Influence of the Common-channel Power on the System Capacity of UMTS FDD Systems that Use Beam Switching

Thomas Baumgartner[1], Ernst Bonek[1,2]
[1]Institut für Nachrichtentechnik und Hochfrequenztechnik
Technische Universität Wien
Gußhausstrasse 25/389, A-1040 Wien, Austria
[2]FTW, Forschungszentrum Telekommunikation Wien
Tech Gate Vienna, Donau-City-Strasse 1/3. Stock, A-1220 Wien, Austria
email: Thomas.Baumgartner@nt.tuwien.ac.at

Abstract—**In mobile communication systems using CDMA common channels needed for proper network operation share the same resource as the dedicated channels for data transmission. However the 3GPP standard does not specify the amount of transmit power for the common channels. So it is up to the network operator to assign appropriate transmit powers to the various common channels.**

In this paper we study the influence of the power assigned to the common channels on the achievable capacity in UMTS FDD systems that use beam switching. For a system with five beams per 120° sector, we show that a change of the common-channel power per beam by only 1 watt can boost capacity by about 70%.

I. Introduction

A mobile communication system like UMTS (Universal Mobile Telecommunication System) needs several common channels in order to work properly. In the downlink of the frequency division duplex (FDD) mode of UMTS these common channels are: Common pilot channel, synchronization channel, primary common control physical channel, secondary common control physical channel, acquisition indicator channel and some additional control channels for handling the packet access. Some of these common channels, e.g. the primary common control channel and the primary common control physical channel, are transmitted all time, whereas others, e.g. the secondary common control physical channel, are transmitted on demand [1]. The 3GPP standard of the UMTS Terrestrial Radio Access Network (UTRAN) leaves the choice of the transmit powers of these common channels open to the radio network planner.

In a CDMA system like UMTS the common channels share the same resource – namely transmit power – as the dedicated channels carrying user data. Therefore, the power assigned to the common channels influences the downlink capacity. In this paper we will study this effect especially for UMTS systems using beam switching – a simple method to increase the downlink capacity of UMTS that is fully compatible with Release 99 of the UTRAN specification, cf. [2].

The basic idea of beam switching [3] is to provide several fixed beams formed by a Uniform Linear Array (ULA) in each 120° sector. The beams are produced with a beamforming network where appropriate antenna weights are applied to the downlink signals. Each beam acts like an ordinary base station. This means that each beam uses its own scrambling code and transmits all necessary common channels like pilot, synchronization and paging channels. The mobiles select the serving beams through the standard cell search procedure according to the received pilot powers [4]. The big advantage of this beam-switching scheme over fully adaptive antenna schemes is that, per equipped sector, it needs only one additional transceiver chain, i.e. a separate one for each beam, a beamforming network and a uniform linear array.

By means of a static Monte Carlo system simulator we will show that the system capacity, measured as the number of satisfied users in the coverage area, can be optimized by proper choice of the power allocated to the common channels. Even small changes in this power, say of the order of 1 watt, will enhance or lower capacity by factors of up to 70%. The influence of the common-channel powers increases with increasing number of beams per sector.

Using the same common-channel power for various base station configurations, i.e. sector antenna or different number of beams per sector for beam switching, gives different receive quality for the common channels in the coverage area. Therefore, in order to make a fair comparison of the achievable system capacity of networks with different base station configurations, we suggest to choose the common-channel power in such a way as to assure a certain minimum receive quality of the common channels in the coverage area. In this paper we will also propose a criterion for the receive quality of the common channels that *does not require system simulations*.

II. Simulator

We used a static Monte Carlo system-level simulator to evaluate system capacity as a function of the chosen common-channel power. We simulated an area of 19 3-sectored base station sites, shown in Figure 1. The traffic of the gray shaded area in Figure 1 is evaluated for assessing the network performance. The surrounding cells contribute to the inter-cell interference. This evaluation method ensures that the interference power in the evaluation area is not underestimated [5].

The static simulator produces trustworthy results by averaging over 50 independent realizations of the user distribution, called "snapshots" for each user density. In each snapshot the

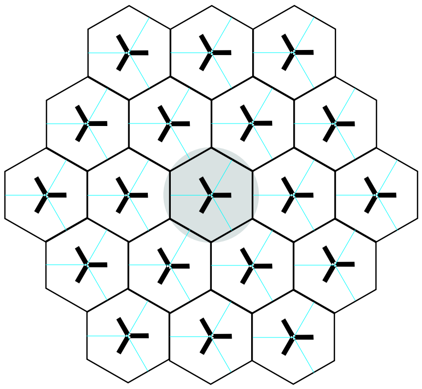

Fig. 1. Simulation area with 19 3-sectored base station sites

users are equally, but randomly distributed over the simulated network area.

A. Creation of a snapshot

Our pathloss model is based on the proposed macrocell model for UMTS system simulations [6]. The pathloss $L_{m,s,b}$ [dB] between mobile m and antenna/beam b of base station site s is given by

$$L_{m,s,b} = L^d_{m,s,b} + L^f_{m,s,b}\,, \quad \text{[dB]} \tag{1}$$

where $L^f_{m,s,b}$ represents the log-normal distributed shadowing with standard deviation of $\sigma_{ln} = 10\text{dB}$. According to [7] $L^f_{m,s,b}$ is calculated in such a way, that the pathloss correlation between two paths from one mobile to two different base stations is considered by a correlation coefficient of 0.5. $L^d_{m,s,b}$ represents the deterministic part of the pathloss which depends on the distance $R_{m,s}$ in km between site s and mobile m and the pattern/antenna gain towards the mobile m

$$L^d_{m,s,b} = 128.1 + 37.6\log_{10}(R_{m,s}) - A(\varphi_{m,s,b})\,. \quad \text{[dB]} \tag{2}$$

The term $A(\varphi_{m,s,b})$ represents the pattern gain towards the direction of mobile m as seen from the ULA which produces beam b (sector antenna that covers sector b in the 3-sectored reference case) at base station site s. The antenna pattern $A(\varphi_{m,s,b})$ of the sector antenna used in the reference case is shown in Figure 2. For systems using beam switching $A(\varphi_{m,s,b})$ is given by

$$A(\varphi_{m,s,b}) = A^P(\varphi_{m,s,b})\,|\boldsymbol{w}(b)\boldsymbol{a}(\varphi_{m,s,b})|\,, \tag{3}$$

where $A^P(\varphi)$ represents the antenna gain towards direction φ of a single element of the ULA shown in Figure 2. The steering vector in the direction φ, $\boldsymbol{a}(\varphi)$, for an inter-element spacing d, a wavelength λ, and N_e antenna elements is given by

$$\boldsymbol{a}(\varphi) = \begin{bmatrix} 1 & \mathrm{e}^{-j\frac{2\pi d}{\lambda}\sin\varphi} & \dots & \mathrm{e}^{-j(N_e-1)\frac{2\pi d}{\lambda}\sin\varphi} \end{bmatrix}^T\,, \tag{4}$$

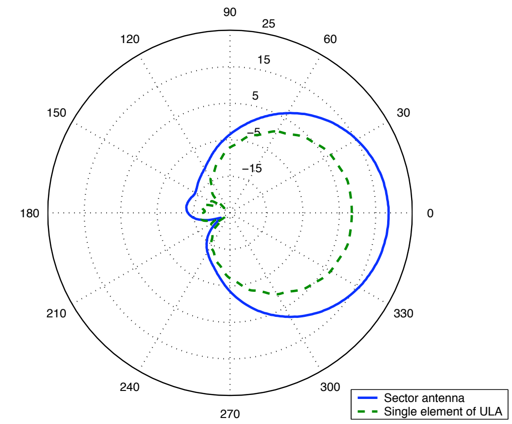

Fig. 2. Antenna pattern of the sector antenna and of a single element of the ULA used for beam switching. Radial unit is dB.

where superscript T stands for transpose. The vector $\boldsymbol{w}(b)$ containing the complex antenna weights is for beam number $0 \le b \le 3(N_b - 1)$ given by

$$\boldsymbol{w}(b) = \boldsymbol{w_a} \odot \boldsymbol{a}\left(\frac{2\pi\,(\mathrm{mod}(b, N_b) + 1)}{3N_b} - \frac{\pi}{3}\right)^T\,, \tag{5}$$

where mod stands for the modulo operation, N_b is the number of beams per 120° sector, and $\boldsymbol{w_a}$ represents the amplitudes of the antenna weights that are tabulated in Table I for each simulated N_b. The antenna weights in Table 1 correspond to Dolph–Chebyshev patterns with different side lobe levels, cf [8].

After calculating the pathloss of each combination of base station antennas/beams and users, the active set AS_m (base station antennas/beams which serve the user m) is determined according to the received pilot powers. For simplicity's sake, we assume equal pilot power for the sectors (beams in the case of beam switching) of all base stations. So the ratio of the strength of the received pilot signals from different sectors/beams is indirect proportional to their pathloss. The active set AS_m (base station antennas/beams which serve the mobile m) is therefore determined by

$$AS_m = (s,b)\,|\,L_{m,s,b} \le \min_{(s,b)}(L_{m,s,b} + \mathrm{ASW})\,. \tag{6}$$

ASW is the active set window which determines the maximum allowed difference between the lowest and the highest pathloss of two links in the active set. In case that AS_m - as determined by Equ. 6 - contains more links than the maximum active set size max_ass, AS_m is limited to the max_ass links corresponding to the lowest total pathloss.

Having determined the active sets the simulator adjusts the code power of all links until all served users are satisfied. A user is satisfied if

$$\left(\frac{E_b}{I_0}\right)_m = \sum_{(s,b)\in AS_m} \frac{P_{m,s,b}G_P}{L_{m,s,b}\left(N_0 + \alpha I^{Intra}_{m,s,b} + I^{Inter}_{s,b}\right)} \tag{7}$$

is within 0.5dB of its predefined quality target [6]. The sum is taken over $(s,b) \in AS_m$, representing all combinations of antennas/beams b and base station sites s that are in the active set of mobile m. The power $P_{m,s,b}$ is the code power used by sector/beam b of base station site s to serve mobile m. Note that, if the sector antenna/beam b of the base station site s is not in the active set of mobile m, $P_{m,s,b}$ will be zero. Here, G_P is the processing gain given by

$$G_P = \frac{\text{chip rate}}{\text{data rate of service}}\,. \tag{8}$$

The terms N_0, α, $I^{Intra}_{m,s,b}$, and $I^{Inter}_{s,b}$ represent the background noise, the orthogonality factor for intra-cell interference, the intra-cell interference, and the inter-cell interference, respectively. The intra-cell interference $I^{Intra}_{m,s,b}$ for the link between mobile m and sector/beam b of base station site s is given by

$$I^{Intra}_{m,s,b} = \frac{1}{L_{m,s,b}} \left(P^c_{s,b} + \sum_{\mu \neq m} P_{\mu,s,b} \right)\,, \tag{9}$$

where $P^c_{s,b}$ is the common-channel power, i.e. the sum of all control channels transmitted by sector/beam s,b. $\sum_{\mu \neq m} P_{\mu,s,b}$ represents the sum of the code power for all mobiles (except the desired mobile m) served by sector/beam b of base station site s. The inter-cell interference at mobile m for a link of sector/beam b of base station site s is given by

$$I^{Inter}_{m,s,b} = \sum_{(\xi,\beta) \neq (s,b)} \frac{1}{L_{m,\xi,\beta}} \left(P^c_{\xi,\beta} + \sum_{\mu} P_{\mu,\xi,\beta} \right)\,. \tag{10}$$

The sum $\sum_{(\xi,\beta)\neq(s,b)}$ is taken over all sectors/beams of all base station sites except the desired sector/beam b of base station site s. The pathloss between sector/beam β of base station site ξ and mobile m, $L_{m,\xi,\beta}$, is given by (1), and $P^c_{\xi,\beta}$ represents the power of all control channels transmitted by sector/beam ξ, β. $\sum_{\mu} P_{\mu,\xi,\beta}$ is the total power used for serving mobiles at sector/beam β of base station ξ.

If there are too many users in the simulation area, the maximum allowed transmit power of one or more sectors is exceeded, and therefore it is not any more possible to serve all users. Then, the user causing most interference is dismissed. This is repeated until all remaining users are satisfied, and no sector exceeds the maximum-power criterion.

B. Received common-channel energy per bit

After having calculated all snapshots, we place probe mobiles on a grid of 20 x 20 m^2 in the evaluation area and calculate a measure of the receive quality of the common channels. For each probe mobile p, this is the ratio of the expected value of the received common-channel energy per chip from beam b of base station site s with the lowest deterministic pathloss and

TABLE I

Amplitudes of the antenna weights $\boldsymbol{w}_a$ for the different number of beams N_b per 120° sector.

N_b	$\boldsymbol{w}_a$
2	[0.31 0.64 0.64 0.31]
3	[0.38 0.60 0.60 0.38]
4	[0.51 0.49 0.49 0.51]
5	[0.48 0.52 0.52 0.48]

the expected value of the received total interference and noise given by

$$\begin{aligned}\gamma &= \frac{\mathrm{E}\{CCH\_E_c\}}{\mathrm{E}\{I_0\}} \\ &= \frac{P^c}{\alpha \overline{P^t_{s,b}} + L^d_{p,s,b} \sum_{(\xi,\beta)\neq(b,s)} \frac{\overline{P^t_{\xi,\beta}}}{L^d_{p,\xi,\beta}} + N_0}\,,\end{aligned} \tag{11}$$

where $\overline{P^t_{s,b}}$ represents the average transmit power of beam b of base station site s over all snapshots.

The main simulation parameters are summarized in Table II.

III. Results

We compared the average number of users in the evaluation area – the gray shaded area in Figure 1 – for all studied base station configurations, in which 95% of the users in the evaluation area are satisfied. That means that 95% of the users have an $\left(\frac{E_b}{I_0}\right)_m$ that is within 0.5dB of its predefined quality target. Figure 3 shows, for the various base station configurations, the

TABLE II

Main system parameters

Number of BS sites	19
Inter-BS distance	1000m
Background noise floor	-105dBm [9]
Pathloss model	3GPP Macro cell [6]
Log-normal large-scale fading	$\mu_{ln} = 0, \sigma_{ln} = 10$dB
Pathloss correlation	0.5
Max. TX power per 120° sector P^{max}	43dBm
Max. code power	40dBm
Min. code power	15dBm
Common-channel power P^c	1, 2, 3W
Active set size	2
Service mix	100% 144kbit/s data users
Activity	100%
Target $\frac{E_b}{I_0}$	4.5dB
No. of antenna elements	4
Inter-element spacing	$d = \frac{\lambda}{2}$
No. of snapshots	50

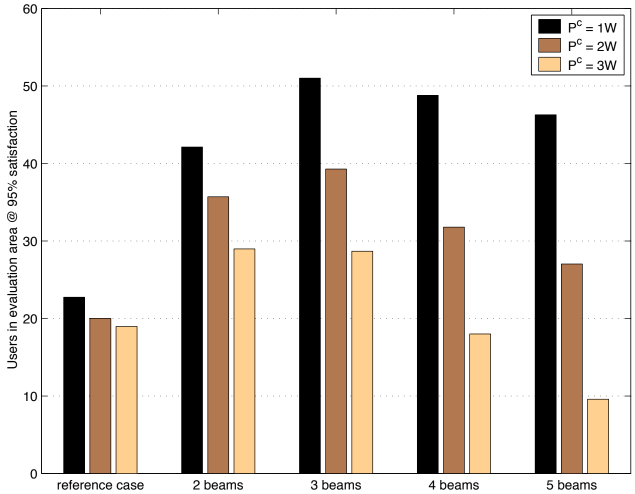

Fig. 3. Average number of users (95% satisfaction) for various base station configurations

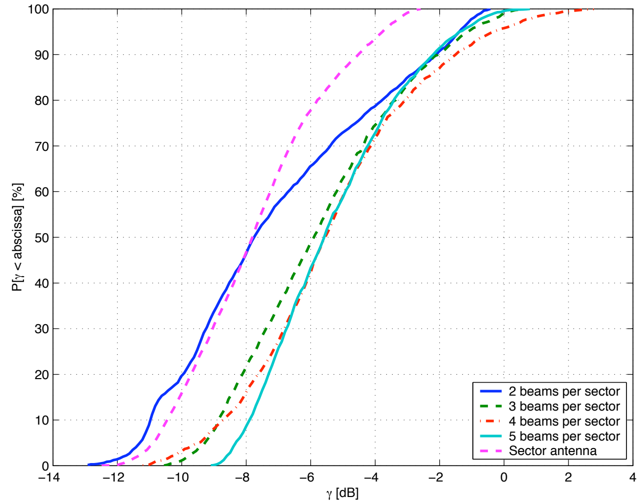

Fig. 4. Expected value of the received common-channel power over the expected value of total interference and noise for a common-channel power of P^c=2W and a system load corresponding to 95% satisfied users.

achievable number of users in the evaluation area for a satisfaction level of 95%. First, we find that the influence of the chosen common-channel power on the system capacity increases with increasing number of beams per 120° sector. Decreasing the common-channel power from 2W to 1W gives a relatively modest capacity increase of less than 14% for a 3-sectored system using sector antennas with a 3dB beamwidth of 65°. In contrast, the same change in common-channel power boosts the capacity tremendously, i.e. by more than 70% for a system with five beams! System capacity is more sensitive to the common-channel power for larger number of beams N_b, because the total transmit power P^{max} of a sector is fixed and the power P^d that is left for transmitting user data in a sector,

$$P^d = P^{max} - N_b P^c \,, \tag{12}$$

is evidently more sensitive to the chosen common-channel power P^c.

Figure 4 gives the cdf of the ratio of the expected value of the received common-channel power and the expected value of total interference-and-noise for a common-channel power of P^c=2W and a system load corresponding to a user satisfaction of 95% – we assume that a system at this working point is fully loaded. Even if all beams transmit their common channels with the same power, the minimum receive quality of the common channels is different for different number of beams per sector. For instance, the minimum receive quality of the common channels for a beam switching system with five beams per sector is about 3dB better than for a beam switching system with two beams. Consequently, assuming that the quality of the common channels is sufficient in the two-beam system, the common channel power can be reduced in the five-beam system, resulting in a much higher capacity.

In order to make a fair comparison of the achievable capacity of beam switching systems with different numbers of beams per sector, it is necessary to specify a criterion for the common-channel power quality in the coverage area. One possible criterion would be the minimum over the coverage area of the ratio of the expected value of the received common channel energy per chip of the strongest received common channels to the expected value of the total interference as given by Equ. 11. This criterion, however, requires considerable system simulations. We therefore propose another criterion, namely

$$\tilde{\gamma} = \min_p \frac{P^c}{\frac{\kappa P^{max}}{N_b}\left(\alpha - 1 - P^c + \sum_{(\xi,\beta)} \frac{L^d_{p,s,b}}{L^d_{p,\xi,\beta}}\right) + N_0}\,, \tag{13}$$

where p specifies the in the coverage area sufficiently narrow spaced probe mobiles, and $\kappa > 1$ is a factor that takes into account that the transmit power of all beams covering a sector can be in the range from $P^c \leq P^t_b \leq P^c + P^d$, whereas the sum of the transmit powers of the beams covering a sector must be not greater than P^{max}. We suggest κ=1.3, which is approximately $\frac{P^{t95} N_b}{P^{max}}$ for each number of beams per sector, where P^{t95} correspond to the 95% level of the transmit powers of the beams over all snapshots at a system load that corresponds to a user satisfaction of 95% – see Figure 5.

IV. Conclusion

We showed quantitatively how system capacity of a UMTS network with switched beams depends on the power used for common channels. The influence of the common-channel power on the system capacity increases dramatically with the number of beams per sector. Thus, a careful choice of the fraction of the total power allocated to the common channels is mandatory in network planning, if the benefit of increased capacity from switched beam antennas is to be exploited in full.

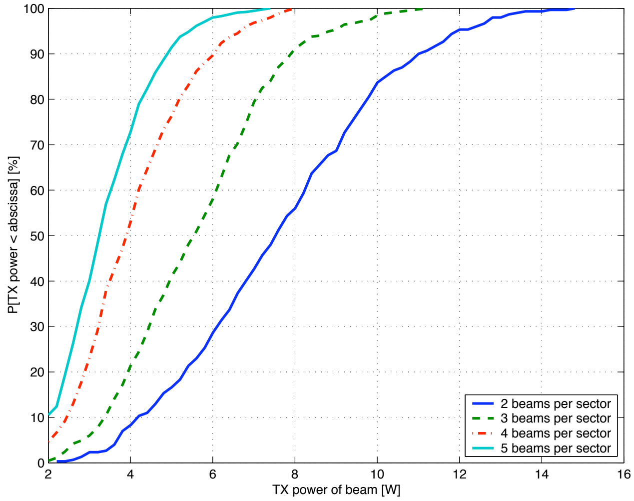

Fig. 5. Cdf of the transmitted power per beam for various beam switching schemes with P^c=2W and a load corresponding to 95% satisfied users (50 snapshots)

In order to make a fair comparison of the achievable system capacity of networks with different base station configurations, it is necessary to choose the common-channel power in such a way that a certain minimum receive quality of the common channels is maintained in the coverage area. To this end, we propose in this paper a new criterion for the receive quality of the common channels that does not require system simulations.

V. Acknowledgment

The authors thank *Mobilkom Austria AG* for financial support of this work. The views expressed in this paper are those of the authors and do not necessarily reflect the views within *Mobilkom Austria*.

References

[1] Harri Holma and Antti Toskala, Eds., *WCDMA for UMTS Radio Access for Third Generation Mobile Communications*, John Wiley & Sons, LTD, Chichester, New York, Weinheim, Brisbane, Singapore, Toronto, 2000.

[2] 3GPP, "3rd generation mobile system Release 1999 specifications," http://www.3gpp.org, December 2001.

[3] Thomas Baumgartner, Thomas Neubauer, and Ernst Bonek, "Performance of a simple downlink beam swithcing scheme for UMTS FDD," in *The* 6^{th} *CDMA International Conference*, Seoul, Korea, October 30 - November 2 2001.

[4] 3GPP, "UE procedures in idle mode and procedures for cell reselection in connected mode - TS 25.304 V4.3.0 (Release 4)," http://www.3gpp.org, December 2001.

[5] Thomas Neubauer, Thomas Baumgartner, and Ernst Bonek, "Necessary and sufficient network size for pole capacity estimation in UMTS FDD," in *ECWT 2000*, Paris, France, October 5-6 2000.

[6] 3GPP, "RF system scenarios - TS 25.942 V2.1.3 (Release 1999)," http://www.3gpp.org, March 2000.

[7] A. J. Viterbi and A. M. Viterbi, "Other-cell interference in cellular power-controlled CDMA," *IEEE Transactions on Communications*, vol. 42, no. 2/3/4, pp. 1501–1504, February 1994.

[8] Robert J. Mailloux, *Phased Array Antenna Handbook*, Artech House Publishers, Boston, London, 1993.

[9] Thomas Neubauer, Herbert Jäger, Josef Fuhl, and Ernst Bonek, "Measurement of the background noise floor in the UMTS FDD band," in *EPMCC 2001*, Vienna, Austria, February 20.-22. 2001.