Capacity Effects of the WCDMA 2.5 GHz DL due to UE-UE Interference

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***Abstract*—This paper derives the capacity reduction of WCDMA downlink due to mobile-to-mobile (UE-UE) interference. The assumed frequency scenario is the FDD UL/DL + additional FDD DL operation at 2.5 GHz band identified by ITU-WP8F. The developed downlink capacity model takes into account the average interference from closely located, spectrally adjacent mobiles. The model assumes non-uniform user distribution. The interference coupling due to basestation-to-basestation (BS-BS) interference has been introduced, as well. Similar calculation method can be utilized when computing the interference effects of closely located, independent TDD systems. The suggested model has been demonstrated with numerical examples. The recognition of these interference phenomenas is very important since unlike the BS-UE interference between operators the UE-UE interference is difficult or even impossible to eliminate with the network planning methods. Results indicate that the effect of user distribution, adjacent network loading, UE-UE propagation, cell sizes and the BS-BS isolation have to be taken into account when comparing the performance of radio systems where the UE-UE interference is present.**

***Index Terms*— Mobile Communications, WCDMA, Mobile-to-mobile Interference, Capacity.**

I. INTRODUCTION

WRC-2000 has identified additional bands 806-960 MHz, 1710-1885, and 2500-2690 MHz for possible use by IMT-2000 systems. In relation to 2.5 GHz band (2500-2690 MHz), ITU-WP8F has defined seven possible scenarios for the frequency arrangements [1]. These scenarios include the operation of FDD DL only, paired FDD UL/DL or TDD or combinations of them at the 2.5 GHz band. This study focuses on one of the ITU 2.5 GHz band (2500-2690 MHz) scenarios, i.e. paired FDD UL/DL + additional FDD DL operation at 2.5 GHz band. The additional DL band will be paired with UL operation in some other frequency band, e.g. the UMTS core UL band. However, the FDD UL/FDD DL frequency border creates new interference scenarios (BS-BS, and UE-UE, Fig.1).

In order to determine the UE-UE interference it has been assumed normally that the users are uniformly located over the network area (in [3], for example). This is not, however, the actual situation but the users in the radio cell locate inside clusters. The indoor users are mainly located inside offices, shopping malls, restaurants etc. The business users are located whithin the open-offices or meeting rooms and the outdoor users are typically located in the squares, pedestrian streets or in the parking areas. Vehicular users are located on the streets or highways with different mobile speeds. This means that users can been assumed to be inside clusters of different shape and size. The propagation inside the cluster is dependent on the type of the cluster. In the case of open office, pedestrian streets and shops, for example, the UE-UE propagation can be modelled quite accurately with free space loss. In some other environments, when there are obstacles, like walls, between the mobiles inside the same cluster, the propagation with slope different from free space loss has to be utilized.

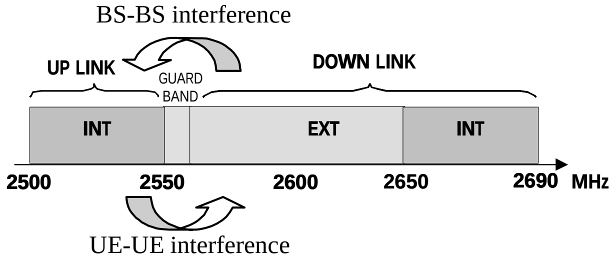

Fig. 1. Interference scenarios at 2.5 GHz frequency band.

This paper has been organized as follows: Section II describes the interference model and the modelling of non-uniform user distribution, Section III shows some numerical results followed by the conclusions in Section IV.

II. INTERFERENCE MODEL

The FDD-FDD UE-UE interference at the 2.5 GHz FDD UL/DL+DL is illustrated in the Fig. 2. It has been assumed that two operators use adjacent frequency bands, so that other operator is using internal band (INT) and the other is using external band (EXT). The question is that what is the needed guard band between the INT and EXT bands in order to have minimal effect on capacity of the system in the external band. The capacity reduction has been defined here as a reduction of number of users which can be supported with a constant base station transmission power compared to the situation without any adjacetn channel operations. The capacity reduction has been depicted in Fig. 3. The effect of the adjacent channel interference whithin the EXT band has been neglected here.

A mathematical model for the average needed base station power will be determined here. The requred E_b/N_0 at the UE can be written as:

$$\frac{(W/R_i)\cdot(p_{tx,i}/L_{1,i})}{\underbrace{\frac{P_{tx}(1-\alpha_i+f_i)}{L_{1,i}}}_{\text{Own + other BS interference}} + \underbrace{N}_{\text{thermal noise}} + \underbrace{\sum_{j\in C}\frac{P_{MS,j}}{L_{j,i}L_{ACIR}}}_{\text{interference from other operator MSs}}} = \rho_{i,} \tag{1}$$

where W=3.84 Mcps, R_i is the bit-rate of the mobile i, $p_{tx,i}$ is the link specific transmission power, $L_{1,i}$ is the total pathloss, including the antenna gains, from the own base station to the mobile i, P_{tx} is the total BS Tx power which is assumed to be the same in all base stations, α_i is the orthogonality of the radio channel, f_i is the average other-to-own cell interference ratio. N is the thermal noise power including the noise figure, ρ_i is the average E_b/N_0 target including the power rise, $P_{MS,j}$ is the mobile station transmission power of the adjacent operator, $P_{MS,k}$ is the mobile station transmission power (own.op), $L_{j,,i}$ is the pathloss from the jth adjacent system MS inside the cluster C to the mobile i and L_{ACIR} is the MS-to-MS adjacent channel attenuation including the effect of out-of-band emission and the adjacent channel selection.

In the following analysis the average mobile station transmission power, $P_{MS,j}$ of the INT system is assumed to be dependent on the total interference level at its own INT BS which is the sum of interference due to loading and the interference from EXT BS. The uplink power from the mobile j of adjacent operator can be thus written as:

$$P_{MS,j} = \frac{\rho_{j,UL} R_{jUL} L_{2,j}}{W}\left(\frac{P_{tx}}{L_{ACIR,BS,BS} L_{BSBS1}} + I_2\right) = \frac{\rho_{j,UL} R_{jUL} L_{2,j}}{W}\frac{P_{tx}}{L_{ACIR,BS,BS} L_{BSBS1}} + \frac{\rho_{j,UL} R_{jUL} L_{2,j}}{W} I_2, \qquad (2)$$

where I_2 is the interference level at Operator 2 BS without system 1 (Operator 1 network), $L_{ACIR,BSBS}$ is the adjacent channel attenuation from BS to BS including the effect of out-of-band emission and adjacent channel selection. L_{BSBS1} is the average attenuation between Operator 1 and Operator 2 BSs including antenna gains. L_{BSBS1} is assumed to be constant throughout this paper. By Inserting $P_{MS,j}$ into (1), the total BS power can be re-written as:

$$P_{tx} = P_{tx}\sum_i \frac{R_i\rho_i}{W}\left(1-\alpha_i + f_i\right) + \sum_i \frac{R_i\rho_i}{W} L_{1,i} N + \sum_i \frac{R_i\rho_i}{W} L_{1,i} \sum_{j\in C}\frac{1}{L_{j,i}L_{ACIR}}\left(A_{1,j}P_{tx} + A_{2,j}\right) + P_c, \qquad (3)$$

where

$$A_{1,j} = \frac{\rho_{j,UL} R_{jUL} L_{2,j}}{W}\frac{1}{L_{ACIR,BS,BS} L_{BSBS1}} \qquad (4)$$

and

$$A_{2,j} = \frac{\rho_{j,UL} R_{jUL} L_{2,j}}{W} I_2. \qquad (5)$$

From this we can solve the needed transmission power of the base station:

$$P_{tx} = \frac{\sum_i \frac{R_i\rho_i}{W} L_{1,i} N + \sum_i \frac{R_i\rho_i}{W} L_{1,i}\sum_{j\in C}\frac{1}{L_{j,i}L_{ACIRM}} A_{2,j} + P_c}{1 - \sum_i \frac{R_i\rho_i}{W}\left(1-\alpha_i + f_i\right) - \sum_i \frac{R_i\rho_i}{W} L_{1,i}\sum_{j\in C}\frac{1}{L_{j,i}L_{ACIRM}} A_{1,j}}. \qquad (6)$$

We will assume constant bit-rates and E_b/N_0-setpoints both in interfering and interfered systems. The orthogonalities and other-to-own cell interference ratios has been assumed constant, average values. The number of users per cell in operator 1 and operator 2 are K_1 and K_2, respectively. The number of users in the system 2 can be expressed through the uplink interference levels. This is:

$$K_2 = \frac{W\left(1-\frac{N_{UL}}{I_B}\right)}{\rho_{UL}R_{UL}\left(1+f\right)}. \qquad (7)$$

When replacing the pathlosses of both system with their average values we can express the base station transmission power with

$$P_{tx} = \frac{\frac{K_1 R\rho\overline{L_1}}{W}\left(N + \frac{\left(I_2 - N_{UL}\right)}{ML_{ACIRM}\left(1+f\right)}\overline{\frac{1}{L_{j,i}}}\,\overline{L_2}\right) + P_c}{\left(1 - \frac{K_1 R\rho}{W}\left(1-\alpha + f + \frac{\left(1-\frac{N_{UL}}{I_2}\right)}{M\left(1+f\right)}\overline{\frac{1}{L_{j,i}}}\,\frac{\overline{L_1}\,\overline{L_2}}{L_{ACIRM}L_{ACIRB}\overline{L_{BSBS1}}}\right)\right)}. \qquad (8)$$

Typically, it has been assumed that the mobiles are uniformly distributed over the network area. In that case the mobile-to-mobile interference is not remarkable since the average distance between the mobiles is large. This is not a realistic assumption but the mobiles are typically clustered to certain locations, like buildings, meeting rooms, shopping malls, pedestrian streets. Therefore, the interference can be

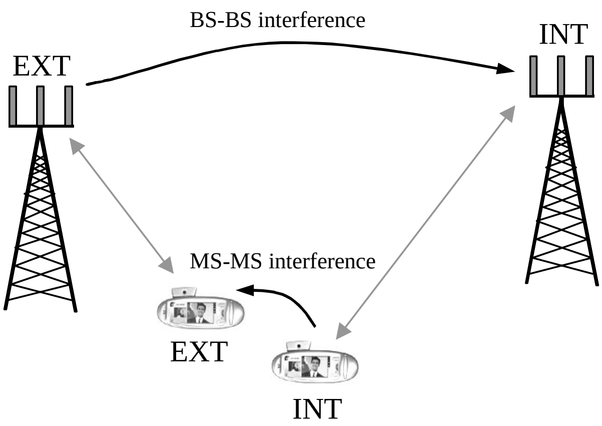

Fig. 2. Interference coupling between two mobile stations operated at adjacent EXT and INT frequency bands in the 2.5 GHz FDD UL/DL+DL frequency scenario.

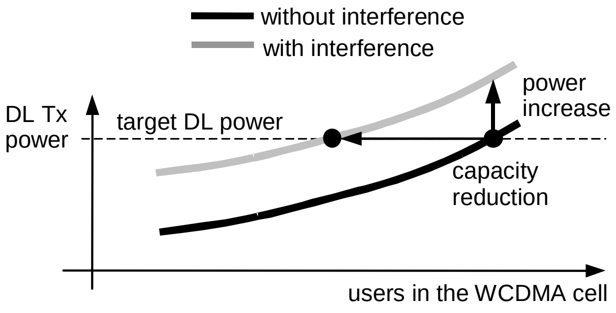

Fig. 3. Definition of the downlink capacity reduction.

assumed to be composed of interference power from the mobiles inside the cluster (Fig. 4). The total interference inside the cluster can be computed based on the pathloss information inside the cluster and the interference level at the adjacent base station. The basic assumption is that the interference in every cluster inside the cell is the same (=average interference) and the varying parameter is the size of the cluster and the number of clusters within one cell. If the cluster is small then the average distance between the mobiles is low and $L_{i,j}^{-1}$ is large and vice versa. It has been also assumed that the average cell size, R is the same in interfered and interfering system. The BSs of two network are assumed to be independently located so that pathlosses are not correlated.

The average over the inverse of the pathlosses $L_{i,j}^{-1}$ inside one cluster can be approximated as:

$$\overline{L_{i,j}^{-1}} \approx \int \frac{1}{L_{i,j}(r)} p_r \, dr \, , \tag{9}$$

where r is the distance between the mobiles, p_r is the average probability density function of the distance.

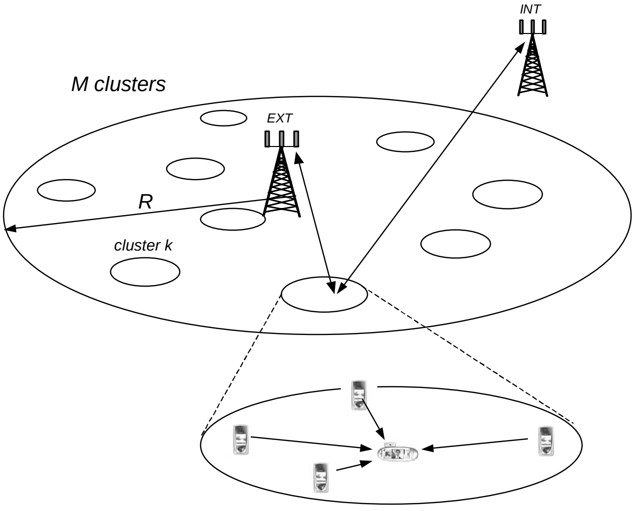

Fig. 4. Non-uniform mobile station distribution where mobiles of both interfering and interfered systems are inside the same clusters.

In here we have assumed that distances are uniformly distributed between distances r_{min} and r_{max}. If the pathloss is in the form of $L(r)=Ar^D$, this inverse can be written as:

$$\overline{\frac{1}{L_{i,j}}} = \frac{1}{A(r_{\min} - r_{\max})(D-1)} \left[\frac{1}{r_{\max}^{D-1}} - \frac{1}{r_{\min}^{D-1}} \right]. \tag{10}$$

In the case of free space pathloss $A=(4\pi/\lambda)^2$ and D=2, where λ is the wavelength. By inserting this equation into (8) we can solve the needed power for the BS as well as the capacity reduction of the WCDMA cell as a function of number of clusters, size of the clusters in meters, average pathloss of the interfering and the interfered cells, loading level of the interfering cell and the adjacent channel attenuation.

III. RESULTS

The capacity reduction as a function of MS-MS ACIR will be shown in this Section. The needed transmission power of the WCDMA BS has been computed with (8) by using the default parameter shown in Table I. The capacity reduction in percentage is the decrease of the number of users the system can support with a given maximum BS power.

TABLE I. DEFAULT MODEL PARAMETERS

N	*-100 dBm*	*f*	*0.65*
R_{DL}	*12200 bps*	P_{max}	*43dBm*
R_{UL}	*12200 bps*	I_2	*-99dBm*
ρ_{DL}	*7 dB*	r_{min}	*2 m*
ρ_{UL}	*5 dB*	r_{max}	*50 m*
P_c	*35 dBm*	*M*	*20*
L_{ACIRB}-L_{ACIRM}	*5 dB*	*R*	*1.4 km*
W	*3.84 Mcps*	*D*	*2*
L_{bsbs}	*120 dB*	*A*	10^4

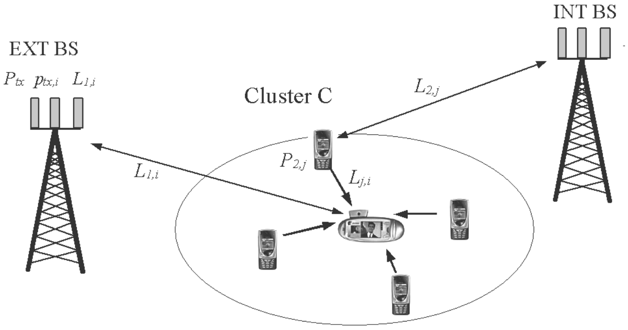

Fig. 5. Interference between mobiles inside one cluster.

The effect of following parameters will be studied: the cell size, the adjacent operator load, the size and the number of clusters, propagation conditions inside the cluster and the BS-BS coupling loss.

A. Effect of the cell size, R

The average pathloss within the cell increases as a function of the size of the cell size which, in turn, increases the needed transmission power of the base station. The effect of the size of the cell to the capacity reduction has been depicted in Fig. 6. It can be shown that when the cell range is 0.8 km the mobile-to-mobile interference does not have a large impact on the system capacity. There are two main reason for this: first the operation point in the downlink load curve is close to the pole capacity of the system and therefore the additional interference does not have large impact on the capacity. Secondly, the interference power from the mobiles of the adjacent operator (and adjacent frequency) are in a quite low level and thus the interference is low.

In the case of the 2.0 km cells the average base power is higher and the operational point is in the low grade part of the load curve. Also the average mobile station power is higher due to higher average pathlosses in the interfering cells.

B. *Effect of the adjacent operator load, I_2*

The effect of the uplink load of adjacent operator network has been shown in Fig. 7. The default value of the total received power is -99 dBm corresponding to about 4 dB noise rise (~60% load) . It can be noticed, that with –96 dBm total received power (~80% load) the capacity decrease about 10-15%. This is because the average mobile station power of the interfereing mobile increases as the load increases.

C. *Effect of the size and the number of clusters, r_{max}, M*

The non-uniform user distribution has been modelled by assuming that users have been grouped into clusters. The adjacent channel mobiles inside the cluster interfere each other but the UE-UE interference between the clusters has been assumed to be negligible. The number of mobiles inside the cell is constant so when the number of clusters, M increases the number of users per cluster decreases, respectively. Also, when the size of the cluster increases the average distance between mobiles inside the cluster increases and the interference and the capacity reduction decreases, correspondingly. This effect has been shown in Fig. 8. The lowest curve corresponds to the situation when there are 200 clusters each allowing 100 m maximum distance between the mobiles which corresponds to relatively uniform network. With the uniform network the capacity reduction is less than 1% when the UE-UE ACIR is 35 dB or more. The distance between the interfering mobiles has been assumed uniformly distributed between r_{min} and r_{max}. Basic shape of the cluster is not necessary circular but it has a general shape. With the non-uniform network the mobiles are grouped increasing the UE-UE interference as indicated in Fig. 8. With 10 clusters each having maximum distance between mobiles of about 10 meters the capacity reduction is 66% when the UE-UE ACIR is 35 dB. This corresponds to the situation where the mobiles are located into same meeting rooms, halls or open offices.

D. *Effect of propagation conditions inside the cluster*

The basic assumption has been that the propagation between the mobiles follows the free space loss propagation model. This is the case in the areas where there are lots of open space so that the mobiles are in line-of-sight (LOS) to each others, like in pedestrian streets, squares, railway-stations, shopping malls and open office type of buildings. When the office type is more traditional so that there are lots of walls between the mobiles the propagation follows, an average, a model with a steeper slope. As an example we have chosen the following three propagation models:

1) $L=40+20\cdot\log_{10}(d[m])$ (LOS-model),
2) $L=37+30\cdot\log_{10}(d[m])$ and
3) $L=37+37\cdot\log_{10}(d[m])$,

where $d[m]$ is the distance between the transmitter and the receiver in meters. Fig. 9 shows the effect of the propagation model. The capacity reduction is less than 10% lower when the ACIR is 35 dB when we use the propagation model 2) instead of the model 1) and about 15% lower when we use model 3) instead of the model 1). This shows that the mobile-to-mobile interference is still considerable even if the propagation environment between the mobiles is more isolating.

E. *Effect of the BS-BS coupling loss, L_{BSBS}*

Fig. 10 shows the effect of the BS-to-BS pathloss to the capacity reduction. The interference from the EXT to INT bands causes increased power coupling between cell layers as explained in Chapter II. In here we have assumed that the BS-to-BS coupling loss is independent on the cell size and the effect of only one interfering BS for each interfered BS has been considered. Results show that when the coupling loss is more than 120 dB its effect is negligible. However, in the case of macrocells with high antenna masts and large gains the attenuation between the BS antennas can be rather low. For example when the distance between the antennas is 2 km the free space pathloss is only 106.4 dB.

For example in [5] the effect of mobile-to-mobile interference in TDD system has been computed with the following assumptions: uniform user distribution, low load in the interfering system, high pathloss between mobiles and BS-BS interference is negligible. In here we have been computed the capacity reduction in the case of FDD UL/DL + additional FDD DL with corresponding parameter settings: I_2=-102 dBm, r_{min}=2 meters, r_{max}=100 meters, M=200, L_{bsbs}=200 dB, A=37, D=3.7, R=2 km. The capacity reduction as a function of MS-to-MS ACIR with these parameter settings has been shown in Fig. 11 (best case). It can be seen that capacity reduction decreases from 0.5% to 0.2% when the ACIR increase from 35 dB to 40 dB. These numbers are quite close to those represented in [5]. With the default parameter settings shown in Table I the respective capacity reductions were from 16.5% (ACIR=35 dB) to 6% (ACIR=40dB).

IV. CONCLUSIONS

This paper shows a simple model which can be used to study the capacity effects of adjacent channel interference in FDD UL/DL + additional FDD DL frequency scenario for 2.5 GHz frequency band. The used model estimates the effect of both MS-to-MS and BS-to-BS interference and the power coupling. The mobiles have been located inside the clusters and thus the non-uniform user distribution can be taken into account, as well.

Results show that there are several critical parameters that have to be taken into account when the effect of MS-to-MS interference is considered: cell size, load of the interfering system, non-uniform user distribution, MS-to-MS propagation and the BS-to-BS interference. When assessing capacity losses in systems which include MS-to-MS interference components, it is not sufficient to assume uniform random MS distributions or to ignore network (BS-BS) interference coupling.

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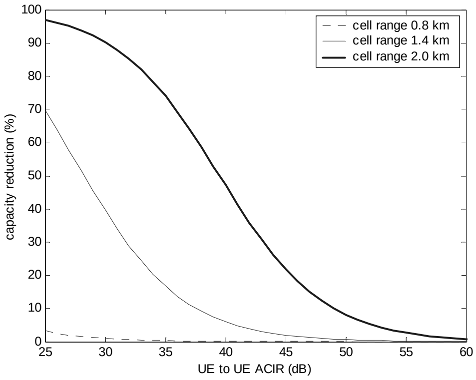

Fig. 6. Effect of the cell range to the capacity reduction as a function of UE-UE ACIR.

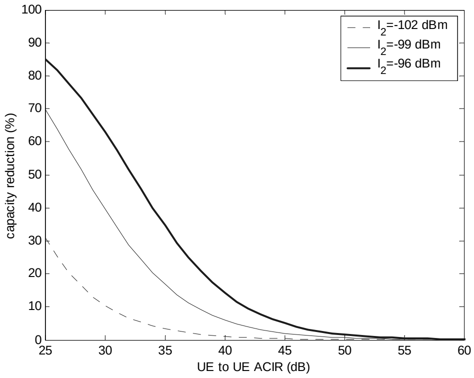

Fig. 7. Effect of the load of the interfering system (I_2) to the capacity reduction as a function of UE-UE ACIR.

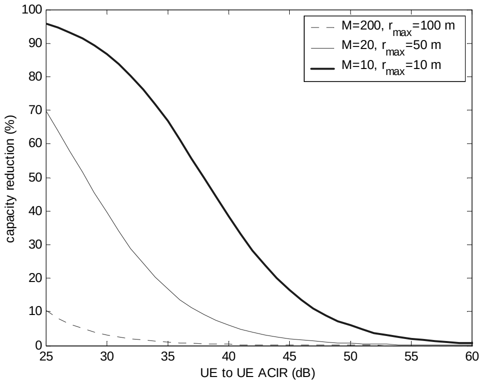

Fig. 8. Effect of the size and the number of clusters to the capacity reduction as a function of UE-UE ACIR.

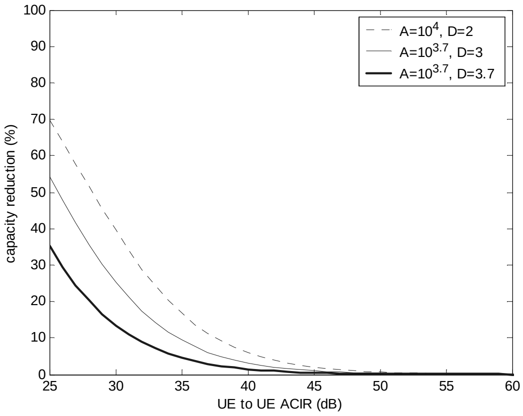

Fig. 9. Effect of the MS-to-MS propagation model to the capacity reduction as a function of UE-UE ACIR.

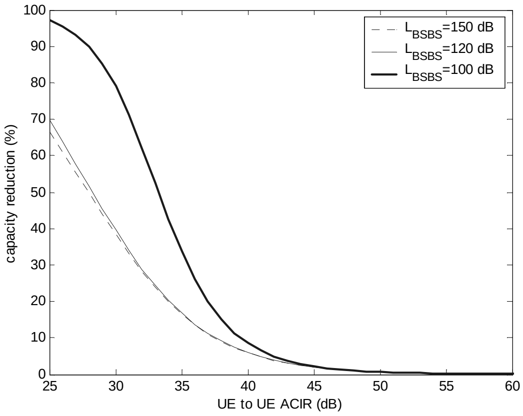

Fig. 10. Effect of the BS-to-BS pathloss to the capacity reduction as a function of UE-UE ACIR.

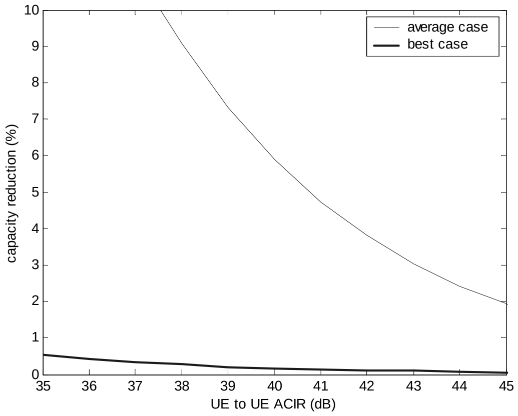

Fig. 11. Effect of using optimum and the average parametrization to the capacity reduction as a function of UE-UE ACIR.