On The Capacity Degradation in W-CDMA Uplink/Downlink Due to Indoor Traffic

J. Pérez-Romero, O. Sallent, R. Agustí

Departament de Teoria del Senyal i Comunicacions
Universitat Politècnica de Catalunya
C/ Jordi Girona, 1 - 08034 Barcelona - Spain
E-mail : [jorperez, sallent, ramon] @ tsc.upc.es

Abstract **Indoor traffic is expected to be key in 3G networks. Nevertheless, the implications of indoor traffic in a 3G WCDMA-based network may be significantly different from those already well know in 2G TDMA-based networks. This papers reveals, by means of a simple analytical model that uplink is much more sensitive than downlink in WCDMA in terms of capacity degradation due to increased indoor traffic levels. Additionally, by means of system level simulation the capacity degradation in different conditions is assessed in both links.**

Keywords: W-CDMA, indoor, capacity, uplink, downlink

I. INTRODUCTION

Indoor traffic is very important in nowadays 2G networks, as remarkable traffic load is originated in buildings. Typically, in GSM in building coverage can be provided in a first step by tuning transmitted power levels. In a second step and to respond also to capacity demands, indoor coverage can also be provided by deploying hierarchical cell structures with micro and picocells.

W-CDMA access networks provide an inherent flexibility to handle the provision of future 3G mobile multimedia services [1]. Although 3G traffic demand profiles are expected to be different from the 2G ones because of the different services nature, clearly indoor traffic will be even more key in 3G since the envisaged high bit rate services will have the tendency for a static user behaviour, in many cases indoor. Furthermore, data traffic will exhibit in many cases an asymmetric behaviour with more traffic generated in the downlink than in the uplink.

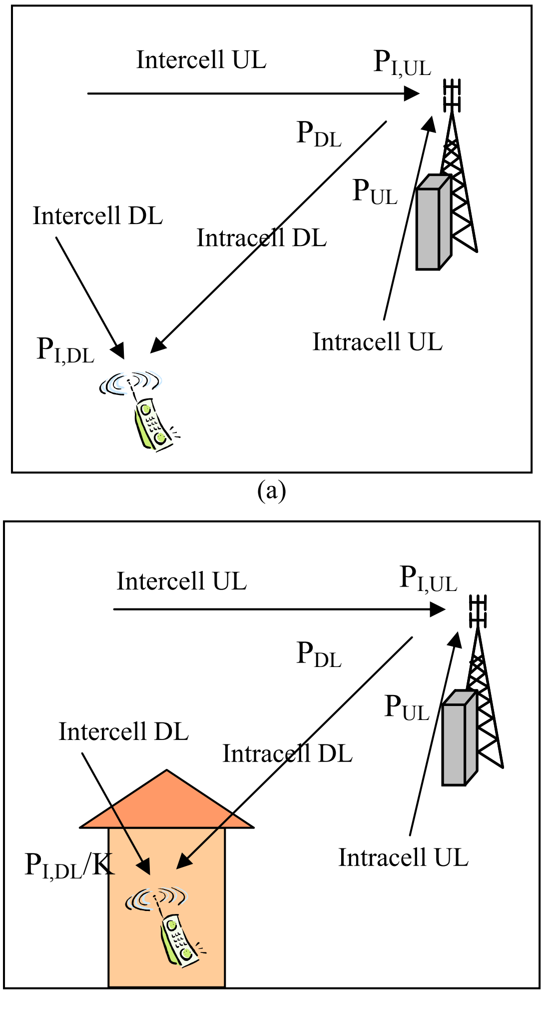
Nevertheless, the implications of indoor traffic in 3G W-CDMA based systems may significantly differ from 2G TDMA-based solutions because transmitted power levels are the key radio resources in W-CDMA. The higher power levels needed for indoor service will lower cell capacity. Consequently, it can be important for a network operator to quantify the impact that indoor traffic may have on the overall system efficiency in order to devise suitable deployment guidelines (i.e. how fast the transition from outdoor macrocell sites to indoor micro and picocells distributions should be carried out). Besides, taking into account different radio bearer services (e.g. 64 kb/s uplink with 64 kb/s downlink; 64 kb/s uplink with 384 kb/s downlink, etc.) different levels of capacity degradation as well as different link direction constraints may appear.

In this framework, this paper is intended to devise the impact on system capacity deriving from different percentages of indoor traffic in the scenario. Firstly, by means of a simple analytical model it will be shown that uplink direction reveals to be much more sensitive to indoor traffic than downlink, so that higher degradations are expected in the uplink. Secondly, different radio bearers with different asymmetry levels are studied by means of system level simulations in both uplink and downlink directions. The complete set of obtained results may help to provide the indications on how and when new infrastructure and/or new cell hierarchies need to be deployed in a given scenario as user density and demanded services evolve. We note that, once the above decision is taken, different works that have been published in the open literature, analysing the problem of indoor coverage in W-CDMA [2-4] can provide the guidelines to succeed in engineering hierarchical cell structures deployment.

The rest of the paper is organized as follows. In Section 2, a simple analytical model to derive the transmitted power increase by an uplink mobile indoor compared to an outdoor mobile is achieved. Similarly, the required downlink Node B transmitted power increase to a downlink indoor user compared to an outdoor one is devised. Then, Section 3 describes the system level simulation set to attain performance figures in Section 4 to conform that indoor traffic is affecting more the uplink than the downlink.

II. INDOOR TRAFFIC IN UPLINK/DOWNLINK

Let consider the two different situations shown in Figure 1: case (a) stands for a given mobile in an outdoor location and case (b) stands for the mobile at the same distance from the cell site but considering it indoor.



(b)

Figure 1 Interference in the outdoor (a) and indoor (b) situations

For the uplink, let denote by $P_{in,UL}$ the mobile transmitted power for the indoor case and $P_{out,UL}$ in the outdoor case. In order to achieve a certain signal to noise plus interference ratio Γ_{UL}, the relations to be ensured in the indoor and outdoor cases are:

$$\frac{\frac{P_{in,UL}}{L\times K}}{P_{N,UL}+P_{I,UL}+P_{UL}}=\Gamma_{UL} \tag{1}$$

$$\frac{\frac{P_{out,UL}}{L}}{P_{N,UL}+P_{I,UL}+P_{UL}}=\Gamma_{UL} \tag{2}$$

where $P_{N,UL}$ is the noise level, $P_{I,UL}$ the intercell interference, P_{UL} the intracell interference, L the path loss, and K the in-building penetration loss. Notice that by setting the same $P_{I,UL}$ and P_{UL} in (1) and (2), it is assumed that neither the intercell nor the intracell interference change due to the fact that the mobile under analysis is indoor or outdoor. As a result, the corresponding required transmitted powers are:

$$P_{in,UL}=L\times K\times\Gamma_{UL}(P_{N,UL}+P_{I,UL}+P_{UL}) \tag{3}$$

$$P_{out,UL}=L\times\Gamma_{UL}(P_{N,UL}+P_{I,UL}+P_{UL}) \tag{4}$$

Thus, the power increase for a user moving from outdoor to indoor in the uplink is given by:

$$\begin{aligned}&(P_{in,UL}-P_{out,UL})=\\&(K-1)\times L\times\Gamma_{UL}(P_{N,UL}+P_{I,UL}+P_{UL})\end{aligned} \tag{5}$$

For the downlink, let denote by $P_{in,DL}$ the base station transmitted power devoted to the user in the indoor case and $P_{out,DL}$ in the outdoor case. Given a certain noise level $P_{N,DL}$, an intercell interference outdoors $P_{I,DL}$, P_{DL} the rest of the base station transmitted power (i.e. the DL intracell interference devoted to other users and to common channels), a path loss L, an in-building penetration loss K, an orthogonality factor ρ and a target signal to interference ratio Γ_{DL}, the corresponding relationships are given by:

$$\frac{\frac{P_{in,DL}}{L\times K}}{P_{N,DL}+\frac{P_{I,DL}}{K}+\rho\frac{P_{DL}}{L\times K}}=\Gamma_{DL} \tag{6}$$

$$\frac{\frac{P_{out,DL}}{L}}{P_{N,DL}+P_{I,DL}+\rho\frac{P_{DL}}{L}}=\Gamma_{DL} \tag{7}$$

Again it has been assumed the simplification that neither the intercell nor the intracell interference change due to the fact that the mobile under analysis is indoor or outdoor. Then, the corresponding required power levels will be:

$$P_{in,DL}=L\times K\times\Gamma_{DL}(P_{N,DL}+\frac{P_{I,DL}}{K}+\rho\frac{P_{DL}}{L\times K}) \tag{8}$$

$$P_{out,DL}=L\times\Gamma_{DL}(P_{N,DL}+P_{I,DL}+\rho\frac{P_{DL}}{L}) \tag{9}$$

Notice that in the downlink direction both the intracell and the intercell interference are diminished by the in-building penetration losses, K. As a result, the power increase for a user moving from outdoor to indoor in the downlink is given by:

$$(P_{in,DL} - P_{out,DL}) = (K-1) \times L \times \Gamma_{DL} \times P_{N,DL} \qquad (10)$$

Comparing the power increase in uplink and downlink given by (5) and (10) respectively, it leads to:

$$\frac{(P_{in,UL} - P_{out,UL})}{(P_{in,DL} - P_{out,DL})} = \frac{\Gamma_{UL}(P_{N,UL} + P_{I,UL} + P_{UL})}{\Gamma_{DL} \times P_{N,DL}} \qquad (11)$$

For equal target qualities and noise level in uplink and downlink, (11) is simplified to:

$$\frac{(P_{in,UL} - P_{out,UL})}{(P_{in,DL} - P_{out,DL})} = 1 + \frac{P_{I,UL} + P_{UL}}{P_{N,DL}} \qquad (12)$$

Thus, it can be observed that in the downlink the power increase depends mainly on noise power while in the uplink it depends mainly on noise plus system interference. As a result, the power increase will be higher in the uplink direction and the higher the load in the system the higher the difference with respect to the downlink will be. Consequently, a lower degradation caused by indoor traffic is expected in the downlink when compared to the uplink. The rationale behind this effect is the higher protection against interference for downlink indoor users provided by the in-building penetration loss.

III. SIMULATION MODEL

In order to attain the capacity degradation caused by indoor traffic in both uplink and downlink a set of system level simulations have been run.

The simulation model considers a macrocellular scenario with 1 km distance between cell sites and two different data services, a symmetric one with 64 kb/s in both uplink and downlink, and another asymmetric, with 64 kb/s in the uplink direction and 384 kb/s in the downlink. The corresponding Radio Access Bearers (RAB) for these two services are defined in [5]. Propagation models are defined in [6], including a lognormal shadowing with 10 dB standard deviation and 20m decorrelation length. The scenario assumes that a fraction p of the users are indoor and they suffer an additional attenuation of K=20 dB due to in-building penetration. The main performance figure that is considered in the simulations is the Block Error Rate (BLER), with a target value of 1%. The corresponding signal to interference ratio value is derived by means of link level simulations. The rest of simulation parameters are summarised in TABLE 1.

TABLE 1 SIMULATION PARAMETERS

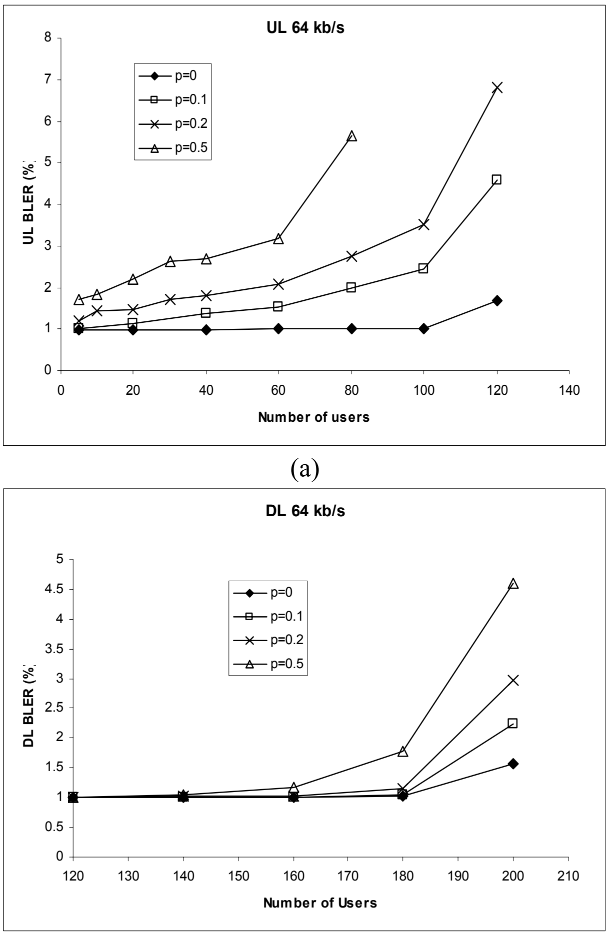
Scenario size	2.25 km x 2.25 km
BS parameters	
Maximum transmitted power	43 dBm
Thermal noise	-106 dBm
Common Control Ch. Power	30 dBm
DL Orthogonality factor	0.4
UE parameters	
Maximum transmitted power	21 dBm
Minimum transmitted power	-44 dBm
Thermal noise	-100 dBm
Handover parameters	
Active Set maximum size	1
Replacement hysteresis	1 dB
Time to Trigger Handover	0.5s
QoS parameters	
BLER target UL/DL	1%
Traffic model	
Activity factor	1
Arrival rate	29 calls/h/user (Poisson)
Call duration	2 min (exp.)

IV. RESULTS

Figure 2 presents the BLER for the 64/64 kb/s RAB in the uplink and in the downlink, as a function of the number of users in the scenario. Results reveal that, under the present conditions, the system is uplink limited and that a severe degradation is observed in the uplink when the fraction of indoor users *p* increases. Besides, Table 2 presents the capacity loss for both uplink and downlink as the fraction of indoor traffic increases. Capacity is defined as the maximum number of users in the scenario that guarantees a BLER ≤ 2%. It can be observed that the degradation due to indoor users is much more significant in the uplink than in the downlink direction. Particularly, when half of the users are indoor (*p*=0.5), the reduction in the uplink is 88% while in the downlink it is only 15%.

When an asymmetric service like the RAB 64/384 kb/s is considered, results are presented for the DL direction in Figure 3 (the UL direction would be the same as in Figure 2a). In the case *p*=0 (i.e. all users are outdoor) the maximum number of users in the system is clearly downlink limited due to the high service asymmetry. However, and as it was observed in the RAB 64/64 kb/s, the capacity degradation when increasing the fraction of indoor users is much more significant in the UL than in the DL, to the extent that when half of the users are indoor (*p*=0.5) the system becomes uplink limited. Results in terms of capacity degradation with respect to the *p*=0 case are also shown in Table 2. Although the capacity reduction for the DL is higher with the 384 kb/s service than with the 64 kb/s service, it is still much lower than the reduction in the uplink.

Additionally, Figure 4 illustrates the effect of indoor users in terms of the total Node B transmitted power when the 64/384 kb/s service is considered with 20 users in the scenario. As an example, for the 90% percentile, a power increase of 3 dB is observed when half of the users are indoor (p=0.5) with respect to the outdoor case (p=0).



(a)

(b)

Figure 2 BLER for the 64 kb/s service and different fractions of indoor users *p* in uplink (a) and downlink (b)

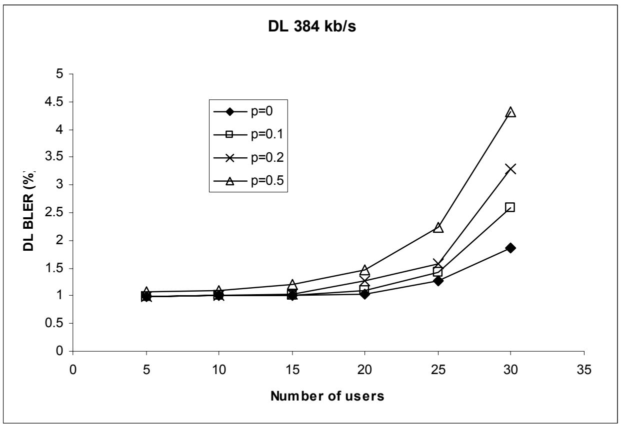


Figure 3 DL BLER for the 384 kb/s service and different *p*

TABLE 2 CAPACITY LOSS (%) RELATIVE TO THE CASE WITH NO INDOOR TRAFFIC (P=0) FOR 64/64 KB/S AND 64/384 KB/S RADIO BEARER

	UL 64 Kb/s	DL 64 Kb/s	DL 384 Kb/s
p=0.1	19.2%	9.3%	12.5%
p=0.2	37.7%	11.6%	18.8%
p=0.5	88.4%	15.3%	25.0%

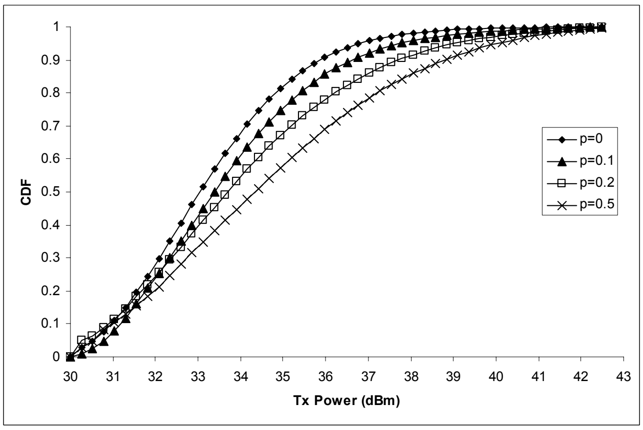


Figure 4 CDF of the total transmitted power in the Node B for different *p* and with the 384 kb/s service

V. CONCLUSIONS

This paper has dealt with the influence of indoor traffic in 3G WCDMA-based networks. A simple analytical model has been presented in order to reveal that uplink is much more affected by indoor traffic than downlink. Some capacity degradation figures have been obtained though simulations, showing that the uplink may become the limiting direction even for asymmetric services such as 64/384 Kb/s when the percentage of indoor traffic increases.

VI. ACKNOWLEDGEMENTS

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