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Abstract

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 the cost-optimal dimensioning of the shared hardware components in the NodeB according to the service specific blocking targets. 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 planning process for CDMA networks like UMTS has to consider that a trade-off between coverage and capacity exists, cf. e.g. [1]. 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. [2] for more details. Models for the estimation of the CDMA soft capacity are investigated in many articles, since this is a crucial point for the network planning process, cf. [1, 3, 4, 5, 6].

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, 9] 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

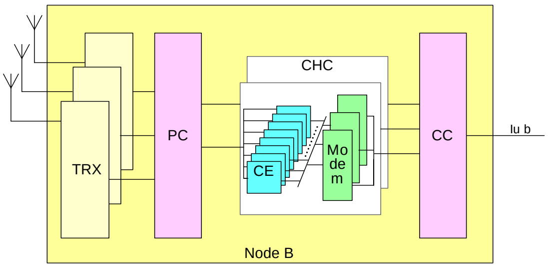

Figure 1: Simplified scheme of a NodeB

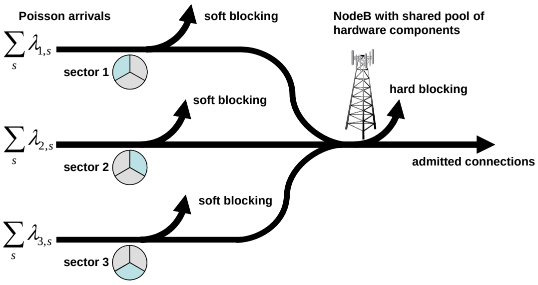

Figure 2: Connection arrivals in the sectors may be soft blocked or hard blocked at the NodeB

but simplified scheme of a NodeB. The primarily hardware components which 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 splitted 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. In general, the channel cards handle the signalling traffic as well as the dedicated user traffic, where the strategies for the signalling traffic differs between the suppliers and between different system releases. The fragmentation of the resources is avoided by efficient refarming strategies. The hardware resources are handled as a pool from which all sectors are served. In case of softer handover connections only one set of resources for the connection is used, but in case of soft handover, resources are occupied on each NodeB in the active set of the mobile station (MS).

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 Section 3 and the radio interface model is presented in Section 4. In Section 5 some numerical results are shown and we conclude our work in Section 6.

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. A service $s \in \mathcal{S}$ is defined by its target-E_b/N_0, where $\hat{\varepsilon}^*_{s,\text{ul}}$ denotes the uplink RAB and $\hat{\varepsilon}^*_{s,\text{dl}}$ the downlink RAB target-E_b/N_0-values, the bitrate R_s and the activity factor ν_s. So, a service is defined by it's uplink and downlink RAB definition. Then for each sector z, the offered load for the Poisson processes s is given by $a_{\text{z, s}} = \frac{\lambda_{z,s}}{\mu_{z,s}}$, 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 considered area. Finally, the NodeB itself has a number of modems M and a number of channel elements C. Each connection consisting of one uplink and one downlink RAB requires r_M modems and $r_{s,\mathrm{CE}}$ channel elements at the NodeB. 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 air interface, which is characterized by soft capacity and soft blocking, resp.

The goal is now to find the hardware configuration with a minimum on costs and with acceptable blocking probabilities. In other words, we search the tuple or set of tuples $\{(M,C)\}_{\mathrm{opt}}$ for which the costs according to a cost function are minimal and for which the blocking probabilities $B_{z,s}$ are just below or equal to the target blocking probabilities $B_{z,s}^{\mathrm{target}}$. If the target blocking probabilities are exceeded because of soft blocking, i.e. the air interface alone limits the capacity, the growth of the blocking probabilities due to hardware limitations should stay below a factor Θ_{soft}. So with $f_{\mathrm{cost}} : (M \times C) \to \mathbb{R}$ as cost function and $B_{z,s}^{\mathrm{soft}}$ as soft blocking probabilities:

$$\{(M,C)\}_{\mathrm{opt}} = \arg(\min\{f_{\mathrm{cost}}(M,C)|, \forall z \in \mathcal{Z}, s \in \mathcal{S} : B_{z,s} \leq \max\{B_{z,s}^{\mathrm{target}}, B_{z,s}^{\mathrm{soft}} \cdot \Theta^{\mathrm{soft}}\}\}) \qquad (1)$$

The obvious approach would be to dimension the number of hardware components according to the multi-dimensional Erlang-B or – for a reduced execution time – according to the Kaufman-Roberts formula [10, 11]. However, this approach neglects the influence of the soft capacity of the air interface. We will show that this can lead to over-dimensioning or even to under-dimensioning, i.e. to QoS-degration. The reason is that the capacity of the air interface in the served sectors may be exceeded long before the hardware limit in the NodeB is hit. Therefore, a dimensioning algorithm has to consider both influencing factors, the hardware components in the NodeB and the capacity of the air 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_{cost}. The coarse structure of the algorithm is as follows:

1. Establish the $|\mathcal{S}|$-dimensional *connection state space* $\Omega_z := \mathbb{N}^{|\mathcal{S}|}$ for each sector $z \in \mathcal{Z}$ and calculate the soft blocking probabilities and the state distribution. A state is denoted by $\bar{n} = (n_1, \ldots, n_{|\mathcal{S}|})$, where n_s is the number of connections per service class. The transition to a higher state may be blocked due to insufficient soft capacity with probability $\beta_{z,s}^{\Omega_z}(m_z, c_z)$. In Figure 3, an example state space with two service classes is shown. The transition rates between the states are reduced by the soft blocking probabilities. For more details see Section 3.1.

2. For each sector, establish the two-dimensional *sector component state space* $\mathcal{X}_z := M_z \times C_z$. A state (m_z, c_z) contains the number of occupied modems m_z and the number of occupied CEs, c_z. A state in $\mathcal{X}_z$ is therefore an aggregate of states in Ω_z for which m_z modems and c_z CEs are occupied. Again, the state distribution and the soft blocking probabilities are calculated. In Figure 4 the mapping from Ω_z to $\mathcal{X}_z$ for an example scenario with three service classes is shown. On the left side the states in the sector component state space are shown, and on the right are the corresponding states in the connection state space for the case of three connections.

3. From the sector component state spaces, build the joint *NodeB component state space* $\mathcal{X} := M \times C$. This is done under the assumption of perfect sectorization, which means that it is assumed that the soft capacity of one sector is not influenced by the other sectors. The NodeB component state space reflects the joint hardware requirements of all sectors. So, in a state (m, c), the number of occupied modems is $m = \sum_{z \in \mathcal{Z}} m_z$ and the number of occupied CEs is $c = \sum_{z \in \mathcal{Z}} c_z$. Due to the assumption of independence among the sectors, the state distribution and the soft blocking probabilities can be calculated. The NodeB component state space is explained in Section 3.3.

4. Narrow the NodeB component state space to states which are reachable with reasonable probability and calculate the total blocking probability for each state. The total blocking probability $B_{z,s}$ consists of the hard blocking probability B_s^{hard}, which is the same in each sector, and the sector-individual soft blocking probabilities $B_{z,s}^{\text{soft}}$. Find the cost-optimal set of hardware configurations $\{(M, C)\}_{\text{opt}}$ according to the cost function f_{cost} out of a set of candidates $\{(M, C)\}_{\text{cand}}$. If the blocking requirements cannot be fulfilled, try to keep the influence of the hard blocking below a certain threshold due to the factor Θ_{soft}.

In the next sections, the operations of the algorithm are explained in more detail.

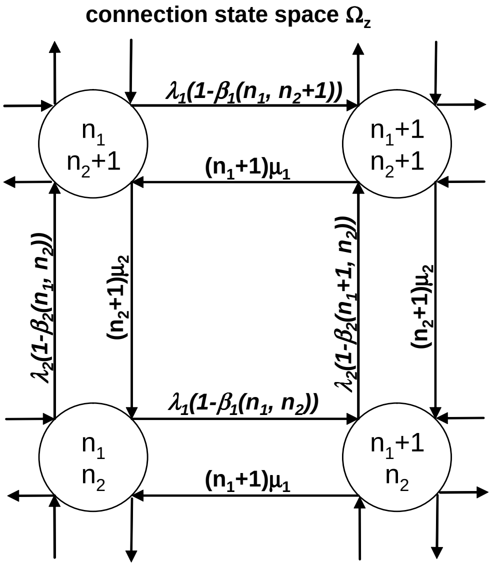

Figure 3: Example connection state space with two service classes

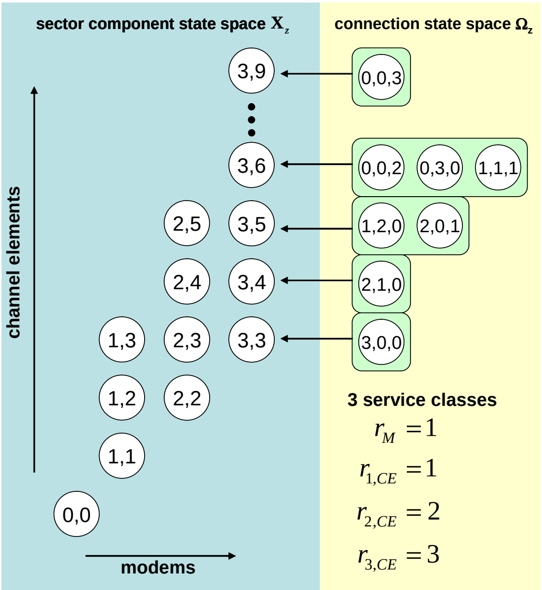

Figure 4: Example for the mapping from Ω_z to $\mathcal{X}_z$

3.1 Modelling and Calculating Soft Blocking in the Connection State Space

In CDMA systems the system capacity cannot be given in terms of a deterministic value. This also means that theoretically in every system state blocking or outage may occure, although the probability for such an event is of course correlated to the number of mobiles in the system. We model this behaviour by applying the probability that an incoming connection is blocked to the state space spanned by the service dependend markov chains, similar as in [12]. So the transition rates $q(\bar{n}, \bar{n} + \bar{1}_s)$ between the states $\bar{n}$ and $\bar{n} + \bar{1}_s$ are supplemented by state dependent soft blocking probabilities $\beta_{z,s}(\bar{n})$. In general, the transition rates are defined as follows:

$$q(\bar{n},\bar{n}+\bar{1}_s) = (1-\beta_{z,s}(\bar{n}))\lambda_s \quad \text{and} \quad q(\bar{n},\bar{n}-\bar{1}_s) = n_s\mu_s. \tag{2}$$

The soft blocking probabilities reflect uplink and downlink soft blocking:

$$\beta_{z,s}(\bar{n}) = 1-(1-\beta_{z,s,\mathrm{ul}}(\bar{n}))(1-\beta_{z,s,\mathrm{dl}}(\bar{n})). \tag{3}$$

The bijective function $\phi : \Omega_z \to \mathbb{N}$ maps the the states $\bar{n}$ in the connection state space Ω_z to $\mathbb{N}$. The transition rate matrix $\mathbf{Q}_z$ is then composed from the transition rates as follows:

$$\mathbf{Q}_z = (q_{ij})_{i,j=1,\ldots,n} \quad \text{with} \quad q_{ij} = \begin{cases} -\sum_{l\neq i} q_{il} & \text{if } i=j, \\ \lambda_{z,s}(1-\beta_{z,s}(\bar{n})) & \text{if } \phi(\bar{n})=i, \phi(\bar{n}+\bar{1}_s)=j, \\ n_{z,s}\mu_{z,s} & \text{if } \phi(\bar{n})=i, \phi(\bar{n}-\bar{1}_s)=j, \\ 0 & \text{else} \end{cases} \tag{4}$$

Since the statespace Ω_z is infinite, the size of the transition rate matrix has to be limited to a maximum of n. For this reason we filter out states which have a soft blocking probability $\beta_z(\bar{n}) > 1-\epsilon$ and which are not higher than the ζ-percentile of the Poisson CDF, i.e. states for which holds $\exists\, n_s \in \bar{n} |\, n_s > F_{a_s}^{-1}(1-\zeta)$ with $F_{a_s}^{-1}$ as inverse Poisson CDF. Then, the state probability vector $\bar{\pi}_z$ is the solution of the matrix equation $\bar{\pi}_z\mathbf{Q}_z = 0$.

Several numerical as well as direct techniques exists to calculate the solution of this equation. We chose the power-method, since usually the iteration converges within an acceptable number of steps. It should be noted that in our implementations, building the transition rate matrix consumed more time than calculating the state distribution. The iterative equation for this numerical method is given by

$$\bar{X}^{(k+1)} \leftarrow (\mathbf{I}+\gamma\mathbf{Q}_z^T)\bar{X}^{(k)}, \quad 0<\gamma<\frac{1}{\max|q_{ii}|} \tag{5}$$

where $\bar{X} = \bar{\pi}_z^T$ and $\bar{X}^{(0)} = (1,0,\ldots,0)^T$. The relaxation factor γ ensures that the matrix $(\mathbf{I}+\gamma\mathbf{Q}^T)$ is stochastic and that the iteration converges, see e.g. [13].

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

$$B_{z,s}^{\mathrm{soft}}(s) = \sum_{\bar{n}\in\Omega} \beta_{z,s}(\bar{n})\bar{\pi}_z(\phi(\bar{n})). \tag{6}$$

3.2 The Sector Component State Spaces

Each connection to the NodeB occupies r_M modems and a certain amount $r_{s,\mathrm{CE}}$ of channel elements (CEs) which depends on the bitrate of the radio bearers. So, the connections in each sector z occupy m_z modems and c_z CEs, with

$$m_z = r_M \sum_{s\in\mathcal{S}} n_s \qquad \text{and} \qquad c_z = \sum_{s\in\mathcal{S}} n_s r_{s,\mathrm{CE}}. \tag{7}$$

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 in the connection state space Ω, cf. Fig. 4. So, the state probabilities and also the local soft blocking probabilities in $\mathcal{X}_z$ can be mapped from Ω_z as

$$p_{\mathcal{X}_z}(m_z,c_z) = \sum_{\bar{n}_s\in\Phi(m_z,c_z)} p(\bar{n}_z) \quad \text{and} \quad \beta_{z,s}^{\mathcal{X}_z}(m_z,c_z) = \frac{\sum_{\bar{n}\in\Phi(m_z,c_z)} p(\bar{n}_z)\beta_{z,s}(\bar{n}_z)}{p_{\mathcal{X}_z}(m_z,c_z)}, \tag{8}$$

where

$$\Phi : \Omega_z \to \mathcal{X}_z, \Phi(m_z, c_z) := \{\bar{n} | r_M \sum n_s = m_z \wedge \sum n_s r_{s,\mathrm{CE}} = c_z\}. \tag{9}$$

The local soft blocking probability between the states $(m_z, c_z) \to (m_z + r_M, c_z + r_{s,\mathrm{CE}})$ is the sum of the connection state soft blocking probabilities conditioned with the state probability in $\mathcal{X}$.

3.3 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 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:

$$m = \sum_{z \in \mathcal{Z}} m_z, \quad c = \sum_{z \in \mathcal{Z}} c_z \quad \text{and} \quad p_{\mathcal{X}}(m, c) = \mathop{\circledast}_{z \in \mathcal{Z}} p_{\mathcal{X}_z}(m, c). \tag{10}$$

The operator $\circledast$ is the two-dimensional discrete convolution operator. The resulting state space reflects the probabilities for all valid state permutations over all sectors. 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:

$$\beta^{\mathcal{X}}_{z,s}(m, c) = \sum_{m'=0}^{m} \sum_{c'=0}^{c} p_{\mathcal{X}_z}(m', c' | \, m, c) \beta^{\mathcal{X}_z}_{z,s}(m', c'). \tag{11}$$

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:

$$\beta^{\mathcal{X}}_{z,s}(m, c) = \left(\mathop{\circledast}_{z' \neq z} p_{\mathcal{X}'_z}(m, c) \right) \circledast \beta^{\mathcal{X}_z}_{z,s}(m, c). \tag{12}$$

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:

$$B^{\mathrm{soft}}_{z,s} = \sum_{\substack{(m,c) | 0 \leq m \leq M - r_m \\ \wedge 0 \leq c \leq C - r_{s,\mathrm{CE}}}} \sum p_{\mathcal{X}_z}(m, c) \beta^{\mathcal{X}}_{z,s}(m, c) \quad \text{and} \quad B^{\mathrm{hard}}_{s} = \sum_{\substack{(m,c) | M - r_M < m \leq M \\ \vee C - r_{s,\mathrm{CE}} < c \leq C}} \sum p_{\mathcal{X}}(m, c). \tag{13}$$

3.4 The Solution Space

In the next step, the algorithm cuts the state space down to states with reasonable state probabilities. This is done in several steps: The light gray area in Figure 5 illustrates

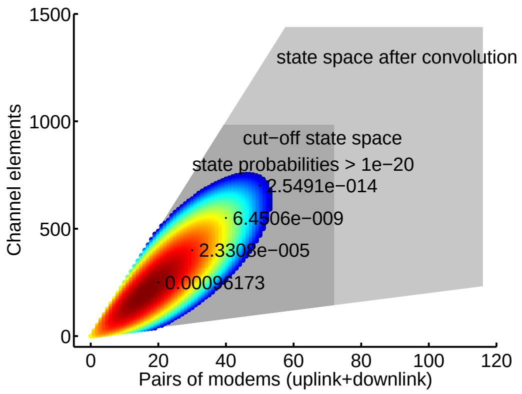

Figure 5: NodeB component state space

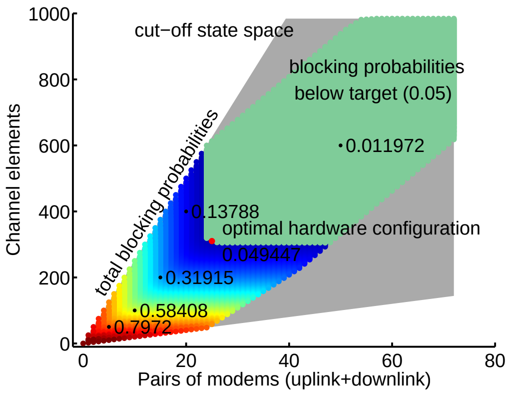

Figure 6: Total blocking probabilities in the solution space

the NodeB component state space directly after the convolution of the sector component state spaces. The darker gray indicates that the row sums of the state probabilities are greater than ζ_r, so the state space is cut off at this point. In this example: $\zeta_r = 10^{-20}$. The colored area are states with probabilities higher than ζ_{cand}, here $\zeta_{\text{cand}} = 10^{-10}$. This is the solution space in which the optimal hardware configuration is searched:

$$\{(M,C)\}_{\text{cand}} := \{(M,C)|p_{\mathcal{X}}(M,C) > \zeta_{\text{cand}}\} \tag{14}$$

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

$$p_{\mathcal{G}}(m,c) = \frac{p_{\mathcal{X}}(m,c)}{\mathbf{N}(M_{\mathcal{G}},C_{\mathcal{G}})} \quad \text{with} \quad \mathbf{N}(M_{\mathcal{G}},C_{\mathcal{G}}) = \sum_{m=0}^{M_{\mathcal{G}}} \sum_{c=0}^{C_{\mathcal{G}}} p_{\mathcal{X}}(m,c) \tag{15}$$

The soft and hard blocking probabilities can then be calculated according to the Equations (13). However, it should be noted that this is an approximation method, because the state dependend local soft blocking probabilities on the state transitions may change if the state space size is changed. Finally, the cost-minimum configurations $\{(M,C)\}_{\text{opt}}$ are found with the cost function f_{cost}, cf. Section 2.

In the example Figure 6, the total blocking probabilities for all configurations $\{(M,C)\}_{\text{cand}}$ is shown. In the colored area, red indicates a high blocking probability while blue indicates a lower blocking probability. The optimal hardware configuration is denoted by the red dot, which is just on the beginning of the area with blocking probabilities below the blocking targets, indicated by the light green color.

The hardware dimensioning algorithm is sketched out in pseudo-code as Algorithm 1. It should be noted that the algorithm is in principle independent of the implemented radio interface model, as long as perfect sectorization can be assumed. The runtime of the pure algorithm is relatively small, the most time takes the establishment of the rate matrizes for the connection state space which requires the calculation of the soft blocking probabilities on each state transitition.

Algorithm 1 Hardware dimensioning algorithm

```
Input: Sectors $\mathcal{Z}$, services $\mathcal{S}$, offered loads $\mathcal{A}$, blocking targets $\mathcal{P}^{\text{target}}$
Output: Cost-optimal hardware configurations $\{(m,c)_{\text{opt}}\}$
{Calculate the sector connection and sector component state space}
for all $z \in \mathcal{Z}$ do
    $p(\Omega_z), \beta_{z,s}(\Omega_z) \leftarrow$ CalcConnectionStateSpace($z, \mathcal{S}, \mathcal{A}_z$)
    $p_{\mathcal{X}_z}(\mathcal{X}_z), \beta_{z,s}^{\mathcal{X}_z}(\mathcal{X}_z) \leftarrow$ CalcSectorComponentStateSpace($p(\Omega_z), \beta_{z,s}^{\Omega_z}(\Omega_z)$)
end for
{Calculate the common component state space}
$p_{\mathcal{X}}(\mathcal{X}) \leftarrow \bigotimes_{z \in \mathcal{Z}} p(\mathcal{X}_z)$
$\beta_{z,s}^{\mathcal{X}}(m,c) \leftarrow \left(\bigotimes_{z' \neq z} p_{\mathcal{X}'_z}(m_{z'}, c_{z'})\right) \otimes \left(p_{\mathcal{X}_z}(m_z, c_z)\beta_{z,s}^{\mathcal{X}_z}(m_z, c_z)\right)$
{Find the minimal hardware configuration and define the solution space}
$(m,c)_{\min} \leftarrow \min\{(m,c)|\, B_{\text{modem}}^{\text{hard}}(m) \le \min(P^{\text{target}}) \wedge B_{\text{CE}}^{\text{hard}}(c) < \min(P^{\text{target}})\}$
$\{(M,C)_{\text{cand}}\} \leftarrow (M_{\min}, \ldots, M) \times (C_{\min}, \ldots, C)$
{Calculate total blocking probabilities for all candidates in the solution space}
for all $(M,C)_{\text{cand}} \in \{(M,C)_{\text{cand}}\}$ do
    $B_{z,s}((M,C)_{\text{cand}}), B_{z,s}^{\text{soft}}((M,C)_{\text{cand}}) \leftarrow$CalcBlockProb($p_{\mathcal{X}}((m,c)_{\text{cand}}), \beta_{z,s}^{\mathcal{X}}((m,c)_{\text{cand}})$)
end for
{Find the cost-optimal hardware configuration}
$\{(M,C)_{\text{opt}}\} = \min\{(m,c)_{\text{cand}}|\, f_{\text{cost}}((m,c)) = \min\{f_{\text{cost}}(\mathcal{Y})\} \wedge \forall z,s : P_{z,s}^{B}(\mathcal{Y}) \le P^{\text{target}},\}$
```

4 Model of the WCDMA Air Interface

From a planning perspective, the uplink and the downlink of the WCDMA air interface are distinguished by their limiting factors. For the uplink, the limiting factor is the interference due to the pseudo-orthogonal scrambling codes. In the downlink, the orthogonal variable spreading factor (OVSF) codes lead to a more efficient use of the interference resource, so often the maximum transmit power of the NodeB (typically 10W or 20W) is the limiting factor. The starting point for the up- and downlink models are in both cases the power control equations (16) and (17), expressing the necessicity to meet the specific E_b/N_0-requirements of the RABs:

$$\hat{\varepsilon}_{k,\text{ul}}^{*} = \frac{W}{R} \frac{\hat{S}_k}{W\hat{N}_0 + \hat{I}_z - \hat{S}_k} \tag{16}$$

and for the downlink:

$$\varepsilon_{k,\text{dl}}^{*} = \frac{W}{R} \frac{\hat{T}_{x,k}\hat{d}_{x,k}}{W\hat{N}_0 + \sum\limits_{z' \in \mathcal{Z}'} \hat{T}_{z',k}\hat{d}_{z',k} + \alpha \hat{d}_{x,k}(\hat{T}_{\text{tot}} - \hat{T}_{x,k})}. \tag{17}$$

In these equations, W is the system chiprate (3.84Mcps), R_k is the bitrate of the RAB, S_k is the received signal power of the MS k at the NodeB, $\hat{N}_0$ is the thermal noise spectral density, $\hat{I}_z$ is the total received interference, $T_{x,k}$ is the transmit power at NodeB x for MS k, $d_{x,k}$ is the corresponding attenuation, $\hat{T}_{\text{tot}}$ is the total transmit power of the NodeB and α is the downlink orthogonality factor.

The fast power control in UMTS is responsible for keeping the received power at the required level. Although this works well for slow fading, fast fading leads to deviations of the received E_b/N_0-values from the target-E_b/N_0, introducing the *power control error*. This error is modelled by assuming the received E_b/N_0-value as normal distributed r.v.

in the dB-domain, with the target-E_b/N_0 as mean value, cf. [4]. From the power control equations we derive a service specific load factor ω_s which is similar as in [1]. The load factor ω_s describes the load a single connection adds to the system given an interference based load function:

In order to model soft blocking and soft capacity, we have to model the call admission control (CAC) mechanisms used in the system. Our model relies on the approach introduced in [2], where for the uplink an interference based CAC and for the downlink a transmit power based CAC is proposed. Then, the calculation of the soft blocking probabilities requires to formulate a load function $\Theta(\bar{n})$ for both directions. The load function depends on the number of connections $\bar{n} = (n_1, \ldots, n_{|\mathcal{S}|})$ differentiated by the utilized service. Blocking occurs if either on the uplink or downlink the call admission control rejects an incoming call, i.e. if either $\Theta_{\text{ul}}(\bar{n}) \geq \Theta^*_{\text{ul}}$ or $\Theta_{\text{dl}}(\bar{n}) \geq \Theta^*_{\text{dl}}$, with Θ^* as blocking threshold.

In both cases, it is required to know either the received powers of the mobiles or the transmit powers for the mobiles at the considered NodeB. We distinguish between the signal source and say power coming from or designated for mobiles in our own cell is the *own-cell interference* $\hat{I}_{\text{own}}$, while power coming from surrounding mobiles or NodeBs is the *other-cell interference* $\hat{I}_{\text{oc}}$. So the interefence can be written as $\hat{I} = \hat{I}_{\text{own}} + \hat{I}_{\text{oc}}$. In a real system both variables depend on each other because of the CDMA scheme, see e.g. [14]. However the exact computation of the interferences, if possible at all, is computational complex. Therefore we use a simplified interference model and take the other-cell interferences as independent lognormal r.v. as in [6] and [15].

4.1 Uplink Load Model

For the calculation of the WCDMA uplink load we rely on the work presented in [1, 6, 16], where the sector interference is calculated. The uplink interference can be calculated from the number of connected mobiles by solving the power control equation for the received powers and building the sum. Together with the other-cell interference, it is formulated as

$$\hat{I}_{z,\text{ul}}(\bar{n}) = \frac{\eta_z(\bar{n})}{1 - \eta_z(\bar{n})} \left(W\hat{N}_0 + \hat{I}_{\text{oc}} \right) + \hat{I}_{\text{oc}}, \tag{18}$$

where $\eta_z(\bar{n})$ is the own cell load and is the sum of all load factors of all mobiles in the considered sector z. The own cell load also considers the activity of the connections with the activity factor ν_s. Note that we assume that connections of the same service class also have the same activity:

$$\eta_z(\bar{n}) = \sum_{s \in \mathcal{S}} \nu_s n_s, \quad \eta_z(\bar{n}) < 1 \tag{19}$$

The load function itself is based on the *noise rise*, which measures the sector interference and is formulated as

$$\frac{\hat{I}_{\text{ul}}(\bar{n})}{\hat{I}_{\text{ul}}(\bar{n}) + W\hat{N}_0} < \Theta^*_{\text{ul}} \quad \Leftrightarrow \quad \eta_z(\bar{n}) + \omega_s + \Gamma < \Theta^*_{\text{ul}}, \quad \Gamma = \hat{I}_{\text{oc}} \frac{1 - \Theta^*_{\text{ul}}}{\hat{N}_0} \tag{20}$$

See [2] for a more detailed explanation of the noise rise. The inequation reflects the CAC on the uplink – a new connection is admitted, if the load, consisting of the own-cell load, the load of the additional connection, and the other-cell load Γ is below the admission threshold. (Rechtfertigung dass lognormal) So, the probability that an incoming connection with service class s is blocked can be formulated as

$$\beta_{s,\text{ul}}(\bar{n}) = P\left(\eta_z(\bar{n}) + \omega_s + \Gamma < \Theta^*_{\text{ul}}\right) \qquad \Rightarrow \qquad \beta_{s,\text{ul}}(\bar{n}) = 1 - \text{LN}_{\mu^{\text{ul}}_{z,s}, \sigma^{\text{ul}}_{z,s}}(\Theta^*_{\text{ul}}), \tag{21}$$

where LN is the lognormal CDF with location and shape parameters $\mu_{z,s}$ and $\sigma_{z,s}$. The parameters are calculated from the first two moments of the own-cell load, the service load factor and the other-cell interference.

4.2 Downlink Load Model

On the downlink, the position of the mobile in the sector plays an important role. Mobiles more distant to the NodeB need more power and contribute more to the sector load than near mobiles.

On the downlink, the CAC and also the load function are transmit power based. The transmit power $\hat{I}_z$ comprises the transmit power for the dedicated channels of the mobiles, $\hat{T}_{x,k}$, and a constant power part for the pilot and shared channels, $\hat{I}_c$:

$$\hat{I}_z = \sum_{k\in\mathcal{K}} \hat{T}_{x,k} + \hat{I}_c \quad \Leftrightarrow \quad \hat{I}_z = \sum_{k\in\mathcal{K}} \omega_k \left(W\hat{N}_0 \tfrac{1}{\hat{d}_{x,k}} + \sum_{y\in\mathcal{Y}} \hat{I}_y \tfrac{\hat{d}_{y,k}}{\hat{d}_{x,k}} + \alpha_{\mathrm{dl}} \hat{I}_z \right) + \hat{I}_c, \tag{22}$$

where $\hat{d}_{x,k}$ is the attenuation factor between NodeB x and MS k. The CAC condition can now be formulated as

$$\hat{I}_z < \hat{I}_{\max} \quad \Leftrightarrow \quad \sum_{s\in\mathcal{S}_z} \nu_{s,\mathrm{dl}} n_s \omega_{s,\mathrm{dl}} Q < \Theta^*_{\mathrm{dl}} \tag{23}$$

where $\Theta^*_{\mathrm{dl}} = \hat{I}_{\max} - \hat{I}_c$. The r.v. Q describes the influence of the position and the other-cell interference on the cell load and is defined as

$$Q = W\hat{N}_0 \tfrac{1}{\hat{d}_x} + \sum_{y\in\mathcal{Y}} \hat{I}_y \tfrac{\hat{d}_y}{\hat{d}_x} + \alpha \hat{I}_{\max}. \tag{24}$$

Note that we assume that the attenuation factors $\hat{d}_x$ and $\hat{d}_y$ are i.i.d. for all MS k. As in the uplink model, the RAB load factor ω_s is approximated with a lognormal distributed r.v. due to imperfect power control. We assume that the left hand side of (23), the "load", is also lognormal distributed and calculate analogously to the uplink case the blocking probability for the service class s:

$$\beta_{s,\mathrm{dl}}(\bar{n}) = 1 - P\left(\sum_{s\in\mathcal{S}_z} \nu_{s,\mathrm{dl}} n_s \omega_{s,\mathrm{dl}} Q < \Theta^*_{\mathrm{dl}} \right) \quad \Rightarrow \quad \beta_{s,\mathrm{dl}}(\bar{n}) = 1 - \mathrm{LN}_{\mu^{\mathrm{dl}}_{z,s}, \sigma^{\mathrm{dl}}_{z,s}}(\Theta^*_{\mathrm{dl}}) \tag{25}$$

A more detailed description of the model can be found in [15].

5 Numerical Results

In this section we validate the dimensioning algorithm and show that it is superior to a simple hardware dimensioning that ignores soft blocking. We do this by defining a reference scenario and service mix. 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 is given in Table 1 and the other system parameters are given in Table 2. The system load is scaled by the total offered traffic a_z per sector z such that the offered traffic of service s in sector z is $a_{z,s} = p_s \cdot a_z$ and the probability $p(s)$ of a service s is defined by the service mix.

Table 1: Service Mix

service	prob.	req.	Uplink RAB			Downlink RAB		
	$p(s)$	CEs	bit rate	E_b/N_0	activity	bit rate	E_b/N_0	activity
Voice	0.2	2	12.2kbps	5.5dB	0.5	12.2kbps	5.5dB	0.5
Web	0.4	13	64kbps	4dB	0.1	144kbps	3dB	0.5
Streaming (Down)	0.2	25	12.2kbps	5.5dB	0.5	384kbps	2dB	1.0
Streaming (UP)	0.2	10	144kbps	3dB	1.0	12.2kbps	5.5dB	1.0

Table 2: Parameter of the reference scenario

orthogonality factor	α =0.2	power of other sectors	
chipping rate	W=3.84Mcps	mean	$E[\hat{T}_z]$ =4575mW
thermal noise spectral density	N_0=-174dBm/Hz	standard deviation	$Std[\hat{T}_z]$ =515mW
uplink load threshold	Θ^*_{ul}= 0.5	othercell load	
downlink power threshold	$\hat{T}_{max}$=6000mW	mean	$E[\eta_{oc}]$ =0.1
constant downlink power	$\hat{T}_{const}$=2000mW	standard deviation	$Std[\eta_{oc}]$ =0.02

At a first step we validate the accuracy of step one of our algorithm, the computation of the soft blocking probabilities for a sector without hardware limitations. Therefore, we use an event-driven simulation for the traffic process. 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. In later simulations, that consider a limited number of hardware components, a user can of course also be blocked if no free modems or channel elements are available.

Figure 7 shows the soft blocking probabilities obtained by simulation and by analysis. The solid lines represent the analysis and the dashed lines the simulation. 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.

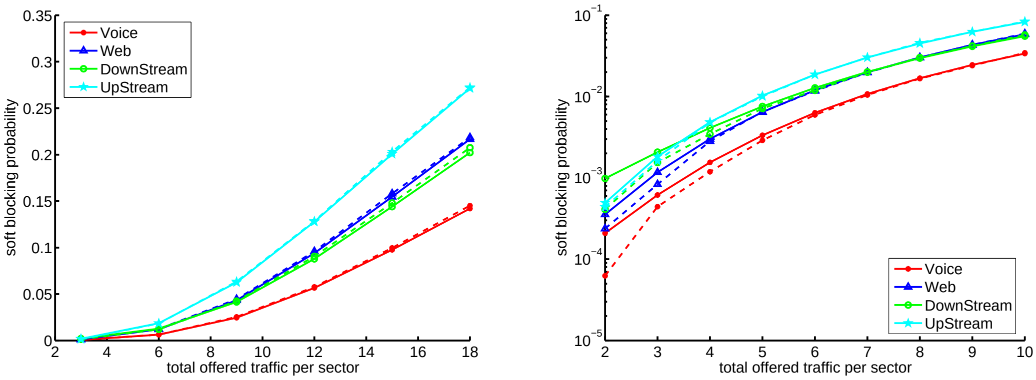

Figure 7: Validation of soft blocking probabilities for a single sector

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 indicate 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. We set the cost of a channel element to one and the cost of a pair of modems, one for the uplink and one for the downlink, to five. The blocking targets for the four services are 2% for voice, 5% for web, and 10% for the two steaming services. The threshold for adapting the target blocking probability to the inevitable soft blocking probability is Θ^{soft}=1.1. 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 modems and channel elements. 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 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.

After studying the impact of the load for equally loaded sectors, we are now interested in what happens if we consider sectors with different loads. Therefore, we keep the total load of all sectors together at 27 users what corresponds to the nine users per sectors in the equally loaded case, and distribute the total offered load unevenly between the three sectors. The results are shown in Figure 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. Actually, the voice service is here the service that is crucial for the hardware requirements.

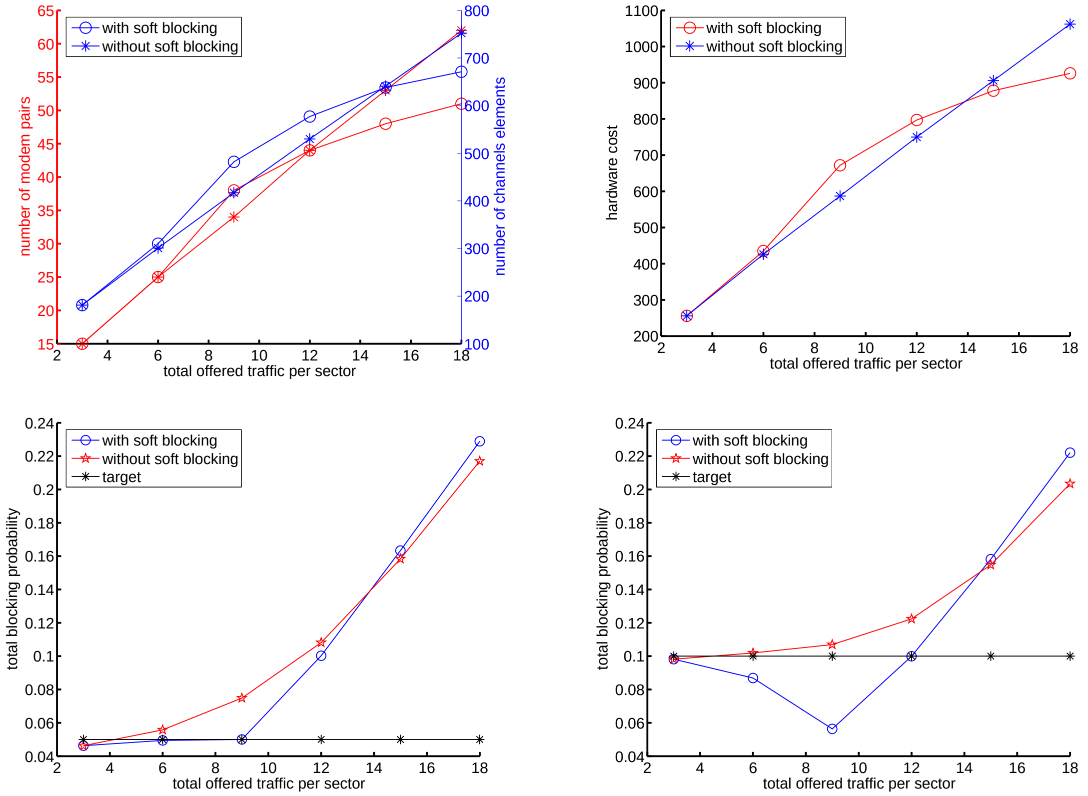

Figure 8: Impact of the offered traffic on the required hardware with fixed target blocking probabilities

6 Conclusion and Outlook

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 and an arbitrary number of sectors and their up- and downlink soft capacity. The state and blocking probabilities of the sectors are calculated and then under the assumption of independency 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, if existing, for which the target blocking probabilities of the service classes are met.

In the process of generating the numerical results, we could verify that the algorithm is suitable fast for planning purposes and delivers results of satisfying accuracy. It is therefore a good candidate for the use in mobile network planning tools. The results show that the influence of the soft capacity on the dimensioning should not be neglected.

For further research, the influence of inter-sector interference as well as softer handover could be included explicitly in the calculation of the soft capacities of the sectors. Also, new emerging technologies like HSDPA and the enhanced uplink DCH surely have an impact to the hardware requirements at the NodeBs.

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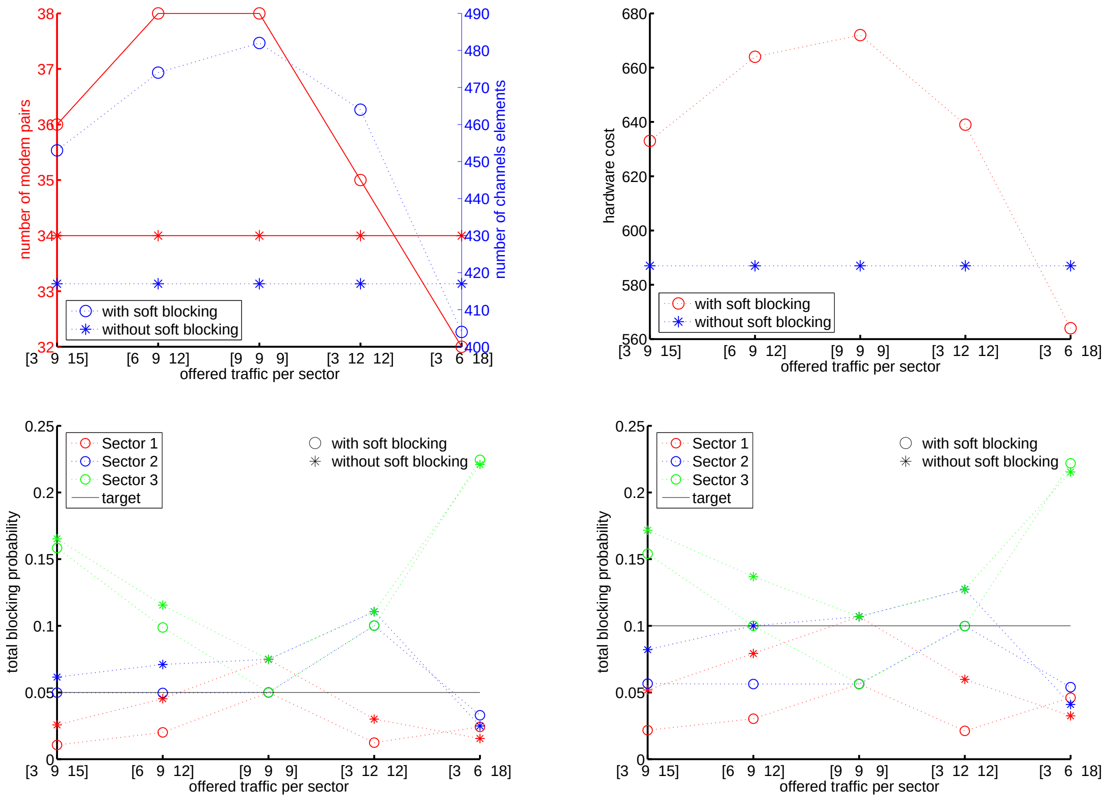

Figure 9: Impact of the traffic balance between the sectors with constant total traffic

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