S-72.610 Mobile Communications Services and Systems

Tutorial 1, November 12, 2004

1. Calculate the Carrier to Interference Ratio (CIR) in uplink (at the BS) for the setup given in figure.

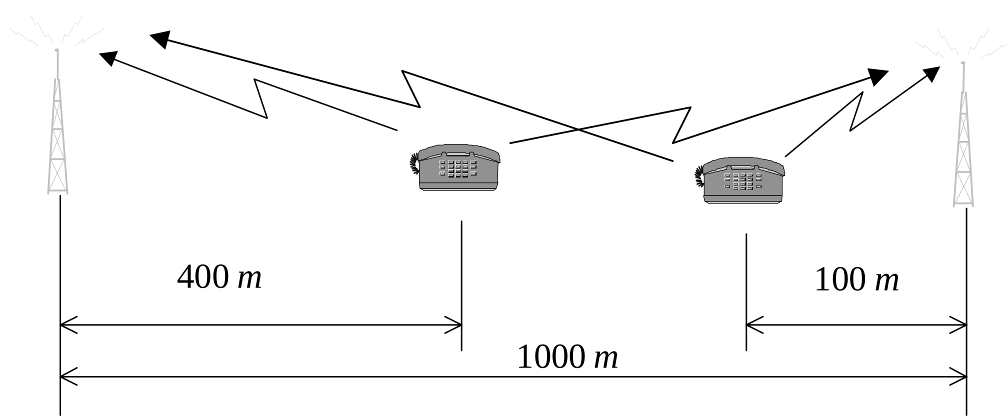
Attenuation is modeled as $d^{-3.5}$

Receiver Noise density is $-166\,dBm\,/\,Hz$

Transmitted power is 100 mW.

Signal bandwidth is 200 kHz

What would be the CNR if the other user does not transmit?



1. Signal to interference ratio is relationship between the received signal and noise plus interference.

$$CIR_i \qquad \frac{P_{tr,i} d_i}{N \qquad \underset{j,j \quad i}{} P_{tr,j} d_j}$$

$$CIR_1 = \frac{100 \cdot 400^{-3.5}}{10^{-166/10} \cdot 200000 + 100 \cdot 900^{-3.5}} = 17.06$$

	User 1	User 2
CIR	17.06 (12.32 dB)	528.95 (27.23 dB)
CNR	1.5 10^4 (41.92 dB)	2 10^6 (63 dB)

2. In a cellular system CIR must be 15 dB at least 50 % of time. The attenuation constant is $\alpha = 3.5$

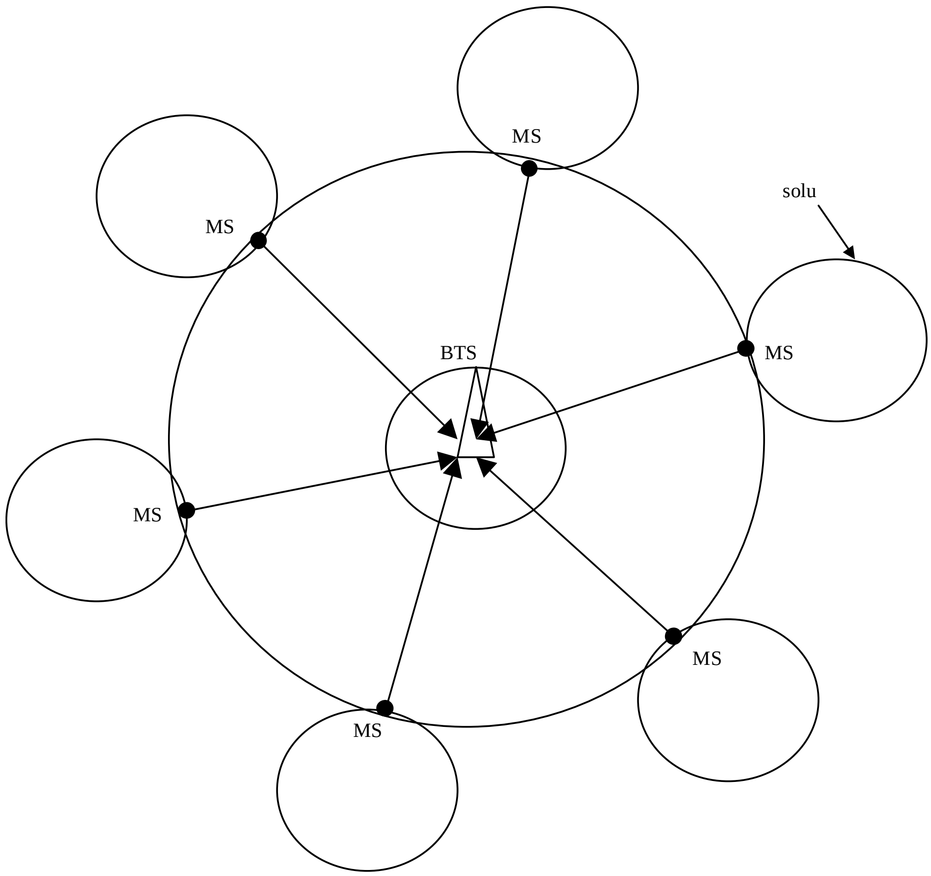
a) Estimate the minimum frequency reuse pattern in an ideal hexagonal cell structure with "omni-directional" base stations at the center of the cells.

b) How much the reuse pattern can be reduced if the service area topography is such that there will be only two significant interferers in each cell?

Hint: For hexagonal cells the reuse distance (ratio between the co-channel cells D and the cell radius R) should satisfy $\frac{D}{R} = \sqrt{3k}$ where $k = i^2 + j^2 + i \cdot j$ and $i, j = 1, 2, 3, \dots$.

2)

The frequency reuse describes the distance between two cells using the same frequency channel. It is expressed as ratio of the distance between two co-channel cells and cell radius. Because of the omni-directional antenna the strength of interferers from all directions is the same. A hexagonal cell model gives us 6 co-channel cells that have at the cell border nearly the same interfering signal strength. The situation for the uplink is described on the figure below.



The signal to interference ratio is calculated as signal strength C divided to a sum of a noise power N and interference I

$$\frac{C}{I}=\frac{C}{N+I}=\frac{C}{N+\sum_{j=1}^{n}I_j}\approx\frac{C}{\sum_{j=1}^{n}I_j}$$. We could simplify the equation by assuming that the interference power significantly exceeds the noise power.

The signal strength is equal to the transmitted power P and attenuation in the channel.

$$\frac{C}{I}\geq\frac{1}{6}\frac{PR^{-\alpha}}{P(D-R)^{-\alpha}}=\frac{1}{6}\frac{(D-R)^{\alpha}}{R^{\alpha}}$$

Where attenuation is approximated as distance in power of attenuation constant $R^{-\alpha}$

$$\frac{C}{I} \geq \frac{1}{6}\frac{(D-R)^{\alpha}}{R^{\alpha}} \rightarrow \left(6\frac{C}{I}\right)^{\frac{1}{\alpha}} = q = \frac{D-R}{R} \rightarrow D-R = qR$$

$$D = (q+1)R \rightarrow \frac{D}{R} = q+1$$

The CIR target 15 dB allows us to evaluate $\frac{D}{R} \geq (\frac{1}{6}10^{15/10})^{1/3.5}+1=5.48$.

For the hexagonal cell the reuse distance should satisfy $\frac{D}{R} = \sqrt{3k}$ where

$k = i^2 + j^2 + i \cdot j$ and $i, j = 1, 2, 3, \ldots$.

We calculate for k k=1,3,4,7,9,12,13,16,19,21,25,27.

$$k \geq \frac{1}{3}\left(\frac{D}{R}\right)^2 = \frac{1}{3}5.48^2 = 10.01$$

Because to k only certain values could be assigned, we select the value that is next highest compare to $\frac{D}{R}$. The reuse distance will be $k = 12$.

If the dominant part of the interference is generated by only two co-channel cells, the CIR can be calculated as:

$$\frac{C}{I} \geq \frac{1}{2}\left(\frac{D-R}{R}\right)^{3.5}$$

By evaluating as above we get $\frac{D}{R} \geq 4.27$, and reuse distance is

$$k > \frac{1}{3}4.27^2 = 6.08 \rightarrow k = 7$$

3. Calculate the minimum frequency reuse distance normalized to cell radius as a function of the required CIR-value, which is based on average path losses. The average path loss distance parameter is α. Give numerical results for idealized hexagonal cell structure with "omni-directional" base stations and sectored (120°) base stations. Calculate the reuse distance for the values given in the table below.

CIR	9 dB	12 dB	15 dB	18 dB	21 dB	24 dB
$\alpha = 2$						
$\alpha = 2.5$						
$\alpha = 3$						
$\alpha = 3.5$						
$\alpha = 4$						
$\alpha = 4.5$						
$\alpha = 5$						

3.

a) We use similar theoretical calculation as in the previous exercise. Worst case interference for omni-directional antenna is generated by 6 interferers.

$$\frac{C}{I} \quad \frac{1}{6}\frac{D \quad R}{R} \qquad 6\frac{C}{I}^{\ \frac{1}{\ }} \quad q \quad \frac{D \quad R}{R} \quad D \quad R \quad qR$$

$$D = (q+1)R \rightarrow \frac{D}{R} = q+1$$

The reuse distance is

$k \geq \frac{1}{3}\left(\frac{D}{R}\right)^2$, where k=1,3,4,7,9,12,13,16,19,21,25,27…279…

CIR	9 dB		12 dB		15 dB		18 dB		21 dB	
	D/R	K	D/R	k	D/R	K	D/R	K	D/R	k
$\alpha = 2$	7.90	20.8	10.75	38.5	14.8	72.7	20.5	139.5	28.48	270.4
$\alpha = 2.5$	5.69	10.8	7.18	17.2	8.15	22.4	11.75	46.0	15.17	76.7
$\alpha = 3$	4.62	7.11	5.56	10.3	6.75	15.1	8.23	22.6	10.11	34.0
$\alpha = 3.5$	4.02	5.38	4.67	7.26	5.48	10.0	6.45	13.9	7.64	19.5
$\alpha = 4$	3.63	4.39	4.12	5.65	4.71	7.39	5.41	9.76	6.24	13.0
$\alpha = 4.5$	3.36	3.76	3.75	4.68	4.21	5.9	4.74	7.49	5.36	9.58
$\alpha = 5$	3.17	3.34	3.49	4.06	3.86	4.97	4.28	6.1	4.76	7.6

For 120^0 sector antenna we use the same algorithm as before but with only 2 main interferes.

CIR	9 dB		12 dB		15 dB		18 dB		21 dB	
	D/R	K	D/R	k	D/R	K	D/R	K	D/R	k
$\alpha = 2$	4.99	8.30	6.63	14.7	8.95	26.70	12.23	49.86	16.87	94.9
$\alpha = 2.5$	4.02	5.38	4.98	8.27	6.25	13.02	7.92	20.9	10.13	34.2
$\alpha = 3$	3.51	4.11	4.16	5.77	4.98	8.27	6.02	12.1	7.31	17.8
$\alpha = 3.5$	3.20	3.41	3.68	4.51	4.27	6.08	4.98	8.27	5.85	11.4
$\alpha = 4$	3.00	3.00	3.37	3.79	3.82	4.86	4.35	6.31	4.98	8.27
$\alpha = 4.5$	2.85	2.71	3.16	3.33	3.51	4.11	3.33	5.14	4.42	6.51
$\alpha = 5$	2.74	2.50	3.00	3.00	3.29	3.61	3.63	4.39	4.02	5.39

4.

a) What is the ideal downlink cell radius in city environment according to the Hata-model with the following system parameters:

carrier frequency fc = 960 MHz,

base station output power 20 W $\leftrightarrow$ 43.0 dBm,

base station antenna gain including feeder loss G_{bs} = 8 dB,

base station antenna height h_{bs} = 30 m,

mobile station net antenna gain Gms = –3 dB,

mobile station antenna height h_{ms} = 1.0 m,

mobile station sensitivity S_{ms} = –102 dBm,

when i) 50% coverage probability is required at the cell border, ii) 90% coverage probability is required at the cell border. The slow fading standard deviation is = 8 dB.

b) What is the cell radius with the above system parameters (except for MS antenna height) if also indoor coverage is required when:

i) 50% coverage probability is required at the cell border,

ii) 90% coverage probability is required at the cell border.

The average wall penetration loss is log-normally distributed with 20 dB mean and standard deviation 10 dB. In this case the minimum mobile antenna height is 3.0 m.

4. Solution

a)

i) First the maximum allowable average path loss is calculated with the given system parameters and applying the radio link power budget:

$$\begin{aligned} S_{ms} &\leq P_{bs} + G_{bs} - L_{path} + G_{ms} \\ \rightarrow L_{path} &\leq P_{bs} + G_{bs} + G_{ms} - S_{ms} \\ &\leq 43.0 + 8.0 - 3.0 + 102.0 = 150.0 \text{ dB} \end{aligned}$$

Next the system and propagation environment parameters are inserted into the Hata average loss formula:

$$
\begin{aligned}
L_{path} &= 69.6 + 26.2\log(f) - 13.8\log\left(h_{bs}\right) - A\left(h_{ms}\right) \\
&\qquad + \left(44.9 - 6.55\log\left(h_{bs}\right)\right)\log(r) \\
&= 69.6 + 26.2\log(960) - 13.8\log(30) - A\left(h_{ms}\right) \\
&\qquad + \left(44.9 - 6.55\log(30)\right)\log(r) \\
&= 69.6 + 78.1 - 20.4 - A\left(h_{ms}\right) + 35.2\log(r) \\
&= 127.3 - A\left(h_{ms}\right) + 35.2\log(r)
\end{aligned}
$$

The term describing mobile station antenna height is now 3 m.

$$
\begin{aligned}
A\left(h_{ms}\right) &= \left(1.1\log(f) - 0.7\right)h_{ms} - \left(1.5\log(f) - 0.8\right) \\
&= \left(1.1\log(960) - 0.7\right)\cdot 1 - \left(1.5\log(960) - 0.8\right), \\
&= 2.6 - 3.9 = -1.3 \text{ dB}
\end{aligned}
$$

giving the average path loss

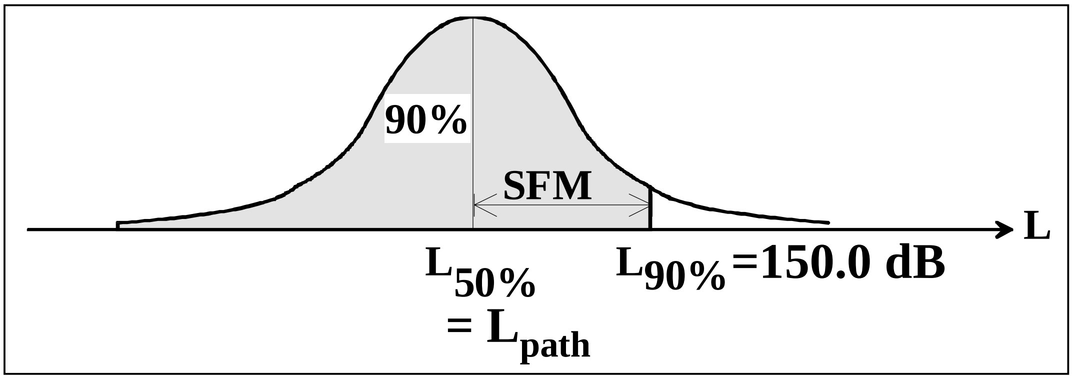
$$L_{path} = 127.3 + 1.3 + 35.2\log(r) = 128.6 + 35.2\log(r)$$

Now the maximum cell radius for 50 % coverage at cell border can be calculated

$$\log(r) = \frac{L_{path} - 128.6}{35.2} \rightarrow r = 10^{\frac{150.0-128.6}{35.2}} = 4.05 \text{ km}$$

ii) For 90 % coverage probability a slow fade margin (SFM) must be used. The average path loss is reduced by the value of SFM. The allowable total loss in the radio link budget will not change. The value for the allowable path loss L_{path} is determined by the system parameters. Now we reserve some part from the budget, slow fading margin, to guarantee that the signal is always above the allowable path loss level. The Hata model provides us with the average attenuation on the radio path. One can assume that on top of it is slowly changing process – slow fading. This process can be approximated by lognormal probability distribution. In order to guarantee that the signal is over allowable level 90 % of time we have to calculate the 10 % level from this probability distribution. We were given the variance and this level depends only from the mean of the distribution.

The situation is demonstrated in the figure below



From the figure follows:

$$Q\left(\frac{SFM}{\sigma}\right) = 0.1 \rightarrow SFM = INVQ(0.1) \cdot \sigma = 1.28 \cdot 8 = 10.2 \text{ dB}$$

which gives the allowable average path loss

$$L_{path} = 150.0 - 10.2 = 139.8 \text{ dB} \rightarrow \text{r}=10^{\frac{139.8-128.6}{35.2}} = 2.08 \text{ km}$$

b) The system parameters are unchanged except for the MS antenna height term, which is now

$$\begin{aligned} A(h_{ms}) &= (1.1\log(f) - 0.7)h_{ms} - (1.5\log(f) - 0.8) \\ &= (1.1\log(960) - 0.7) \cdot 3 - (1.5\log(960) - 0.8) \\ &= 7.7 - 3.9 = 3.8 \text{ dB} \end{aligned}$$

This gives

$$L_{path} = 127.3 - 3.8 + 35.2\log(r) = 123.5 + 35.2\log(r)$$

The wall penetration loss consumes 20 dB from the allowable maximum path loss, so the outdoor average path loss is now

$$L_{path} = 150.0 - 20.0 = 130.0 \text{ dB} \rightarrow \text{r}=10^{\frac{130.0-123.5}{35.2}} = 1.53 \text{ km}$$

For 90 % coverage at cell border the standard deviation of the total log-normal fading (slow fading + wall penetration variation) must first be determined. The two log-normal processes may be assumed statistically independent. Because of the independence we can replace the sum of two lognormal process with a new lognormal process with the deviation calculated from the initial processes deviations as

$$\sigma_{tot} = \sqrt{8^2 + 10^2} = 12.81$$

$$Q\left(\frac{SFM}{\sigma}\right) = 0.1 \rightarrow SFM = INVQ(0.1) \cdot \sigma$$

$$= 1.28 \cdot 12.81 = 16.4 \text{ dB}$$

The allowable average path loss is

$L_{path} = 150.0 - 20 - 16.4 = 114.6$ dB

$\rightarrow$ r=$10^{\frac{114.6-128.6}{35.2}} = 0.400$ km

5. Calculate the mean path loss in the middle of each room along the signal propagation path as seen on the figure below. The room high is 3 m and with 10 m. We assume the wall penetration loss 8,0 dB, floor penetration loss 15,0 dB, carrier frequency 1800 MHz, constant loss $L_c = 0$ dB.

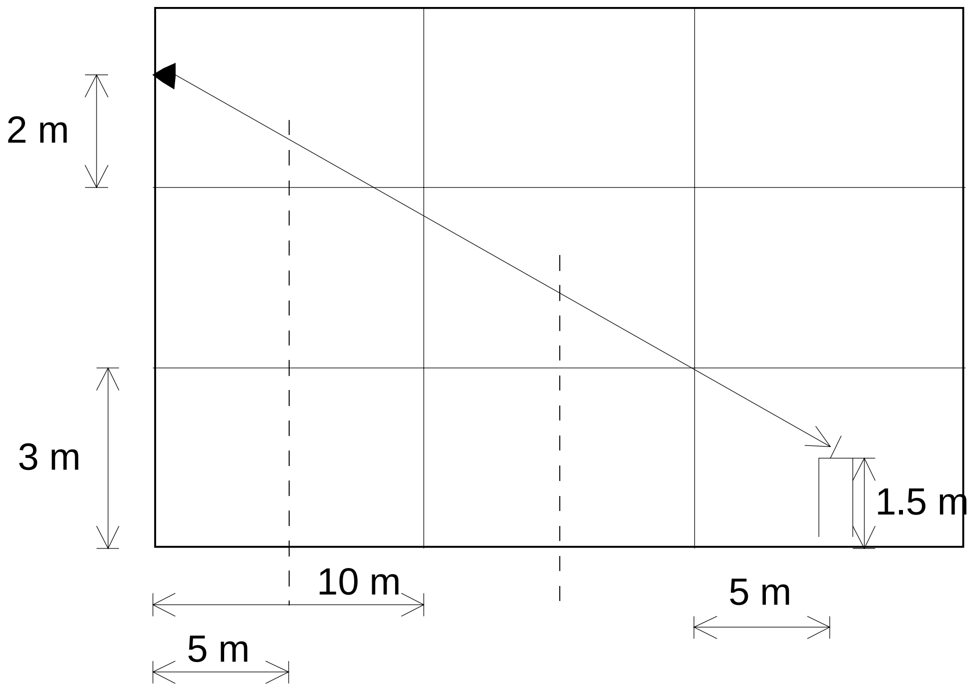


Figure 1.

We calculate the average path loss accordingly to Keenan-Motley-model:

$$L_{path} = L_o + L_c + \sum_{i=1}^{I} k_{wi} L_{wi} + \sum_{j=1}^{J} k_{fj} L_{fj} .$$

where

L_o is the free space loss in dB,

L_c is a constant loss term,

k_{wi} is the number of penetrated walls of type i

k_{fj} is the number of penetrated floors of type j,

L_{wi} is the penetration loss of wall type i,

L_{fj} is the penetration loss of floor type j,

I is the number of different wall types,

J is the number of different floor types.

free space loss:

$$L_o \quad L_c \quad 32{,}5 \quad 20\lg 1800 \quad 20\lg r$$

For our set up the distances from transmitter to the measurement points are

r $[m]$	5.16	16.49	25.83

For these distances the free space path losses are

L_o $[dB]$	111.87	121.4	125.85

The indoor path loss is calculated by taking into account the number of floors and walls that the signal is penetrating:

$$L_{path} = L_o + L_c + k_w L_w + k_f L_f$$

L_{in} $[dB]$	111.87	144.41	171. 85