DOWNLINK CAPACITY ESTIMATION FOR UMTS NETWORK : IMPACT OF USERS' POSITION, SERVICE BIT RATES AND CELL RADIUS

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ABSTRACT

In this paper, we investigate downlink power allocation and capacity for UMTS network. It is a well-known fact that in UMTS network, downlink capacity is mainly limited by the total transmitted power at the base station (BS). Our work emphasizes the impact of the users' repartition in the cell (or their distances from serving BS), the service bit rate and the cell radius on power allocation and capacity estimation. We look at the performance limitation for a total power BS of 20 watts, by leading some simple simulations (perfect power control and no macro-diversity).

1. INTRODUCTION

In third generation wireless radio mobile such as Universal Mobile Telecommunications System (UMTS), the downlink, as compared to the reverse link, is more likely to be the limiting factor for the system capacity ([1]). Downlink radio capacity is in fact constrained by the maximum allowed transmit power at the base station (BS) since this power is a common resource to be shared by all users in the cell. If one user requires a large fraction of the allowed transmit power, the overall capacity will indeed be decreased. Downlink radio capacity is also limited by the number of available orthogonal codes, but we only focus our study on power limitation impact.

In UMTS network, one user requires more power if he undergoes significant interferences, which are tightly linked to his location. Downlink capacity is then inevitably related to the distribution of the mobiles in the cell. Moreover, the increase of the service bit rate seriously affects the downlink radio capacity. The aim of this paper is to point out these constraints by simulations made on different scenarios in case of perfect power control and without soft handover.

Besides, coverage and downlink capacity are often associated in the radio network dimensioning ([1, 2]). We also will illustrate this interrelation in our work. So, in addition to the impact of mobiles distribution and the service bit rates, we study the impact of the cell radius on power allocation and downlink capacity. Several works (e.g. [2-5]) have examined the downlink capacity by developing some analytical models. Our work, with respect to the previous studies, aims to underline downlink constraints in UMTS and give a simple analysis of the downlink radio capacity.

In the next section, we give more details about the considered system model and present the link quality equation. Then, the downlink power allocation equation is developed in section 3. Our simulation results relative to the impact of the users' location, service bit rates and of the cell radius on downlink radio capacity are respectively commented in section 4. Finally, section 5 concludes this paper.

2. SYSTEM MODEL AND LINK QUALITY EQUATION

An hexagonal cell scenario is considered, given by a central cell and one surrounding ring, knowing that considering more than one ring won't change the conclusions we derive in our study (Figure 1). A base station (BS) is referred by $b=1,..,B$ ($B=7$) and is located in the center of the cell with an omni-directional antenna. All the cells are assumed to have the same mobiles distribution. The total transmit powers from the BSs are, consequently, equal. The study is based on the central cell, referred with BS1.

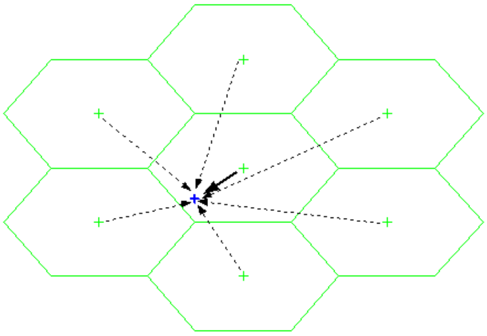

Figure 1. Model layout and downlink interferences

It is assumed that the short-term fluctuations caused by multi-path propagation are mitigated by the receiver and the fast power control loop. Therefore, the propagation model only considers path loss and slow variations caused by shadowing. Like in [1, 2], path loss is determined by the Okumura-Hata propagation model for urban areas.

For a MS m in the reference cell, interferences come from its own cell and from other cells (Figure 1). Let α, $\alpha \leq 1$, be the orthogonality factor ($\alpha = 1$ corresponds to perfect orthogonality) and $g_{b,m}$ is the link gain from other BS b to MS m. The total power at BS1, P (also referred as P_{total}), is assumed to be the same at all BSs. The bit energy-to-noise density $(Eb/N_0)_m$ of MS m is thus expressed by :

$$\left(\frac{E_b}{N_0}\right)_m = \frac{W}{R_m} \times \frac{p_m \; g_{1,m}}{(1-\alpha)\; P\; g_{1,m} + P \sum_{b=2}^{B} g_{b,m} + P_N} \qquad (1)$$

where p_m is the power transmit at BS1 for the MS m, W is the chip rate, R_m is the bit rate and P_N is the noise power.

3. DOWNLINK POWER ALLOCATION

In UMTS, the BS power P has two parts : one part, P_{CCH}, is relative to the common control channels, the other one to Dedicated Physical Channels (DPCH); P_{CCH} is typically around 15% of the total BS power budget [1]. As most of common control channels are not power controlled, P_{CCH} can be modeled by a constant [2]. The total transmit power of BS1 is then :

$$P = \sum_{m=1}^{M} p_m + P_{CCH} \qquad (2)$$

where p_m is the allocated power to MS m and M is the total number of mobiles in the reference cell.

Assuming a perfect power control, mobiles are able to track the target Eb/N_0 i.e. $(Eb/N_0)_m \approx [Eb/N_0]_t$. Required transmit power p_m for MS m can then be deduced from the link quality equation (1) [2-4].

$$p_m = \left[\frac{E_b}{N_0}\right]_t \frac{R_m}{W} \left[(1-\alpha)\; P + P \;\; f_{DL,m} + P_N / g_{1,m} \right] \qquad (3)$$

where $f_{DL,m} = (\sum_{b=2}^{B} g_{b,m}) / g_{1,m}$ is the other-over-own cell received power ratio.

The term linked to noise power is not predominant in the equation (3), as P_N is set to about –100 dBm. Capacity estimates are evaluated under this condition. The required power p_m for MS m is then strongly dependent on the ratio $f_{DL,m}$ and on the user's service bit rate R_m. We specially notice that p_m becomes important for higher ratios of $f_{DL,m}$. As link gains $g_{b,m}$ depend on distances from MS m to different BSs, $f_{DL,m}$ is linked to mobile's location. Figure 2 illustrates $f_{DL,m}$ values versus mobile's location. It shows that this ratio becomes important, if the mobile is located by the edge of the cell. In fact, it lies between 0.1 and 0.6 for MS m in the middle of the cell, whereas it is more 0.6 for MS m at a distance r superior to 75% of the cell radius R from the BS. It even can exceed 2 if the MS is in the corners of the hexagonal cell. Mobiles near the cell edge will then clearly require much power than those being next to the BS. This will have an impact on the capacity as we will show in the next paragraph.

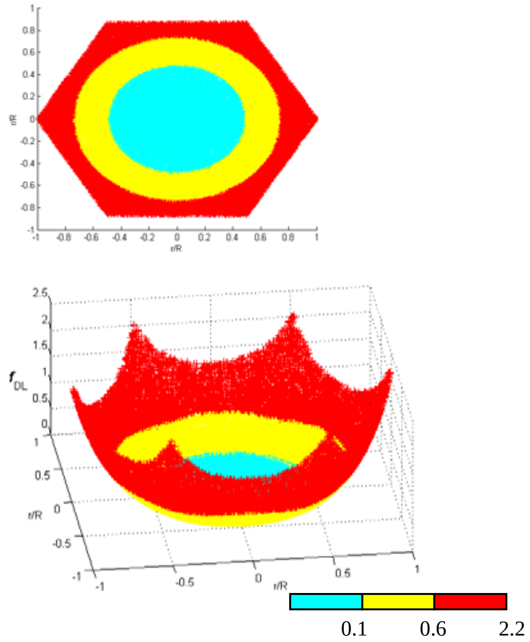

Figure 2. Other-to-own interference magnitude versus user's location in the cell.

4. CAPACITY ESTIMATION

Downlink air interface capacity (i.e. the maximum number of users served in the cell) is achieved if the required total power reaches the total available power at the base station fixed to P = 20 watts in our work. The system constraint equation is then given by :

$$\sum_{m=1}^{M} p_m \leq p_{\max} \qquad (4)$$

where $p_{max} = 0.85\,P$.

Downlink radio capacity is often estimated based on snapshot analysis [3-5]. In each of the snapshots, the MS distribution and the shadowing constellation are generated totally independent of the other snapshots. The MSs are assumed motionless, too.

We study in the following the impact of MS distribution and their service bit rate using the simulation parameters in Table 1 [1, 2].

Table 1. Simulation parameters.

Simulation parameters	Values
Number of snapshots	1000
Bit rate R_v for voice service(kbps)	12.2
Bit rate R_d for data service (kbps)	64 and 144
Eb/No target for voice service (dB)	8
Eb/No target for 64 kbps data service (dB)	2.5
Eb/No target for 144 kbps data service (dB)	2.3
Orthogonality factor	0.5
Noise power (dBm)	-100
Maximum total power available at the BS (dBm)	43

4.1. Influence of Users' Repartition and Cell Radius

Usually ([1-5]), a uniform distribution of the mobiles in the whole cell is considered. In our work, we also consider a uniform distribution of the mobiles, but the latter are located in tree different ways (Figure 3) : near the BS ($r \leq R/2$), in the entire cell, and by the boundary of the cell ($r \geq 0.75R$).

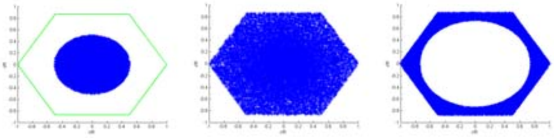
(a) (b) (c)

Figure 3. Zones of MS distribution considered in our study : (a) near the BS, (b) in the entire cell and (c) by the boundary of the cell.

Figure 4 illustrates the required total power at the BS as a function of the number of mobiles in the reference cell for speech service and for a cell radius *R* of 1.4 km. We notice that capacity is very reduced if the users are located near the edge of the cell (scenario (c)), as compared to the case where they are close to the BS (scenario (a)). It is about 35 MS/cell in scenario (c) against 125 MS/cell in scenario (a) and 72 Ms/cell in scenario (b) which leads to a reduction of 51.4% of the capacity given by the scenario (b). This is due to the high inter-cell interference level by the cell edge. Mobiles are generally uniformly distributed in the cell (scenario (b)) and radio capacity is situated between the two bounds. It is here almost equal to 72 MS/cell.

As mentioned before, capacity is estimated by averaging the required transmit power over all snapshots. A common alternative is to consider an outage probability inferior or equal to 2%. Assuming that the required total power at the BS is normally distributed (when making statistics over different snapshots), the total transmit power in 98% of the cases P_{total_max98}, is therefore equal to :

$$P_{total\_98} = P_{total}\,(1 + 1.69\,\sigma_{rel}) \qquad (5)$$

where P_{total} is the mean total base station power and $\sigma_{rel} = \sigma_P / P_{total}$ the relative standard deviation of the required power for a given number of MSs in the cell.

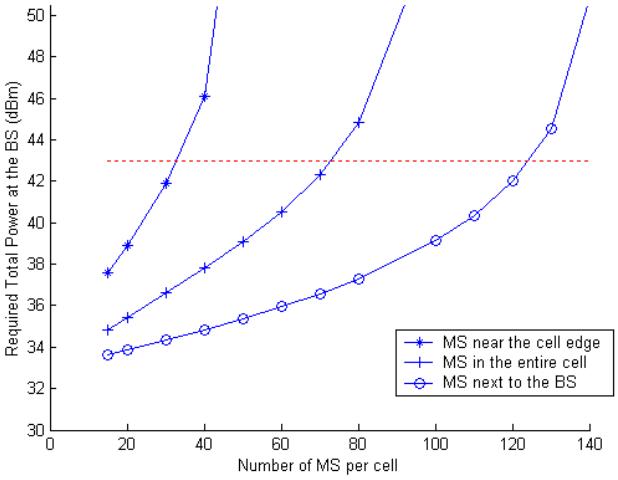

Figure 4. The required BS total power as a function of speech users for a cell radius *R* = 1.4km.

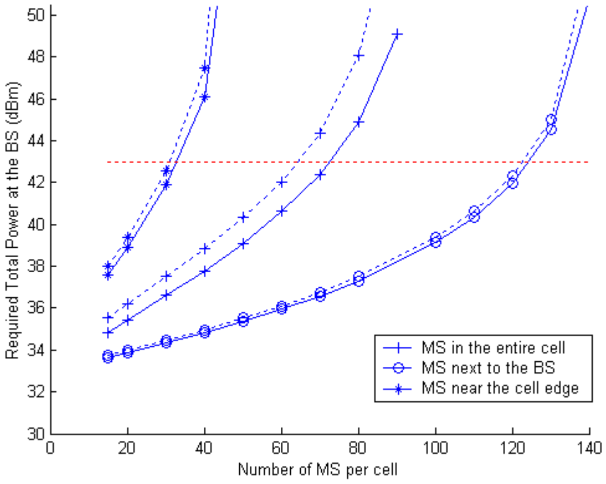

Figure 5. Comparison between the average required power at the BS (–) and its 98% probability level (- -) for a cell radius *R* = 1.4km.

Figure 5 illustrates the mean of the required total power at the BS (P_{total}) and its 98% probability level (P_{total_98}). In 98% of the cases, the maximum served speech users' number is 65 rather than 72 MS/cell. Notice that the relative standard deviation is not very significant in scenario (a) and (c) because of the restricted area in users' distribution.

Radio capacity can be improved if we reduce the cell radius. In fact, as shown in Figure 6, the results are enhanced when the cell radius is lessened to *R* = 0.7 km. For the same number of users in the cell, less transmit power is required at the BS. For the scenario (c), capacity is increased by 17.1%, and by 12.5% for scenario (b) as well. This phenomenon is known as *cell breathing*.

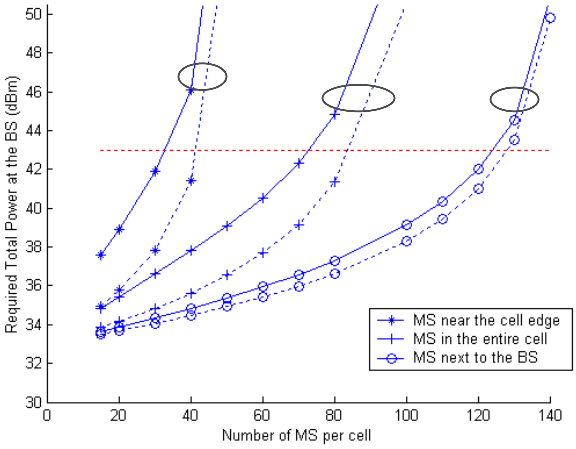

Figure 6. Comparison between the required total power at the BS for cell radius of R = 1.4km (–) and of R = 0.7 km (- -).

4.2. Influence of the Service Bit Rate

In Figure 7, we compare the number of served MS/cell for 64 kbps data traffic to 144 kbps data traffic. One can notice that as expected, increasing user's bit rate increases required power at the BS (with a factor larger than rate rise). Compared to 64 kbps data traffic alone, the maximum mobiles' number per cell can be reduced up to 55% if we only have 144 kbps data traffic. As a matter of fact, for higher bit rate service, the downlink of the UMTS-Release'99 remains very limited (capacity limitation as we have already illustrated, theoretical peak bit rate of 2 Mbps…). The UMTS-Release 5, which integrates High Speed Downlink Packet Access HSDPA, is expected to provide a higher bit rate for the downlink link (up to 12 Mbps) and to increase radio capacity for applications requiring a significant bit rate [6, 7].

5. CONCLUSION

Our study, based on some simple scenarios, has illustrated how UMTS downlink power allocation and capacity estimation are strongly dependent on user's location, service bit rates and cell radius. It has shown that users located by the edge of the cell decrease the radio capacity by more than 50% in case of speech traffic. Data traffic at 144 kbps also reduces radio capacity by more than 50% as compared to 64 kbps data traffic. For higher bit rate service, capacity is very lessened and new techniques in next UMTS releases (Release 5 and 6), mainly the HSDPA, will likely overcome this system performance degradation.

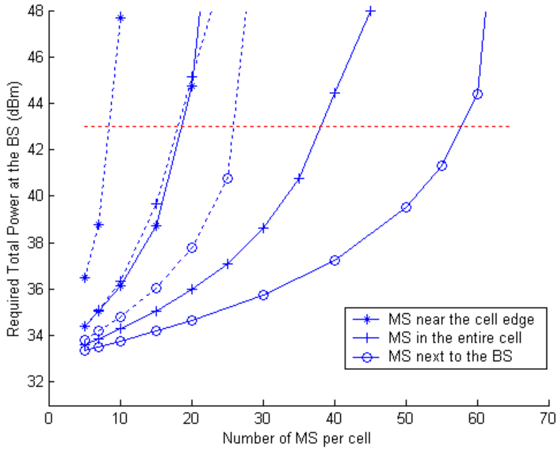

Figure 7. The required BS power as a function of users' number in the cell for a cell radius R = 0.7 km : Comparison between the 64kbps users' case (–) and 144kbps users' case (- - -).

6. REFERENCES

[1] Holma H., Toskala A. "WCDMA Radio Access for Third Generation Mobile Communications". J.Wiley, 2001, 2nd Ed.

[2] Sipilä K., Honkasalo Z.C., Laiho-Steffens J. Waker A., "Estimation of Capcity and Required Transmission Power of WCDMA Downlink based on Pole Equation.", IEEE Vehicular Technology Conference Proceedings, Vol.2, pp.1002–1005, May 2000.

[3] Gilhousen K.S., Jacobs I.M., Padovani R., Viterbi A.J., "On the Capacity of a Cellular CDMA System", IEEE Transactions on Vehicular Technology, Vol. 40, No. 2, pp. 303-312, May, 1991.

[4] Zhang Q., "UMTS Air Interface Voice/Data Capacity – Part2 : Forward Link Analysis", IEEE Vehicular Technology Conference Proceedings, Vol.4, pp.2730–2734, May 2001.

[5] Hilutnen K., De Bernardi R., "WCDMA Downlink Capacity Estimation", IEEE Vehicular Technology Conference Proceedings, Vol.1, pp.992–996, May 2000.

[6] Assaad M., Zeghlache D., "On the Capacity of HSDPA", Global Telecommunications Conference, 2003. GLOBECOM'03. IEEE Volume 1, 1-5 Dec. 2003. pp.60 - 64 Vol.1

[7] Forkel I., Klenner H., "High Speed Downlink Packet Access (HSDPA) – A Means of Increasing Downlink Capacity in WCDMA Cellular Networks?", Proceedings European Wireless 2004, Feb. 24-27, 2004, Barcelona, Spain.