CS 515 - Mobile and Wireless Networking
Homework 1 Solutions

Assignment Date: Oct 16, 2002, Wednesday

You may benefit from the following tools if you wish:
- A scientific calculator
- A function plotter like matlab, gnuplot, or any free tool that you can find on the web.
- Tables for Q-function, erf-function, erfc-function
- A programming language and its math library functions

1. Assume a 1Amp-hour battery that is used on a cellular phone. Also assume that the cellular phone draws 35mA in idle mode and 250mA during a call. How long would the phone work:
1. If the user leaves the phone always continually (powered on) and has one 3-minute call every day.
2. If the user leaves the phone always continually (powered on) and has one 3-minute call every 6 hours.
3. If the user leaves the phone always continually (powered on) and has one 3-minute call every hour.
4. What is maximum talk time?

Hint: 1Amp-hour describes a battery that can supply 1 Amp of current for a period of 1 hour (The same battery can supply 100mA for 10 hours, etc).

Answer:

1 day has 1440 minutes.
1. Average current drawn is: (3x250mA + (1440-3)x35mA)/1440 = 35.448mA. If battery can supply 1A current for one hours, then it can provide x hours of 35.448mA current.
   x = 1A-H/35.448mA = 28.21 hours = 1 day, 4 hours, 12 minutes.
2. Average current drawn is: (12x250mA + (1440-12)x35mA)/1440 = 36.79mA.
   x = 27.18 hours = 1 day, 3 hours, 10 minutes.
3. Average current drawn is: (72x250mA + (1440-72)x35mA)/1440 = 45.75mA.
   x = 1/0.004575 = 21.85 hours = 21 hours, 51 minutes.
4. Average current drawn is: 250mA.
   x = 1/0.250 = 4 hours.

2. If P_t = 1W, G_t = 0dB, G_r = 0dB, and f_c = 2.4GHz, find P_r in Watts at a free space distance of 50 m.

Answer:

Using Friis free space equation: $P_r(50m) = (P_tG_tG_r\lambda^2)/(4\pi)^2d^2$
$\lambda = c/f = 3x10^8m/2.4GHz = 0.125m$
$P_r(50m) = (1x(0.125)^2)/(4\pi)^2(50)^2$ = $\underline{3.96x10^{-8}\ W.}$

3. Assume a receiver is located 10 km from a 150 W transmitter. The carrier frequency is 6 GHz and free space propagation is assumed, G_t=1, G_r = 1.

1. Calculate the transmit power in dBW.
2. Calculate the transmit power in dBm.
3. Find the power at the receiver in in Watts and dBm.

Answer:

1. Pt(dBW) = 10log(150W/1W) = <u>21.76dBW.</u>
2. Pt(dBm) = 10log(150W/0.001W) = <u>51.76dBm</u>
3. $\lambda = c/f = 3x10^8m/6GHz = 0.05m$.
   $P_r(10,000) = (150x1x1x(0.05)^2)/(4\pi)(10,000)^2$ = $\underline{2,37X10^{-11}W}$
   P_r (10,000) (dBm) = 10log(2,37X10^{-11}W / 0.001W) <u>= -76.25dBm</u>.

4. A base station radiates at a the transmit power of 50W. Let the carrier frequency, f_c, be 900MHz. Let d_0 be 100m. Assume free space path loss model between transmitter and d_0, and log-normal shadowing loss model for distances greater than d_0. Assume path loss exponent, *n*, of 3 and σ of 5dB for log-normal shadowing model.
Find out:

1. The received power (in dBm) at 100m.
2. The *mean* path loss (in dB) from transmitter at 500m.
3. The mean received power (in dBm) at 500m.
4. The probability that P_r(500m) >= 0.01mW.

Answer:

1. $P_r(100m) = (P_tG_tG_r\lambda^2)/(4\pi)d^2 = 50x(0.33)^2 / (4\pi)^2x100^2 = 3.45x10^{-6}W$. = -24.62 dBm.
2. mean-PL(d) (dB) = mean-PL(d_0)(dB) + 10nlog(d/d_0)
   mean-PL(500) (dB) = 10log(50W / 3.45x10^{-6}W) + 10*3*log(500/100)
   mean-PL(500) (dB) = 71.61 + 20.96 = <u>92.57dB</u>
3. mean-Pr(500)[dBm] = Pt[dBm] – mean-PL(500m)[dB]
   mean-Pr(500)[dBm] = 10log(50/0.001) – 92.57dB
   mean-Pr(500)[dBm] = 10log(50/0.001) – 92.57dB
   = <u>-45.58 dBm</u>.
4. 0.01mW = -20dBm.
   We are interested in Probability(Pr(500) >= -20dBm)
   From Equation 4.71 in the book:
   $$\Pr((P_r(d) >= \gamma) = (\gamma - \overline{P_r}(d))/\sigma$$
   Prob(Pr(500) >= -20dBm) = Q((-20 – mean-Pr(500m))/5dB)
   Prob(Pr(500) >= -20dBm) = Q((-20 – (-45.58))/5dB)
   Prob(Pr(500) >= -20dBm) = Q((-20 – (-45.58))/5dB) = Q(5.116)
   For value greater than 3, Q-function can be approximated by (look to the explanation of Q-function in the appendix of the book):

$$Q(z) = \left[\frac{1}{z\sqrt{2\pi}}\right]\exp(\frac{-z^2}{2})$$

Then
Q(5.116) = 0.0441 x exp(-13.09) = $9.11x10^{-8}$
then
Prob(Pr(500) >= 0.01mW) = $\underline{9.11x10^{-8}}$

5. If the received power at a reference distance d_0 = 1km is equal to 1 microwatt, find the received powers at distances of 2 km, 5 km, 10km, and 20km from the same transmitter for the following path loss modes:

1. Free space
2. *n* = 3
3. *n* = 4

Answer

1. Pr(2km) = Pr(1km) X $(1/2)^2$ = 0.25 microwatt.
   Pr(5km) = Pr(1km) X $(1/5)^2$ = 0.04 microwatt.
   Pr(10km) = Pr(1km) X $(1/10)^2$ = 0.01 microwatt.
   Pr(20km) = Pr(1km) X $(1/20)^2$ = 0.0025 microwatt.

2. Pr(2km) = Pr(1km) X $(1/2)^3$ = 0.125 microwatt.
   Pr(5km) = Pr(1km) X $(1/5)^3$ = 0.008 microwatt
   Pr(10km) = Pr(1km) X $(1/10)^3$ =.0.001 microwatt
   Pr(20km) = Pr(1km) X $(1/20)^3$ = 0.000125 microwatt.

3. Pr(2km) = Pr(1km) X $(1/2)^4$ = 0.0625 microwatt.
   Pr(5km) = Pr(1km) X $(1/5)^4$ = 0.0016 microwatt
   Pr(10km) = Pr(1km) X $(1/10)^4$ =.0.0001 microwatt
   Pr(20km) = Pr(1km) X $(1/20)^4$ = 0.00000625 microwatt.

6. Five received power measurements were taken at distances of 50m, 100m, 200m, 400m and 1000m from a transmitter. The measured values are given in the table below. It is assumed that the path loss for these measurements follow the log-normal shadowing environment formula, where d_0 is 50m. Assume the received power at d_0 is found to be 0dBm also by analytical models.

1. Find the value of n that minimizes the mean square error (MSE) for the data shown on the table below.
2. Calculate the standard deviation about the mean value of the received power.
3. Write down the exact formula for the resulting model.
4. Estimate the mean received power at *d* = 500m using the resulting model.
5. Predict the likelihood that the received signal level at 500m will be greater than -25dBm.
6. Predict the percentage of area within a 500m radius cell that receives signals greater than -25dBm.

Distance from Transmitter	**Received Power**

50m	0 dBm
100m	-10dBm
200m	-15dBm
400m	-25dBm
1000m	-50dBm

Answer

1. First compute the estimates of the received power at various distances assuming received power model that depends on n using the formula: Pr(d) = Pr(d0) – 10nlog(d/d0) (you can easily derive this formula from the long distance path loss model formula)
   Pr(50)[dBm] = 0 dBm – 10nlog(0) = 0dBm
   Pr(100)[dBm] = 0 - 10nlog(100/50) = -3.01n dBm
   Pr(200)[dBm] = 0 – 10nlog(200/50) = -6.02n dBm
   Pr(400)[dBm] = 0 – 10nlog(400/50) = -9.03n dBm
   Pr(1000)[dBm] = 0 – 10nlog(1000/50) = -13.01 dBm

Distance	**Actual Received Power**	**Estimate**
50m	0	0
100m	-10	-3.01n
200m	-15	-6.02n
400m	-25	-9.03n
1000m	-50	-13.01n

   Mean square error is computed by the following formula:
   $$MSE = \sum_{i=1}^{k} (p_i - \hat{p}_i)^2$$
   Using the above table for measured and estimated values of received power at various distances:
   MSE = $(0-0)^2 + (-10-(-3.01n))^2 + (-15-(-6.02n))^2 + (-25-(-9.03n))^2 + (-50-(-13.01n))^2$
   MSE = $(-10+3.01n)^2 + (-15+6.02n)^2 + (-25+9.03n)^2 + (-50+13.01n)^2$
   MSE = $100 - 60.2n + 9.06n^2 + 225 – 180.6n + 36.24n^2 + 2500 – 1301n + 169.3n^2$
   MSE(n) = $2825 – 1541.8n + 214.6n^2$

   We are interested in the minimum MSE (MMSE). So we would like to find the n, that minimizes MSE(n). To find that, we should derivate MSE(n) with respect to n, and then make it equal to zero.
   d(MSE(n))/*dn* = -1541.8 + 429.2n = 0
   <u>n = 3.59</u>

   <u>MSE(3.59)</u> = $2825 – 1541.8*3.59 + 214.6*(3.59)^2$ = <u>55.72</u>

2. σ^2 = MSE(3.59) / 5 = 55.72 / 5 = 11.14 dB
   σ = sqr_root(11.4) = <u>3.34 dB</u>
3. Pr(d)[dBm] = 0– 10*3.59*log(d/50) + $X\sigma$ where σ = 3.34 dB

4. mean_Pr(500m) = 0– 10*3.59*log(500m/50m)
   mean_Pr(500m) = -35.9 dBm
5. Prob(Pr(500m) > -25dBm) = ?
   Using the equation 4.71 from the book:
   Prob(Pr(500m) > -25) = Q((-25 – mean_Pr(500) / std_dev))
   Prob(Pr(500m) > -25) = Q((-25 – (-35.9)) / 3.34)) = Q(3.26) ~= Q(3.2)
   from the Q-function tabulation (which I gave as a handout)
   Q(3.2) = 0.00069
   So, Probability (or likelihood) that Pr(500m) will be greater than -25 dBm is roughly 0.00069

6. By use of equation 4.79 from the book:
   b = (10*3.59*log(e)) / (3.38*sqr_root(2)) = 3.26
   U(γ) = percentage of cell that will receive power greater than γ dBm.
   Here γ = -25 dBm.
   U(-25 dBm) = ½[1+exp((1/sqr(b))(1-erf(1/b))]
   = ½[1+exp(0.094)(1-erf(0.306)]
   = ½[1+(1.098*erf(0.306)] ~= ½[1+(1.098*erf(0.3)] (by using the erf-function table from the handout that I gave or from the appendix F of the book)
   = ½[1+(1.098*0.32863]
   = 0.68

   68% of the coverage area (cell with 500m radius) will receive desired service (received power will exceed -25 dBm)

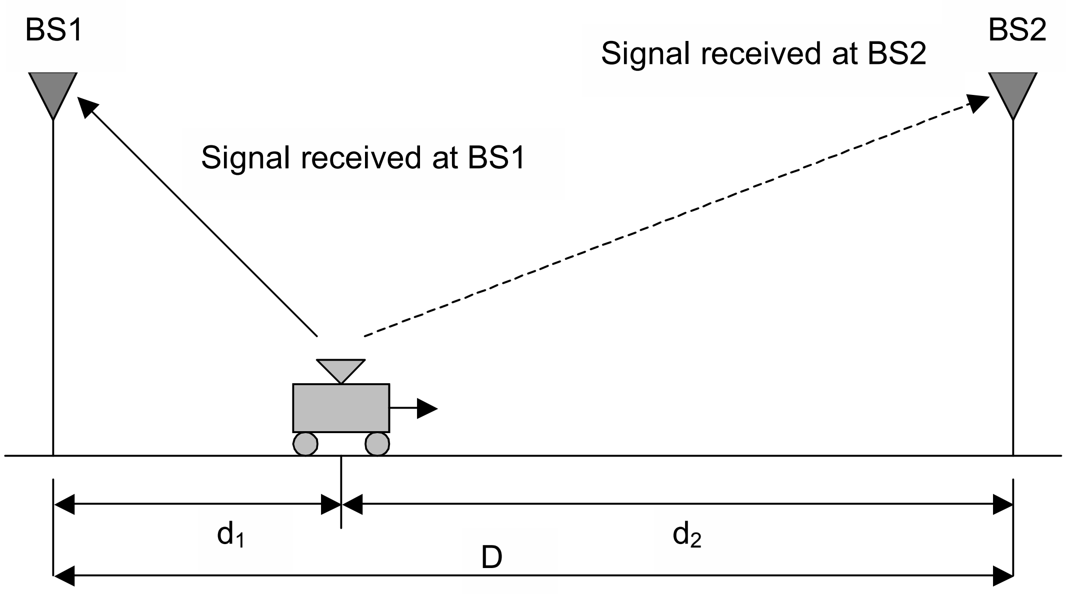
7. Suppose that a mobile is moving along a straight line between base station BS1 and BS2, as shown in the figure below. The distance between the base stations is D = 1600m. The received power (in dBm) at base station i, from mobile station, is modeled as (reverse link):

$$P_{r,i}(d) = P_0 - 10n\log(d_i / d_0) - X_i \text{ (dBm)} \quad i = 1,2$$

where d_i is distance between the mobile and base station i, in meters, P_0 is the received power at distance d_0 from the mobile antenna, and n is the path loss exponent. The term $P_0 - 10n\log(d_i / d_0)$ is usually called *local area mean power*. The terms X_i are zero-mean Gaussian random variables with standard deviation σ, in dB, that model the variation of the received signals due to shadowing. Assume that the random components X_i of the signals received at different base stations are independent of each other, n is the path loss exponent.

The minimum usable signal for acceptable voice quality at the base station receiver is $P_{r,min}$, and the threshold level for handoff initiation is $P_{r,HO}$, both in dBm.

Assume that the mobile is currently connected to BS1. A handoff occurs when the received signal at the base station BS1, from mobile, drops below threshold $P_{r,HO}$, and the signal received at candidate base station BS2 is greater than the minimum acceptable level $P_{r,min}$.



Parameter	Value
n	4
σ	6 dB
P_0	0 dBm
d_0	1 m
$P_{r,min}$	-118 dBm
$P_{r,HO}$	-112 dBm

Using the parameters in the table above, determine:

1. The probability that a handoff occurs (*Pr[handoff]*), as a function of distance between the mobile and its serving base station BS1. You can include the Q-function or error functions in your handoff probability function.
2. The probability that handoff occurs at 100m, 500m, 1000m distances from base station BS1.

Answer:

1. Let PH(d) denote the probability of handoff at a distance d from B1.
   Let P1(d) denote the received power at B1 when distance between B1 and mobile is d.
   Let P2(d) denote the received power at B2 when distance between B2 and mobile is d.
   Let Ph be equal to $P_{r,HO}$
   Let Pm be equal to $P_{r,min}$

   Then
   PH(d1) = Prob(P1(d1) < Ph) x Prob(P2(1600-d1) > Pm)

P1(d1) = 0 – 10*4*log(d1/d0) + X = -40log(d1) + X
P2(d2) = 0 – 10*4*log(d2/d0) + X = -40log(d2) + X
X is random variable with mean equal to zero and std_dev equal to 6 dB.

mean_P1(d1) = -40log(d1)
mean_P2(d2) = -40log(d2)

Prob(P1(d1) < Ph) = Q((mean_P1(d1) – Ph) / std_dev)
= Q((-40log(d1) – (-112)) / 6)
Prob(P1(d1) < Ph) = Q(-6.6log(d1) + 18.6)

Prob(P2(1600-d1) > Pm) = Q((Pm – mean_P2(1600-d1)) / std_dev)
= Q((-118 – (-40log(1600-d1))) / 6)
Prob(P2(1600-d1) > Pm) = Q(-19.6 + 6.6log(1600-d1))

Then
PH(d1) = Q(-6.6log(d1) + 18.6) * Q(-19.6 + 6.6log(1600-d1))
This is the probability that handoff occurs at a distance d1 from B1 to mobile.

2. PH(100) = Q(5.4) * Q(1.36) = 1.94×10^{-8} * 0.08076 = $\underline{1.56 \times 10^{-9}}$
I looked to the value of Q(1.36) from the Q-function tabulation.
I computed the value of Q(5.4) from the closed-form approximation of the Q-function.

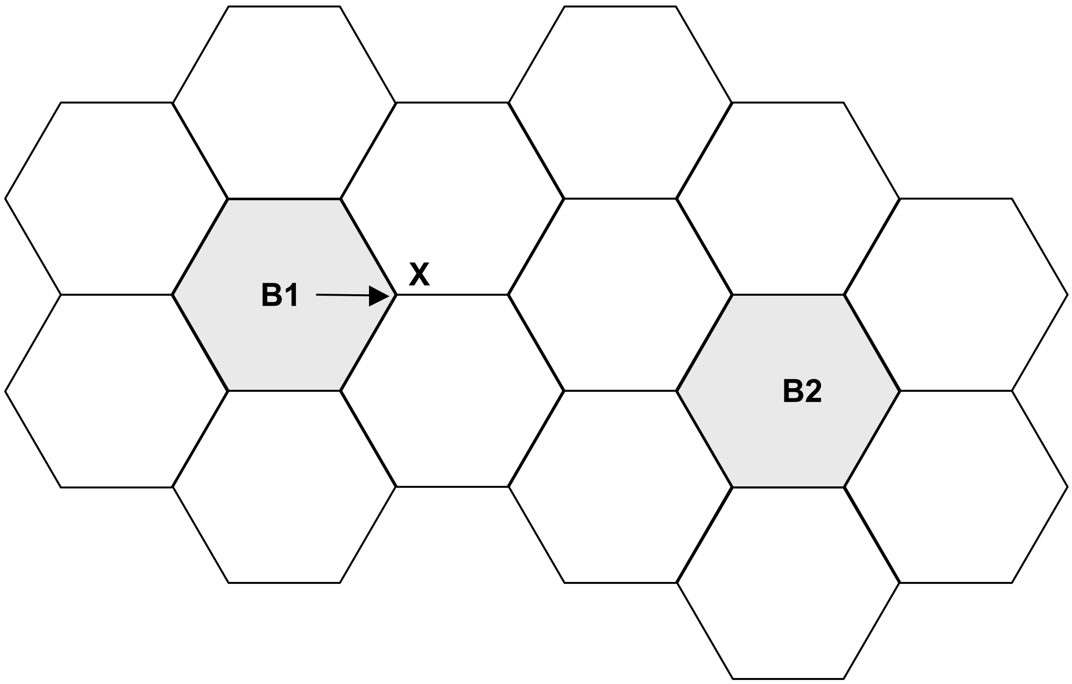
PH(500) = Q(0.78) * Q(0.47) ~= Q(0.8) * Q(0.5)
by looking to the Q-function tabulation we can find out the value of Q(0.8) and Q(0.5).
PH(500) = 0.21286 * 0.30854 = <u>0.065</u>

PH(1000) = Q(-1.2) * Q(-1.26) = (1-Q(1.2)) * (1-Q(1.3))
= (1-0.11507) * (1-09680) = 0.88 * 0.90 = <u>0.792</u>

8. Consider the coverage region below that are covered by cells modeled as hexagons. The structure uses frequency-reuse scheme. Cells belonging to base stations B1 and B2 are using the same frequency for transmission and all other cells are using different frequencies. Therefore, co-channel interference could exist only between cells B1 and B2. Cell B1 is our desired cell where our vehicle is moving in, and B2 is co-channel cell that can create interference. Assume the following:

1. Co-channel interference is due to base station B2 only.
2. Carrier frequency is 900MHz.
3. Reference distance d_0 is 1km (Assume free space propagation from transmitter B1 or B2 to d_0).
4. Cell radius is 10 km.
5. Assume omni-directional antennas for both transmitter and receiver, where gain of transmitter antenna is 6dB and gain of mobile antenna is 3dB.
6. Transmitter power of **10W** for all base stations.

7. Path loss formula between mobile and base station B1 is given with:
   $PL(d_1)(dB)$ = mean_$PL(d_0)$ + $10(2.5)\log(d_1 / d_0) + X_\sigma$ (dBm) $\sigma = 0$dB.
8. Path loss formula between mobile and base station B2 is given with:
   $PL(d_2)(dB)$ = mean_$PL(d_0)$ + $10(4.0)\log(d_2 / d_0) + X_\sigma$ (dBm) $\sigma = 7$dB.



For a mobile moving on a line that connects the center of B1 to point X, a horizontal line, answer the following:

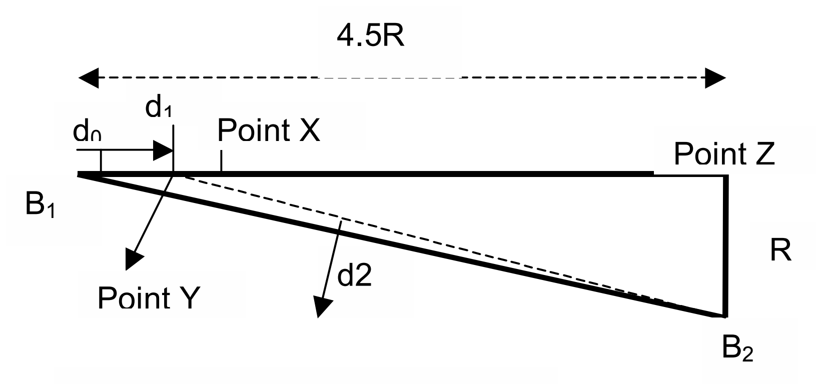
1. Express the C/I (carrier-to-interference ratio) value as a function of distance *d* between B1 and mobile ($d_0 <= d <= R$)
   Hint: Your formula may include a random variable.
   C/I is also called SIR (signal-to-interference ratio)
2. Express the mean_C/I_value as a function of distance *d* between B1 and mobile ($d_0 <= d <= R$)
   Hint: Your formula should not include a random variable.
3. Compute the mean C/I value at a distance of 5km from B1.
4. Compute the mean C/I value at a distance of 10km from B1 (at point X).

Answer

1. Transmit power is 10W, which makes 40dBm = Pt(dBm)

   First find the received power at d0 using Friis equation:

6dB antenna has a gain of 4 (6 ~= 10log4)
3dB antenna has a gain of 2 (3 ~= 10log2)
λ = c/f = 0.33m
Pr(d0) = $[10W*4*2*(0.33)^2] / [(4\pi)^2*(1000m)^2] = 5.52x10^{-8}W$ = -42.6 dBm
PL(d0) = $10\log(10W/5.52x10^{-8}W)$ = 82.6 dB.



Above figure shows the distance relationship from mobile to B1 and B2. We can obtain this by carefully looking to the hexagons and using hexagon geometry properties.

From the figure above:
$|YB_2|$ = d2 = *square_root*[*square*(|YZ|) + square($|ZB_2|$)]
|YZ| = 4.5R – d1
Then
d2 = distance between mobile and B2
= *square_root*[*square*(4.5R - d1) + square(R)]
d1 = distance between mobile and B1 and d0 <= d1 <= R, 1km < d1 < 10km

PL1(d1) = PL(d0) + 10*2.5*log(d1/d0) + X1
PL2(d2) = PL(d0) + 10*4log(d2/d0) + X2

Pr1(d1)(W) : *power received by mobile from base station B1 at distance d1 from B1 (this is carrier signal (C))*
Pr2(d2)(W) : *power received by mobile from base station B2 at distance d2 from B2. (this is interfering signal (I))*

C/I = Pr1(d1)(W) / Pr2(d2)(W)

PL1(d1) = 10log(Pt/Pr1(d1))
PL2(d2) = 10log(Pt/Pr2(d2))
Then
Pr1(d1)(W) = $Pt / 10^{PL1(d1)/10}$
Pr2(d2)(W) = $Pt / 10^{PL2(d2)/10}$

C/I = Pr1(d1)(W) / Pr2(d2)(W)
= $[Pt / 10^{PL1(d1)/10}] / [Pt / 10^{PL2(d2)/10}]$
= $10^{PL2(d2) / 10} / 10^{PL1(d1) / 10} = 10^{(PL2(d2) / 10) - (PL1(d1) / 10)}$

$= 10^{(PL2(d2) - PL1(d1)) / 10}$

[PL2(d2) – PL1(d1)] / 10 = [- 25log(d1/d0) + 40log(d2/d0) + X2] / 10

Then

$$C / I = 10^{4\log(d2/d0) - 2.5\log(d1/d0) + (X_2/10)}$$

$$d2 = \sqrt{(4.5R - d1)^2 + R^2}$$

X_2 is a random variable with μ=0 and σ=7dB
X_1 is a random variable with μ=0 and σ=0dB, so we excluded it from the formulas.

Lets call d1 as d.

$$C / I = \left[\frac{\sqrt{(4.5R - d)^2 + R^2}}{d_0}\right]^4 \left[\frac{d}{d_0}\right]^{-2.5} 10^{\frac{X_2}{10}}$$

2. We can also express mean value of C/I as a function of d, distance of mobile from B1 in meters (R = 10000m).

$$C / I = \frac{1}{d_0^{1.5}} \frac{[(4.5R - d)^2 + R^2]^2}{d^{2.5}}$$

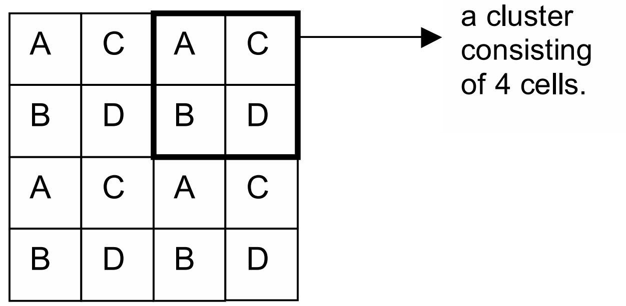
$$d_0 = 1000m$$

$$R = 10000m$$

3. C/I (5km) = ?
   plug in the value on the above formula for C/I
   C/I (5000) = 51697 = 47.13dB
4. C/I (10km) = ?
   plug in the value on the above formula for C/I
   C/I (10000) = 5551 = 37.44dB

9. A PCS operator plans to build a wireless network to cover a big city. The PCS band given to him is: 1850 to 1880 MHz (reverse link) and 1930 to 1960 MHz (forward link). They intend to use DCS1900 like radio equipment which provides GSM-like service and supports 8 users per 200kHz radio channel using TDMA. The path loss exponent is 4 and the system will be deployed using a simple four-cell frequency reuse scheme.

A simple four-cell frequency reuse scheme is as follows. The all available channels are divided into 4 groups (called a cluster): A, B, C, and D. The set of frequencies in these four groups are disjoint (the set of frequencies in group A is completely different than the set of frequencies in group B for example). The coverage region is covered by these clusters. Thereby the frequencies are re-used (for example, the set of frequencies in group of a cluster is used somewhere else in an other cluster).



Answer the following:

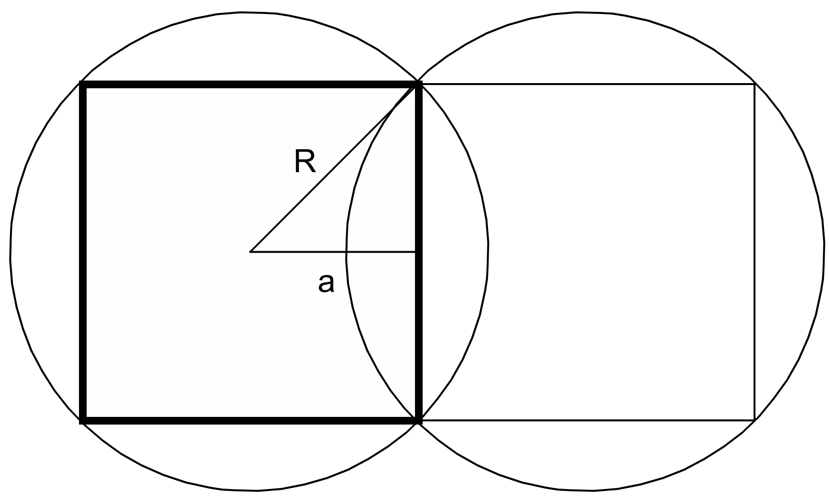
1. At most how many users can be supported in a cluster (4 cells) (Remember a user needs to have a forward and also a reverse channel allocated to himself/herself).
2. The operator wants to cover a big city of 2500 square km. The base stations use 20W transmitter power and 10dB gain omni-directional antennas. Determine the forward link coverage area (radius (R)) of a base station and number of cells (or base stations) required to provide forward cell coverage to the whole city. Assume that:
   - The city is square-shaped with dimensions: 50km x 50km.
   - Four-cell frequency re-use scheme.
   - Path loss exponent of 4.
   - Standard deviation of 8dB for log-normal shadowing path loss model for the city
   - An average required signal level of -90dBm should be received at the boundary of a cell (d=R)
   - Each mobile is using 3dBi gain antenna
   - d_0 is 1km.
   - Assume $PL(d_0)$ is 85 dB and assume it is independent of the carrier frequency (f).
3. What is the capacity of the system that you designed. (Number of users that can simultaneously use the system).
4. What is the percentage of a cell that will receive signal that is equal or greater than -90 dBm.

Answer:

1. The number of reverse channels = (30MHz / 200KHz) * 8 = 1200
   The number of forward channels = (30MHz / 200KHz) * 8 = 1200

   Each user will have a forward and a reverse channel.
   Hence, a total of 1200 users can be supported in a cluster.

2. First determine R:
   mean-PR(r) = Pt – PL(d0) – 10nlog(r/d0)
   Pt = 20W = 43 dBm, PL(d0) = 85 dB
   mean-Pr(R) = 43 – 85 – 10*4*log(R/1000) = -90 dBm
   R = 15849 m = 15,8 km.



Assume in the model a square represent a base station cell. Then we have to put a base station on that cell such that the range (R) of the base station is length_of_dioganal_of_square / 2.

$$R^2 = \sqrt{2a^2}$$

$$a = \frac{R}{\sqrt{2}}$$

a = R / 1.414 = 15,8 / 1.414 = 11,17
2a = 22,34 (length of one edge of the square in the model)
In the coverage model, each cell is represented with a square which has edge-length of 22,34km.

Then we need $\left\lceil \frac{50km}{22,34km} \right\rceil^2$ number of cells, which is 9.

3. A cluster can support 1200 users. A cluster has 4 cells. Hence a cell can support 1200 / 4 = 300 users. The system can support 9*300 = 2700 users.

4. By use of the equation 4.79 on page 142 of the book:
   $U(\gamma)$ = U(-90 dBm) = 1/2[1+exp(1/b^2)(1-erf(1/b))]
   where b = [10*n*log(e)] / [σ*sqrt(2)]
   b = 1.53 (just put the value of the variables in the formula above)

   U(-90 dBm) = 1/2[1+ (1.53 * (1-erf(0.7))]
   U(-90 dBm) = 1/2[1+ (1.53 * (1-0,67780)]
   U(-90 dBm) = 0.75, which is 75%

10. Provide brief answers for the following questions:

1. Write down your dream application of ubiquitous computing.

   The answer is limited with your imagination and dreams.

2. Write down the characteristics of wireless links that are different than wire-line links and that affects the design of mobile computing systems and applications.

   - High error rate
   - Low bandwidth
   - Disconnections

3. Who invented wireless telegraphy and in which year.

   Guglielmo Marconi invented wireless telegraphy in 1896.

4. Write down the differences between CDMA2000 and W-CDMA

   W-CDMA:
   - Channel bandwidth: 5 MHz
   - Data rate of 2Mbps

   CDMA2000
   - Channel bandwidth: 1.25 MHz
   - Data rate of 144 Kbps, 2Mbps, or 2.4Mbps depending on the type of CDMA2000.

5. Write down the differences between GSM, GPRS and EDGE.

   GSM provide voice transfer only
   - 200 KHz channel bandwidth,
   - GMSK modulation,
   - TDMA multiple access,

   GPRS provides voice and data service
   - 200 KHz channel bandwidth,
   - 171.2 Kbps data rate.

EDGE provide voice and data service
- 200 KHz channel bandwidth,
- 384 Kbps data rate.

6. Give complete names of the following acronyms: AMPS, BER, CDMA, EDGE, ETSI, FDD, TDMA, FSK, LOS, PSTN, RSSI, UMTS.

- AMPS: Advanced Mobile Phone System
- BER: Bit Error Rate
- CDMA: Code Division Multiple Access
- EDGE: Enhanced Data Rates for GSM Evolution
- ETSI: European Telecommunications Standard Institute
- FDD: Frequency Division Duplex
- TDMA: Time Division Multiple Access
- FSK: Frequency Shift Keying (A modulation scheme)
- LOS: Line-of-sight
- PSTN: Public Switched Telephone Network
- RSSI: Received Signal Strength Indicator
- UMTS: Universal Mobile Telecommunications System

7. Write down differences between CDPD and GPRS

- CDPD is a wireless data service that is overlayed over AMPS analog cellular network in USA
    - Provides bit rates in the order of 19.2 Kbps.
    - Uses un-used voice channels in the AMPS system
    - Uses GMSK BT = 0.5 modulation
- GPRS is wireless data network that uses dedicate channels of GSM for data transmission
    - Provides bit rates in the order of 171.2 Kbps
    - It is in the category of 2.5 Generation Wireless Networks.
    - GPRS is on the evolution path of GSM towards the goal of supporting voice and data on the same wireless network.

8. Write down the differences and similarities between WLANs (for example IEEE 802.11b networks) and PLANs (for example Bluetooth networks) . (It is enough if you compare only IEEE 802.11b and Bluetooth).
- 802.11b
    - Data-rate: 11 Mbps which can be shared by lots of users
    - Range: 100m-300m
    - MAC: Carrier-Sense Multiple Access variation
    - Spectrum usage technique to reduce interference: DSSS or FHSS
    - Spectrum band: 2400-2483.5 MHz
- Bluetooth
    - Data-rate: 1 Mbps which can be shared by at most 8 devices.
    - Range: 10m. (can be increased to 100m by increasing the transmitter power).

- MAC: Polling based TDMA kind of protocol, called TDD.
- Spectrum usage technique to reduce interference: FHSSS with 1600 hops/second
- Spectrum band: 2400-2483.5 MHz
- Modulation: GFSK modulation

9. Compare and contrast the following systems: AMPS, GSM, CDMA, PDC for the following features
    - Modulation technique that is used
    - Duplexing scheme (FDD or TDD)
    - Multiple Access Technique (FDMA, TDMA, or CDMA)
    - Voice (Speech) encoding scheme and rate
    - Channel bandwidth (such as 200KHz)
    - Allocated spectrum range (band) that the system is using
    - Number of channels: forward and reverse

	AMPS	**GSM**	**CDMA (IS-95)**	**PDC**
Modulation	FM	GMSK with BT=0.3	BPSK with Quadrature Spreading	$\pi/4$ DQPSK
Duplexing	FDD	FDD	FDD	FDD
Multiple Access	FDMA	TDMA	CDMA	TDMA
Voice Encoding		RPE-LTP at 13 kpbs	CELP at 13 kpbs EVRC at 8kbps	VSELP at 7.95 kbps
Channel BW	30 KHz	200 KHz	1.25 MHz	25 KHz
Spectrum Range (uplink)	824-849 MHz	890-915 MHz (Europe)	824-849 MHz	810-1501 MHz
Spectrum Range (downlink)	869-894 MHz	935-960 MHz (Europe)	869-894 MHz	
Number of F and R Channels	Divide spectrum range by channel bandwidth			

10. What are the similarities and differences between SNOOP and AIRMAIL

    - Both are trying to provide reliability for data transmission at the link-layer.
    - SNOOP is application/protocol specific: works only for TCP
    - SNOOP is a proxy that is located at a base station
    - AIRMAIL is a data link layer protocol that provides reliability solution
        - Provides reliability at the link layer by use of FEC and ARQ techniques
        - Uses asymmetric design
    - AIRMAIL may interact with TCP

11. Write down the advantages of caching in the Coda File System.

- Increases availability for mobile in disconnected mode.
- Increases performance of file access.

12. What does hoarding mean?.

    Means periodically transferring selected files from a wireline-located server into the local cache of a mobile computer.