MODELING AND DIMENSIONING OF THE IUB INTERFACE IN THE UMTS NETWORK

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ABSTRACT
The article presents a new analytical method for blocking probability determination in the interface of the UMTS network. In our consideration we use a modified model of full-availability group with multi-rate traffic. The proposed scheme is applicable for cost-effective IuB resource management in 3G mobile networks and can be easily applied to network capacity calculations.

Keywords: modeling, dimensioning, UMTS, IuB interface

1 INTRODUCTION

Universal Mobile Telecommunications System (UMTS) using the WCDMA radio interface is one of the standards proposed for third generation cellular technologies (3G). According to the 3rd Generation Partnership Project (3GPP) recommendations, 3G systems should include services with circuit switching and packet switching, transmit data at a speed of up to 7,2 Mbit/s, and ensure access to multimedia services [1].

The dimensioning process for the UMTS system should make it possible to determine such a capacity of individual elements of the system that will secure - with the assumed load of the system - a pre-defined level of Grade of Service (GoS).

With dimensioning the UMTS system, the most characteristic constraints are: radio interface and the IuB interface. When the radio interface is a constraint, then, in order to increase the capacity, access technology should be changed or subsequent branches of the system should be added (another NodeB). If, however, the constraint on the capacity of the system results from the capacity of the IuB interface, then a decision to add other stations (nodes) can be financially unfounded, having its roots in incomplete or incorrect analysis of the system. This means that in any analysis of the system, a model that corresponds to the IuB interface should be routinely included.

Because of the possibility of resource allocation for different traffic classes, the capacity determination of the WCDMA radio interface is much more complex than in the case of GSM systems. The capacity of the WCDMA interface is limited by the increase in interference, which is caused by the users serviced by other cells of the system who make use of the same frequency channel as well as by the users making use of the adjacent radio channels and by the multipath propagation occurring in the radio channel. To ensure an appropriate level of service in UMTS it is thus necessary to limit interference by decreasing the number of active users or the allocated resources employed to service them.

Several papers have been devoted to traffic modelling in cellular systems with the WCDMA radio interface [2-14,21]. To date, however, no IuB models that take the dynamic resource allocation for different services into account have been considered by any author simultaneously.[1] This article presents a blocking probability determination method for a cellular system with the IuB interface and a dynamic resource allocation scheme.

The article has been divided into five sections. Section 2 discusses basic dependencies describing the IuB interface in the UMTS network. Section 3 presents an analytical model applied for a blocking probability determination for static and dynamic resource allocation for different traffic classes. The following section includes the results obtained in the study of the system. The final section sums up the discussion.

2 ARCHITECTURE OF THE UMTS NETWORK

Let us consider the structure of the UMTS network presented in Fig. 1. The presented network consists of three functional blocks designated respectively: UE (User Equipment), UTRAN (UMTS Terrestrial Radio Access Network) and CN (Core Network). The following notation has been adopted in Fig. 1: RNC is the Radio Network Controller, Uu is the radio interface and IuB is the interface connecting Node B and RNC.

[1] This article is the extended version of the paper published on CSNDSP 2008 [20].

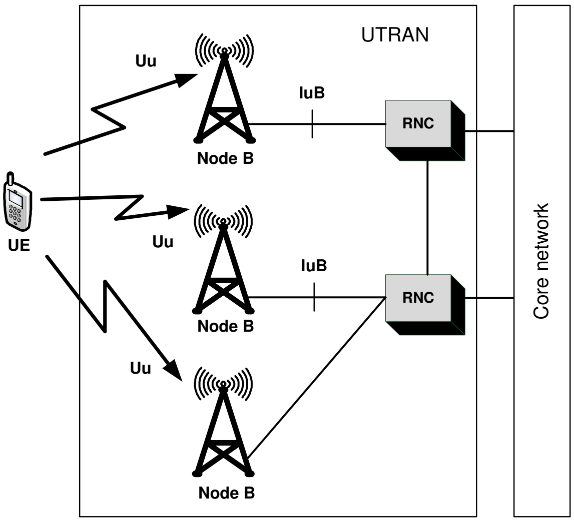

Figure 1: Elements of the UMTS network structure

In the designing process for the UMTS network, an appropriate dimensioning of the connections in the access part (UTRAN) has a particular significance, i.e. the radio interface between the user and NodeB and the IuB connections between NodeB and RNC. The issues pertaining to radio interface dimensioning are widely discussed in the subject literature, for example in earlier works of the authors [5-8,12-14,21], whereas those dealing with dimensioning of the IuB interface have not been raised so far.

Figure 2 shows two ways of the organization of the IuB interface. It is assumed that separate dedicated groups are designed to service R99 traffic (Release 99) [15] and HSDPA (High-Speed Downlink Packet Access) [16] (Fig. 2a), or that the capacity of the IuB interface makes just one group and the resources that are unused by R99 traffic are assigned for HSDPA traffic transmission (Fig. 2b). The figure also shows exemplary classes of services that are part of traffic designated either as HSDPA or R99.

Preselected parameters of the services carried by the IuB interface are presented in Table 1, where R_{DL} is the peak rate for particular services and *DL overhead* is additional packet size coming from the encapsulation in ATM (Asynchronous Transfer Mode) layer.

Table 1: Exemplary services with constraints in ATM layer.

ATM layer (PS-non real time)	R_{DL}	***DL overhead***
voice	12.2	40%
data 64/64	64	25%
data128/64	64	30%
HSDPA	various	30%

	(max. 7.2 Mbps)	

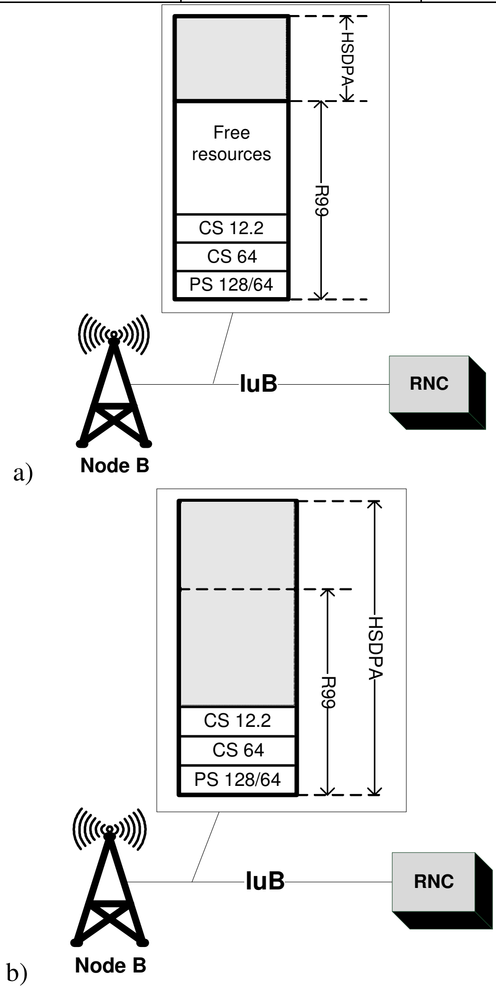

Figure 2: Elements of the UMTS network structure network: a) division of the interface into two dedicated groups b) interface divides R99 and HSDPA resources dynamically

3 MODEL OF THE SYSTEM

The IuB interface in the UMTS network can be treated as a full-availability group (FAG) with multi-rate traffic. Let us assume that the total capacity of the group is equal to V Basic Bandwidth Units (BBUs). The group is offered M independent classes of Poisson traffic streams having the intensities: λ_1, λ_2, ..., λ_M. The class i call requires t_i BBUs to set up a connection. The holding time for calls of particular classes has an exponential distribution with the parameters: μ_1, μ_2,..., μ_M. Thus, the mean traffic offered to the system by the class i traffic stream is equal to:

$$A_i = \lambda_i / \mu_i \qquad (1)$$

The demanded resources in the group for servicing particular classes can be treated as a call demanding an integer number of BBUs [17]. The value of BBU, i.e. t_{BBU}, is calculated as the greatest common divisor of all resources demanded by the traffic classes offered to the system:

$$t_{BBU} = \mathrm{GCD}(R_1,...,R_M)\,, \qquad (2)$$

where R_i is the amount of resources demanded by class i call in *kbps*.
The multi-dimensional Markov process in the FAG can be approximated by the one-dimensional Markov chain which can be described by Kaufman-Roberts recursion [18,19]:

$$n[P_n]_V = \sum_{i=1}^{M} A_i t_i [P_{n-t_i}]_V \,, \qquad (3)$$

where $[P_n]_{\mathrm{V}}$ is the probability of state n BBUs being busy, and t_i is the number of BBUs required by a class i call:

$$t_i = \left\lfloor \frac{R_i}{t_{BBU}} \right\rfloor, \qquad (4)$$

On the basis of formula (3), the blocking probability E_i for class i stream can be expressed as follows:

$$E_i = \sum_{n=V-t_i+1}^{V} [P_n]_V \,, \qquad (5)$$

where V is the total capacity of the group and is expressed in BBUs ($V=\lfloor V_{\mathrm{IuB}}/t_{\mathrm{BBU}}\rfloor$, where $\mathrm{V}_{\mathrm{IuB}}$ is the physical capacity of group in kbps). The diagram in Fig. 3 corresponds to Eq. (3) for the system with two call streams (M=2, t_1=1, t_2=2). The $y_i^{\mathrm{I}}(n)$ symbol denotes reverse transition rates of a class i service stream outgoing from state n. Based upon [18,19], we obtain:

$$y_i^{\mathrm{I}}(n) = \begin{cases} A_i[P_{n-t_i}]_V / [P_n]_V & \text{for} \quad n \le V, \\ 0 & \text{for} \quad n > V. \end{cases} \qquad (6)$$

The value of $y_i^{\mathrm{I}}(n)$ parameter, in a given state of the system, forms the basis for the method of the occupancy distribution calculation in the group presented in Fig. 3.
Let us consider now two organization schemes of the IuB interface presented in Fig. 2. Figure 2a shows the organization of the IuB interface according to which it is divided into two dedicated groups servicing independently R99 and HSDPA traffic. The analysis of such a system corresponds to the independent analysis of two FAGs servicing multi-rate traffic. In either case it is possible then to determine, after determining the occupancy distribution $[P_n]_{\mathrm{V}}$, the blocking probability E_{i} for class i stream on the basis of Eq. (5).
Figure 2b shows a more complex case in which HSDPA traffic can use resources dedicated to R99 traffic. This occurs when R99 traffic does not entirely make use of the allocated resources and occupies at least G BBUs, where $G < V$. Such a case can be interpreted as a dynamic limitation of resources for R99 traffic classes that is accompanied by unlimited HSDPA traffic.

In order to determine the occupancy state of the group in which there is a dynamic limitation of resources, we introduce the function $G(n)$, defined as follows:

$$G(n) = \begin{cases} \sum_{i=1}^{M} y_i^{\mathrm{I}}(n) t_i & \text{for} \quad i \in S, \\ 0 & \text{for} \quad i \notin S, \end{cases} \qquad (7)$$

where S is a set of constrained traffic classes (for example, R99 traffic classes).

The function $G(n)$ determines the average number of BBUs occupied by calls of selected (constrained) classes, in the state n. The problem is to find such a state n in which the number of BBUs occupied by calls of constrained classes meets the condition:

$$G(n) = G\,. \qquad (8)$$

Let us denote such a found state n as N. The state N determines a possibility of limiting access to the resources of the system for traffic classes that belong to the set S. We assume that in all states older than n only those classes which have no constraint are serviced (Fig. 4).
Let us modify the occupancy distribution of FAG in accordance with the considered organization of the IuB interface.

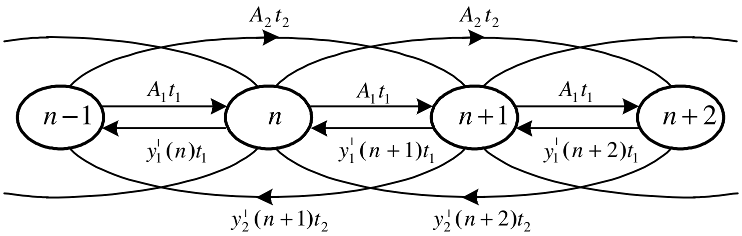

Figure 3: Fragment of a diagram of the one-dimensional Markov chain in a multi-rate system (M=2, t_1=1, t_2=2)

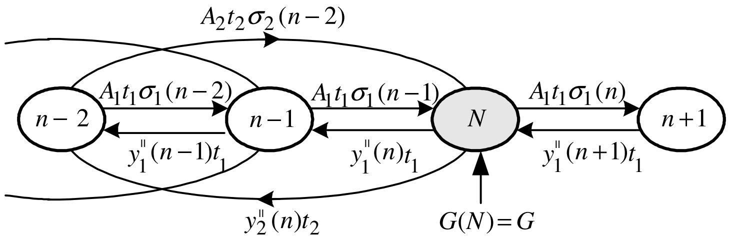

Figure 4: Fragment of a diagram of the modified one-dimensional Markov chain in a multi-rate system (M=2, t_1=1, t_2=2, $G(n)$=G, S={2})

The modification of the serviced process shown in Fig. 4 results in a transformation in the occupancy distribution (Eq. (3)) into the generalized Kaufman-Roberts distribution:

$$n[P_n]_V = \sum_{i=1}^{M} A_i t_i \sigma_i(n-t_i)[P_{n-t_i}]_V \,, \tag{9}$$

where $\sigma_i(n)$ is the conditional state-passage-probability between adjacent states of the process. In the considered system shown in Fig. 4, the parameter $\sigma_i(n)$ can be determined in the following way:

$$\sigma_i(n) = \begin{cases} 1 & \text{for} \quad i \in S \quad n \le N - t_i, \\ 0 & \text{for} \quad i \in S \quad n > N - t_i, \\ 1 & \text{for} \quad i \notin S \quad n \le V, \end{cases} \tag{10}$$

where S is a set of constrained traffic classes.

The parameter $\sigma_i(n)$ has to be also considered in the reverse transition rates of a class i service stream outgoing from state n (Fig 4):

$$y_i^{II}(n) = \begin{cases} A_i \sigma_i(n-t_i)[P_{n-t_i}]_V / [P_n]_V & \text{for} \quad n \le V, \\ 0 & \text{for} \quad n > V. \end{cases} \tag{11}$$

The value of $y_i^{II}(n)$ parameter, in a given state of the group, forms the basis of the method of the occupancy distribution calculation in the group presented in Fig. 4.

The function $G(n)$ for the modified one-dimensional Markov chain can be determined as follows:

$$G(n) = \begin{cases} \sum_{i=1}^{M} y_i^{II}(n) t_i & \text{for} \quad i \in S, \\ 0 & \text{for} \quad i \notin S. \end{cases} \tag{12}$$

In the determination of the blocking probability of calls of individual traffic classes serviced in the system shown in Fig. 4, one has to take into consideration the differences in the availability of the group for different traffic classes. Therefore, we get:

$$E_i = \begin{cases} \sum_{n=N-t_i+1}^{V} [P_n]_V & \text{for} \quad i \in S, \\ \sum_{n=V-t_i+1}^{V} [P_n]_V & \text{for} \quad i \notin S. \end{cases} \tag{13}$$

On the basis of the above considerations, the algorithm of blocking probability calculations in IuB may be written as follows:

1. Calculation of offered traffic load A_i of class i (Eq. (1)).
2. Determination of the value of t_{BBU} as the greatest common divisor (Eq. (2))
3. Designation of the value of t_i as the integer number of demanded resources by class i calls (Eq. (4))
4. Calculation of state probabilities $[P_n]_V$ in FAG (Eq. (3)).
5. Determination of reverse transition rates $y_i^{I}(n)$ in the FAG (Eq. (6)).
6. Designation of the function $G(n)$ for $y_i^{I}(n)$ in FAG (Eq. (7)).
7. Determination of state N in FAG, in which condition (8) is fulfilled.
8. Calculation of the occupancy distribution $[P_n]_V$ in the modified Markov chain (Eqs. (9) and (10)).
9. Determination of reverse transition rates $y_i^{II}(n)$ in the modified distribution (Eq. (11)).
10. Designation of the function $G(N)$ for $y_i^{II}(n)$ in the modified distribution (Eq. (12)).
11. Checking condition (8) for state N in the modified distribution
12. If the condition (8) is not fulfilled, then we check the value of N and if $N \in [1;V-1]$, we adopt N ($N=N\pm1$) and proceed to step 8.
13. If the condition (8) is fulfilled, then we determine the values of blocking probabilities for all traffic classes in the modified distribution (Eq. (13)).

4 NUMERICAL EXAMPLES

The proposed analytical model of the IuB interface is an approximate one. Thus, the results of the analytical calculations of the IuB were compared with the results of the simulation experiments. In the study we compare the results obtained for both organization schemes of the IuB interface.

The study was carried out for users demanding a set of services with encapsulation in ATM layer in the downlink direction (Tab. 1):

- t_1 = 12.2 x 1.4 ≃ 18 kbps = 18 BBUs,
- t_2 = 64 x 1.25 ≃ 80 kbps = 80 BBUs,
- t_3 = 64 x 1.3 ≃ 84 kbps = 84 BBUs,
- t_4 = 384 x 1.3 ≃ 500 kbps = 500 BBUs (HSDPA).

We assume that the amount of resources demanded for HSDPA traffic (class 4) in the IuB interface is

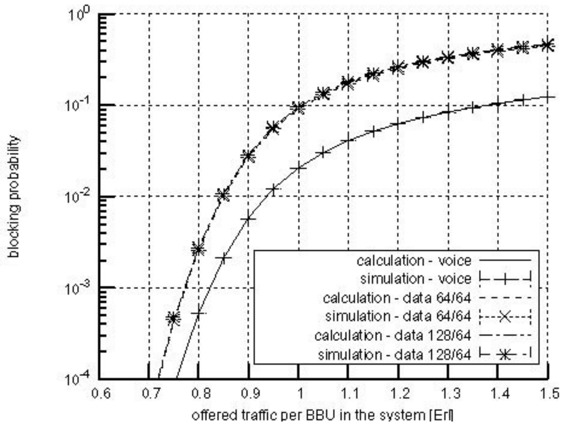

Figure 5: Blocking probability for R99 traffic classes presented in Tab. 1 (classes 1-3, V=8,000 BBUs)

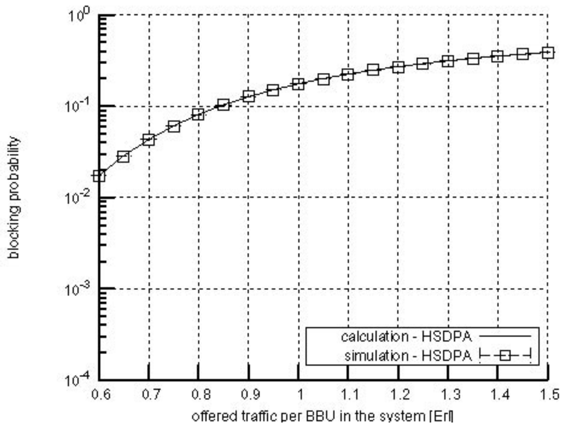

Figure 6: Blocking probability for HSDPA traffic class presented in Tab. 1 (t_4=500 BBUs, V=5,360 BBUs)

equal to 500 BBUs. This value is assumed by mobile network operator and determines the amount of resources which can be assigned to HSDPA user with predefined probability.

In the first step of our evaluation we discuss the influence of the organization schemes on the blocking probabilities for the R99 and HSDPA traffic classes.

Additionally, it was assumed that:

- t_{BBU} is equal to 1 kbps,
- a physical capacity of IuB in the downlink direction is equal to V_{IuB}= 13,36 Mbps (13,360 BBUs),
- the services were demanded in the following proportions: $A_1t_1 : A_2t_2 : A_3t_3 : A_4t_4$=1:1:1:2.

In the first scenario (Fig. 2a) we assume that dedicated links carried R99 and HSDPA traffic. Figures 5 and 6 present blocking probabilities for the IuB interface that consists of two separated links: the first link carries only R99 traffic classes and has the capacity equal to 8,000 BBUs, whereas the second link carries only HSDPA traffic and has the capacity equal to 5,360 BBUs.

In the second scenario (Fig. 2b) we assumed that all traffic classes were serviced with common resources.

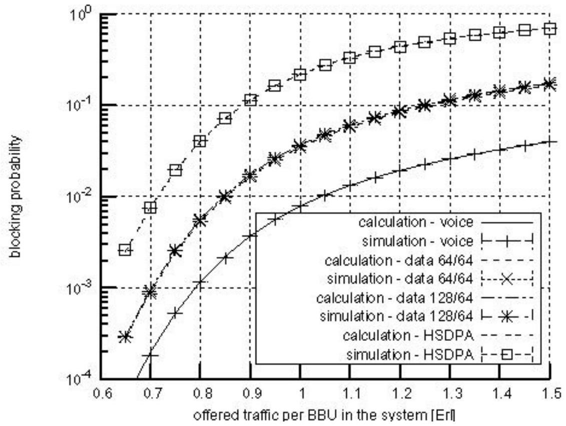

Figure 7: Blocking probability for all traffic classes presented in Tab. 1 (G= V_{IuB} =13,360 BBUs)

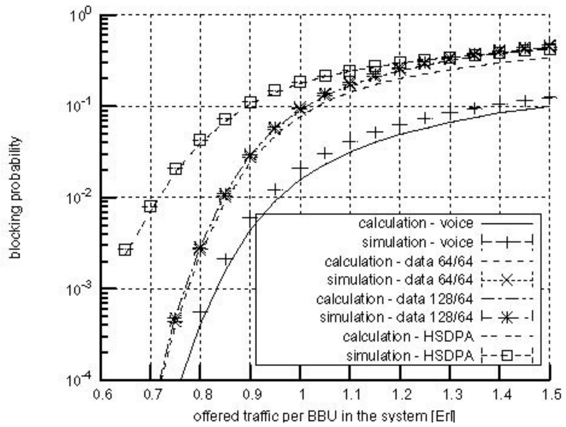

Figure 8: Blocking probability for all traffic classes presented in Tab. 1 (G=8,000 BBUs and V_{IuB}=13,360 BBUs)

In this case, access to the resources was limited for R99 traffic classes whereas for HSDPA classes was unconstrained. Additionally, it was assumed in this model that the limitation G for release R99 was equal to 8 Mbps (8,000 BBUs). Figures 7 and 8 show the results obtained for the traffic classes presented in Tab 1.

Figure 7 shows the blocking probabilities for the IuB interface with unconstrained access to resources. The blocking probabilities for the IuB interface with constrained access to resources for R99 traffic classes to 8,000 BBUs and unconstrained access to resources for HSDPA traffic class are shown in Fig. 8. Comparing the results presented in Figs. 7 and 8 we can note that the limitation of access to resources causes an increase in the value of blocking probability of the constrained traffic classes.

Comparing the results presented in Figs. 5-8 for both IuB organization schemes we may observe that the lowest values of blocking probabilities for R99 traffic classes can be obtained in the case of the link which services HSDPA and R99 traffic classes on common resources (Fig. 7). The lowest value of the blocking probability for HSDPA traffic class was obtained for the second organization scheme of IuB when HSDPA traffic had a guaranteed capacity (similarly to the results presented in Fig. 6) and in some cases (not fully used resources by R99 classes) can also use resources dedicated for R99 traffic classes and this assumption allows to obtain the lowest value of HSDPA traffic in this case (Fig. 8). In mobile networks the importance and also the volume of HSDPA traffic increases, therefore we can expect that the second organization scheme will be treated more effectively.

The results of the simulations in Figs. 5 – 8 are shown in the charts in the form of marks with 95% confidence intervals calculated after the *t*-Student distribution. 95% confidence intervals of the simulation are almost included within the marks plotted in the figures.

Table 2: Exemplary traffic patterns.

No	A_1	A_2	A_3	A_4
1	501	33	3	2.4
2	627	42	4	3.0
3	877	58	5	4.2
4	1002	67	6	4.8

In the second step we evaluate the influence of the organization scheme on the capacity of the IuB interface. The research work was conducted for many values of blocking probabilities and for many different traffic patterns. In the presented results we assume the following values of the blocking probability: E_1=2%, E_2=5%, E_3=5% and E_4=5%. In the discussed research we analyze four exemplary traffic patterns (Tab. 2). The parameters in Tab. 2 were calculated under the assumption that the services were demanded in the following proportions: $A_1t_1 : A_2t_2 : A_3t_3 : A_4t_4$=38:1:1:5. The parameter A_i is determined in the following way:

$$A_i = p_i \frac{aV}{t_i}, \quad (14)$$

where p_i is the participation of class i in the total traffic offered to the IuB interface, V=13360 BBUs and a is the traffic load per BBU in the system. The traffic patterns presented in Tab. 2 correspond to the following set of values of a: {0,8;1,0;1,4;1,6}.

We also assume that the limitation in access to the resources for the R99 traffic classes (G) is equal to 60% of the interface capacity.

Figure 9 presents the comparison of the IuB capacity obtained for the assumed values of blocking probabilities for different traffic classes for the first organization scheme of the IuB, in which R99 and HSDPA traffic classes are carried by independent links. All the presented results that are the sum of the both obtained capacities of the link were obtained for the first organization scheme of the IuB. It was noticed that dividing traffic between the two links implies a necessity of ensuring a greater total capacity of the link as compared to a single link carrying a common mixture mixture of R99 and

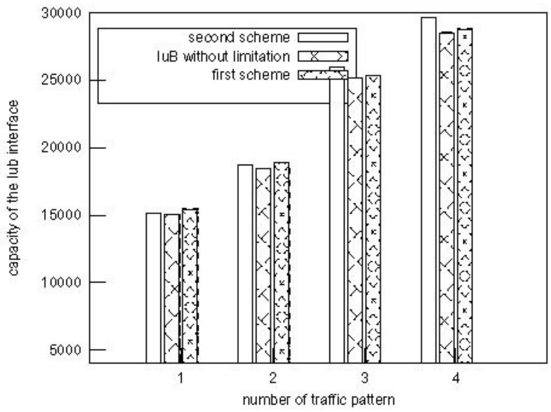

Figure 9: Capacity of the IuB interface in relation to traffic patterns presented in Tab. 2 (scheme 1 and 2)

HSDPA traffic. This dependence is not dependent on the traffic offered to the system.

Figure 9 also presents the capacities of the IuB interface obtained for the assumed values of blocking probabilities for different traffic classes for the second organization scheme in which access to the resources is limited for R99 traffic classes. The introduction of the limitation in access to resources of the IuB interface is followed by the necessity of an increase in the IuB capacity. This relation is dependent on the load of the system: for traffic patterns No 1 and 2 the required capacity of the IuB is lower for scheme 2, but for traffic patterns 3 and 4 the require capacity of the IuB is lower for scheme 1.

Table 3: Influence of the limitation in access to resources on the capacity of IuB for the second traffic pattern (Tab. 2).

G [%]	Capacity of IuB with limitation	Capacity of IuB without limitation
50	23 040	18 442
55	20 946	18 442
57	20 212	18 442
60	19 200	18 442
63	18 442	18 442

Table 3 confirms that efficiency of the second organization scheme of IuB is in relation to the traffic pattern and to the value of limitation. A designation of the appropriate value of G is one of the most important tasks in the dimensioning process – it determines the efficiency of the IuB interface with limitation.

Comparing the results obtained in the second stage of the research, it can be stated that the lowest capacity of the IuB Interface can be obtained for the second organization scheme. In this stage, the simulation results are not included in Fig. 9 for better clarity, but in either case the simulation results confirm the accuracy of the proposed model.

5 CONCLUSION

The dimensioning process for the UMTS system should aim at determining such a capacity of the elements of the system that will allow – with the predefined load of the system – to ensure the assumed level of Grade of Service. In the dimensioning of the UMTS system the most characteristic constraints are: the radio interface and the IuB interface.

The article presents a new calculation method for blocking probability determination for traffic offered in the IuB interface. In our considerations we use a modified model of the full-availability group with multi-rate traffic as a model of the interface.

In the article we also discuss the efficiency of two proposed organization schemes of the IuB interface. The conducted research shows effectiveness of the organization scheme depends on the value of the limitation and on the traffic structure carried by Iub. The research shows that in some cases the first organization scheme, and in other cases the second organization scheme, seem to be more effective. Hence, a decision on the selection of a particular organization scheme results from the adopted techno-economic strategy of operators.

The calculations are validated by a simulation. The proposed method can be easily applied to 3G network capacity calculations.

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