Lecture 2: Wireless propagation mechanisms

In this lecture we will discuss the basic mechanisms that governs the propagation of electromagnetic waves which are used in wireless communications.

Three basic mechanisms are:

- reflection
- diffraction
- scattering.

First we will discuss free space attenuation as the simplest scenario to provide the basics.

1. Free space attenuation:

Consider a transmit and a receive antenna in free space, separated by a distance d.

The received power at the receive antenna is given by

$$P_{RX}(d) = P_{TX} \cdot G_{TX} \cdot \frac{1}{4\pi d^2} \cdot A_{RX}$$

$$= P_{TX} \cdot G_{TX} \cdot G_{RX} \cdot \left(\frac{\lambda}{4\pi d}\right)^2 \quad \text{(Friis' law)}$$

where:

P_{TX} : transmit power

G_{TX} : transmit antenna gain in the direction of the receiver ($G_{TX} = 1$ for isotropic transmit antennas)

G_{RX} : receive antenna gain, $G_{RX} = \frac{4\pi}{\lambda^2} A_{RX}$.

Antenna gains depend on the type of antennas.

A_{RX} : (area) effective area of the receiver's antenna.

λ: wavelength ($\lambda = \frac{c}{f} = \frac{3 \times 10^8}{f}$).

d: distance between transmit and receive antennas.

The validity of Friis' law is restricted to the far field:

$d \gg \lambda$ and $d \gg$ largest dimension of the antenna

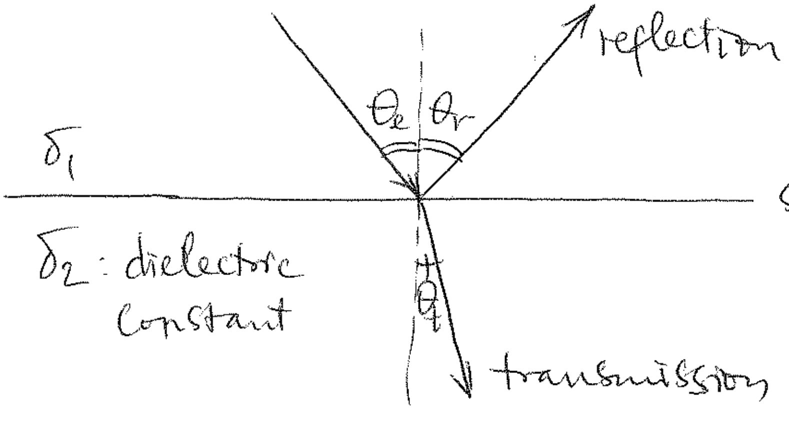
+) Free-space pathloss factor: $\left(\frac{\lambda}{4\pi d}\right)^2$.

We see that signal power decreases as the square of distance. The pathloss factor or pathloss exponent defines how received power varies with distance and is 2 for free space.

+) Wireless communications, however, do not often occur in free space, but in an environment filled with objects that affect the propagation of EM waves (even air particles do).

Next we will examine these effects.

2. Reflection and transmission:



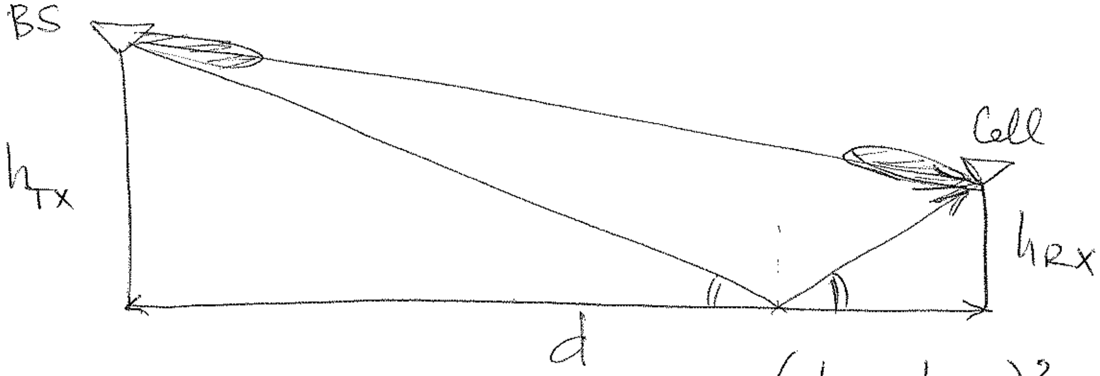
$\theta_r = \theta_e$ reflection

$\frac{\sin\theta_t}{\sin\theta_e} = \frac{\sqrt{\delta_1}}{\sqrt{\delta_2}}$ transmission

Reflection and transmission for a layer of dielectric structure (such as through the wall for cell phones indoor) are complicated to model.

Multilayer structures are often desribed by "effective" dielectric constants or reflection / transmission constants, which are measured directly for each composite structure.

+) Using a two-ray model: a direct path and a reflected path off the ground, we can derive a "text book" model:



$$P_{RX}(d) \simeq P_{TX} G_{TX} G_{RX} \left(\frac{h_{TX} h_{RX}}{d^2} \right)^2$$

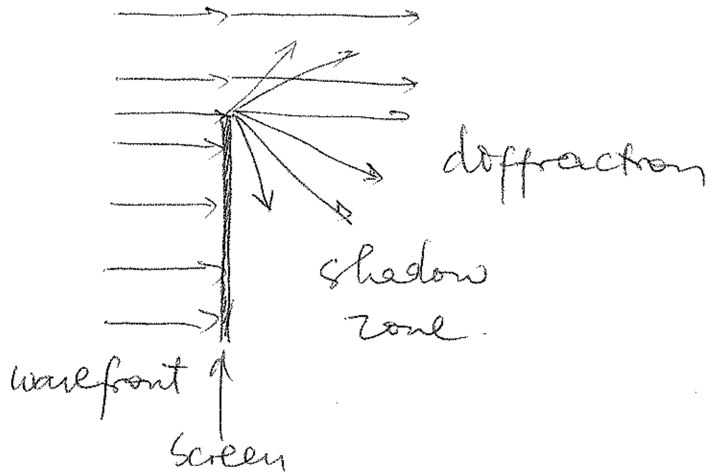
This model predicts power attenuation with path loss factor of 4 ($\sim d^{-4}$) and is independent of the wavelength.

It holds only for $d \gtrsim \frac{4 h_{TX} h_{RX}}{\lambda}$.

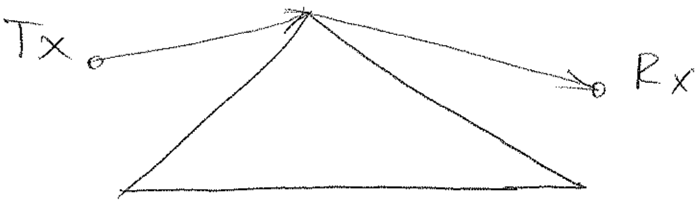
In reality, this model is imprecise (because of the over simplification), and path loss exponent can be measured in the range $1.5 < \gamma < 5.5$.

3. Diffraction: While reflection assumes infinitely extended objects / surfaces, all real objects have finite size! These finite-size objects creates diffraction at the edges.

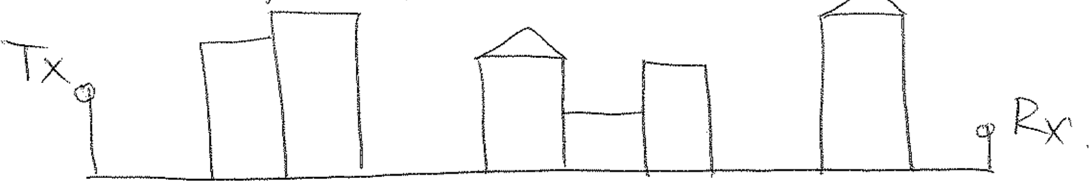
+) Diffraction by a knife edge or screen.



+) Diffraction by a wedge:



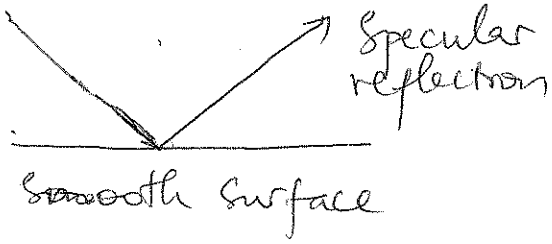
+) Models for diffraction in urban areas (multiple sreen)

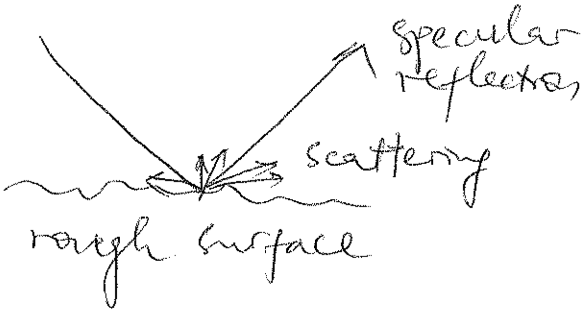


Modeling diffraction by multiple sreens is an extremely challenging mathematical problem and usually does not have exact solutions, though many approximation methods exist.

4. Scattering by rough surfaces:

While reflection assumes a smooth surface, all / most practical surfaces contain some roughness which is usually assumed to be random.





Reflection has been studied extensively due to radar technology, with two main theories evolved: the Kirchoff theory and the perturbation theory.

Large scale propagation model.

$$P_{RX}(d) = P_{TX}(1m) - 20\log(d_{break}/1m) - \gamma\, 10\log(d/d_{break})$$

$$P_r(d) = P_{TX}(1m) + 10\log_{10}K - 10\gamma\log\frac{d}{d_0} - \varphi_{dB}.$$