# Dimensioning of Hardware Components in UMTS Networks with Sectorized NodeBs

Andreas Mäder [1], Dirk Staehle [1] and Bernd Schröder [2]

[1] University of Würzburg
Am Hubland, D-97074 Würzburg
{maeder, staehle}@informatik.uni-wuerzburg.de
[2] T-Mobile Deutschland GmbH
Landgrabenweg 151, D-53227 Bonn
B.A.Schroeder@email.de

**Abstract.** The dimensioning of hardware components takes place at the end of the UMTS radio network planning process when a suitable NodeB site configuration has been found. Each connection to a NodeB requires a service specific number of hardware components and an incoming connection is blocked if not enough components are available. The aim of hardware dimensioning is to find the cost-optimal hardware configuration for given service-specific target blocking probabilities. The challenge for the dimensioning process is that additionally to the hard blocking also system-inherent soft blocking occurs. We propose an algorithm for dimensioning the shared hardware components in the NodeB. The algorithm considers the sector-individual soft capacities and the requirements on the shared hardware pool at the NodeB. We show that ignoring the system-inherent soft blocking of the UMTS radio interface leads to considerable over- or under-dimensioning and therefore has to be included in a proper dimensioning algorithm.

**Keywords:** UMTS, hardware dimensioning, radio network planning, soft capacity

## 1 Introduction

In the last two years the first UMTS networks have been rolled out and are now available in many countries. Nevertheless, it will take some years until the networks are completely built-up. The number of subscribers and in particular the amount of data traffic will grow over the years, so existing networks must be improved and optimized continuously. The term soft capacity means that the capacity on the radio interface is limited by interference. In general, the soft capacity in UMTS is measured by the load in the uplink – meaning the percentage of the pole capacity – and the consumed transmission power of the base stations in the downlink, see e.g. [1] for more details. Models for estimating the CDMA soft capacity are investigated in many articles, since this is a crucial point for the network planning process, cf. [2–6].

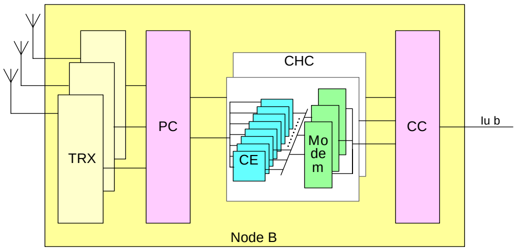


**Fig. 1.** Simplified scheme of a NodeB

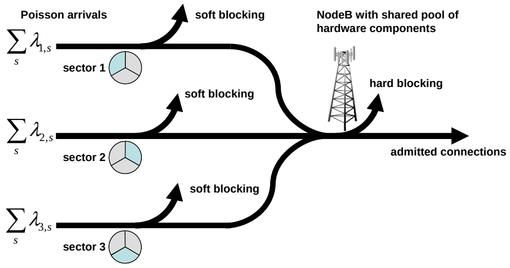


**Fig. 2.** Connection arrivals in the sectors may be soft blocked or hard blocked at the NodeB

Although the hardware-limited capacity, the "hard capacity", affects the coverage in CDMA networks, the planning of the hardware can be done in a second step. This is a consequence of the rule that the hard capacity should never be the bottleneck. Since a mobile network operator has to plan as cost-efficient as possible, efficient dimensioning algorithms for the hardware components are required, cf. [7] or [8] for dimensioning in GPRS networks. In this work, we focus on components in the NodeBs which are typically placed on channel cards (CHC): The modems and the channel elements (CEs).

The implementation of a NodeB is not fully prescribed by the 3GPP standards, so the design and the notation is different from supplier to supplier. Figure 1 sketches a general but simplified scheme of a NodeB. The hardware components which primarily limit the capacity are the modems and the channel elements. A modem is responsible for the coding and decoding of signals, such that every bearer requires one or two modems (one in the case of duplex cards, two in the case of separate receiver/transmitter units). The data stream is split into several so-called AMR-equivalents, each handled by one CE. All suppliers place a fixed set of modems and CEs on a joint channel card, but the actual number of modems and CEs differs even within the product line of a single supplier.

Due to the mentioned restrictions and requirements, the dimensioning process is a complex problem, which has to consider two types of resources in parallel. Furthermore, the soft capacity has to be taken into account to avoid over- or under-dimensioning. Since the dimensioning approach should be independent from the supplier and system release, we consider the number of modems and CEs directly instead of dimensioning the number of channel cards. The dimensioning algorithm we propose implements a two-step strategy: First, the soft capacities and the hardware requirements in each sector are calculated according to the traffic load. Then, the occupation distribution of the shared component pool at the NodeB is calculated and the optimal set of hardware components is found.

A general description of the problem is formulated in the next section. The dimensioning algorithm is introduced in Sec. 3. In Sec. 4 we present our numerical results and we conclude our work in Sec. 5.

## 2 Problem Formulation

We consider a NodeB $x$ with a set of sectors $\mathcal{Z}$ in a network of sectorized WCDMA cells. The sectors of surrounding NodeBs are denoted by the set $\mathcal{Z}'$. For each sector

$z \in \mathcal{Z}$, we assume $|\mathcal{S}|$ Poisson arrival processes of incoming connections, where $\mathcal{S}$ is the set of all services. For each sector $z$, the offered load for the Poisson process $s$ is given by $a_{\mathrm{z,\ s}} = \frac{\lambda_{z,s}}{\mu_{z,s}}$, where $\lambda_{z,s}$ is the arrival rate and $\mu_{z,s}$ is the reciprocal mean of the holding time. We assume that the mobile stations are uniformly distributed over the coverage area.

A service $s \in \mathcal{S}$ is defined by its uplink and downlink target-$E_b/N_0$-values $\hat{\varepsilon}^*_{s,\mathrm{ul}}$ and $\hat{\varepsilon}^*_{s,\mathrm{dl}}$, the bitrate $R_s$, the activity factor $\nu_s$ and the hardware requirements. Each connection consisting of one uplink and one downlink RAB requires $r_M$ modems and $r_{s,\mathrm{CE}}$ channel elements. The NodeB has a number of modems $M$ and a number of channel elements $C$. That means, that all connections controlled by the NodeB $x$ share the same hardware components, so they are a limiting factor for the capacity of the NodeB. The other important limiting factor is the WCDMA radio interface, which is characterized by soft capacity and soft blocking, resp. Figure 2 illustrates the arrival streams and the instances where blocking occures.

The goal is now to find the hardware configuration with minimal costs and with acceptable blocking probabilities. In other words, we search the tuples $\{(M,C)\}_{\mathrm{opt}}$ for which the costs according to a cost function are minimal and for which the total blocking probabilities $B_{z,s}$ are just below or equal to the target blocking probabilities $B^*_{z,s}$. The total blocking probabilities comprise the hard and soft blocking probabilities: $B_{z,s} = B^{\mathrm{hard}}_s + B^{\mathrm{soft}}_{z,s}$. If the target blocking probabilities are exceeded because of soft blocking, i.e. the radio interface is the dominating limiting factor, the increase of the blocking probabilities due to hardware limitations should stay below a threshold which is defined by $\Theta_{\mathrm{soft}}$. So with $f_{\mathrm{cost}}$ as cost function and $B^{\mathrm{soft},\infty}_{z,s}$ as soft blocking probabilities with infinite hardware resources we define the optimal hardware configuration as:

$$\{(M,C)\}_{\mathrm{opt}} := \arg\min_{(M,C)} \Big( f_{\mathrm{cost}}(M,C) | \, \forall z \in \mathcal{Z}, s \in \mathcal{S} : B_{z,s} \leq \max\{B^*_{z,s}, B^{\mathrm{soft},\infty}_{z,s} \cdot \Theta_{\mathrm{soft}}\} \Big)$$

The impact of the soft capacities in the served sectors is twofold: If the soft blocking probabilities are small enough to fullfill the blocking targets, the hardware components must be dimensioned such that $B^{\mathrm{hard}}_s < B^*_{z,s} - B^{\mathrm{soft}}_{z,s}$. So in this case, neglecting the soft capacity leads to an under-dimensioning and to QoS-degradation. On the other hand, if the soft blocking probabilities exceed or are close to the target blocking probabilities, i.e. $B^{\mathrm{soft},\infty}_{z,s} \geq B^*_{z,s}$, the dimensioning of the hardware components to the blocking targets leads to an over-dimensioning. In this case, we adjust the blocking targets with $\Theta_{\mathrm{soft}}$ to a percentage of the soft blocking probabilities. A dimensioning algorithm therefore has to consider both factors, the hardware components in the NodeB and the capacity of the radio interface in the individual sectors.

## 3 The Hardware Dimensioning Algorithm

The main idea of the algorithm is to calculate the state distribution of a joint hardware component state space over all sectors taking into account the sector-individual soft capacities. In this state space, the cost-optimal hardware configurations are found according to a cost function $f_{\mathrm{cost}}$. The coarse structure of the algorithm is as follows:

1. For each sector, establish the $|\mathcal{S}|$-dimensional *connection state space* and calculate the state dependent soft blocking probabilities and the state distribution. Figure 3 shows an example state space with two service classes. The transition rates between the states are reduced by the soft blocking probabilities.
2. For each sector, map the connection state space to the two-dimensional *sector component state space*. A state is defined by the number of occupied modems and CEs. Figure 4 shows the mapping for an example state space with three service classes.
3. From the sector component state spaces, build the joint *NodeB component state space* under the assumption of perfect sectorization. The NodeB component state space reflects the joint hardware requirements of all sectors.
4. Find the cost-optimal set of hardware configurations according to the cost function $f_{\text{cost}}$. If the blocking requirements cannot be fulfilled, try to keep the influence of the hard blocking below a certain threshold due to the factor $\Theta_{\text{soft}}$.

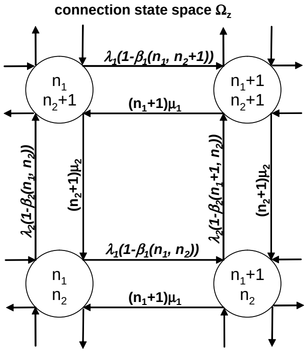


**Fig. 3.** Connection state space with two services

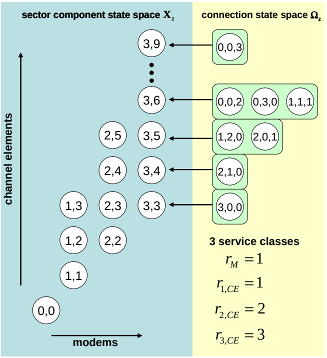


**Fig. 4.** Example for the mapping from $\Omega_z$ to $\mathcal{X}_z$

## Soft Blocking in the Connection State Space

The UMTS utilizes the measured interference and NodeB transmit power for the uplink and downlink admission control (AC). The measured values are no deterministic function of the number of users per service in the sector. They depend also on the interference from surrounding cells and the activity behaviour of the users.

We model the soft blocking by applying the probability that an incoming connection is blocked to the state space spanned by the service dependent Markov chains, similar as in [9]. So the transition rates $q(\bar{n}, \bar{n}+\bar{1}_s)$ between the state $\bar{n}$ with $n_1, \ldots, n_{|S|}$ users and the state $\bar{n}+\bar{1}_s$ with one more user of service $s$ are reduced by state dependent soft blocking probabilities $\beta_{z,s}(\bar{n})$. In general, the transition rates are defined as follows:

$$q(\bar{n}, \bar{n}+\bar{1}_s) = (1-\beta_{z,s}(\bar{n}))\lambda_s \quad \text{and} \quad q(\bar{n}, \bar{n}-\bar{1}_s) = n_s\mu_s \tag{1}$$

and we compute the steady state probabilities $p(\bar{n})$ with the power-method. The soft blocking probabilities reflect uplink and downlink soft blocking:

$$\beta_{z,s}(\bar{n}) = 1 - (1-\beta_{z,s,\text{ul}}(\bar{n}))(1-\beta_{z,s,\text{dl}}(\bar{n})). \tag{2}$$

The computation of the uplink and downlink soft blocking probabilities in a certain state is described in [10]. Since in principle the statespace $\Omega_z$ is infinite, we cut it off when the soft blocking probabilities approach 1. The total soft blocking probability for a service class $s$, i.e. the probability that an incoming connection is blocked in any state, is then given by

$$B_{z,s}^{\text{soft}}(s) = \sum_{\bar{n} \in \Omega} \beta_{z,s}(\bar{n}) p(\bar{n}). \tag{3}$$

**The Sector Component State Spaces**

Each connection to the NodeB occupies $r_M$ modems and $r_{s,\text{CE}}$ channel elements (CEs) which depend on the bitrate of the radio bearers. The state space spanned by the renewal processes of the service classes can be mapped to a sector component state space $\mathcal{X}_z := M_z \times C_z$, where each state $(m_z, c_z)$ is an aggregate of the corresponding states $\bar{n}$ in the connection state space, see Fig. 4. The state probabilities and also the local soft blocking probabilities in $\mathcal{X}_z$ are

$$p_{\mathcal{X}_z}(m_z, c_z) = \sum_{\bar{n}_s \in \Phi(m_z, c_z)} p(\bar{n}_z) \quad \text{and} \quad \beta_{z,s}^{\mathcal{X}_z}(m_z, c_z) = \frac{\sum_{\bar{n} \in \Phi(m_z, c_z)} p(\bar{n}_z) \beta_{z,s}(\bar{n}_z)}{p_{\mathcal{X}_z}(m_z, c_z)}, \tag{4}$$

where $\Phi(m_z, c_z) := \{\bar{n} | r_M \sum n_s = m_z \wedge \sum n_s r_{s,\text{CE}} = c_z\}$. The local soft blocking probability between the states $(m_z, c_z) \to (m_z + r_M, c_z + r_{s,\text{CE}})$ is the sum of the connection state soft blocking probabilities weighted with the state probability in $\mathcal{X}$.

**Hardware as Shared Resource in the NodeB Component State Space**

On the one hand, each sector spans it's own state space $\mathcal{X}_z$, where the state probabilities and the soft blocking probabilities are independent from other sectors. On the other hand, the hardware components are taken from a pool of hardware on the NodeB and are a shared resource for the sector requirements. So, we take the number of occupied resources in the sectors as independent from each other and build a joint NodeB component state space $\mathcal{X}$. Note again that the assumption of independence between the sector state probabilities implies perfect sectorization, i.e. that the sector interferences are independent of each other. The number of modems and CEs in the NodeB component state space is the sum of the modems and CEs in the individual sectors. The state probability distribution is then the two-dimensional convolution of the sector state distributions:

$$m = \sum_{z \in \mathcal{Z}} m_z, \quad c = \sum_{z \in \mathcal{Z}} c_z \quad \text{and} \quad p_{\mathcal{X}}(m, c) = \bigcircledast_{z \in \mathcal{Z}} p_{\mathcal{X}_z}(m, c). \tag{5}$$

Figure 5 shows the state probabilities of an example NodeB component state space. For the soft blocking probabilities, we calculate the probability that a connection of service class $s$ arrives in a combined state $(m, c)$ in sector $z$ and is blocked:

$$\beta_{z,s}^{\mathcal{X}}(m, c) = \sum_{m'=0}^{m} \sum_{c'=0}^{c} p_{\mathcal{X}_z}(m', c' | \, m, c) \beta_{z,s}^{\mathcal{X}_z}(m', c'). \tag{6}$$

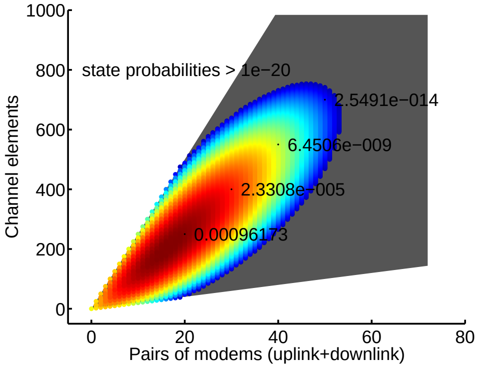


**Fig. 5.** NodeB component state space

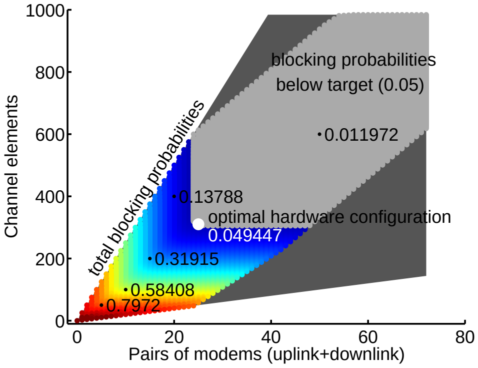


**Fig. 6.** Total blocking probabilities in the solution space

This means, we summarize the soft blocking probabilities of all possible state combinations in $\mathcal{X}_z$ under the condition that in total, the state is $(m,c)$. This equation can also be expressed with the convolution operator as:

$$\beta^{\mathcal{X}}_{z,s}(m,c) = \left(\mathop{\circledast}_{z'\neq z} p_{\mathcal{X}'_z}(m,c)\right) \circledast \beta^{\mathcal{X}_z}_{z,s}(m,c). \tag{7}$$

The total soft blocking probability for sector $z$ and service $s$ is the sum over all $\beta^{\mathcal{X}}_{z,s}(m,c)$ weighted with the state probabilities. The hard blocking probability is the sum over the state probabilities, in which a new connection would be blocked due to hardware limitations:

$$B^{\text{soft}}_{z,s} = \sum_{\substack{(m,c)|0\leq m\leq M-r_m \\ \wedge 0\leq c\leq C-r_{s,\text{CE}}}} \sum p_{\mathcal{X}_z}(m,c)\beta^{\mathcal{X}}_{z,s}(m,c) \quad \text{and} \quad B^{\text{hard}}_{s} = \sum_{\substack{(m,c)|M-r_M<m\leq M \\ \vee C-r_{s,\text{CE}}<c\leq C}} \sum p_{\mathcal{X}}(m,c). \tag{8}$$

### The Cost-Optimal Solution

Next, the hard and soft blocking probabilities for all configurations in the state space are calculated. Each configuration $(M,C)$ spans a sub-state space $\mathcal{G}$ in which the state probabilities are obtained by renormalization:

$$p_{\mathcal{G}}(m,c) = \frac{p_{\mathcal{X}}(m,c)}{\mathbf{N}(M_{\mathcal{G}},C_{\mathcal{G}})} \quad \text{with} \quad \mathbf{N}(M_{\mathcal{G}},C_{\mathcal{G}}) = \sum_{m=0}^{M_{\mathcal{G}}}\sum_{c=0}^{C_{\mathcal{G}}} p_{\mathcal{X}}(m,c) \tag{9}$$

The soft and hard blocking probabilities are then calculated according to Eq. (8). This is an approximation method because the state dependent local soft blocking probabilities may change if the state space size changes. Finally, the cost-minimum configurations $\{(M,C)\}_{\text{opt}}$ are found with the cost function $f_{\text{cost}}$, see Sec. 2.

In Fig. 6, the total blocking probabilities of an example state space are shown. The optimal hardware configuration for this example is marked by the white dot.

# 4 Numerical Results

In this section we validate the dimensioning algorithm and show that it is superior to simple hardware dimensioning that ignores soft blocking. The reference scenario consists of a central NodeB which is the one that we model and one tier of surrounding NodeBs. We further assume perfect sectorization such that every NodeB has three non-overlapping 120° sectors. The service mix and the other system parameters are given in Tab. 1. The system load is scaled by the total offered traffic $a_z$ per sector $z$ such that the offered traffic in numbers of users per service $s$ in sector $z$ is $a_{z,s} = p_s \cdot a_z$. The probability $p_s$ of a service $s$ is defined by the service mix.

**Table 1.** Service Mix and system parameters

| service | prob. |  | req. | Uplink RAB |  |  | Downlink RAB |  |  | power oth. sectors |
|---|---|---|---|---|---|---|---|---|---|---|
|  | $p(s)$ | $B_s^{target}$ | CEs | bit rate | $E_b/N_0$ | $\nu_s$ | bit rate | $E_b/N_0$ | $\nu_s$ | $E[\hat{T}_z]$ =4575mW |
| Voice | 0.2 | 0.02 | 2 | 12.2kbps | 5.5dB | 0.5 | 12.2kbps | 5.5dB | 0.5 | $Std[\hat{T}_z]$ =515mW |
| Web | 0.4 | 0.05 | 13 | 64kbps | 4dB | 0.1 | 144kbps | 3dB | 0.5 | othercell load |
| Streaming (Down) | 0.1 | 0.2 | 25 | 12.2kbps | 5.5dB | 0.5 | 384kbps | 2dB | 1.0 | $E[\eta_{oc}]$ =0.1 |
| Streaming (UP) | 0.2 | 0.1 | 10 | 144kbps | 3dB | 1.0 | 12.2kbps | 5.5dB | 1.0 | $Std[\eta_{oc}]$ =0.02 |

|  |  |
|---|---|
| orthogonality factor $\alpha$ =0.2 | chip rate W=3.84Mcps |
| thermal noise spectral density $N_0$=-174dBm/Hz | uplink load threshold $\Theta_{ul}^{*}$= 0.5 |
| downlink power threshold $\hat{T}_{max}$=6000mW | constant downlink power $\hat{T}_{const}$=2000mW |
| cost function $f_{cost}(M, C) = 5 \cdot M + C$ | blocking target adapt. factor $\Theta_{soft} = 1.1$ |

First, we validate the accuracy of step one of our algorithm, the computation of the soft blocking probabilities for a sector without hardware limitations, with an event-driven simulation. At every arrival instant we generate an independent system snapshot for which we evaluate the uplink load and the downlink transmit power. Accordingly, the admission control decides whether to accept or block the incoming user. Figure 7 shows the soft blocking probabilities obtained by simulation (solid lines) and by analysis (dashed lines). The simulation results are presented without confidence intervals as they are too small to be visible. On the x-axis of the left figure the load varies from three users per sector to 18 users per sector and the right figure shows the blocking probabilities with logarithmic scale for smaller loads between two and ten. The soft blocking probabilities for the analysis and the simulation match quite well for offered loads of at least three users per sector.

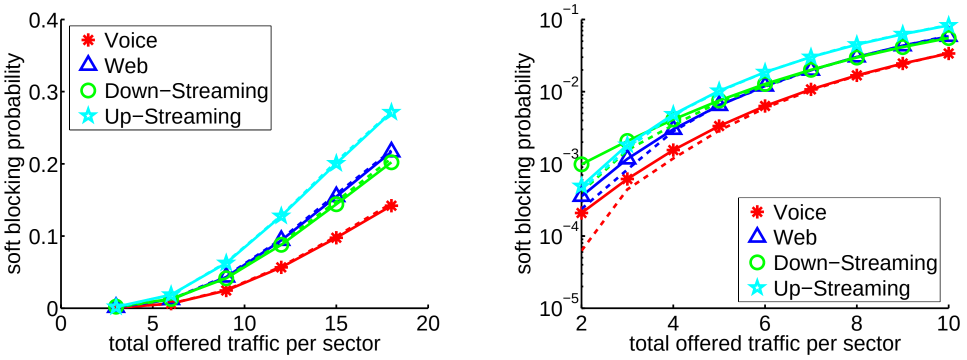
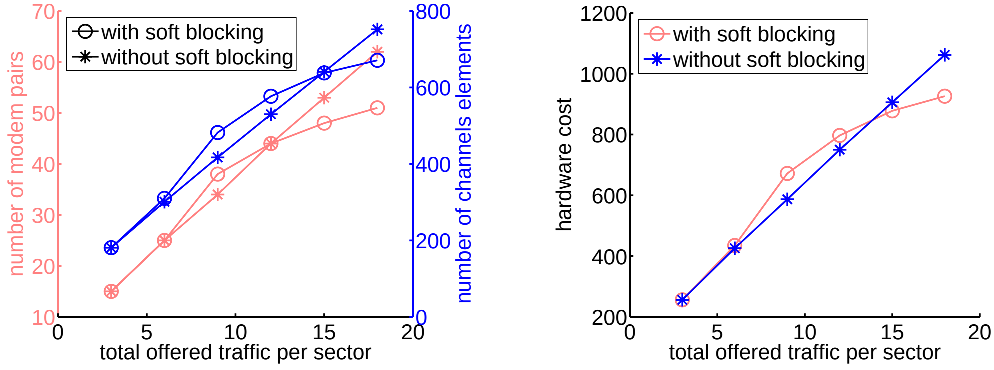
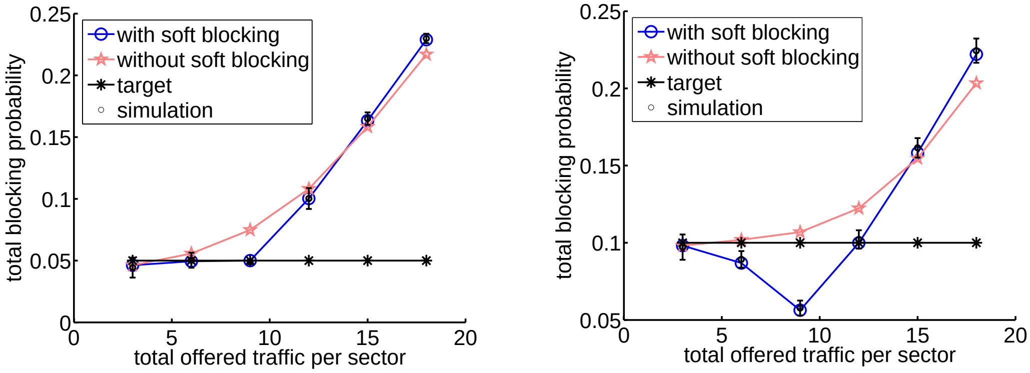


**Fig. 7.** Validation of soft blocking probabilities for a single sector



modems and channel elements

hardware costs

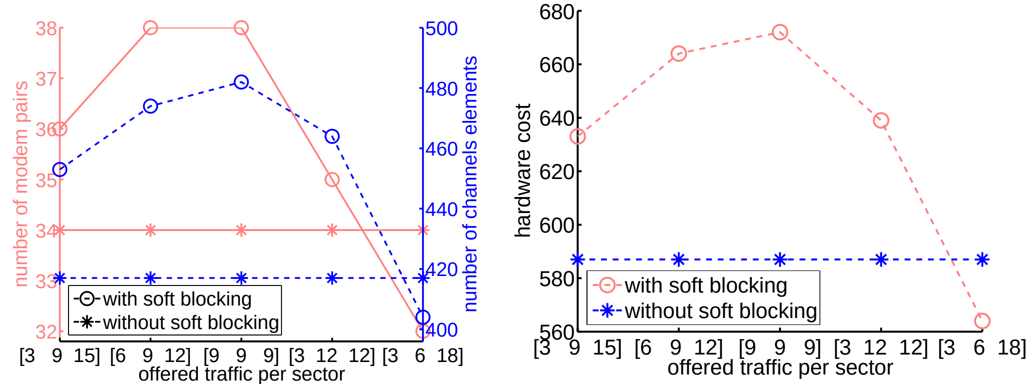


web service

down-streaming service

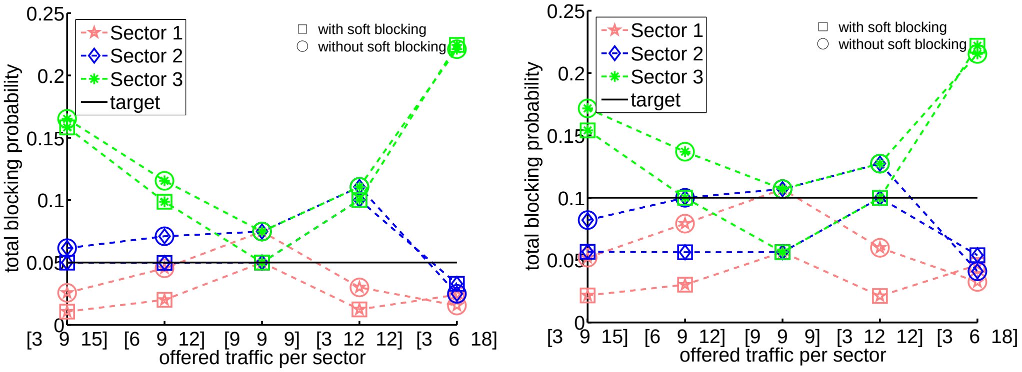
**Fig. 8.** Impact of the offered traffic on the required hardware with fixed target blocking probabilities

With the next results we intend to justify our relatively complex dimensioning algorithm that considers soft blocking. Therefore, we compare it with another dimensioning algorithm that ignores soft blocking and dimensions the hardware components only according to the offered load. In the following figures we refer to our proposed algorithm as "with soft blocking" and the alternative algorithm as "without soft blocking". At first, we consider a scenario with equally loaded sectors and offered loads between three users per sector and 18 users per sector. Figure 8 compares the results obtained by the two dimensioning algorithms. The upper left figure shows the found hardware configuration and the upper right figure shows the corresponding hardware costs. For a low load the two algorithms lead to the same result as almost no soft blocking occurs. Then, starting at a load of six users per sector, the "with soft blocking" algorithm requires more hardware. This applies up to a load of about 16 where the two curves intersect and the hardware requirement of the "without soft blocking" algorithm becomes the larger one. The reason for this behavior becomes clear if we investigate the resulting total - soft plus hard - blocking probabilities of the web and the down-streaming service that are plotted in the lower left and right figure, respectively. The "with soft blocking" algorithm is able to meet the blocking target for the web service up to a load of nine users per sector. For higher loads, the soft blocking probability already exceeds the target. In contrast, the "without soft blocking" algorithm can not even keep the target for a



modems and channel elements

hardware costs



web service

down-streaming service

**Fig. 9.** Impact of the traffic balance between the sectors with constant total traffic

load of six users and leads to blocking probabilities that exceed the target for the web service by up to three percent with nine users per sector. A similar behavior occurs for the down-streaming service. For loads between two and ten users this service profits from the tighter blocking target of the web service and the corresponding larger number of channel elements. For a load of twelve, the soft blocking probability for the web service exceeds the target and the hardware components are dimensioned according to the requirements of the down-streaming service that can still keep its blocking target. Again, the "without soft blocking" algorithm exceeds the target blocking probability by more than two percent.

The scenarios up to now considered evenly loaded sectors. Now we consider sectors with different loads. Therefore, we keep the total load of all sectors together at 27 users and distribute the total offered load unevenly between the three sectors. The results are shown in Fig. 9, where the four subfigures have the same meaning as in the previous figure. On the x-axis, you can find the allocation of the load to the three sectors. The "without soft blocking" algorithm yields the same results for all allocations which is obvious as it only depends on the total offered traffic. In contrast, the results for the "with soft blocking" algorithm show a considerable difference of up to six pairs of modems and 90 channel elements. The most hardware is required for the equally loaded scenario and the least hardware is required for the most uneven scenario on the right. The reason is obviously that in an unevenly loaded scenario the highest loaded sector experiences extensive soft blocking and thus requires less hardware. This becomes clear when looking at the soft blocking probabilities. In the equally loaded scenario the hardware requirement is determined by the web service in sector three. In all other scenarios the soft blocking probability for the web service in sector three exceeds the target blocking probability. At the most extreme case, [3 6 18], the target blocking probability for neither the web nor the down-streaming service can be met.

## 5 Conclusion

We presented an algorithm for the dimensioning of hardware components in a NodeB. The algorithm considers two types of hardware components, modems and channel elements, different service classes in multiple sectors and the up- and downlink soft capacities. The state and soft blocking probabilities of the sectors are calculated under the assumption of infinite hardware resources and then combined to a joint component state space for the shared pool of hardware resources at the NodeB. Then, the algorithm finds the cost-minimal hardware configuration which keeps the service-specific target blocking probabilities.

The numerical results show that our proposed dimensioning algorithm is superior to a pure hardware dimensioning which ignores soft blocking. Neglecting the sector-individual soft capacities can either lead to under- or over-dimensioning. The first case occurs if the soft blocking probabilities are close to the target blocking probabilities. The second case occurs if the system-inherent soft blocking probabilities already exceed the target blocking probabilities. The quintessence of our results is that the impact of the soft capacity has to be considered for a proper hardware dimensioning.

**ACKNOWLEDGEMENTS**
The authors want to thank Tobias Hoßfeld for the programming support.

## References

1. Holma, H., (Eds.), A.T.: WCDMA for UMTS. John Wiley & Sons, Ltd. (2001)
2. Veeravalli, V.V., Sendonaris, A.: The coverage-capacity tradeoff in cellular CDMA systems. Transactions on Vehicular Technology **48** (1999) 1443–1450
3. Viterbi, A., Viterbi, A.: Erlang Capacity of a Power Controlled CDMA System. IEEE Journal on Selected Areas in Communications **11** (1993) 892–900
4. Staehle, D., Mäder, A.: An Analytic Approximation of the Uplink Capacity in a UMTS Network with Heterogeneous traffic. In: 18th International Teletraffic Congress, Berlin (2003)
5. Staehle, D., Mäder, A.: An Analytic Model for Deriving the Node-B Transmit Power in Heterogenous UMTS Networks. In: IEEE Vehicular Technology Conference 2004-Spring, Milan, Italy (2004)
6. Mäder, A., Staehle, D.: Analytic Modelling of the WCDMA Downlink Capacity in Multi-Service Environments. In: 16th ITC Specialist Seminar, Antwerp, Belgium (2004) 229–238
7. Jeon, W.S., Jeong, D.G.: Call Admission Control for CDMA Mobile Communication Systems Supporting Multimedia Services. IEEE Trans. on Wireless Comm. **1** (2002)
8. Pedraza, S., Romero, J., noz, J.M.: (E)GPRS Hardware Dimensioning Rules with Minimum Quality Criteria. In: IEEE Vehicular Technology Conference 2002 - Fall, Vancouver, Canada (2002)
9. Choi, W., Kim, J.: Forward-link Capacity of a DS/CDMA System with Mixed Multirate Sources. IEEE Trans. on Veh. Tech. **50** (2001) 737–749
10. Mäder, A., Staehle, D., Schröder, B.: Dimensioning of Hardware Components in UMTS Networks with Sectorized NodeBs. Technical Report 365, University of Würzburg (2005)