# Impact of Traffic Hotspots in 3G W-CDMA Networks

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*Abstract*— **This paper focuses on the analysis of 3G mobile communications systems in scenarios with non-uniformly distributed traffic. Special attention is paid to the impact of hotspots on RRM strategies such as uplink admission control. Users path loss is examined for different hotspot configurations, and degradation suffered by users in terms of BLER is observed by varying hotspot density and distance from base station. Results reveal that the performance of the system in the uplink depends on traffic distribution and that some parameters of RRM strategies should be adapted to these varying situations.**

*Keywords: Hotspot, W-CDMA, Radio Resource Management, Admission threshold.*

## I. INTRODUCTION

Third generation (3G) mobile communications systems have been designed to be able to support different sorts of multimedia services. To do so in a proper and efficient way, it is necessary to use all available resources without congesting the network. Thus, the main target in these systems is to maximize the network usage for a given set of QoS (Quality of Service) requirements [1]. This may be reached by means of network planning and Radio Resource Management strategies. On one hand, cell planning is essentially of static nature and therefore it cannot deal with casual fluctuations and variations of a priori considered situations. On the other hand, RRM is the key to control effects derived from system dynamics, which are tightly coupled to the amount of interference in the air interface. In W-CDMA based systems, soft capacity concept appears to be one of the most important points, since it includes a flexibility degree to admit or reject connections depending on system load. This is an advantage with respect to 2G systems, which have a fixed capacity value, but it also makes 3G systems performance much more sensitive to environment variations, specially those having remarkable impact on interference level. Although for relatively low loads an efficient management of radio resources may not involve an important benefit, when the number of users in the system increases to a critical number, a good management will be necessary in order to prevent, control and solve network congestion situations. Additionally, RRM strategies are not subject of standardization, so that they can be a differentiation issue among manufacturers and operators.

Most real scenarios present certain areas with specific traffic density (the so-called hotspots) that may degrade not only transmission quality of terminals placed in that area but the whole system performance. As traffic distribution may have an important impact on air interface interference, it is also expected to affect RRM strategies somehow.

Some studies in the literature have been carried out about non-uniformly distributed traffic environments. There are different views from which they face the problem. Many of them are concentrated on the coverage. Solutions proposed are the use of embedded microcells in macrocell systems to guarantee the coverage regardless of the presence of hotspots [2][3][4]. In particular, [2] uses a two cells system to compare call dropping and coverage, paying special attention to power assignment algorithms. A different approximation is made in [3], where the overall capacity is analysed. [4] studies a single hotspot microcell embedded to a single macrocell.

Another extended point of view considers the possibility of internetworking between UMTS and WLAN. [5] is an overview of the architecture that a UMTS-WLAN system should have. An example of architecture study is presented in [6]. Finally, in [7] a real scenario with WLAN access points and UMTS Node-Bs is simulated in order to obtain the maximum achievable throughput for different configurations. Simulations are done for two different standards: IEEE 802.11a and HIPERLAN2. A study where theoretical expressions of cell capacity are obtained in a single cell system for different traffic distribution functions is presented in [8].

This paper differs from previous work in that neither microcells nor WLAN access points are considered. Hereinafter hotspot situations are solved by means of RRM strategies, without considering the deployment of new infrastructure elements. In the paper, the impact of hotspots without CAC has been initially studied. Afterwards, CAC parameters have been adjusted.

The rest of this paper is organized as follows. In Section II simulation model is explained, providing information on the most important parameters value as well as on different model

considerations. Section III contains results obtained by means of simulation. Firstly, no CAC procedure is applied. Then, CAC parameters are designed according to previous results. Finally, Section IV summarizes the study.

## II. SIMULATION MODEL

For the evaluation of traffic hotspot impact on RRM strategies, and more particularly on Call Admission Control, a system level simulator has been developed. Only videophone users have been simulated and only uplink direction has been considered. The scenario is composed of a single isolated cell. In the physical layer, a link level simulator that includes the 1500 Hz closed loop power control, 1/3 turbo coding effect and channel impulse response estimation, provides BLER (Block Error Rate) statistics used by the system level simulator [9]. Simulation parameters are summarized in Table 1. Propagation models are the standards used in UTRA evaluation for the macrocellular environment, taking a standard deviation for shadowing of 3 dB. Also, a standard mobility model is considered [10], with 10 km/h mobile speed. Characteristics of the radio access bearer are taken from [11] and given by a Transmission Time Interval (TTI) of 20 ms, a Transport Block (TB) size of 640 bits and a Transport Format allowing to send 2 Transport Blocks per TTI. Taking into account the CRC and turbo-encoding process such transmission requires a spreading factor equal to SF=16 in the uplink.

Table 1. Simulation parameters

| Cell radius | 1000 m |
|---|---|
| **BS parameters** | |
| Cell type | Omnidirectional |
| Maximum transmitted power | 43 dBm |
| Thermal noise | -103 dBm |
| Pilot and common control channel power | 32 dBm |
| Shadowing deviation | 3 dB |
| Shadowing decorrelation length | 20 m |
| **UE parameters** | |
| Maximum transmitted power | 21 dBm |
| Minimum transmitted power | -44 dBm |
| Thermal noise | -99 dBm |
| Mobile speed | 10 km/h |
| **Traffic model** | |
| Call duration | 120s |
| Offered bit rate | 64 kb/s (CBR) |
| Activity factor | 1 |
| Call rate | 15 calls/h/user |
| **QoS parameters** | |
| BLER target | 1% |
| Eb/No target | 2.95 dB |

Statistics collected in order to assess the behavior of the system are BLER and admission probability. BLER (Block Error Rate) depicts the percentage of erroneous TB (Transport Block) received by the base station. Admission probability is the probability of admitting a connection request.

The scenario is composed of an isolated cell, with a hotspot placed $d$ meters far from the base station. There is a total traffic T. $\alpha$T is concentrated within the hotspot and the rest of the traffic is homogeneously distributed around the cell. (see Figure 1). Hotspot radius is 25 m.
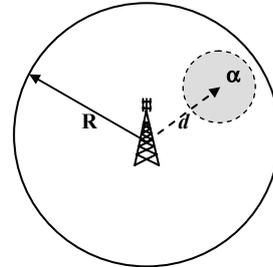


Figure 1. Simulation scenario.

## III. PERFORMANCE EVALUATION

In this section, some results obtained from the considered non-uniformly distributed traffic environment will be exposed.

## III.A IMPACT OF TRAFFIC LOAD DISTRIBUTION

In order to highlight the effects of hotspot, different traffic load distributions will be analysed by varying $\alpha$ and d. It seems to be clear that different traffic distributions lead to different path loss patterns, that is to say, statistics regarding users path loss are tightly dependant on hotspot positions as well as on its density.

Figure 2 and Figure 3 show the probability density function of users path loss for different $\alpha$ values as well as for different hotspot distances (d). It is observed that statistics of path loss suffered by users change if $\alpha$, d or both of them vary. Path loss pdf with $\alpha$=1.0 is equal to path loss of users within the hotspot, which depends on its location and dimension.

Figure 2 and Figure 3 depict that, for high d, as $\alpha$ increases path loss pdf concentrates and shifts to high values. For low d, path loss pdf presents a two peak shape. If $\alpha$ increases, low path loss values become more probable and high values less probable. If $\alpha$ decreases, low values are less probable and high values are more probable. In the case of high d, high path loss values correspond to hotspot users path loss. In case of low d, low path loss values correspond to hotspot users path loss.

In Figure 4, there is a variation of d for a fixed $\alpha$. It is possible to see that as d grows, path loss pdf goes from a two peak shape to a concentrated shape in high values. So, depending on hotspot location and concentration high path loss situations may appear. Since path loss and transmitted power are tightly coupled, this is directly reflected in QoS performance due to power limitations.
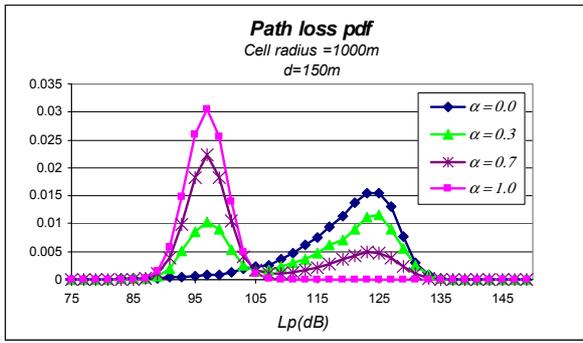
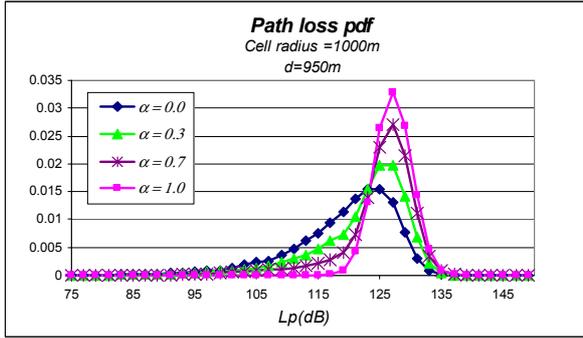Figure 2. Pdf of users' path loss with a hotspot d=150m far from base station.



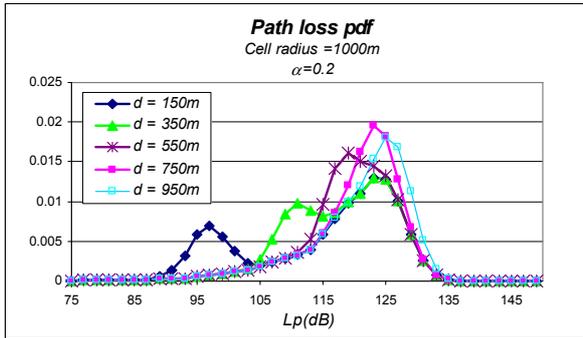Figure 3. Pdf of users' path loss with a hotspot d=950m far from base station.



Figure 4. Pdf of users' path loss with α=0.2 and different hotspot distance.

Table 2 presents uplink BLER values in three different situations. The first column (α= 0.0) corresponds to uniform traffic distribution whereas the second and the third column ($\alpha$ = 0.3 and $\alpha$ = 0.5 ) corresponds to a scenario with a hotspot whose centre is placed 950m from the base station. Results have been obtained with 40 users in both cases. BLER is referring to the total BLER, BLER Hotspot denotes BLER observed only for those users within the hotspot and BLER no Hotspot is for users out of the hotspot. It is worth noting that hotspots with high d results in a remarkable increase in total BLER. However, this effect is solely caused by degradation of hotspot users quality, since users not belonging to hotspot keep their quality approximately constant. Table 2 also shows that BLER increases as α increases. Hotspot BLER is very

high, and the higher α is, the more contribution to global BLER it will represent. BLER obtained is over the target of 1%, but it is so because no CAC has been applied.

Similarly, Table 3 shows the evolution of BLER as a function of hotspot distance (d). As it could be expected, total BLER increases as d increases. Regarding hotspot BLER, it also grows for large d. On the contrary, no hotspot users BLER is lower for high d. This is because power limitation of hotspot users grows and the amount of interference decreases.

Table 2. BLER for three different traffic distributions and 40 users (20 Er of overall traffic).

|  | $\alpha$=0.0 | $\alpha$=0.3 | $\alpha$=0.5 |
|---|---|---|---|
| BLER (%) | 1.53 | 1.86 | 2.04 |
| BLER Hotspot (%) | N/A | 2.63 | 2.60 |
| BLER no Hotspot (%) | 1.53 | 1.53 | 1.53 |

Table 3. BLER for three different hotspot distances, α=0.5 and 40 users (20 Er of overall traffic).

|  | d=150m | d=550m | d=950m |
|---|---|---|---|
| BLER (%) | 1.46 | 1.48 | 2.04 |
| BLER Hotspot (%) | 1.00 | 1.07 | 2.56 |
| BLER no Hotspot (%) | 1.93 | 1.89 | 1.51 |

### III.B  CAC DESIGN FOR HOTSPOT SCENARIOS

RRM strategies are the mechanisms in charge of controlling interference and assure QoS levels. Among different RRM strategies, the paper focuses on uplink CAC (Call Admission Control). In the uplink, condition (1) should be accomplished in order to accept a new connection.

$$\eta + \Delta\eta \leq \eta_{max} \qquad (1)$$

where η is the load factor, Δη is the estimate of the load increase that the establishment of the bearer request would cause in the radio network and $\eta_{max}$ is a threshold set to avoid increasing the load excessively, since it would lead to situations where some users couldn't reach the required $(E_b/N_o)$.

CAC design is based on the election of a suitable maximum allowed load factor ($\eta_{max}$) but, according to Table 2, $\eta_{max}$ is dependant on traffic distribution. For similar load factors, total BLER presents different behaviour. The target is to see the impact of path loss on quality requirements as a function of load factor. Thus, as shown in (2), the transmitted

power depends on path loss, noise power, load factor, transmission rate and $(E_b/N_o)$.

$$P_T = L_P \frac{P_N}{1-\eta} \frac{1}{\dfrac{\left(\dfrac{W}{R_b}\right)}{\left(\dfrac{E_b}{N_0}\right)_T}+1} \qquad (2)$$

where $L_p$ is the path loss, $P_N$ is the noise power, $\eta$ is the load factor, $W$ is the total bandwidth (3.84 MHz), $R_b$ is the transmission rate and $(E_b/N_o)_T$ is target quality requirement.

Probability to be below the quality requirement is defined as:

$$p\left(\left(\frac{E_b}{N_0}\right)<\left(\frac{E_b}{N_0}\right)_T\right)=$$
$$=p\left(L_P > \frac{P_{T\max}(1-\eta)}{P_N}\left(\frac{\left(\dfrac{W}{R_b}\right)}{\left(\dfrac{E_b}{N_0}\right)_T}+1\right)\right) \qquad (3)$$

Path loss statistics may be used to predict (3). With the cumulative density function of $L_p$ it is possible to determine the maximum path loss for a certain percentage of time. Once determined $L_p^*$ value and using the expression (4), the admission threshold that should be used can be found out.

$$\eta_{\max} = 1 - \frac{L_p^* P_N}{P_{T\max}} \frac{1}{\dfrac{\left(\dfrac{W}{R_b}\right)}{\left(\dfrac{E_b}{N_0}\right)_T}+1} \qquad (4)$$

Thus, making use of an admission threshold equal to $\eta_{\max}$ it is expected to be enough to achieve the required QoS. As all these calculations are obtained by means of (3), it appears to be necessary to relate both, (3) and BLER. Thus, for numerical results purposes, (3) is set to 0.5%. By means of simulations it has been observed that 0.5% corresponds to a 1.3% BLER. Following the process described by (3) and (4), a suitable admission threshold is obtained , as shown in Table 4.

Table 4. Maximum load factor for 0.5% probability below quality requirements.

| | $\eta_{max}$ |
| --- | --- |
| $\alpha = 0.0$ | 0.77 |
| $\alpha = 0.5$ | 0.68 |

Figure 5 depicts the BLER achieved with different CAC threshold setting. For the uniform distribution ($\alpha=0$) $\eta_{max}=0.77$ is a suitable admission threshold since it maintains a low BLER. However, $\eta_{max}=0.77$ is not a suitable threshold if

$\alpha=0.5$ since BLER presents a high level. In this case, it is possible to re-establish BLER requirements by decreasing $\eta_{max}$ to 0.68. Regarding hotspot BLER, the suitable setting keeps a low BLER level, whereas an unsuitable value for $\eta_{max}$ cannot avoid the increase of BLER in hotspot (Figure 6). Figure 6 shows that admission threshold has to be decreased in order to maintain QoS requirements when hotspot density ($\alpha$) increases.
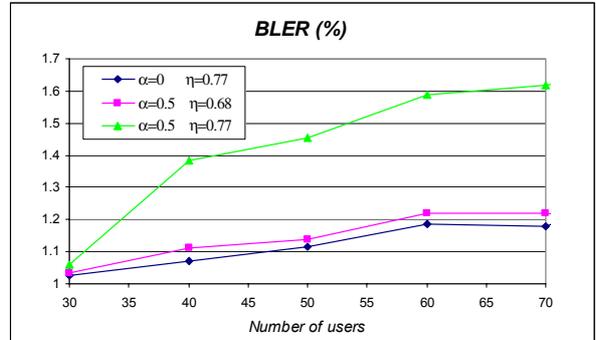
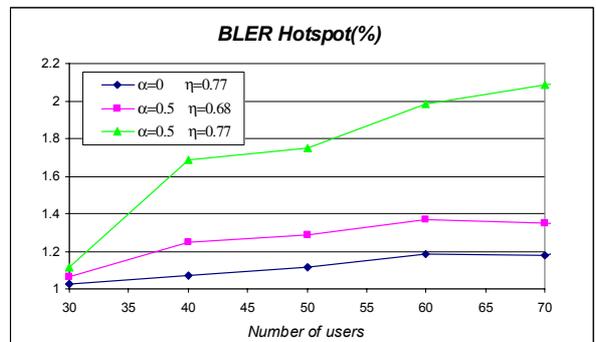Figure 5. BLER for different cases when applying CAC..

Figure 6. BLER of hotspot users for different $\eta_{max}$.

In terms of admission probability, Figure 7 reveals that it decreases as $\eta_{max}$ is decreased. For instance, admission probability is about 90% for 40 users if $\alpha=0.5$ and $\eta_{max}=0.68$. If $\alpha=0$ and $\eta_{max}=0.77$, admission probability reaches 90% for about 45 users.
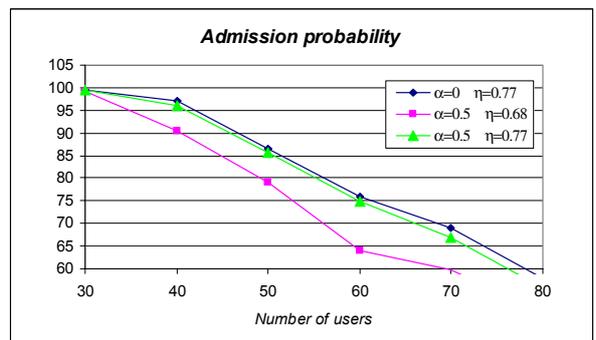
Figure 7. Admission probability when applying CAC.

## IV. CONCLUSIONS

This paper has evaluated QoS features in non-uniformly distributed traffic scenarios (scenarios containing hotspots). It has been shown that, when no admission control is used, a QoS degradation is observed if hotspot d and $\alpha$ are high. The paper has devised a method to deal with this problem by suitably setting the uplink admission control threshold. In order to maintain the BLER, it has been seen that admission threshold has to be decreased. Thus, by adjusting $\eta_{max}$ it is possible to achieve similar BLER for both, uniform traffic distribution and non-uniform traffic distribution.

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