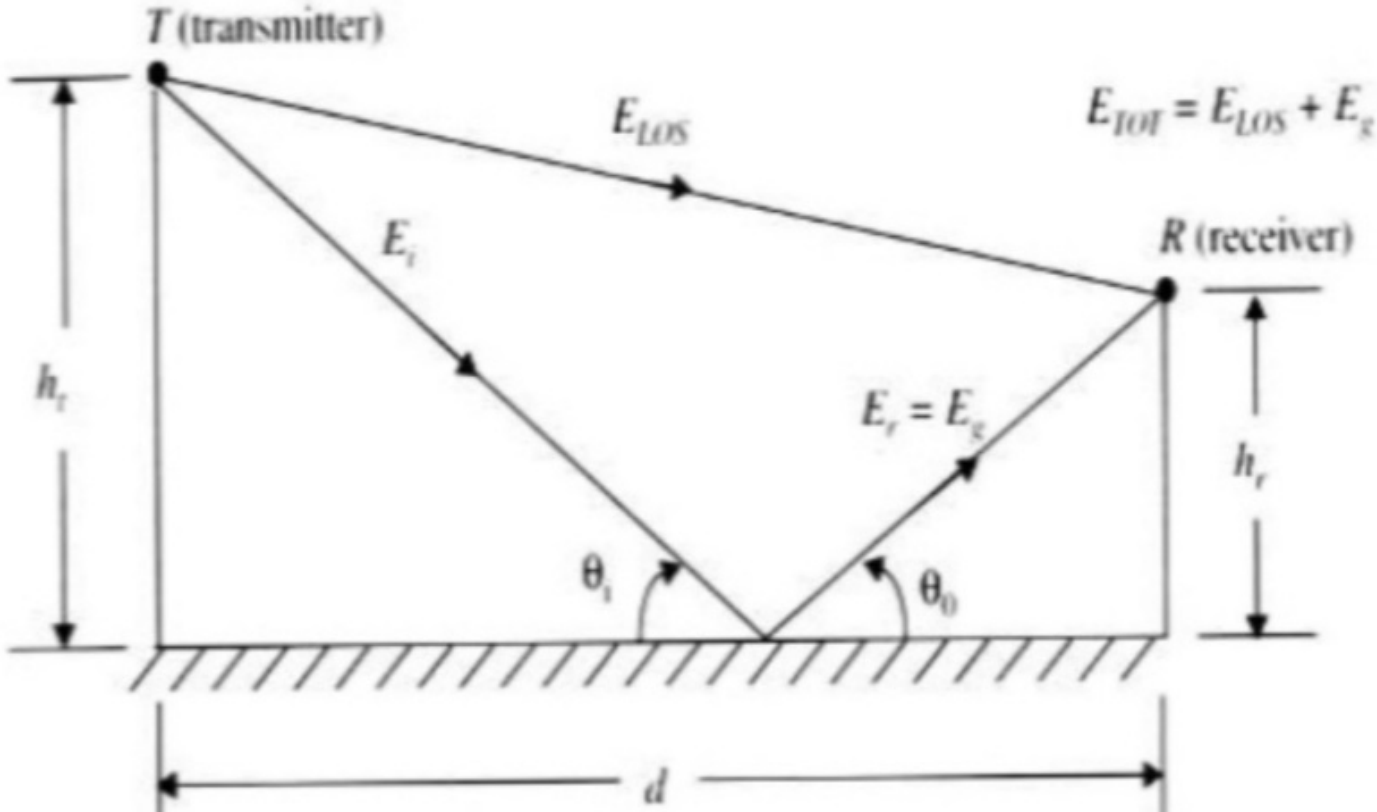


Figure 4.7 Two-ray ground reflection model.

Ground Reflection(Two Ray) Model

$$\vec{E}_{TOT} = \vec{E}_{LOS} + \vec{E}_g$$

let E_o be $|\vec{E}|$ at reference point d_o then

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

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

$$\vec{E}_{TOT}(d,t) = \left(\frac{E_0 d_0}{d'}\right)\cos\left(\omega_c\left(t - \frac{d'}{c}\right)\right) + \Gamma\left(\frac{E_0 d_0}{d''}\right)\cos\left(\omega_c\left(t - \frac{d''}{c}\right)\right)$$

$$E_{TOT}(d,t) = \frac{E_0 d_0}{d'}\cos\left(\omega_c\left(t - \frac{d'}{c}\right)\right) + (-1)\frac{E_0 d_0}{d''}\cos\left(\omega_c\left(t - \frac{d''}{c}\right)\right)$$

Ground Reflection(Two Ray) Model

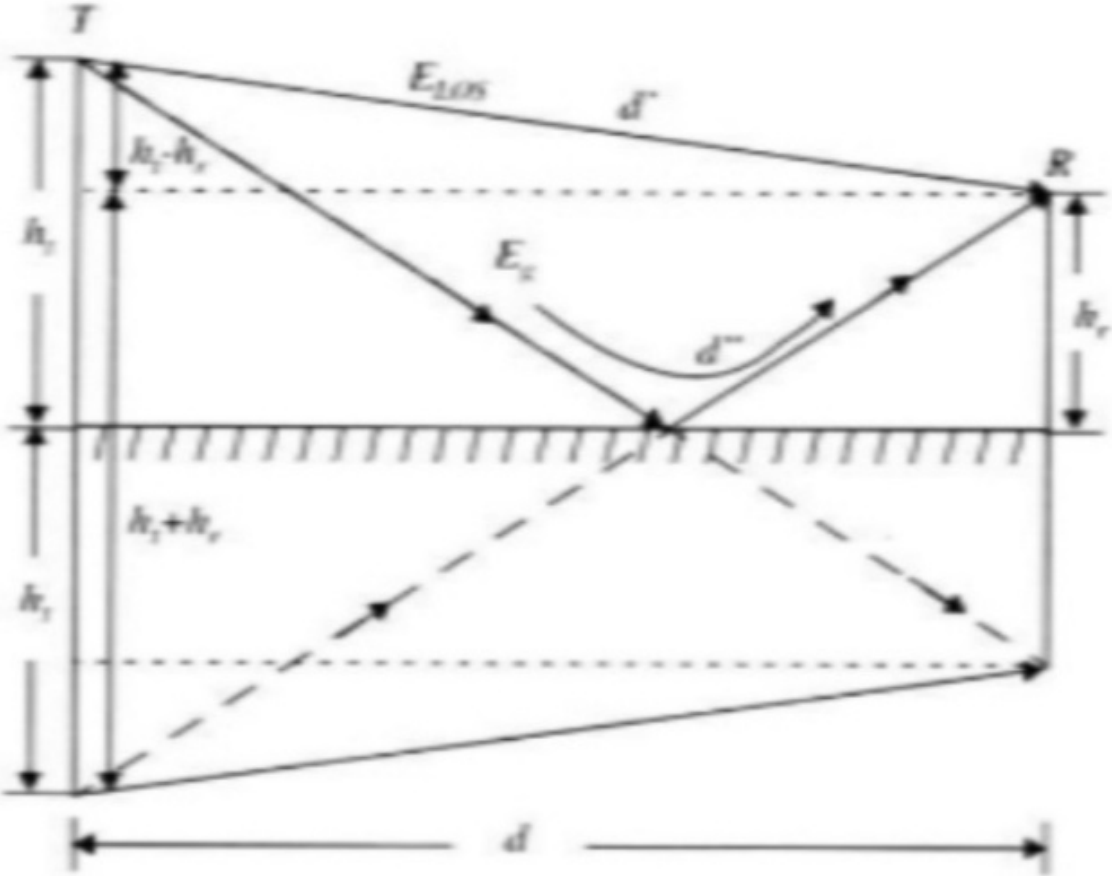


Figure 4.8 The method of images is used to find the path difference between the line-of-sight and the ground reflected paths.

Path Difference

$$\Delta = d'' - d' = \sqrt{(h_t + h_r)^2 + d^2} - \sqrt{(h_t - h_r)^2 + d^2}$$

$$= d\sqrt{\left(\left(\frac{h_t + h_r}{d}\right)^2 + 1\right)} - d\sqrt{\left(\left(\frac{h_t - h_r}{d}\right)^2 + 1\right)}$$

$$\approx d\left(1 + \frac{1}{2}\left(\frac{h_t + h_r}{d}\right)^2\right) - d\left(1 + \frac{1}{2}\left(\frac{h_t - h_r}{d}\right)^2\right)$$

$$\approx \frac{1}{2d}\left((h_t + h_r)^2 - (h_t - h_r)^2\right)$$

$$\approx \frac{1}{2d}\left(\left(h_t^2 + 2h_t h_r + h_r^2\right) - \left(h_t^2 - 2h_t h_r + h_r^2\right)\right)$$

$$\approx \frac{2h_t h_r}{d}$$

Phase difference

$$\theta_\Delta \text{ radians} = \frac{2\pi\Delta}{\lambda} = \frac{2\pi\Delta}{\left(c/f_c\right)} = \frac{\omega_c\Delta}{c}$$

$$\left|E_{TOT}(t)\right| = 2\frac{E_0 d_0}{d}\sin\left(\frac{\theta_\Delta}{2}\right)$$

$$\frac{\theta_\Delta}{2} \approx \frac{2\pi h_r h_t}{\lambda d} < 0.3 \text{ rad}$$

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

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

Diffraction

- Diffraction is the bending of wave fronts around obstacles.

- Diffraction allows radio signals to propagate behind obstructions and is thus one of the factors why we receive signals at locations where there is no line-of-sight from base stations

- Although the received field strength decreases rapidly as a receiver moves deeper into an obstructed (shadowed) region, the diffraction field still exists and often has sufficient signal strength to produce a useful signal.

Knife-edge Diffraction Model

- Estimating the signal attenuation caused by diffraction of radio waves over hills and buildings is essential in predicting the field strength in a given service area.
- As a starting point, the limiting case of propagation over a knife edge gives good in sight into the order of magnitude diffraction loss.
- When shadowing is caused by a single object such as a building, the attenuation caused by diffraction can be estimated by treating the obstruction as a diffracting knife edge

Knife-edge Diffraction Model

Consider a receiver at point *R located in the shadowed region. The field strength at point R is a vector sum of the fields due to all of the secondary Huygens sources in the plane above the knife edge.*

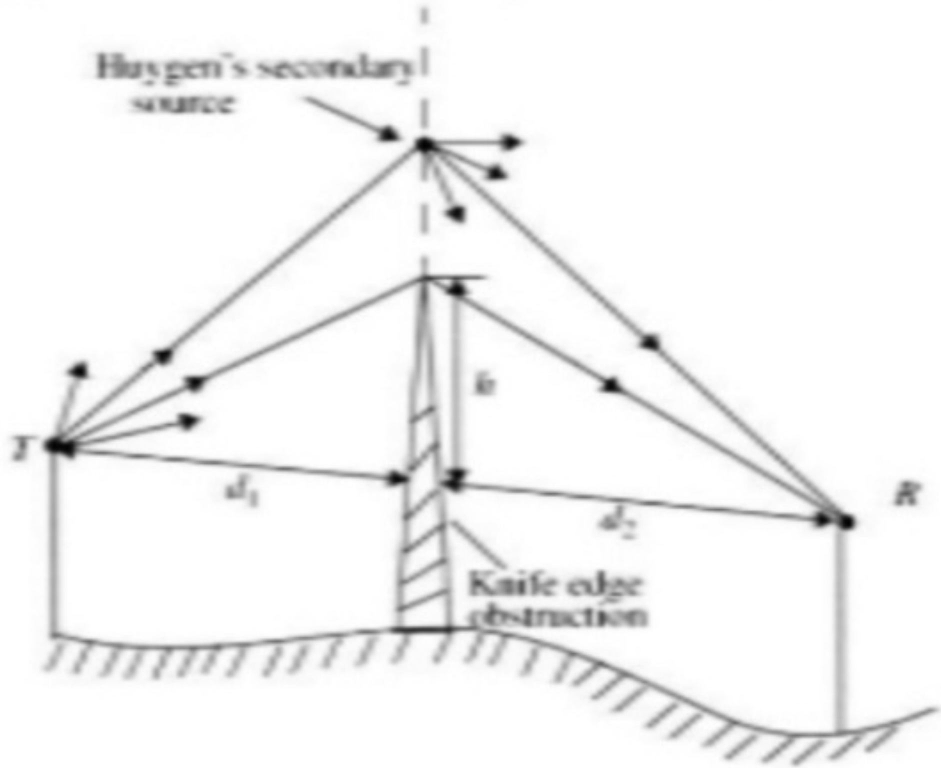


Figure 4.13 Illustration of knife-edge diffraction geometry. The receiver *R* is located in the shadow region.