# Wireless Communication Systems

# Module 2: Mobile Radio Propagation

Main reference: Rappaport Chapter 4,5
Minor reference: Stallings Chapter 5

## Part 2

Main Reference: Rappaport Chapter 4, Sections 4.4-4.10
Minor reference: Stallings Chapter 5, Section 5.4

## Large scale fading

**Propagation mechanisms** (Rappaport Section 4.4 and bits of 4.5, 4.7, 4.8)

Propagation paths: Line-of-sight (LOS) and Non-line-of-sight (NLOS).
NLOS paths include those involving reflections, diffraction and/or scattering.

Reflection

- When propagating EM waves impinge on object which has dimensions much larger than wavelength of EM wave.
- For f=1GHz, $\lambda$=30cm….. reflections from earth's surface, buildings, walls.
- In general, fraction of incident energy is also transmitted into body of reflecting object.
- E.g. If the reflecting object (i.e. transmitting medium) is a perfect conductor then all of the incident energy is reflected, otherwise only part of the incident energy is reflected.
- In general, fraction of reflected energy $\Gamma$ depends on the material properties of the incident and transmitting media, and on the properties of the propagating EM waves (angle of incidence, polarization ,frequency).

Diffraction

- Bending of propagating EM waves around large objects lying between the Tx and Rx.
- Enables transmitted signal to be received when receiver in the `shadow' of an object … signal diffracts around the object.
- Diffraction is explained by Huygen's principle:
    1. all points on a wavefront can be considered as point sources for the production of secondary wavelets
    2. Strength of the total signal at any point is given by the phasor sum of the secondary wavelets.
    3. The wavefront corresponds to the line of points at which constructive phasor summing occurs. In absence of obstructing objects, the wavefront is circular/spherical. In the presence of obstructing objects, the wavefront (line of constructive phasor summing) bends around the object.

- Let us denote diffracting object/edge by *obs* (obstructing object). Diffracting signal strength dependent on the diffracting angle (angle between the line Tx-obs and the line obs-Rx) and the distance between Tx and Rx. Note: the diffracting angle (and therefore the diffracting signal strength) is dependent on the relative heights of Tx, obs and Rx.
- The strength of the diffraction signal is also affected by the roughness of the diffracting/obstructing object. Reason: an object with a rough edge/surface causes random scattering waves. These interfere with the constructive phasor summing, leading to a weaker diffraction signal.

Scattering

- Caused by:
    1. rough surfaces (variation in surface height comparable to, or larger than EM wavelength);
    2. small objects (dimensions small compared to EM wavelength).
    3. large number of (small) objects per unit volume.
- Rough surface: reflected energy spreads out in `all' directions. In general, all reflective surfaces cause some scattering.
- Examples of small objects: lampposts, street signs, foliage.

Received signal strength

$P_R$(NLOS)=reflected strength + diffracted strength + scattered strength.

$P_R$(NLOS+LOS) can be greater than or less than $P_R$(LOS).

**Large Scale Fading Propagation models** (Rappaport Sect 4.6, 4.9, 4.10)

- Used to predict large scale fading effects … attenuation (or path loss).
- Three model categories: (1) general models, (2) empirical models, (3) analytical models.
- Analytical models are site specific (specific location of RX, TX in a given environment) and are based on detailed analysis of reflection, diffraction and scattering effects. Examples: 2-ray Ground reflection model, Longley-Rice model, Durkin model.
- Empirical models: heuristically derived path loss equations involving relevant parameters, such as TX antenna height, signal frequency, TX-RX separation distance. The parameter coefficients, for a particular environment (e.g. suburban), are determined using measured path loss data. Examples: Hata model, Okumura model.
- General models: very general models. Example: log normal shadowing model.

**Analytical model: 2-ray Ground Reflection model** (Sect 4.6 Rappaport)

This model is the simplest of the analytical model types. It is reasonably accurate for predicting large scale fading effects in various mobile radio system environments, particularly microcell environments with LOS.

Received signal equals sum of LOS signal and signal reflected from ground. See Figure 4.7 Rappaport.

Let $h_T$ and $h_R$ be the height of the transmitter Tx and receiver Rx, respectively, above the ground.
Let d be the distance along the ground between Tx and Rx.
Let d'=distance traveled by LOS signal and d''=distance traveled by NLOS signal.
Let $\theta = 2\pi (d''-d')/\lambda$ = *phase delay* of NLOS signal relative to LOS signal.
Assume $d >> h_T, h_R$ (that is incident angle and reflection angle are small), then:

$\theta \sim= 4\pi h_T h_R / (d \lambda)$

and $\Gamma \sim= -1$.
Hence total phase difference between NLOS and LOS signals is $\Delta\theta = \pi + \theta$.

Amplitude $V_R$ of received signal is determined via phasor addition of

LOS signal (amplitude proportional to 1/d` ~= 1/d; phase $\phi$)

and NLOS signal (amplitude proportional to 1/d'' ~= 1/d; phase $\phi - \Delta\theta$).
We find: amplitude of received signal $V_R$ proportional to $(1/d)\sin(\theta/2)$.
For small $\theta$, we have $\sin(\theta/2) \sim= \theta/2 \sim= 2\pi h_T h_R / (d \lambda)$. Hence received power $P_R$ proportional to $h_T^2 h_R^2 / (d^4 \lambda^2)$.

**General Path Loss model** (Section 4.9 Rappaport).

Used for obtaining approximate estimate of received signal strength as a function of distance (for a given general environment type)….useful for determining maximum coverage for given transmitted power $P_T$.

Consider a given environment e.g. suburban. Consider a large ensemble of TX-RX pairs within this environment, each of the pairs has the same TX-RX separation distance d. Let PL denote large scale fading path loss ($P_T/P_R$). Let $PL_{AVE}(d)$ denote the PL ensemble average, at TX-RX separation distance d.

**Log distance path model** (applicable to outdoor or indoor environments)
$PL_{AVE}(d)$ increases logarithmically with distance:

$PL_{AVE}(d)$ proportional to $d^n$

where n=path loss exponent, which depends on the environment type e.g. suburban.
Note: 2-ray ground reflection model corresponds to n=4, while free space propagation model corresponds to n=2.

More generally, we use:

$$PL_{AVE}(d) = PL_{AVE}(d_0)\,(d/d_0)^n$$

or $PL_{AVE}(d)\ dB = PL_{AVE}(d_0)\ dB + 10n\log(d/d_0)$

where $d>d_0$ and $d_0$ is a close-in reference distance → $PL_{AVE}(d_0)$ is determined from actual measurements.

See Table 4.2 Rappaport … path loss exponents for different environments.

1. Free space (LOS only): n=2
2. In building with LOS (i.e. LOS+NLOS): n<2.
3. In building without LOS (i.e. NLOS only): n>2
4. Urban area with LOS cellular radio: n>2
5. Urban area without LOS: n>2.

**Log normal shadowing model**

The *log distance model* describes the ensemble average path loss….however, it provides no indication of how the individual PL(d) values vary about this average (or mean).

The *log normal shadowing model* assumes the individual PL(d) *decibel* values form a Gaussian distribution with mean $PL_{AVE}(d)\ dB$ and variance $\sigma^2$.

That is the actual path loss (*decibels*) for a given Tx-Rx location is

$$PL(d)\ dB = PL_{ave}(d)\ dB + X_\sigma$$

where $X_\sigma$ is a sample from a zero mean normal (Gaussian) distribution with standard deviation $\sigma$. This log-normal distribution describes the different *shadowing* effects which occur within the environment.

The log normal shadowing model parameters n,$\sigma$ are dependent on the environment type.

See Rappaport Example 4.9(a),(b) for an example of calculating n and $\sigma$.

Received power:

$$P_R(d) dB = P_T\ dB - PL_{AVE}(d)\ dB - X_\sigma$$
$$= P_{R,AVE}(d)\ dB - X_\sigma.$$

Can predict probability of $P_R(d)\ dB$ falling below certain level.

1. Important for predicting probability of communication errors (or rate of communication errors).
2. Error rate depends on $P_R/P_N$ (where $P_N$ is the receiver noise power). The exact dependence depends on `modulation' scheme employed by transmitter
3. $P_N$ can be determined for a particular receiver (see Appendix B Rappaport).
4. Hence for given $P_R$ and given receiver can predict probability of error occurring.
5. See section 4.9.2 Rappaport.

Percentage of coverage area

1. Consider base-station with cellular radius R.
2. Suppose it has been decided that to achieve particular (sufficiently small) error rate, the received power (at any location within the cell) must be $P_R > \gamma$.
3. Aim is to determine the probability of $P_R(d) > \gamma$ for $0 <= d <= R$ … this is denoted by $U(\gamma)$ in Rappaport. $U(\gamma).100$ % is the percentage of coverage area for the selected error rate.
4. $U(\gamma)$ depends on the environment ($n$, $\sigma$) and the specified error rate (or equivalently the $P_R$ threshold $\gamma$).
5. Fig 4.18 Rappaport … use to determine $U(\gamma)$ for given $n$, $\sigma$ and specified error rate at the cell boundary $d=R$ (i.e. probability of $Pr(R) > \gamma$).

General approach to calculating percentage of coverage area $U(\gamma).100$ %

1. Determine $P_N$ (dB) for given receiver.
2. Choose required bit error rate.
3. For the given modulation scheme employed by the transmitter, calculate the required SNR (dB).
4. Calculate required $\gamma = SNR(dB) + P_N(dB)$
5. For given $n$, $\sigma$, $\gamma$, $R$ calculate $Prob[P_R(R) > \gamma] = Q([\gamma - P_{R,AVE}(R)]/\sigma)$ .
6. Use Fig 4.18 to determine $U(\gamma)$.

See Example 4.9 Rappaport