S72-238 WCDMA systems

Tutorial 4 8.01.2002.

Solutions

1.

In WCDMA system are 10 users at the distances to BS $1, 2, 3, \ldots, 10 \ \ km$ accordingly. Data rate to each user is 30 $\frac{kbit}{s}$ and the spread bandwidth is 3.84 $\frac{Mchip}{s}$. The target SIR for all users is 10 dB.

Is the system in interference (capacity) or noise limited?

a) In uplink when maximum transmitted power of one user is $0.1 \ \ W$.
b) In downlink when total transmitted power of the BS is $10 \ \ W$.
c) What would be transmitted power for each user if they were in the network alone and minimal transmission power is $-50 \ \ dB$.

Attenuation in the channel is 3, 4,and Okomura-Hata. (Height of the BS is $h_{bs} = 50\, m$).

1.

The system is in interference outage when the required SIR target can not be satisfied for all users with positive transmission powers. System is noise limited when the required transmission power, required to achieve the target SIR, is more than the maximal allowed transmission power of the transmitter.

Since in CDMA all users affect each other we create the matrix equation containing interference from all the users. The equation contains transmission power, noise, attenuation and target CIR for each user. From this equation we solve the required transmission powers for each user.

The system described by the matrix can be interference or noise limited. If the calculated received powers are all positive the system is not interference limited.

In order to verify whether the system is noise limited we have to check whether the user can transmitted enough power in order to compensate attenuation in the channel. If this can not be done the system is noise limited.

The equation for the up and downlink are very similar. Therefore for we derive the general equation describing the system and add to it the necessary peculiarities for different links.

For each user we can write the equation for signal to interference ratio

$$SIR_k = \frac{W}{R_k} \frac{P_k f\left(d_k\right)}{\sum\limits_{\substack{n=1 \\ n \neq k}}^{N} P_n f\left(d_n\right) + N_0},$$

where SIR_j is target SIR value, $\frac{W}{R_k}$ is coding gain, P_k signal power for k th user at the transmitter, $f\left(d_k\right)$ is attenuation in the channel, N_0 noise spectral density, and N is a total number of users in the system.

For convenience the SIR_k value may be replaced by $CIR_k = SIR_j \frac{R_k}{W}$.

By combining this equation for each user we get

$$\begin{array}{llllll} f\left(d_1\right)\frac{P_1}{CIR_t} & -f\left(d_2\right)P_2 & -\ldots & -f\left(d_{10}\right)P_{10} & -\eta & =0 \\ f\left(d_1\right)P_1 & +f\left(d_1\right)\frac{P_1}{CIR_t} & -\ldots & -f\left(d_{10}\right)P_{10} & -\eta & =0 \\ & & \vdots & & & \\ f\left(d_1\right)P_1 & -f\left(d_2\right)P_2 & -\ldots & +f\left(d_{10}\right)\frac{P_{10}}{CIR_t} & -\eta & =0 \end{array},$$

$$\mathbf{A} \times \mathbf{P_r} = \mathbf{N_0}.$$

Where

$$\mathbf{A} = \begin{array}{cccc} \frac{1}{CIR_t} & -1 & \ldots & -1 \\ -1 & \frac{1}{CIR_t} & \ldots & -1 \\ \vdots & \vdots & \ddots & \vdots \\ -1 & -1 & \ldots & \frac{1}{CIR_t} \end{array},$$

$$P_r = \begin{array}{c} P_1^r \\ P_2^r \\ \vdots \\ P_{10}^r \end{array} = \begin{array}{c} f\left(d_1\right)P_1 \\ f\left(d_2\right)P_2 \\ \vdots \\ f\left(d_{10}\right)P_{10} \end{array}.$$

We assume that the target signal to interference ratio is equal for all the users.

$$N_0 = 4 \cdot 10^{21} \cdot 3.84 \cdot 10^6 = 1.536 \cdot 10^{-14}.$$

Gain in the system is $G = \frac{3.84 \cdot 10^6}{30 \cdot 10^3} = 128$.

$$SIR_t \frac{R_k}{W} = CIR_t = 10^{10/10}\frac{1}{G} = 0.078.$$

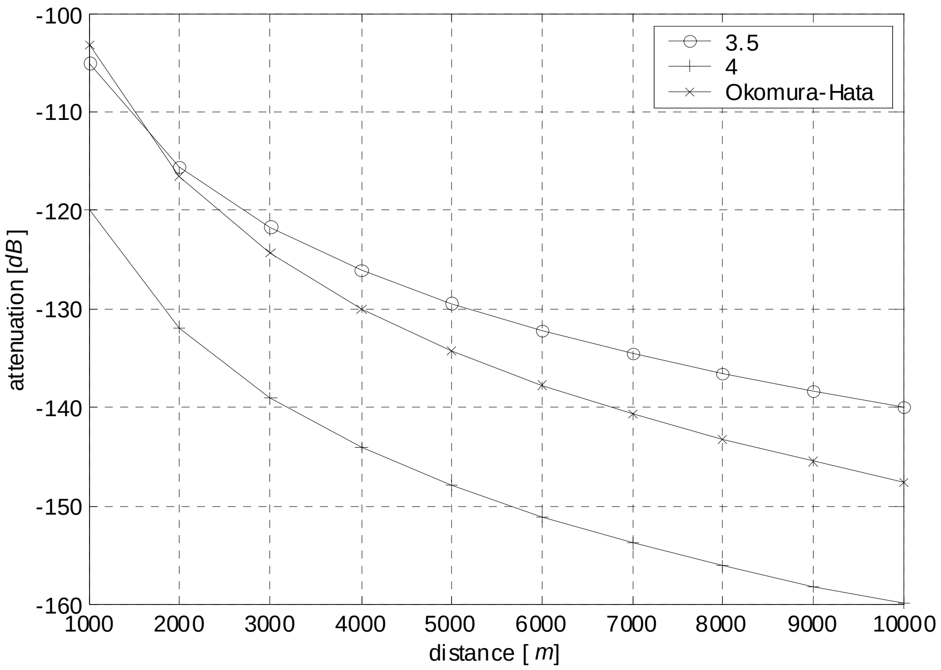
By solving the equation we get required received powers are equal for each user and $P_r = 4.8 \cdot 10^{-15}\ W$. Since all the powers are positive the system is not interference limited. This is true for both up and downlink.

In order to check whether the system is noise limited we have to make assumptions about the attenuation in the channel. We check the capacity for two different attenuation models: simple power law attenuation with constant 3.5, 4, and Okomura-Hata model. We recall that attenuation accordingly to Okomura-Hata is calculated by following formula

$$L_c = 157.3 - 13.82 \lg\left(h_{BS}\right) + \left(44.9 - 6.55 \lg\left(h_{BS}\right)\right) \lg\left(d\right).$$

In order to use this formula we assume that high of the BS is $h_{bs} = 50 \quad m$.

The attenuation in the channel is seen also in the figure below.



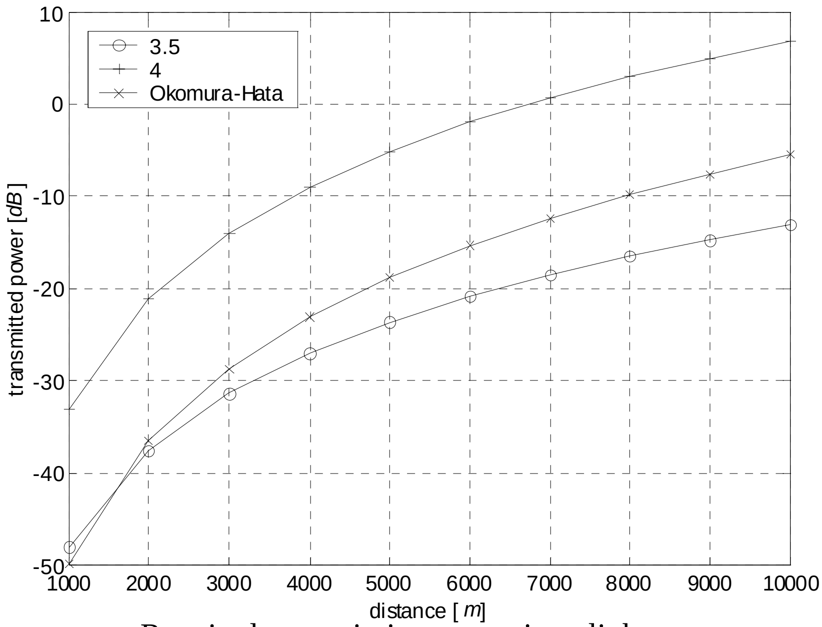
Attenuation in the channel for all the users.

Whether the system is noise limited we have to investigate separately for the up- and downlink.

a) Uplink.

The system is in noise outage if the power it has to use is more than maximum power its transmitter can emit. The attenuation and corresponding transmission powers are described in the table and figure below.

Attnuation 3.5		Attenuation 4		Okomura-Hata	
$d_i^{-3.5}$ $[dB]$	P_i $[dB]$	d_i^{-4} $[dB]$	P_i $[dB]$	L_e	P_i $[dB]$
-105.0	-48.1	-120.0	-33.1	103.2	-49.9
-115.5	-37.5	-132.0	-21.1	116.6	-36.5
-121.7	-31.4	-139.1	-14.1	124.4	-28.7
-126.1	-27.0	-144.1	-9.0	129.9	-23.2
-129.5	-23.7	-148.0	-5.2	134.3	-18.9
-132.2	-20.9	-151.1	-2.0	137.8	-15.3
-134.6	-18.5	-153.8	0.7	140.6	-12.4
-136.6	-16.5	-156.1	3.0	143.3	-9.8
-138.4	-14.7	-158.2	5.1	145.6	-7.5
-140.0	-13.1	-150.0	6.9	147.6	-5.5



Required transmission power in uplink
as a functions of the location of the user.

The maximum transmitted power for the handset was limited to the $0.1 \quad W$ (-10 dB). Because of that limit we see if the attenuation in the channel follows the attenuation law -4 the users farther than 7000 m are all in the outage i.e. they do not have enough power to be connected to the BS.

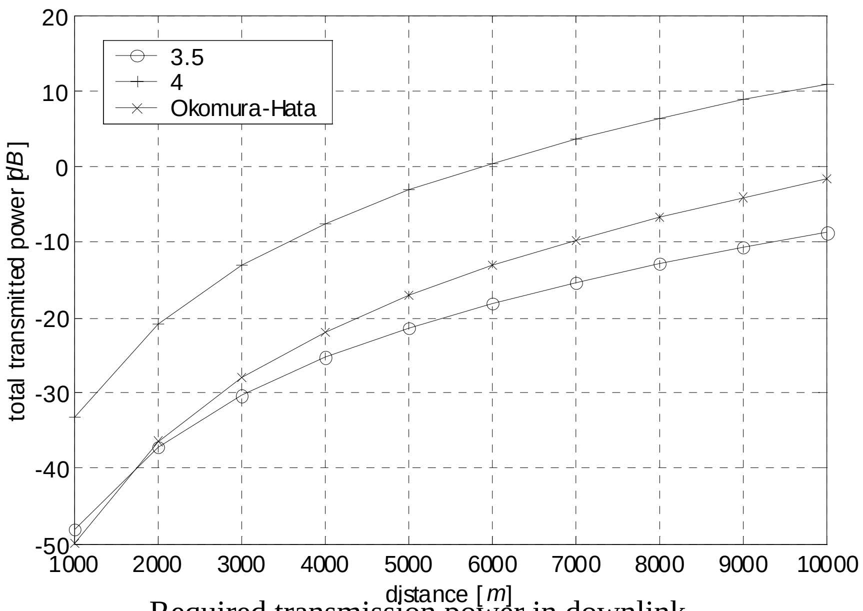
b) Downlink

In downlink we can communicate with all the users when the total transmitted power from BS does not exceed the limiting power of BS transmitted. This limiting power in our case is $10 \quad W$. When the required power exceeds the available power the question is how the power is distributed among the users. In our analysis we assume that the user that requires maximal power is set to outage and the signal to him is not transmitted. In this context the total transmitted power for different cases is counted as sum of powers of all users that are nearer than the user i.

$$P_{total}^{i} = \sum_{j=1}^{i} f\left(d_j\right) P_j .$$

Attnuation 3.5		Attenuation 4		Okomura-Hata	
$d_i^{-3.5} \ [dB]$	$P_i \ [dB]$	$d_i^{-4} \ [dB]$	$P_i \ [dB]$	L_e	$P_i \ [dB]$
-105.0	-48.1	-120.0	-33.1	103.2	-49.9
-115.5	-37.2	-132.0	-20.8	116.6	-36.3
-121.7	-30.4	-139.1	-13.2	124.4	-28.0
-126.1	-25.4	-144.1	-7.6	129.9	-21.9
-129.5	-21.4	-148.0	-3.2	134.3	-17.1
-132.2	-18.1	-151.1	0.5	137.8	-13.1
-134.6	-15.3	-153.8	3.5	140.6	-9.7
-136.6	-12.9	-156.1	6.3	143.3	-6.7

-138.4	-10.7	-158.2	8.7	145.6	-4.1
-140.0	-8.7	-150.0	10.9	147.6	-1.7



Required transmission power in downlink
as a functions of the location of the user.

The outage in downlink occurs only if to assume that the attenuation is accordingly attenuation factor 4 and in this case also only if all 10 users are communicating.

2.

For the same parameters as in exercise 1 what is the situation in uplink and downlink when to consider other cell interference factor to be 0.65.

2.

Again we have to check whether the target SIR for each user can be satisfied with giver power constraints. The impact of the intercell interference is considered by incorporating the interference factor into SIR equation.

For each user we can write the equation for signal to interference ratio becomes:

$$SIR_k = \frac{W}{R_k} \frac{P_k f\left(d_k\right)}{(1+i)\sum\limits_{\substack{n=1 \\ n\neq k}}^{N} P_n f\left(d_n\right) + N_0}$$

where SIR_j is target SIR value, $\frac{W}{R_k}$ is coding gain, i other cell interference factor, P_k signal power for k th user at the transmitter, $f\left(d_k\right)$ is attenuation in the channel, N_0 noise spectral density, and N is a total number of users in the system.

For convenience the SIR_k value may be replaced by $CIR_k = SIR_j \frac{R_k}{W}$.

By combining this equation for each user we get

$$\begin{array}{cccccc} f(d_1)\frac{P_1}{CIR_t} & -(1+i)f(d_2)P_2 & -\dots & -(1+i)f(d_{10})P_{10} & -\eta & =0 \\ (1+i)f(d_1)P_1 & +f(d_1)\frac{P_1}{CIR_t} & -\dots & -(1+i)f(d_{10})P_{10} & -\eta & =0 \\ & & \vdots & & & \\ (1+i)f(d_1)P_1 & -(1+i)f(d_2)P_2 & -\dots & +f(d_{10})\frac{P_{10}}{CIR_t} & -\eta & =0 \end{array},$$

$\mathbf{A} \times \mathbf{P_r} = \mathbf{N_0}$.

Where

$$\mathbf{A} = \begin{matrix} \frac{1}{CIR_t} & -1 & \dots & -1 \\ -1 & \frac{1}{CIR_t} & \dots & -1 \\ \vdots & \vdots & \ddots & \vdots \\ -1 & -1 & \dots & \frac{1}{CIR_t} \end{matrix},$$

$$P_r = \begin{matrix} P_1^r \\ P_2^r \\ \vdots \\ P_{10}^r \end{matrix} = \begin{matrix} (1+i)f(d_1)P_1 \\ (1+i)f(d_2)P_2 \\ \vdots \\ (1+i)f(d_{10})P_{10} \end{matrix}.$$

We assume that the target signal to interference ratio is equal for all the users,
$N_0 = 4 \cdot 10^{21} \cdot 3.84 \cdot 10^6 = 1.536 \cdot 10^{-14}$.

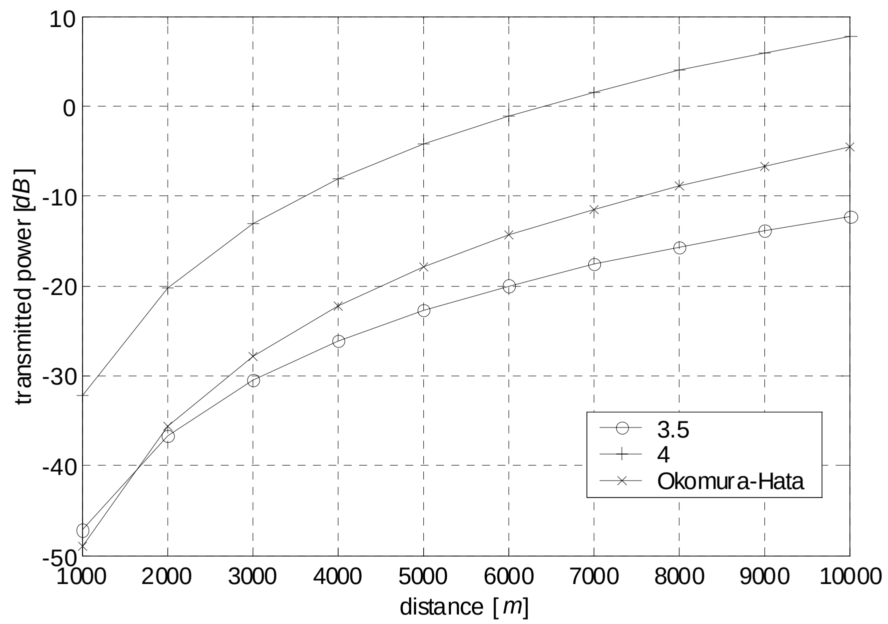
Gain in the system is $G = \dfrac{3.84 \cdot 10^6}{30 \cdot 10^3} = 128$.

$SIR_t \dfrac{R_k}{W} = CIR_t = 10^{10/10} \dfrac{1}{G} = 0.078$.

By solving the equation we get required received powers are equal for each user and $P_r = 6 \cdot 10^{-16}\ W$. Since all the powers are positive the system is not interference limited. This is true for both up and downlink.

a) Uplink

For the uplink we repeat the procedure done in exercise 1. The required transmitted power is given in the table below and illustrated on the figure below.



Attenuation in the channel for all the users.

As we see only when the attenuation is assumed to be accordingly to Okomura-Hata model we can support the connection for all users.

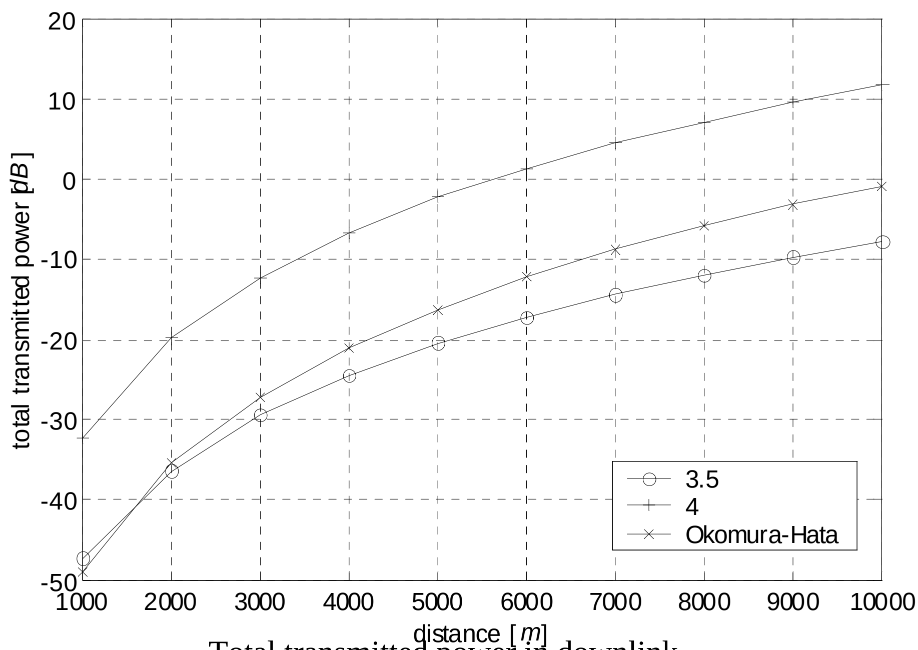
Attnuation 3.5		Attenuation 4		Okomura-Hata	
$d_i^{-3.5}$ $[dB]$	P_i $[dB]$	d_i^{-4} $[dB]$	P_i $[dB]$	L_e	P_i $[dB]$
-105.0	-47.2	-120.0	-32.2	103.2	-49.0
-115.5	-36.7	-132.0	-20.2	116.6	-35.6
-121.7	-30.5	-139.1	-13.1	124.4	-27.8
-126.1	-26.2	-144.1	-8.1	129.9	-22.3
-129.5	-22.8	-148.0	-4.3	134.3	-18.0
-132.2	-20.0	-151.1	-1.1	137.8	-14.4
-134.6	-17.6	-153.8	1.5	140.6	-11.5
-136.6	-15.6	-156.1	3.9	143.3	-8.9
-138.4	-13.8	-158.2	6.0	145.6	-6.6
-140.0	-12.2	-150.0	7.8	147.6	-4.6

b) Downlink

As in the previous we calculate the total transmitted power by summing the power to all users who are nearer to BS as user j. The allowed power is exceeded for the attenuation factor 3.5 and distance more than $8000\ m$.

Attnuation 3.5		Attenuation 4		Okomura-Hata	
$d_i^{-3.5}$ $[dB]$	P_i $[dB]$	d_i^{-4} $[dB]$	P_i $[dB]$	L_e	P_i $[dB]$
-105.0	-47.2	-120.0	-32.2	103.2	-49.0

-115.5	-36.3	-132.0	-20.0	116.6	-35.4
-121.7	-29.5	-139.1	-12.3	124.4	-27.1
-126.1	-24.5	-144.1	-6.7	129.9	-21.0
-129.5	-20.5	-148.0	-2.3	134.3	-16.2
-132.2	-17.2	-151.1	-1.3	137.8	-12.2
-134.6	-14.4	-153.8	4.5	140.6	-8.8
-136.6	-12.0	-156.1	7.2	143.3	-5.9
-138.4	-9.8	-158.2	9.6	145.6	-3.2
-140.0	-7.8	-150.0	11.8	147.6	-0.8



Total transmitted power in downlink.

3.

Calculate the noise rise for different load factors. When the system has chip rate $3.84\ \frac{Mchip}{s}$, target user $SIR = 5\ dB$, user data rate $30\ \frac{kbit}{s}$, orthogonality factor in downlink $\alpha = 0.4$.

Calculate the following noise rises:

a) Uplink.

b) Uplink with other cell to own cell interference $i = 0.65$.

c) Downlink.

d) Downlink with $i = 0.65$.

3.

The noise rise is defined as the ratio of the total received wideband power to the noise power

$$Noise\ \ rise = \frac{I_{tot}}{P_k}.$$

If the signal to interference ratio is constant, the noise rise describes how much the transmitted power should be increased in order to compensate the multiple access interference (interference from other users).

a) For the uplink the noise rise can be calculated as

$$Noise\ rise = \frac{I_{tot}}{P_k} = \frac{1}{1-\eta_{UL}}.$$

Where the term η_{UL} is called uplink load factor. When η_{UL} is close to 1, the corresponding noise rise approaches to infinity and the system has reached its pole capacity.

The load factor for the uplink can be calculated as $\eta_{UL} = \sum_j^N L_j$.

Where L_j is a load factor of one connection. It is calculated by expressing the transmitted power from the energy per user bit divided by the noise spectral density,

$$\frac{E_b}{N_0} = \text{Processing gain of user j } \frac{\text{Signal of user j}}{\text{Total received power}},$$

$$\frac{E_b}{N_0} = \frac{W}{R}\frac{P_j}{I_{total} - P_j},$$

$$P_j = \frac{1}{1+\frac{W}{\frac{E_b}{N_0}R}} I_{total},$$

$$P_j = L_j I_{total}.$$

The total interference excluding the thermal noise P_N can be written

$$I_{total} - P_N = \sum_j^N L_j I_{total},$$

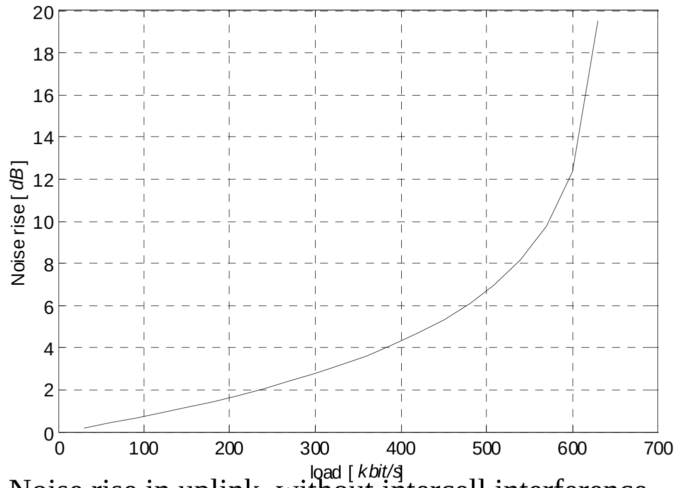
$$P_N = \left(1 - \sum_j^N L_j\right) I_{total},$$

$$\frac{I_{total}}{P_N} = \frac{1}{1-\sum_j^N L_j}.$$

For our parameters the load factor is

$$L_j = \frac{1}{1+\frac{3.84\cdot 10^6}{30\cdot 10^3}\frac{1}{10^{5/10}}} = 0.0241.$$

The calculated noise rise is given on the figure below.



Noise rise in uplink, without intercell interference.

b) The other cell interference can be accounted by scaling the load factor by the intercell interference factor $(1+i)$.

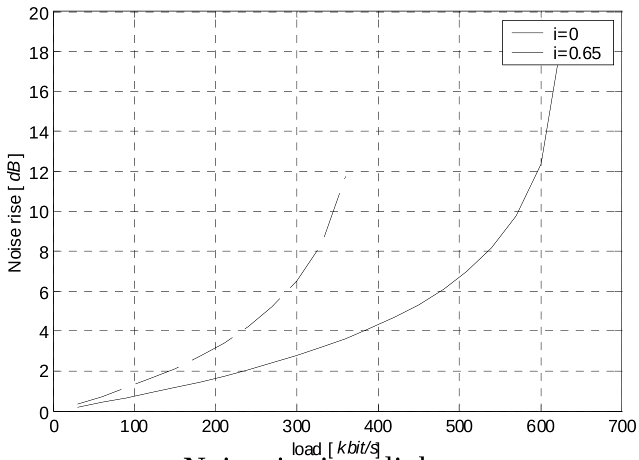
$$\eta_{UL} = (1+i)\sum_{j}^{N} L_j = (1+i)\sum_{j}^{N} \frac{1}{1+\frac{W}{\frac{E_b}{N_0}R}}.$$

For our parameters

$$\eta_{UL} = (1+i)NL_j = (1+i)N\frac{1}{1+\frac{W}{\frac{E_b}{N_0}R}},$$

$$(1+i)L_j = 0.0398.$$

The noise rise for different cell load is presented on the figure by dashed line.



Noise rise in uplink.

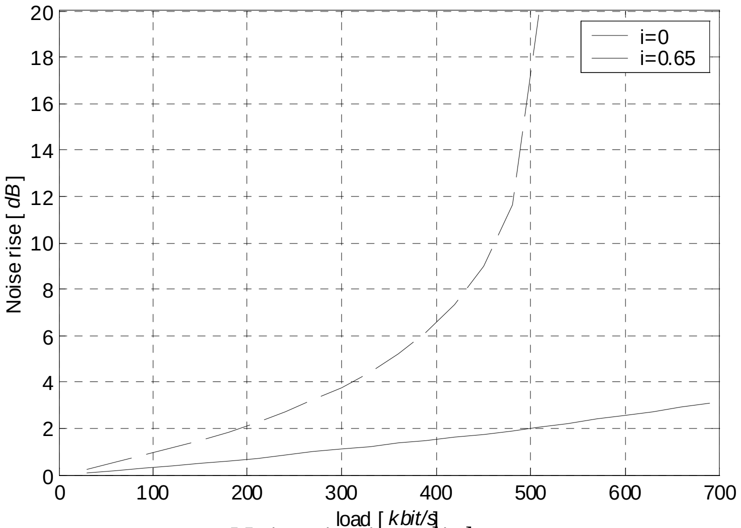
c) In downlink the load factor η_{DL} is slightly different from the uplink load factor

$$\eta_{DL} = \sum \frac{E_b/N_0}{W/R}\left[\left(1-\alpha_j\right)+i_j\right].$$

The term $-10\log_{10}\left(1-\eta_{DL}\right)$ is equal to noise rise over the thermal noise. If no intercell interference is presented the term $i=0$.

The term α that differs from the uplink load factor describes the orthogonality factor in downlink.

The noise rise is seen on the figure.



Noise rise in uplink.