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WCDMA Uplink Capacity of Highways Cigar-Shaped Microcells with Incorporated HSUPA Service

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Abstract: The multi-service (voice, data and HSUPA) uplink capacity and the interference statistics of the sectors of the cigar-shaped WCDMA microcell are studied using a model of 5 highway microcells. The two-slope propagation loss model with lognormal shadowing is used in the analysis. It is concluded that the voice and data service are significantly affected by HSUPA users and sector capacity decreases dramatically when one of these users gets connected to a given sector or to one next to it. Also it has been concluded that the capacity decrement is highly sensitive to the location of the HSUPA users. Thus, no more than one HSUPA with a process gain of 16 can be connected to a given base station. In this case, the HSUPA user should interrupt its transmission when it is near to the sector border. No more than one HSUPA user with a process gain of 8 is permitted in a given sector and the sector next to it. When the HSUPA user is at the sector border, its transmission should be disabled.

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1- Introduction

High-Speed Uplink Packet Access (HSUPA) is a 3G mobile telephony protocol in the HSPA family with up-link speeds up to 5.76 Mbit/s. The name HSUPA was created by Nokia. The 3GPP does not support the name 'HSUPA', but instead uses the name Enhanced Uplink (EUL) [1]. The specifications for HSUPA are included in Universal Mobile Telecommunications System Release 6 standard published by 3GPP. – "The technical purpose of the Enhanced Uplink feature is to improve the performance of uplink dedicated transport channels, i.e. to increase capacity and throughput and reduce delay.

HSUPA uses an uplink enhanced dedicated channel (E-DCH) on which it will employ link adaptation methods similar to those employed by HSDPA, namely: shorter Transmission Time Interval enabling faster link adaptation; HARQ (hybrid ARQ) with incremental redundancy making retransmissions more effective. Similarly to HSDPA, HSUPA uses a packet scheduler, but it operates on a request-grant principle where the UEs request a permission to send data and the scheduler decides when and how many UEs will be allowed to do so. A request for transmission contains data about the state of the transmission buffer and the queue at the UE and its available power margin. However, unlike HSDPA, uplink transmissions are not orthogonal to each other.

In addition to this scheduled mode of transmission the standards also allows a self-initiated transmission mode from the UEs, denoted non-scheduled. The non-scheduled mode can, for example, be used for VoIP services for which even the reduced TTI and the Node B based scheduler will not be able to provide the very short delay time and constant bandwidth required.

Each MAC-d flow (i.e. QoS flow) is configured to use either scheduled or non-scheduled modes; the UE adjusts the data rate for scheduled and non-scheduled flows independently. The maximum data rate of each non-scheduled flow is configured at call setup, and typically not changed frequently. The power used by the scheduled flows is controlled dynamically by the Node B through absolute grant (consisting of an actual value) and relative grant (consisting of a single up/down bit) messages.

At Layer 1, HSUPA introduces new physical channels E-AGCH (Absolute Grant Channel), E-RGCH (Relative Grant Channel), F-DPCH (Fractional-DPCH), E-HICH (E-DCH Hybrid ARQ Indicator Channel), E-DPCCH (E-DCH Dedicated Physical Control Channel) and E-DPDCH (E-DCH Dedicated Physical Data Channel).

E-DPDCH is used to carry the E-DCH Transport Channel; and E-DPCCH is used to carry the control information associated with the E-DCH.

The key specification parameters that are introduced by the use of HSUPA are:

- **Increased data rate:** The use of HSUPA is able to provide a significant increase in the data rate available. It allows peak raw data rates of 5.74 Mbps.
- **Lower latency:** The use of HSUPA introduces a TTI of 2 ms, although a 10ms TTI was originally used and is still supported.
- **Improved system capacity:** In order to enable the large number of high data rate users, it has been necessary to ensure that the overall capacity when using HSUPA is higher.

- **BPSK modulation:** Originally only BPSK modulation that adopted for UMTS, was used. Accordingly it did not support adaptive modulation schemes. Higher order modulation was introduced in Release 7 of the 3GPP standards when 64QAM was allowed.
- **Hybrid ARQ:** In order to facilitate the improved performance the Hybrid ARQ (Automatic Repeat reQuest) used for HSDPA is also employed for the uplink, HSUPA.
- **Fast Packet Scheduling:** In order to reduce latency, fast packet scheduling has been adopted again for the uplink as for the downlink, although the implementation is slightly different.

At the core of HSUPA, High Speed Uplink Packet Access is a member of new technologies that are very similar to those used with HSDPA. However there are a few fundamental differences resulting from the different conditions at either end of the link.

- The uplink in UMTS and HSUPA is non-orthogonal because complete orthogonality cannot be maintained between all the UEs. As a result there is more interference between the uplink transmissions within the same cells.
- The scheduling buffers are located in a single location (NodeB) for the downlink, whereas for the uplink they are distributed within several UEs for the uplink. This requires the UEs requirement to send buffer information to the scheduler in the NodeB so that it can then provide an overall schedule for the data transmission.
- In the downlink, the shared resource is the transmission power. In the uplink, the resource is limited by the level of interference that can be tolerated and this depends upon the transmission power of the multiple UEs.
- High order modulation techniques are able to provide higher data rates for high signal level links in the downlink. This is not the case in the uplink where there is no need to share channelization codes between users and the channel coding rates are therefore lower, although higher order modulation was introduced under Release 7.

Table 1 represents a comparison between HSDPA, HSUPA and DCH meanwhile Table 2 represents the HSUPA terminal categories. Table 3 shows the E-DPDCH slot formats.

Several previous works evaluated the performance of HSUPA at the link level and extended them to the system level [2], [3] and [4] where macrocells deployment has been assumed.

The conditions that describe the highway cigar-shaped microcells under this study are:

- The number of directional sectors of the cigar-shaped microcell is two and a directional antenna is used in each sector.
- The sector has typically a range of 1km.

Propagation over LOS paths (highways for example) may be modeled using a single regression slope γ for all distance r from the base station, or by a two segment regression fit having slope γ_1 within a break point distance R_b and slope γ_2 for distances greater than R_b. The two segment fit represents more accurately the overall variation of the path loss, so that the standard deviation σ_1 and σ_2 before and after break distance are smaller than the standard deviation σ of the single slope model [5].

Many works dealing with the uplink capacity of UMTS (WCDMA) cigar-shaped microcells can be found in the literature. In [5], Min et al. studied the performance (uplink capacity and cell radius) of the CDMA highway microcell using one slope propagation model and two slope propagation models without taking into account the interference variance. They have concluded that, the two slope propagation model is most adequate to be used in the study of the microcells capacity. In reference [6], the impact of the cell size and the propagation model parameters on the performance of microcellular networks has been studied. Here also the two-slope model of propagation has been used in the analysis. In [7], WCDMA uplink capacity of highways cigar-shaped microcells has been studied assuming voice users only and data users only. In this work, the combined service of voice and data has not been investigated. In [8], WCDMA multiservice (voice service only, data service only and the combined service of both) uplink capacity of highways cigar-shaped microcells has been investigated. No one of the two above mentioned works has taken into account the HSUPA users as possible users of the WCDMA (UMTS) system.

The major contribution of this work is to investigate the effect of the HSUPA users on the voice and traditional data (120 Kbps data) uplink capacity of WCDMA (UMTS) highways microcells when they share the same carrier frequency.

The paper has been organized as follows. In section 2, the propagation model is given. Section 3 explains the method to calculate the capacity and the interference statistics of the uplink. Numerical results are presented in section 4. Finally, in section 5 conclusions are drawn.

2- Propagation Model

In [5], it has been shown that the two-slope model of propagation is the best model that can be used to study the capacity of the sector of cigar-shaped microcells in highways. Thus, we will use the two-slope propagation model with lognormal shadowing in the calculations of the capacity and the interference statistics. The exponent of the propagation is assumed to be γ_1 until the break point (R_b) and then it converts into a larger value γ_2. In this way the path loss at a distance r from the base station is given by:

$$L_p(dB) \approx L_b + L_g + 10\gamma_1 \log_{10}\left(\frac{r}{R_b}\right) + \xi_1 \qquad \text{If } r \le R_b \qquad (1)$$

$$L_p(dB) \approx L_b + L_g + 10\gamma_2 \log_{10}\left(\frac{r}{R_b}\right) + \xi_2 \qquad \text{If } r > R_b \qquad (2)$$

L_b (the loss at a distance R_b) and R_b are given by [9]:

$$L_b(dB) = 20\log_{10}\left(\frac{4\pi}{\lambda}\right) + 10\gamma_1 \log_{10}(R_b) \qquad (3)$$

$$R_b \approx \frac{4 h_b h_m}{\lambda} \qquad (4)$$

Where

- L_g is the car window penetration loss = 3 dB,
- h_b is the base station antenna height,
- h_m is the mobile antenna height,
- λ is the wavelength and
- ξ_1 and ξ_2 are Gaussian random variables of zero-mean and a standard deviation of σ_1 and σ_2 respectively. ξ_1 and ξ_2 represent the effect of shadowing (loss deviation from the mean value)

Practical values of s_1, s_2, σ_1, σ_2 and R_b are [8]:

- γ_1 = 2.0 to 2.25,

- γ_2 = 4.0 to 5.0,
- σ_1 = 2 to 3 dB,
- σ_2 = 4 to 6 dB and
- R_b = 300m.

3- Uplink Analysis

In this section we will present a mathematical analysis of the interference statistics giving the expected value and the variance of the intercellular interference and the intracellular interference. Then we will calculate the E_b/N_o for each service.

Fig. 1 shows the azimuth radiation pattern of the directional antenna used in each sector and the cigar-shaped microcell azimuth coverage. Fig. 2 depicts the configuration of the 5 microcells model used in analysis where the sector range is assumed to be R. In WCDMA systems, each microcell controls the transmitted power of its users. If the interfering user i is at a distance r_{im} from its base station and at a distance r_{id} from the reference microcell base station as shown in Fig. 3, then the ratio of the interference signal $L(r_{id},r_{im})$ due to the distance only is given as:

- If $r_{id} > R_b$ and $r_{im}<R_b$ then $L(r_{id},r_{im})$ is given as:

$$L(r_{id},r_{im}) = R_b^{(\gamma_2-\gamma_1)} r_{im}^{\gamma_1} / r_{id}^{\gamma_2} \tag{5}$$

- If $r_{id} < R_b$ and $r_{im}>R_b$ then $L(r_{id},r_{im})$ is given as:

$$L(r_{id},r_{im}) = R_b^{(\gamma_1-\gamma_2)} r_{im}^{\gamma_2} / r_{id}^{\gamma_1} \tag{6}$$

- If (r_{id} and $r_{im} > R_b$) then $L(r_{id},r_{im})$ is given by:

$$L(r_{id},r_{im}) = \left(\frac{r_{im}}{r_{id}}\right)^{\gamma_2} \tag{7}$$

Now, the ratio of the interference signal $L_{shd}(r_{id},r_{im})$ due to the distance and shadowing is given by:

$$L_{shd}(r_{id},r_{im}) = 10^{(\xi_{id}-\xi_{im})/10} L(r_{id},r_{im}) \tag{8}$$

ξ_{id} and ξ_{im} are given as:

- If $r_{id} > R_b$ and $r_{im}<R_b$ then $\xi_{id} = \xi_2$ and $\xi_{im} = \xi_1$.
- When $r_{id} < R_b$ and $r_{im}>R_b$ then $\xi_{id} = \xi_1$ and $\xi_{im} = \xi_2$.
- In case of (r_{id} and $r_{im} > R_b$) then $\xi_{id} = \xi_2$ and $\xi_{im} = \xi_2$.

We will divide the total intercellular interference (I_{inter}) into interference from users in the S0 region (I_{S0}) and interference from users in the S1 region (I_{S1}), where these regions are shown in Fig. 2. We will find the capacity and the interference statistics of the right sector (drawn in black in Fig. 2) that provides half of the coverage to microcell d. We assume that users in the region S0 and S1 connect with the best (with lower propagation loss) of the two nearest microcells. In the S1 region, we will use the upper limit approximation (users in S1 never communicate with C1) to calculate the interference statistics. This will compensate the use of only 6 sectors to calculate the intercellular interference statistics instead of using unlimited number of sectors (microcells).

Let the mean value of the desired signal power received by the base station for a given service s be $P_{r,s}$. The mean value of the interference from an active user communicating with the reference microcell assuming the same service will be also $P_{r,s}$. A user i in the S0 region will not communicate with the reference base station d (C1) but rather with base station m (C2 or C3) whenever the propagation loss between the user i and base station m is lower than the propagation loss between the user i and the base station C1, i.e., if $\phi(\xi_{id} - \xi_{im}, r_{id}/r_{im}) = 1$, where

$$\phi(\xi_{id} - \xi_{im}, r_{id}/r_{im}) = \begin{cases} 1, & if \quad L(r_{id}, r_{im}) 10^{(\xi_{id} - \xi_{im})/10} \le 1 \\ 0, & otherwise. \end{cases} \tag{9}$$

Assuming a uniform density ρ_s of users for each service, the density of users in each sector is $\rho_s = N_{u,s}/R$ users per unit length. For the right part of *S0* the expected value of I_{S0} for a given service s is given as:

$$E[I_{S0}]_{r,s} = \alpha_s \ \rho_s \int_{S0r} L(r_{id}, r_{im}) \ f\left(\frac{r_{id}}{r_{im}}\right) \ dr \tag{10}$$

where

$$f\left(\frac{r_{id}}{r_{im}}\right) = E\left[10^{(\xi_{id} - \xi_{im})/10} \phi(\xi_{id} - \xi_{im}, r_{id}/r_{im})\right] \tag{11}$$

$$= e^{(\beta\sigma)^2/2} Q\left[\beta \sqrt{\sigma^2} + \frac{10}{\sqrt{\sigma^2}} \log_{10}\{1/L(r_{id}, r_{im})\}\right] \tag{12}$$

Where β = ln10/10 and α_s is the activity factor of the user for the service s (0.66 for voice users and 1.0 for data users).

Now the general value of σ^2 is given as:

- If $r_{id} \le R_b$ and $r_{im} > R_b$ or $r_{id} > R_b$ and $r_{im} \le R_b$ then the value of σ^2 is given by

$$\sigma^2 = (\sigma_1 - \sigma_2)^2 + 2(1 - C_{dm})\sigma_1\sigma_2 \tag{13}$$

Where C_{dm} is the inter-sites correlation coefficient.

- When (r_{id} and $r_{im} > R_b$) then $\sigma_{id} = \sigma_2$,, also $\sigma_{im} = \sigma_2$ then

$$\sigma^2 = 2(1 - C_{dm})\sigma_2^2 \tag{14}$$

Q(x) is given by

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-v^2/2} dv \tag{15}$$

The upper limit of the expected value of I_{S1} due to right part of the S1 region for the service s is given as:

$$E[I_{S1}]_{r,s} \approx \alpha_s\ \rho_s \int_{S1r} L(r_{id}, r_{im})\, E\left[10^{(\xi_{id} - \xi_{im})/10}\right]\ dr \tag{16}$$

The expected value of the intercellular interference from the right side of the regions S0 and S1 for the service s is:

$$E[I]_{r,s} = E[I_{S0}]_{r,s} + E[I_{S1}]_{r,s} \tag{17}$$

Thus the expected value of the total interference from the left and right sides for the service s is given as:

$$E[I]_{\text{int}\,er,s} = E[I]_{r,s}\ (1 + Sll) \tag{18}$$

where *Sll* is the side lobe level of the directional antenna used in each sector.

The expected value of the total intercellular interference power for the service s is given as:

$$E[P]_{\text{int}\,er,s} = P_{r,s}\ E[I]_{\text{int}\,er,s} \tag{19}$$

The expected value of the intracellular interference power due to the service s is given by:

$$E[P]_{\text{int}\,ra,s} = P_{r,s}\ E[I]_{\text{int}\,ra,s} \approx P_{r,s}\ \alpha_s\ N_{u,s}(1 + Sll) \tag{20}$$

Taking into account an imperfect power control with standard deviation error of σ_c (dB), the total expected interference power for the service s will be:

$$E[P_{\text{int}\,f}]_{t,s} = e^{\beta^2\sigma_c^2/2}(E[P]_{\text{int}\,ra,s} + E[P]_{\text{int}\,er,s}) \tag{21}$$

These calculations assume a uniform density of users which can be closed to reality when talking about the voice or data services. Services like HSUPA are not that popular yet and we'll likely find a much smaller number of users so this assumption does not suit.

When working on HSUPA, interference statistics will be calculated for a single user rather than integrating the expected value along the whole region.

Assuming the single user will be located in the right part of S0, no interference will be generated in the right part of S1 or in the left part of S0 or S1.

In the same way as for the other services, the ratio of interference signals is calculated as given in (3), (4) and (5) and the values of σ^2 as given in (10)(11).

Thus, the expected value of intercellular interference power is calculated as:

$$E[P]_{inter,HSUPA} = P_{r,HSUPA}\ E[I]_{inter,HSUPA} = P_{HSUPA}\,\alpha_{HSUPA}\ L(r_{id}, r_{im})\ f\left(\frac{r_{id}}{r_{im}}\right) \qquad (22)$$

where α_{HSUPA} is the activity factor of the HSUPA assumed to be 1.

From now on, l and m will be the probability of the terminal being connected to a base station different than the reference one.

$$l = Q\left[\beta\sqrt{\sigma^2} + \frac{10}{\sqrt{\sigma^2}}\log_{10}\{1/L(r_{id}, r_{im})\}\right] \qquad (23)$$

$$m = Q\left[2\beta\sqrt{\sigma^2} + \frac{10}{\sqrt{\sigma^2}}\log_{10}\{1/L(r_{id}, r_{im})\}\right] \qquad (24)$$

The expected value of the intracellular interference power due to the HSUPA service is given by:

$$E[P]_{intra,HSUPA} = P_{r,HSUPA}\ E[I]_{intra,HSUPA} \approx P_{r,HSUPA}\,\alpha_{HSUPA}\ (1-l) \qquad (25)$$

Taking into account an imperfect power control with standard deviation error of σ_c (dB), the total expected interference power for the HSUPA service will be:

$$E[P_{int}]_{HSUPA} = e^{\beta^2\sigma_c^2/2}(E[P]_{intra,HSUPA} + E[P]_{inter,HSUPA}) \qquad (26)$$

Using the Soft Handoff, Ψ of the sector users will be in connection with more than one base station (practically with two base stations). In this case, the expected value of the interference power for a given service s will be:

$$E[P_{intf}]_{t,s} = K_{SHO}\ e^{\beta^2\sigma_c^2/2}(E[P]_{intra,s} + E[P]_{inter,s}) \qquad (27)$$

where K_{SHO} is an interference reduction factor that can be derived from [10].

$$K_{SHO} = (1-\psi) + \frac{\psi}{G_{SHO}} \tag{28}$$

where G_{SHO} is the Soft Handoff gain. Practical value of K_{SHO} in quasi 1D case (our case for which the width of the highways is neglected since it is very low in comparison with the sector radius) is 0.95 to 0.98.

The expected value of the total interference power due to all services will be:

$$E[P_{\text{int}\,f}]_t = \sum_{s=1}^{S} E[P_{\text{int}\,f}]_{t,s} \tag{29}$$

where S is the number of the services that the system supports.

The variance of the interference power P_{S0} due to right part of S0 for the service s is given as [8]:

$$\text{var}[P_{S0}]_{r,s} = \rho_s\ P_{r,s}^2 \int_{S0r} [L(r_{id}, r_{im})]^2 \left\{ p\alpha_s\ g\left(\frac{r_{id}}{r_{im}}\right) - q\alpha_s^2\ f^2\left(\frac{r_{id}}{r_{im}}\right) \right\} dr \tag{30}$$

where

$$g\left(\frac{r_{id}}{r_{im}}\right) = E\left[10^{(\xi_{id}-\xi_{im})/10} \phi(\xi_{id} - \xi_{im}, r_{id} / r_{im})\right]^2 \tag{31}$$

$$= e^{2(\beta\sigma)^2} Q\left[2\beta\sqrt{\sigma^2} + \frac{10}{\sqrt{\sigma^2}} \log_{10}\{1/L(r_{id}, r_{im})\} \right] \tag{32}$$

$$p = e^{2\beta^2\sigma_c^2} \tag{33}$$

$$q = e^{\beta^2\sigma_c^2} \tag{34}$$

The upper limit of the variance of P_{S1} due to right part of S1 for the service s is given as

$$\text{var}[P_{S1}]_{r,s} \approx \rho_s\ P_{r,s}^2 \int_{S1r} [L(r_{id}, r_{im})]^2 \left\{ p\alpha_s\ E\left[(10^{(\xi_{id}-\xi_{im})/10})^2\right] - q\alpha_s^2\ E^2\left[10^{(\xi_{id}-\xi_{im})/10}\right] \right\} dr \tag{35}$$

Thus the variance of total intercellular interference power due to the total region S0 and S1 for the service s is given by:

$$\text{var}[P]_{\text{inter},s} = \left\{ \text{var}[P_{S0}]_{r,s} + \text{var}[P_{S1}]_{r,s} \right\} \quad (1 + Sll^2) \tag{36}$$

The variance of the intracellular interference power due to the service s is calculated as:

$$\text{var}[P]_{\text{intra},s} = N_{u,s}\ P_{r,s}^2\ (1 + Sll)\left(p\alpha_s - q\alpha_s^2\right) \tag{37}$$

The variance of the total interference power due to the service s is given by:

$$\mathrm{var}[P]_{t,s} = \mathrm{var}[P]_{inter,s} + \mathrm{var}[P]_{intra,s} \tag{38}$$

The variance of the total interference power due to all service s is given by:

$$\mathrm{var}[P_{intf}]_t = \sum_{s=1}^{S} \mathrm{var}[P]_{t,s} \tag{39}$$

Again, these calculations assume a uniform density of users which does not suit the HSUPA service. Therefore, interference power variance will be calculated for a single user.

The variance of the intercellular interference power due to the HSUPA service is calculated as:

$$Var[P]_{inter,HSUPA} = P^2_{r,HSUPA} \quad Var[I]_{inter,HSUPA} \tag{40}$$

$$= P^2_{r,HSUPA} \; [L(r_{id}, r_{im})]^2 \left\{ p\alpha_{HSUPA} \; g\left(\frac{r_{id}}{r_{im}}\right) - q\alpha^2_{HSUPA} \; f^2\left(\frac{r_{id}}{r_{im}}\right) \right\} \tag{41}$$

The variance of the intracellular interference power due to the HSUPA service is given by:

$$Var[P]_{intra,HSUPA} = P^2_{r,HSUPA} Var[I]_{inter,HSUPA} \tag{42}$$

$$= P^2_{r,HSUPA} \; \left[p\alpha_{HSUPA}(1-m) - q\alpha^2_{HSUPA}(1-l)^2 \right] \tag{43}$$

Since the intracellular and intercellular interference are independent random variables, the variance of the total interference power due to the HSUPA service will be:

$$Var[P_{int}]_{HSUPA} = Var[P]_{intra,HSUPA} + Var[P]_{inter,HSUPA} \tag{44}$$

In the uplink only $\varepsilon P_{r,s}$ of $P_{r,s}$ is used in the demodulation (ε = 15/16 = 0.9375). Thus, for a given outage probability, the uplink carrier-to-interference ratio $\left[\frac{C}{I}\right]_s$ for a given service s is given as:

$$\left[\frac{C}{I}\right]_s = \frac{\varepsilon \; P_{r,s}}{E[P_{intf}]_t + P_N + \gamma\sqrt{\mathrm{var}[P_{intf}]_t}} \tag{45}$$

Where P_N is the receiver noise power and γ is a factor that depends on the outage probability (2.13 for outage probability of 2% and it is 2.33 for an outage probability of 1%).

For a given service, the $(E_b / N_o)_s$ ratio is given as [11]:

$$\left[\frac{E_b}{N_o}\right]_s = \left[\frac{C}{I}\right]_s \quad G_{p,s} \tag{46}$$

Where $G_{p,s}$ is the processing gain of the service s.

Assuming a given number of users for each service, the relation (outage probability versus number of users) can be got using (45 and 46).

When mixing services, the HSUPA user maximum transmitted power to the maximum transmitted power of the data users given in dB should be [8]:

$$\left(\frac{P_{tHSUPA}}{P_{td}}\right)_{dB} = (1+\delta_1) \quad \left[10 \log_{10}\left(\frac{G_{pd} \ / \left(\frac{E_b}{N_o}\right)_d}{G_{pHSUPA} \ / \left(\frac{E_b}{N_o}\right)_{HSUPA}}\right)\right] \tag{47}$$

Meanwhile the HSUPA user maximum transmitted power to the maximum transmitted power of the voice users given in dB should be [8]:

$$\left(\frac{P_{tHSUPA}}{P_{tv}}\right)_{dB} = (1+\delta_2) \quad \left[10 \log_{10}\left(\frac{G_{pv} \ / \left(\frac{E_b}{N_o}\right)_v}{G_{pHSUPA} \ / \left(\frac{E_b}{N_o}\right)_{HSUPA}}\right)\right] \tag{48}$$

Where

- P_{td} is the transmitted power of the data users the exists in the sector border,
- P_{tv} is the transmitted power of the voice users the exists in the sector border,
- P_{tHSUPA} is the transmitted power of the HSUPA users the exists in the sector border,
- G_{pv} is the voice service processing gain,
- G_{pd} is the data service processing gain,
- G_{pHSUPA} is the HSUPA service processing gain,
- $(E_b/N_o)_v$ is the required (E_b/N_o) for voice service given in natural numbers and
- $(E_b/N_o)_d$ is the required (E_b/N_o) for data service given in natural numbers.
- $(E_b/N_o)_{HSUPA}$ is the required (E_b/N_o) for HSUPA service given in natural numbers.
- δ_1 and δ_2 are correction factors with a value of (-0.1 to 0.1).

4- Numerical results

In this section we will present the WCDMA (UMTS) uplink capacity for the voice service and traditional data service with and without the HSUPA users.

For our calculations some reasonable figures are applied. The azimuth side lobe level is assumed to be –15 dB, the correlation coefficients C_{dm} = 0.5, γ_1 = 2, γ_2 = 4, σ_1 = 3 dB, σ_2 = 6 dB and R_b = 300 m and R = 1km unless other values are mentioned. Also we assume the following:

- A maximum transmitted power $P_{t\text{-}max}$ of 30 dBm for the HSUPA service,
- Process gains of 16 (240kbps) an 8 (480kbps) for the HSUPA service,
- Process gain of 32 for the traditional data service,
- Process gain of 256 for the voice service,
- Required E_b/N_o of 4dB for the traditional data service,
- Required E_b/N_o of 7dB for the voice service,
- Receiver noise power of -100 dBm assuming that the receiver noise figure is 7 dB,
- Base station net antenna gain of 12 dB with SLL of -15dB,
- Power control error with a standard deviation σ_c of 1 dB.

We assume an accepted outage probability of 1% and the capacities shown are calculated at this probability.

Using equation (47) and (48), the maximum transmitted power $P_{t\text{-}max}$ of other services has been calculated for different values of the HSUPA service process gain.

	$G_{p,HSUPA}$ = 16	$G_{p,HSUPA}$ = 8
Voice	20.0 dBm	17.0 dBm
Data	26.2 dBm	23.1 dBm

The required values of E_b/N_o for the HSUPA service have been extracted from [12], where values were calculated supposing a pedestrian user moving at 3km/h (PB3 ITU channel). Since this study is focused on networks deployed along highways, we assume users are moving in vehicles at a speed of 120 km/h (VA120 ITU channel). In order to compensate this difference, the required E_b/N_o has been increased by 0,8dB [13]:

	$G_{p,HSUPA}$ = 16	$G_{p,HSUPA}$ = 8
E_b/N_o	4.8 dB	4.8 dB

First of all, let us study the uplink capacity assuming that only voice users are communicating. Fig 4 shows the sector capacity of the voice service when this is the only service used. It can be noticed that, the sector capacity is 55 simultaneous voice users.

Now, let us see what will happen to the uplink voice capacity when we include one or two HSUPA users.

Fig.5 shows the sector capacity of the voice service when there is a single HSUPA user at a certain distance from the reference base station. In this case, we assume that the HSUPA could exist at any point of the zones presented in Fig. 2. Outside the S0 region, capacity is almost not affected because the interference power received from this user is very low. Due to the low SLL of the base station antenna, interference power received from the left side of both regions S0 and S1 is even lower. Therefore, capacity gets reduced significantly only in the right side of the S0 region and that is why this study will focus on this area.

Fig. 6 shows the sector capacity of the voice service when there is a single HSUPA user in the right part of the S0. In this case, we assume that the HSUPA could exist at any point of the right S0 zone presented in Fig. 2. Two values of HSUPA process gain has been used i.e., 16, and 8. For a HSUPA process gain of 16, the lowest capacity is obtained when the user is almost 1200 m from the reference base station. For a HSUPA process gain of 8, sector capacity becomes zero when HSUPA user exists in almost the mid way between base stations.

Next, we will include another HSUPA user. Figs. 7 and 8 show the capacity of the voice service when there are two users connected to the HSUPA service in the right part of S0 zone at certain distances from the reference base station. Fig. 7 shows that the sector capacity is zero when both HSUPA users are at a distance of 1000m to 1200m from the reference base station meanwhile Fig. 8 shows that the sector capacity is zero whenever the distance between the base station under study and each one of the HSUPA users is lower than 1550m.

Let us study the uplink capacity assuming that only data users are communicating. Fig. 9 shows the sector capacity of the data service when this is the only service used. It can be noticed that, the sector capacity is 9.5 simultaneous data users.

Now, let us see what will happen to the uplink data capacity when we include one or two HSUPA users.

. Fig. 10 shows the sector capacity of the data service when there is a single HSUPA user at a certain distance from the reference base station. In this case, we assume that the HSUPA could exist at any point of the right S0 zone presented in Fig. 2. Again, capacity gets reduced significantly only in the right side of the S0 region (0 to 2000 m distance) and we will focus on this area.

Fig. 11 shows the sector capacity of the voice service when there is a single HSUPA user in the right part of the S0. In this case, we assume that the HSUPA could exist at any point of the right S0 zone presented in Fig. 2. Two values of HSUPA process gain are used i.e., 16, and 8. The lowest capacity is obtained when the user is around 1200 m. For a HSUPA process gain of 8, sector capacity becomes zero when HSUPA user is at a distance of 1025 to 1315 m from the reference base station.

Next, we will include another HSUPA user. Figs. 12 and 13 show the capacity of the data service when there are two users connected to the HSUPA service in the S0 sector at certain distances from the reference base station.

From Fig. 12, it can be noticed that the sector capacity becomes zero data users when the HSUPA is a t a distance of 1000 to 1200 m from the reference base station. Fig. 13 shows that the sector capacity is zero data users when both of the HSUPA users are at a distance lower than 1800 m from the reference base station.

So, in order to guaranty the availability of these services (voice and normal data), the system should not allow using the lowest process gains (associated with the highest data rates) near this point.

Fig. 14 shows that the sector uplink capacity will be 5 HSUPA users with a processing gain of 16 or 2 HSUPA with a processing gain of 8 when they did not share the same carrier frequency used by voice and traditional data services. In this case, the voice and traditional data uplink capacity will be what was presented in Fig. 4 and Fig. 9 respectively.

We have to mention that, reducing the user's maximum velocity from its initial assumed velocity (120 Km/hour), will increase the uplink capacity. At very small velocity (due to an accident for example), uplink capacity could be 15% higher than the previously given capacities without forgetting that the user's spatial density is higher.

5- Conclusion

A model that studies the capacity and interference statistics of multi-service W-CDMA highway cigar-shaped microcells including users of HSUPA has been presented. The capacity of the sector has been studied using a general two-slope propagation model with lognormal shadowing assuming imperfect power control and finite transmitted power.

It has been concluded that the voice and data service are significantly affected by HSUPA users and sector capacity decreases dramatically when one of these users gets connected to a given sector or to one next to it. Also it has been concluded that the capacity decrement is highly sensitive to the location of the HSUPA users. Thus, no more than one HSUPA with a process gain of 16 can be connected to a given base station. In this case, the HSUPA user should interrupt its transmission when it is near to the sector border. No more than one HSUPA user with a process gain of 8 is permitted in a given sector and the sector next to it. When the HSUPA user is at the sector border, its transmission should be disabled.

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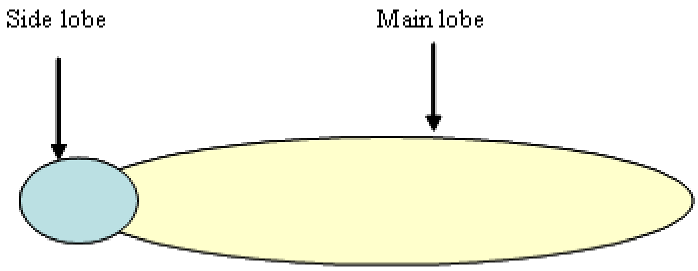
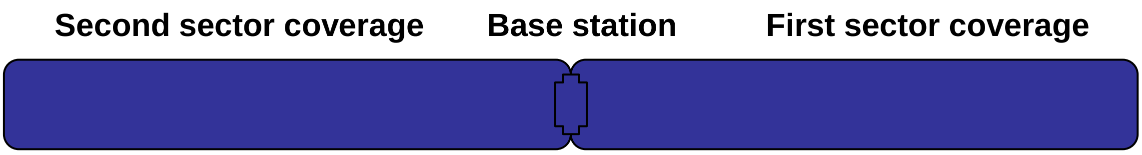


A



B

Fig. 1: The sector and microcell coverage**.**

A- Sector antenna azimuth pattern.

B- Microcell azimuth coverage.

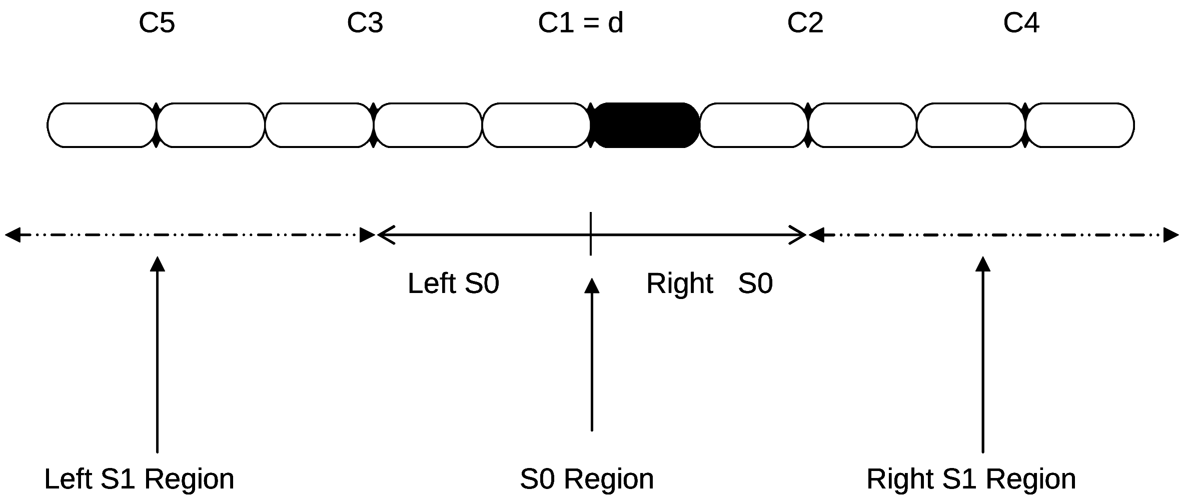


Fig. 2: The 5 microcells model.

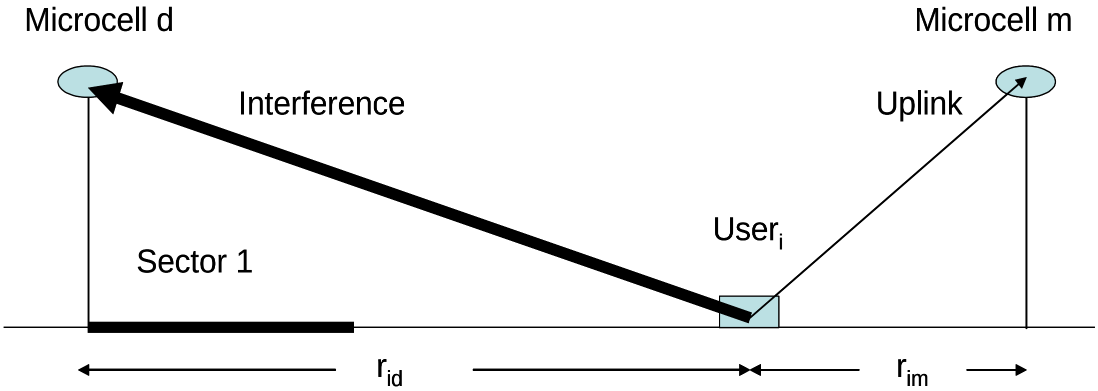


Fig. 3: Schematic diagram of base stations and mobiles for highway microcells.

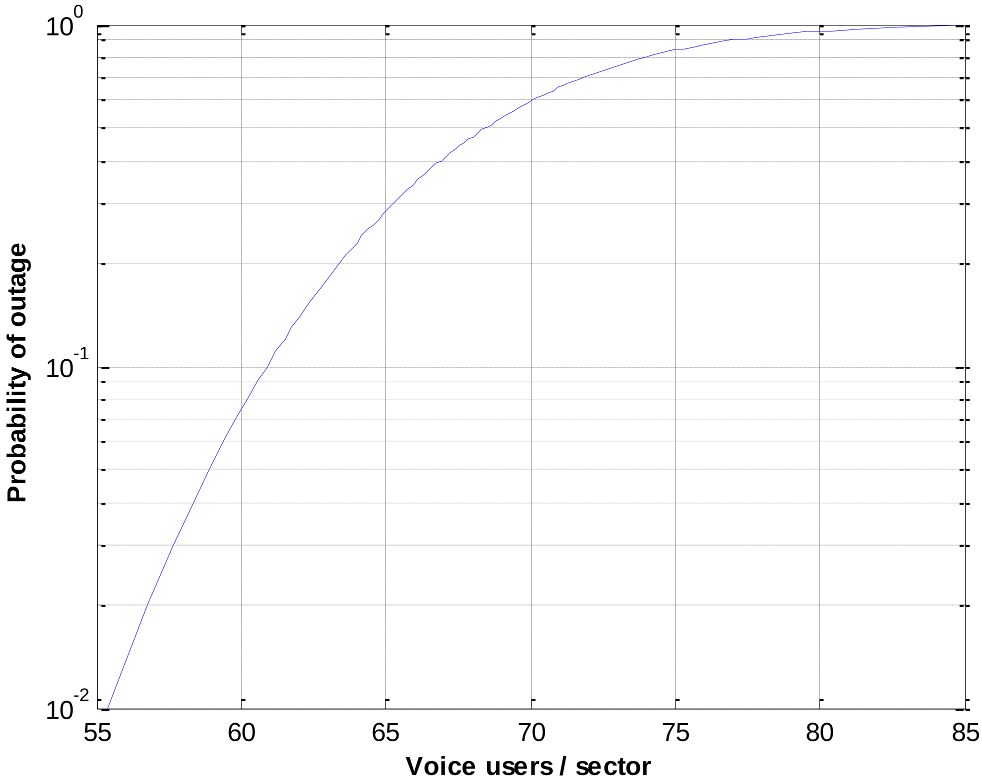


Fig. 4: Outage probability of the sector for voice users only.

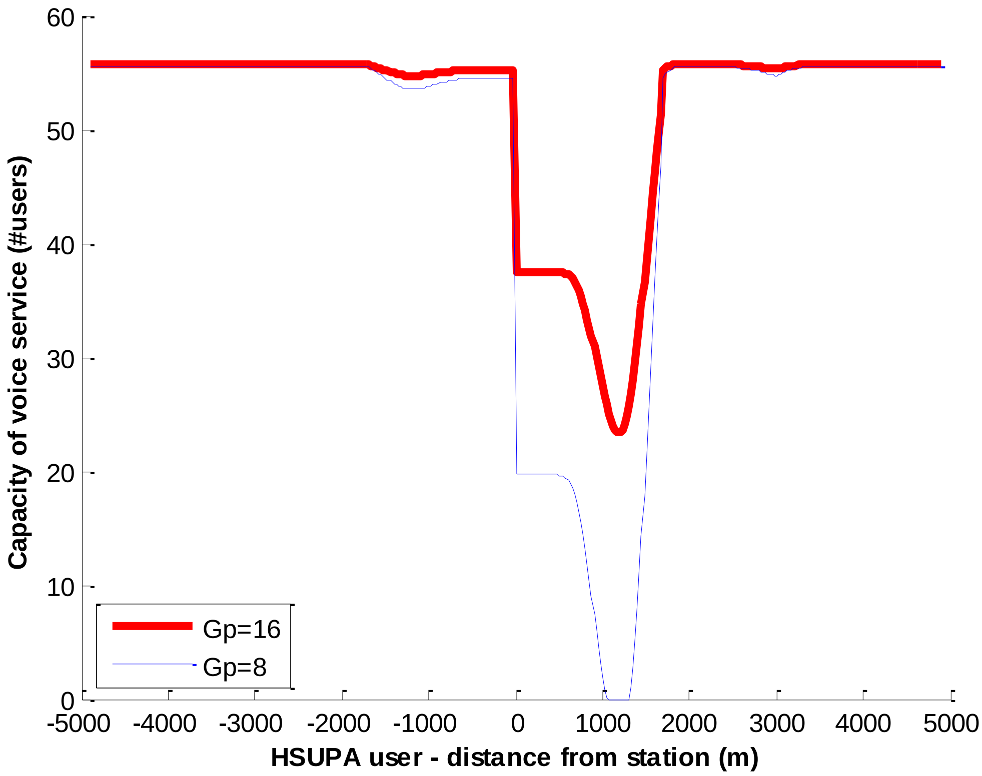


Fig. 5: Sector uplink capacity for voice users assuming that one HSUPA user exists around the base station under study.

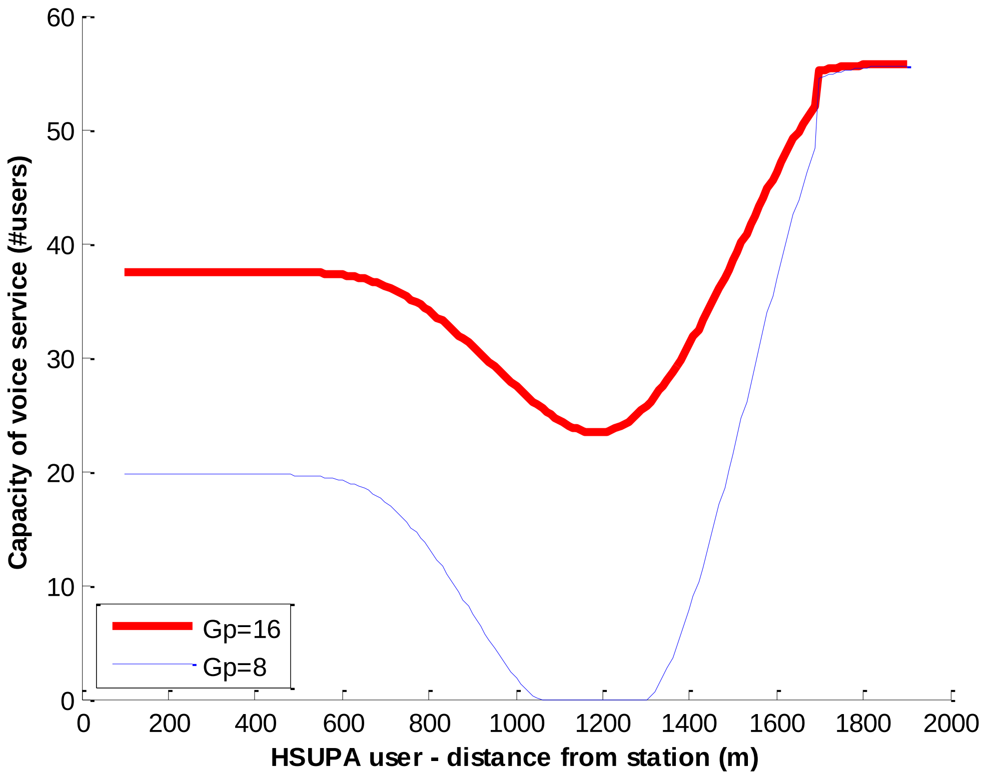


Fig. 6: Sector uplink capacity for voice users assuming that one HSUPA user exists within the right side of S0 region.

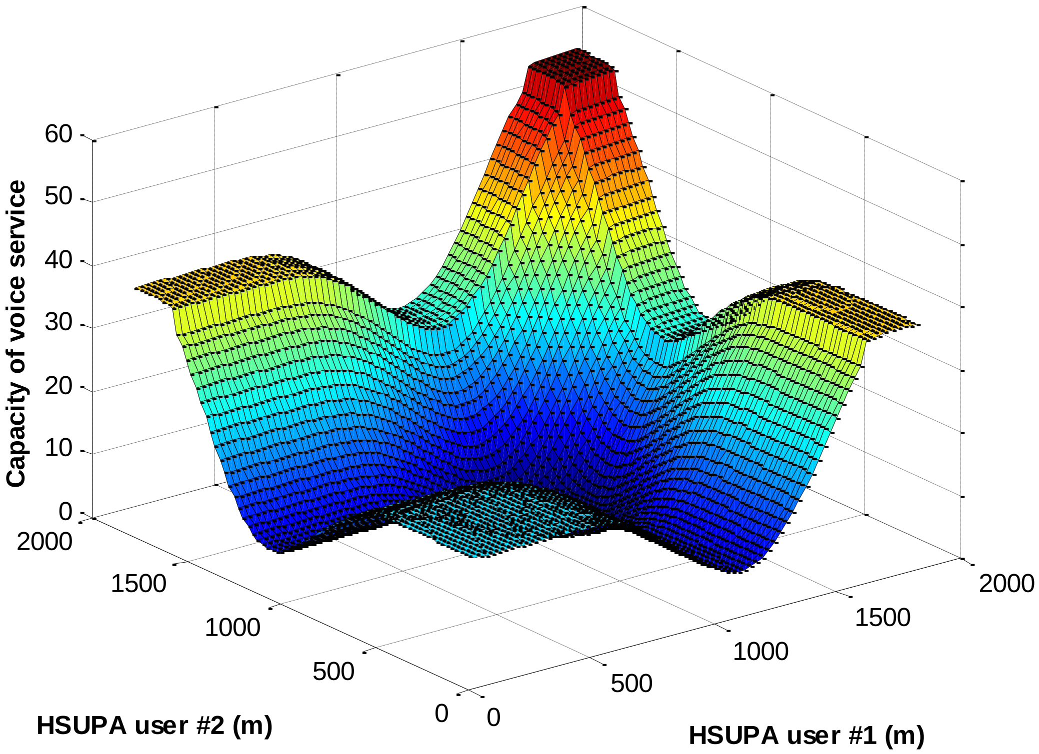


Fig. 7: Sector uplink capacity for voice users assuming that two HSUPA user exist within the right side of S0 region (HSUPA users with G_p =16).

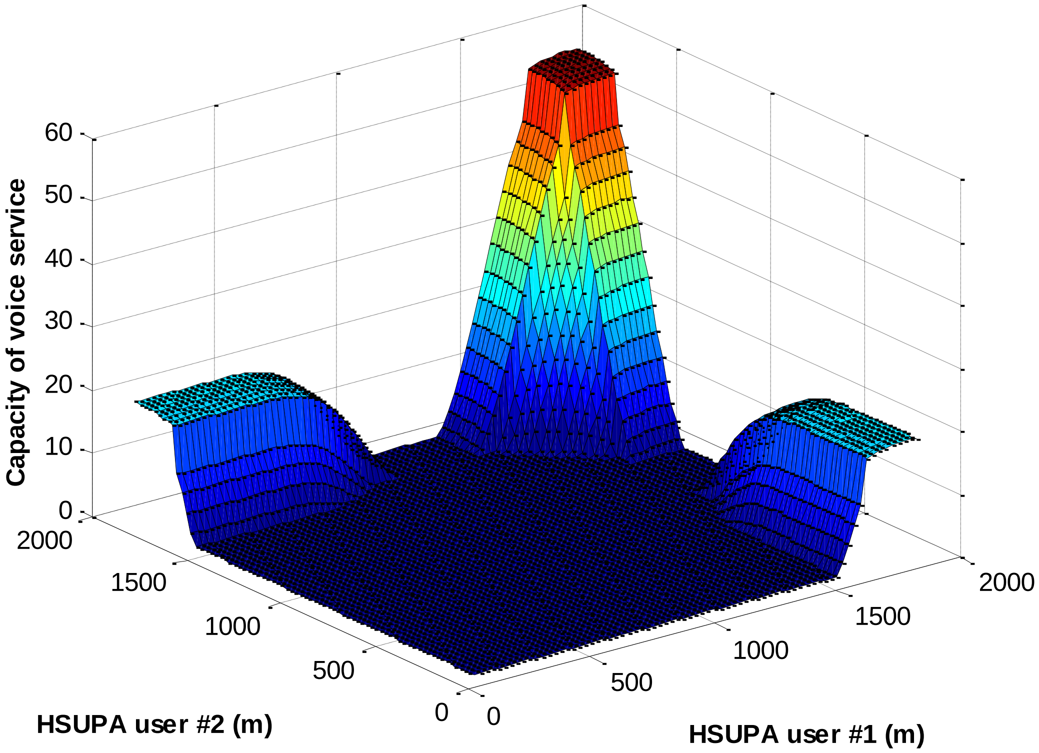


Fig. 8: Sector uplink capacity for voice users assuming that two HSUPA user exist within the right side of S0 region (HSUPA users with $G_p = 8$).

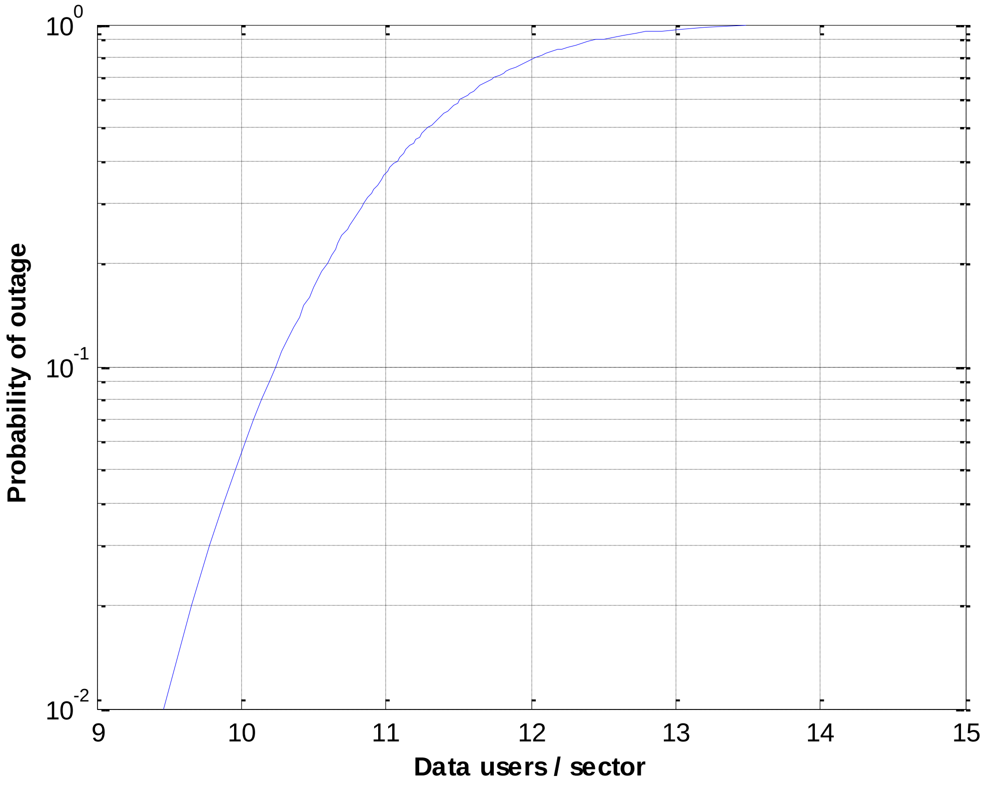


Fig. 9: Outage probability of the sector for data users only.

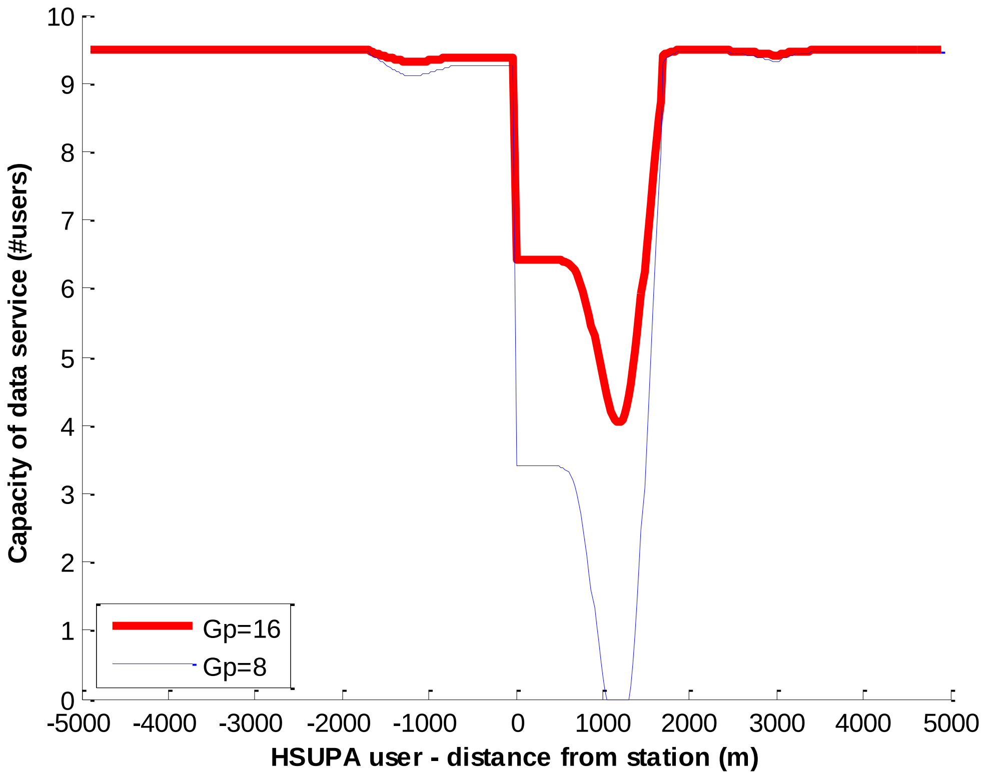


Fig. 10: Sector uplink capacity for data users assuming that one HSUPA user exists around the base station under study.

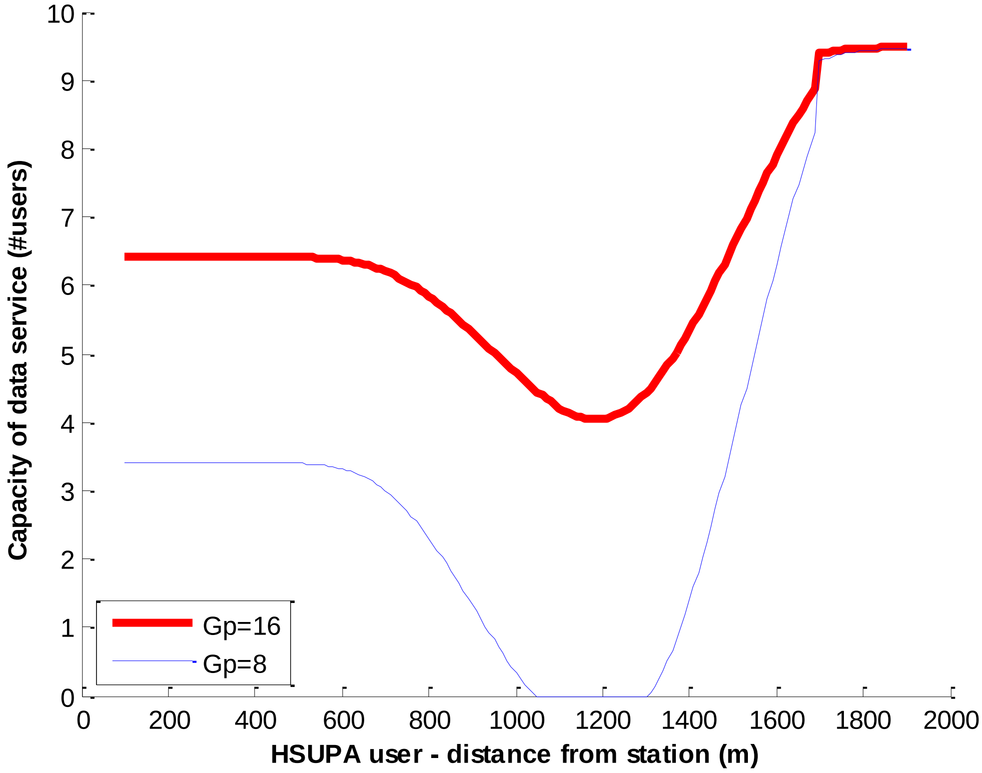


Fig. 11: Sector uplink capacity for data users assuming that one HSUPA user exists within the right side of S0 region.

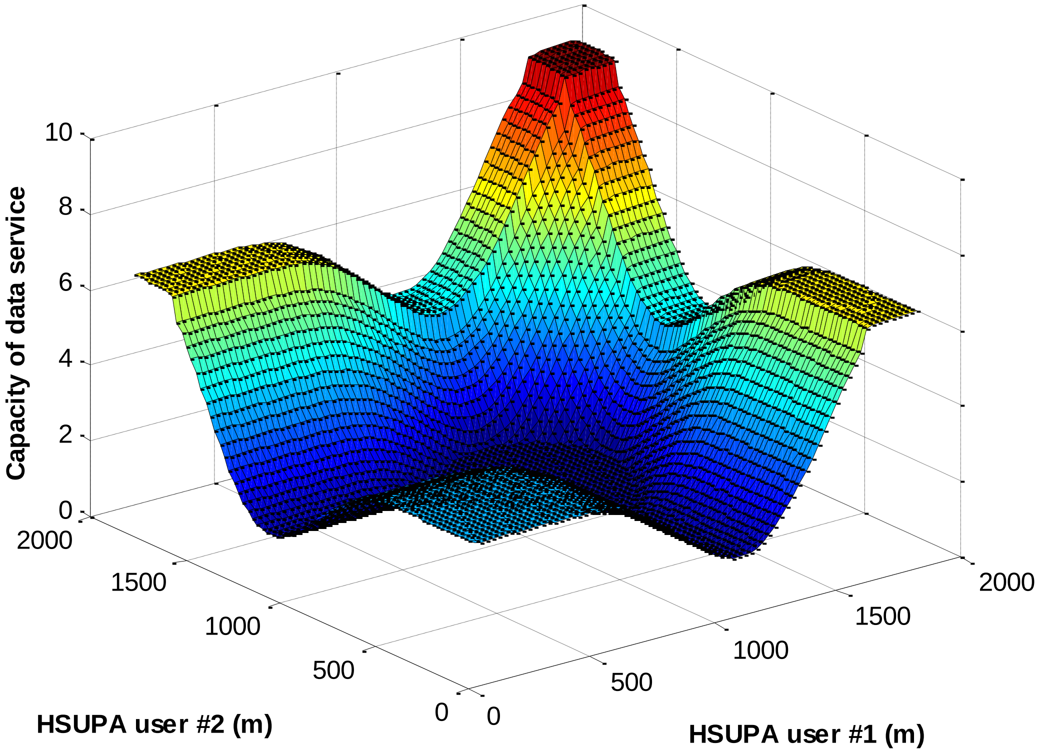


Fig. 12: Data sector capacity (2 HSUPA users with G_p =16).

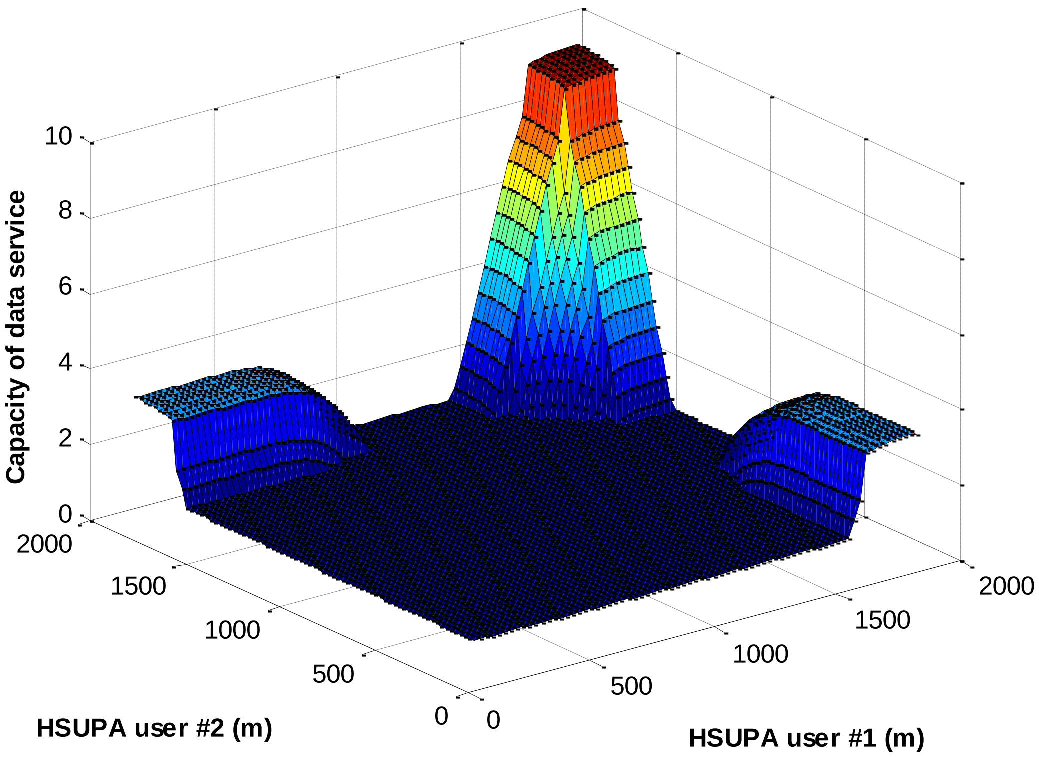


Fig. 13: Data sector capacity (2 HSUPA users with $G_p = 8$).

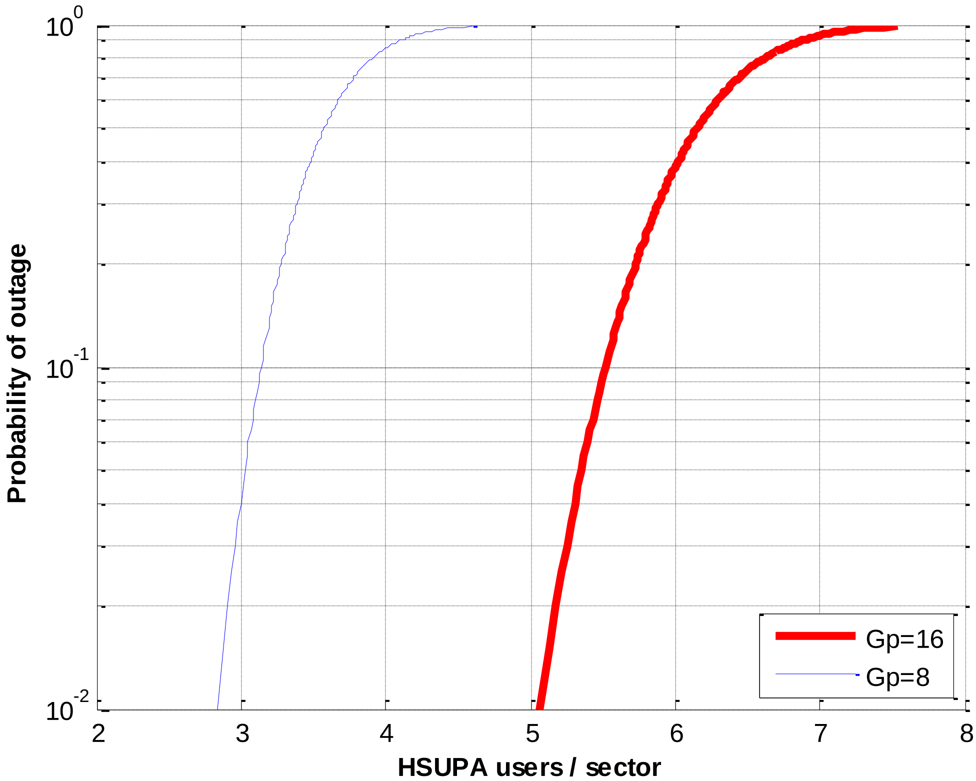


Fig. 14: HSUPA uplink capacity of the sector when they did not share the same frequency of voice and traditional data services.

Table 1: HSDPA, HSUPA and DCH comparison table.

Feature	DCH	HSDPA (HS-DSCH)	HSUPA (E-DCH)
Variable Spreading Factor	Yes	No	Yes
Fast Power Control	Yes	No	Yes
Adaptative Modulation	No	Yes	No
Node-B based Scheduling	No	Yes	Yes
Fast L1 HARQ	No	Yes	Yes
Soft Handover	Yes	No	Yes
TTI Length (ms)	80,40,20,10	2	10 , 2

Table 2: HSUPA terminal categories.

UE Cat.	Modulation	Maximum number of E-DPDCH and smallest SF	Supported TTIs (ms)	Maximum data rate with 10ms TTI (Mbps)	Maximum data rate with 2ms TTI (Mbps)
1	BPSK	1 x SF4	10ms	0.72	N/A
2	BPSK	2 x SF4	10ms & 2ms	1.45	1.45
3	BPSK	2 x SF4	10ms	1.45	N/A
4	BPSK	2 x SF2	10ms & 2ms	2	2.91
5	BPSK	2 x SF2	10ms	2	N/A
6	BPSK	2xSF4 + 2xSF2	10ms & 2ms	2	5.76
7	BPSK / 4PAM	2xSF4 + 2xSF2	10ms & 2ms		

Table 3: E-DPDCH slot formats

Slot Format	Bit Rate (kbps)	SF	Bits/ Frame	Bits/ Subframe	Bits/Slot
0	15	256	150	30	10
1	30	128	300	60	20
2	60	64	600	120	40
3	120	32	1200	240	80
4	240	16	2400	480	160
5	480	8	4800	960	320
6	960	4	9600	1920	640
7	1920	2	19200	3840	1280

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