Personal Communication Systems (Lecture 11)

Preparation for Midterm Exam 1

Halcons will be tested on

1) Calculations in dB, down / Linear - dB conversion / cellular system basics
2) Path loss models
   - Free space path loss model
   - 2-ray path loss model
   - Log-distance path loss model
   - Hata-Okumura / COST 231 path loss model
3) Capacity planning
   - Edge reliability
   - Area reliability
   - Faded margin calculations
4) Link budget analysis & neural cell planning

Exam: Open book / open notes
Time: 1 hour & 15 min
# problems: 3-4

Sample problems:

1. Consider microwave link with following unusual data

   Operating frequency: \( f = 66 \text{ GHz} \)
   TX PA power: 2W
   RX noise figure: 8dB
   Connector loss on TX side: -0.5 dB
   Connector loss on RX side: -0.5 dB
   Cable loss on TX side: -3 dB
   Cable loss on RX side: -3 dB
   Antenna gain on TX side: 14 dB
   Antenna gain on RX side: 10 dB

   (C/I) requirements: 13 dB, Fade margin: 10 dB
Calculate:
1) RX sensitivity of the RX
2) EPP on the TX side
3) Minimum RSS at point A before the RX antenna
4) Maximum allowable free space loss
5) Minimum distance between TX & RX

\[ R_{50dBm} = 10 \log (kTB) + FEB3 + (S/N) \]
\[ = 10 \log \left( \frac{4.16 \times 0.5}{15.16} \right) + 5.3 + 13 \text{ dB} = -91.2 \text{ dBm} \]

1) EPP = 33 dBm - 0.5 - 3 + 14 = 45.5 dBm

2) \[ P_{SA} = -91.2 \text{ dBm} + 0.5 + 3 - 10 = -97.7 \text{ dBm} \]

3) \[ FSPL_{max} = EPP - P_{SA} - PM = 43.5 - (-97.7) - 10 = 131.2 \text{ dB} \]

4) \[ FSPL_{max} = 36.5 + 20 \log(f) + 20 \log(d) \]

\[ 131.2 = 36.5 + 20 \log(6000) + 20 \log(d) \]

\[ d = 9.85 \text{ miles} \]
2) Consider two signals existing in the same frequency band (co-channel interference). The power of the first signal is $P_1 = 4 \times 10^7$ mW and the power of the second one is $8 \times 10^7$ mW. What is the signal to interference ratio expressed in dB?

$P_1 = 4 \times 10^7$ mW = $-64$ dBm

$P_2 = 8 \times 10^7$ mW = $-90 + 3 + 8 + 2 = -81$ dBm

$(S/I) = P_1 [\text{dBm}] - P_2 [\text{dBm}] = -64 \text{dBm} - (-81 \text{dBm}) = 17 \text{dB}$

3) Consider situation depicted in the figure. Calculate the signal to interference ratio. Use two-ray path loss model.

- $E_{SP1} = 50 \text{dBm}$
- $f = 800 \text{MHz}$
- $E_{SP2} = 90 \text{dBm}$
- $d_1 = 3 \text{m}$
- $d_2 = 7 \text{m}$
- $d = 1 \text{m}$

$S/I = \text{Signal of interest}$

$\text{RSL}_1 = E_{SP1} - P_1$

$P_1 = 40 \log_10(d_1) - 20 \log_10(f) - 20 \log_10(4) = 40 \log_10(1000) - 20 \log_10(30) - 20 \log_10(3)$

$\approx 81.17 \text{dB}$

$\text{RSL}_1 = 50 \text{dBm} - 81.17 \text{dB} = -31.17 \text{dBm}$

$\text{RSL}_2 = E_{SP2} - P_2$

$P_2 = 40 \log_10(d_2) - 20 \log_10(f) - 20 \log_10(4) = 40 \log_10(1000) - 20 \log_10(30) - 20 \log_10(3)$

$\approx 81.17 \text{dB}$

$\text{RSL}_2 = 90 \text{dBm} - 81.17 \text{dB} = 8.83 \text{dBm}$
\[ P_{L_b} = 40 \log (d_1) - 20 \log (d_2) + 20 \log (d_3) \]
\[ = 40 \log (7) \frac{1}{10} 4 \log (15) - 20 \log (3) = 119.46 \text{ dB} \]
\[ P_{L_b} = P_{L_{dB}} - 119.46 \text{ dB} = -71.46 \text{ dBm} \]
\[ P_{L_{dB}} = P_{L_{dB}} - P_{L_{dB}} = -39.17 \text{ dBm} - (-71.46 \text{ dBm}) = 32.3 \text{ dB} \]

Consider deployment of a cellular system in Brevard county. Following data is known:

a) Site of the county = 12.68 miles²
b) Minimum PSL_{min} = -80 dBm
c) ERP of the cell site = 50 dBm

d) Propagation can be modeled using log-distance path loss model with
\[ P_L(d) = 104 \text{ dBm} + 20 \log (d) \]

a) Estimate the size of a cell
b) Estimate the area of a cell

c) How many cells are needed to cover Brevard county?

\[ P_{L_{max}} = P_{L_{dB}} - P_{L_{min}} = 50 \text{ dBm} - (-80 \text{ dBm}) = 130 \text{ dB} \]
\[ P_{L_{dB}} = P_{L_{dB}} + 10 \log (d_{max}) \]
\[ 50 \text{ dBm} = 104 + 38.4 \log (d_{max}) \Rightarrow d_{max} = 3.5 \text{ miles} \]
b) \( A = \pi d^2 = \pi (3.5 \text{ miles})^2 = 38.98 \text{ miles}^2 \)

c) \( N = \frac{1269}{38.98} = 32.55 \text{ cells} \)

d) Consider a cell with following parameters:

\[ E_{pp} = 50 \text{dBm} \]

\[ P_l(d_x) = 109 \text{dB} \]

\[ M = 40 \text{ dBm} / \text{dec} \]

\[ e = 8 \text{dB} \]

\[ d_x = 1 \text{ mile} \]

a) Calculate average distance to RSL = -80 dBm contour.

b) Estimate the \( Pr \{ PSL > -90 \text{dBm} \} \) on the contour.

c) Estimate the \( Pr \{ PSL > -70 \text{dBm} \} \) on the contour.

d) What contour provides 

good reliability of 70%? For \( PSL = -80 \text{dBm} \)

\[ a) \quad P_L = E_{pp} - \text{RSL} = 50 - (-80) = 130 \text{dB} \]

\[ P_L = P_l(d_x) + 10 \log (d_x) \]

\[ 130 = 109 + 40 \log (d_x) \]

\[ d_x = 3.34 \text{ miles} \]

\[ b) \quad Pr \{ PSL > -90 \text{dBm} \} = \frac{1}{\sqrt{2\pi \sigma^2}} \int_{-\infty}^{\infty} \exp \left( -\frac{(x - (-80))^2}{2\sigma^2} \right) dx \]

\[ \text{Substituting} \quad x = \frac{x - (-80)}{\sigma} \]

\[ Pr \{ PSL > -90 \text{dBm} \} = \frac{1}{\sqrt{2\pi \sigma^2}} \int_{-\infty}^{0} \exp \left( -\frac{t^2}{2} \right) dt = \frac{1}{\sqrt{2\pi \sigma^2}} \int_{-\infty}^{-5} \exp \left( -\frac{t^2}{2} \right) dt = \frac{1}{\sqrt{2\pi \sigma^2}} \int_{-5}^{0} \exp \left( -\frac{t^2}{2} \right) dt \]
\[ P \left( \text{PSL} > -90 \text{ dBu} \right) = 1 - Q(1.25) \]

From appendix E table, \( Q(1.25) \approx 0.1 \)

\[ P \left( \text{PSL} > 93 \text{ dBu} \right) = 1 - 0.1 = 0.9 = 90\% \]

\[ P \left( \text{PSL} > -70 \text{ dBu} \right) = \int_{-70}^{\infty} \frac{1}{\sqrt{2\pi}} \exp \left( - \frac{(x-(-80))^2}{2 \cdot 8^2} \right) \, dx \]

\[ = \frac{1}{\sqrt{2\pi}} \int_{(-70)-(-80)}^{\infty} \exp \left( - \frac{t^2}{2} \right) \, dt = Q(1.25) \approx 0.1 = 10\% \]

\[ r > -80 \text{ dBu} \] is 0.7

\[ \int_{-\infty}^{-80} \frac{1}{\sqrt{2\pi}} \exp \left( - \frac{(x-80)^2}{2 \cdot 8^2} \right) \, dx = \int_{-\infty}^{-80} \exp \left( - \frac{t^2}{2} \right) \, dt = 0.7 \]

\[ \frac{-80 - r}{8} = 0.7 \Rightarrow \frac{r - (-80)}{8} = 0.3 \]

\[ r = (-80) + 4 = -76 \text{ dBu} \]
Cell system needs to guarantee 95% area reliability of in-building coverage. Following data are given.

Environment: \( PL(dB) = 115 dB, m = 38.4 dB/dec, B_w = 7 dB \)

Path loss: \( L_m = 18 dB, G_p = 6 dB \)

Technology: \( E_{pp} = 50 dBm \)
\( P_{L_{min}} = -104 dBm \)

a) Calculate composite STD
b) Estimate Fade margin of the in-building coverage

c) Determine minimum RSSI outside building

d) Determine normal cell site radius

\[ G_c = \sqrt{G_p^2 + 5_p^2} = \sqrt{7^2 + 6^2} = 9.2 dB \]

b) \( n = 3.84 \)
\( \frac{\delta}{n} = 2.4 \)
\[ 2 \cdot \sigma_{\delta} (R = 90/4, \frac{\delta}{n} = 2.4) = 0.71 \]
\[ PL_{dB} = 0.71 \times 9.2 = 6.53 dB \]

c) \( RSSI = -104 dBm + 17 dB + 6.53 dB = -79.47 dBm \)

d) \( PL_{\text{loss}} = 50 dBm - (-79.47 dBm) = 129.47 dB \)
\[ PL_{\text{loss}} = PL(dB) + m \log_10(d/1) \]
\[ 129.47 = 115 + 38.4 \log_10(d) \] \( \Rightarrow d = 2.38 \text{ miles} \)
(e) From Peck's curve - one reads edge reliability ~ 75%

1. Use Hohe planum to provide cell radius of a cell opening at frequency $f = 800$ MHz in an urban area of a small city. The maximum path loss that can be tolerated is 125 dB. The height of the base station is 30 m and the height of the mobile is 1.5 m.

$$P_{L(m)} = 69.55 + 26.16 \log f - 13.82 \log d + \left(44.9 - 65.7 \log d\right) \log d - \lambda \log d$$

In this case:

$$a(100) = 0 \quad (\text{for } \lambda = 1.5 \text{ m, there is no correction})$$

$$125 = 69.55 + 26.16 \log (800) - 13.82 \log (30) + \left(44.9 - 65.7 \log (30) \right) \log d$$

After some elementary manipulations $d = 1$ km.