RF propagation (Lecture 10)

Preparation for Midterm Exam

Problem 1: Consider the μ-wave system in Fig. 1

Parameters of the system are given as follows:

- Operating frequency: $f = 2.4 \text{ GHz}$
- Signal BW: $B = 12 \text{ MHz}$
- TX power: $P_t = 4 \text{ W}$
- TX cable losses: $L_{TX} = 2 \text{ dB}$
- TX Antenna Gain: $G_{TX} = 12 \text{ dB}$
- RX Antenna Gain: $G_{RX} = 10 \text{ dB}$
- RX Cable Loss: $L_{RX} = 2 \text{ dB}$
- RX Noise Figure: $F = 8 \text{ dB}$
- Desired C/N ratio: $(C/N)_r = 12 \text{ dB}$

4) Calculate the RX sensitivity

$$R_{x,Sensitivity} = 10 \log (KTB) + F [\text{dB}] + (C/N)_r$$

$R_{x,Sensitivity}$ defined as a minimum RSSI required by the RX successful operation

$$R_{x,Sensitivity} = 10 \log \left( \frac{4 \cdot 10^{-12} \text{ W}}{1.2 \cdot 10^6 \text{ Hz}} \right) + 8 \text{ dB} + 12 \text{ dB}$$

$$= -93.19 \text{ dBm}$$
b) Calculate ERP in dBm

\[ \text{ERP (dBm)} = 26 \text{ dBm} - 2 \text{ dB} + 12 \text{ dB} = 46 \text{ dBm} \]

c) Calculate minimum RSL at point A (rigid before RX antenna)

\[ \text{RSL}_A = \text{Rx Sensitivity} + L_{0x} - G_{Rx} = \]

\[ = -93.19 + 2 \cdot 10 = -101.19 \text{ dBm} \]

d) Calculate maximum separation between TX & RX using Friis's equation

\[ \text{PL}_{\text{max}} = \text{ERP} - \text{RSL}_A = 46 \text{ dBm} - (-101.19 \text{ dBm}) = 146.19 \text{ dB} \]

\[ \text{PL}_{\text{max}} = 36.5 + 20 \log(f) - 20 \log(d_{\text{mile}}) \rightarrow \]

\[ 20 \log(d_{\text{mile}}) = \text{PL}_{\text{max}} - 36.5 - 20 \log(2400) = 42.09 \]

\[ d_{\text{mile}} = 10^{42.09/20} = 127.4 \text{ miles} \]

e) Recalculate maximum distance if 10 dB margin is used to provide a guard against rain attenuation and antenna misalignment

\[ \text{PL}_{\text{max,2}} = \text{PL}_{\text{max}} - 10 \text{ dB} = 146.19 \text{ dB} - 10 \text{ dB} = 136.19 \text{ dB} \]

\[ d_{\text{mile,2}} = 10^{37.09/20} = 40 \text{ miles} \]

Problem 2: Consider the communication system shown in Fig 2.
Assume that the two-ray model for the path loss may be applied. Use the following numerical data:

- $P_{tx} = 5 W$ - transmitted power
- $P_{sl} = -100 \text{ dBm}$ - required PSL at the RX side
- $h_{tx} = 5 \text{ m}$ - height of TX antenna
- $h_{rx} = 5 \text{ m}$ - height of RX antenna

Estimate the maximum distance between TX and RX

$P_{l_{max}} = 10 \log(1500) - (-100 \text{ dBm}) = 134 \text{ dB}$

$P_{l_{max}} = 40 \log d - 20 \log h_{tx} - 20 \log h_{rx}$

$134 \text{ dB} = 40 \log d - 20 \log (5) - 20 \log (5)$

$d = 3534.7 \text{ m} \approx 2.2 \text{ miles}$

Problem 2: Consider the situation shown in the figure. Assume following numerical parameters:

- TX power: $P_{tx} = 2 W$
- Cable losses: $L_{tx} = 3 \text{ dB}$
- Antenna gain: $G_{tx} = 12 \text{ dB}$
- Path loss $PL(d_0) = 109 \text{ dB}$
- Log-distance path loss model
- $m = 3.84 \text{ dB/dec}$
- $d_0 = 1 \text{ mile}$
Calculate the maximum distance to the receiver if the RX uses dipole antenna (2.16 dB gain) and spatial diversity with average gain of 3 dB. The minimum required RSSL is -100 dBm (at RX RX)

\[
ERP = Pt [dBm] - L_{tx} + G_{rx} = \\
= 33 \text{ dBm} - 8 \text{ dB} + 12 \text{ dB} = 42 \text{ dBm}
\]

\[
RSSL = RSSL_{minimum} - \text{Diversity gain} - \text{antenna gain} \\
= 100 \text{ dBm} - 3 \text{ dB} - 2.16 \text{ dB} \\
= -105.16 \text{ dBm}
\]

\[
PL_{max} = ERP - RSSL = 42 \text{ dBm} - (-105.16 \text{ dBm}) = 147.16 \text{ dB}
\]

For log-distance path loss model one obtains

\[
PL_{max} = P_L(d_0) + 10 \log(d/d_0)
\]

\[
147.16 = 109 + 38.4 \log(d/1)
\]

\[
d = 10^{(147.16-109)/38.4} = 9.85 \text{ miles (x)}
\]

Note: the number in (x) does not include random shadowing component. When that component is included the radius is usually smaller than 9 miles.
Problem 4. Consider the antenna pattern in the Figure.

Assume that within the main beam the pattern may be approximated by
\[ G(\theta) = \cos^2(2\theta) \quad \theta \in (-\pi/2, \pi/2) \]

The receiver is located in suburban environment characterized by
\[ PL(d_0) = 115 \text{ dB} \text{ and } -m = 36.4 \text{ dB/dec } (d_0 = 1 \text{ mile}) \]. Calculate
RSL at points A & B which are at distances 3 & 8 miles from TX.

For point A:
\[ \theta = 0 \]
\[ G(\theta) = 0 \text{ dB} \]
\[ RSL_A = 50 \text{ dBm} - 115 \text{ dB} - 36.4 \log(3) = -83.32 \text{ dBm} \]

For point B:
\[ G = \frac{G_0}{4} \]
\[ G(\theta) = \cos^2\left(2\cdot\frac{\pi}{6}\right) = 0.25 \rightarrow -6.02 \text{ dB} \]
\[ RSL = 50 \text{ dBm} - 6.02 \text{ dB} - 115 \text{ dB} - 36.4 \log(8) = -89.34 \text{ dBm} \]

Problem 5. Consider the situation depicted in the Figure. Calculate the KED losses. Assume operating frequency of \( f = 1900 \text{ MHz} \).
\[
X = \frac{\ln x - \ln x'}{d_1 + d_2} \Rightarrow X = \frac{d_2 (\ln x - \ln x')}{d_1 + d_2}
\]

\[
X = \frac{2000 (50 - 20)}{7000} = 8.57 \text{ m}
\]

\[
q = 40 - 8.57 - 20 = 11.43 \text{ m}
\]

\[
\gamma = \frac{c/\phi}{1900 \times 10^9 / \text{s}} = 0.1579 \text{ m}
\]

\[
\nu = k \sqrt{\frac{2}{d_1 d_2}} = 11.42 \sqrt{\frac{2}{0.1579 \times 2000 \times 5000}} = 1.076
\]

\[
G(\nu) = 20 \log (0.04 - \sqrt{0.0184 - (0.38 - 0.12)^2})
\]

\[
G(\nu) = -14.4 \text{ dB}
\]

Problem 5: Calculate effective antenna height for the siluahum depicted in the figure below. Use slope method.
\[ \tan(\theta) = \frac{h_{ref} - h_{nx}}{d} \Rightarrow h_{nx} = h_{ref} - d \tan(\theta) \]

\[ h_{nx} = 40 + 1000 \text{ ton} \left( 10 \times 0.01 \right) = 210.2 \text{ m} \]

**Problem 7.** Use Lee model with slope method for effective height calculation to estimate RSL at point A in the figure below

\[ \text{Distance: } d = d_1 + d_2 \cos(\theta) = 2 \text{ km} + 2 \text{ km} \cos(5 \times 0.01) = 3.99 \text{ km} = 3.99 \text{ miles} \]

\[ h_{ref} = h_{nx} + d \tan(\theta) = 80 \text{ m} + 2000 \text{ ton} (5 \times 0.01) = 204.97 \text{ m} = 672.32 \text{ feet} \]

\[ \text{RSL} = -69 - 42.15 \log(2.48) + 15 \log \left( \frac{672.32}{150} \right) + 10 \log \left( \frac{2 \times 3.18}{10} \right) + 47 - 50 \]

\[ = -78.86 \text{ dB} \mu \]

**b)** Estimate for RSL if the frequency of operation is doubled

\[ \text{RSL}_{1000} = \text{RSL}_{ref} + 20 \log \left( \frac{1}{2} \right) = \]

\[ = -69 \text{ dB} \mu + 20 \log \left( \frac{1}{2} \right) = -75 \text{ dB} \mu \]

\[ \text{RSL}_{2} = -78.86 \text{ dB} \mu - 6 \text{ dB} = -84.86 \text{ dB} \mu \]
Problem 8: Consider the situation shown in figure below.

\[ \text{Problem 8: Consider the situation shown in figure below.} \]

Assume \( RSL_{ref} = -59 \text{ dBm} \) \( m = 38.4 \text{ dB/dec} \) (Lee model).

(a) Calculate RSL at the serving sites at \( M_1 \) and \( M_2 \).

\[ RSL_{M_1} = -59 \text{ dBm} - 38.4 \log (2.5) + 15 \log \left( \frac{48 - 3.28}{150} \right) + 10 \log ( \frac{6}{10} ) = -76.72 \text{ dBm} \]

\[ RSL_{M_2} = -59 \text{ dBm} - 38.4 \log (2) + 15 \log \left( \frac{22.3 - 3.28}{150} \right) + 10 \log ( \frac{6}{15} ) + (AP - 50) \]

\[ = -83.87 \text{ dBm} \]

(b) Calculate RSL of the interfering sites at \( M_1 \) and \( M_2 \).

\[ RSL_{M_2} = -59 \text{ dBm} - 38.4 \log (5.5) + 15 \log \left( \frac{48 - 3.28}{150} \right) + 10 \log ( \frac{6}{10} ) \]

\[ = -89.33 \text{ dBm} \]

\[ RSL_{M_2} = -59 \text{ dBm} - 38.4 \log (6) + 15 \log \left( \frac{22.3 - 3.28}{150} \right) + 10 \log ( \frac{6}{15} ) + (AP - 50) \]

\[ = -95.43 \text{ dBm} \]

(c) Calculate \( C/I \) (carrier to interference) ratio at \( M_1 \) and \( M_2 \).
\[ \left( \frac{C}{\pm} \right)_1 = -76.18 \text{ dBm} - (-89.32) \text{ dBm} = 13.15 \text{ dB} \]
\[ \left( \frac{C}{\pm} \right)_2 = -83.87 \text{ dBm} - (-95.43) \text{ dBm} = 11.55 \text{ dB} \]

About Exam:

- **Time:** 1 hour 15 minutes
- **Write:** open book / open notes
- **Material:**
  1) dB calculations / conversion between linear and log domain
  2) Free space propagation
  3) 2 ray model
  4) Log distance model
  5) KED channel (single and multiple)
  6) Hata antenna height
  7) Lee Model
  8) Hata model

**Problems:** 4-5