# On Inter-Domain Admission Control Supported by Measurements in Multi-domain IP QoS Network

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## Abstract

*Enabling end-to-end QoS in the multi-domain network requires developing an efficient admission control mechanism. The paper discusses the issues related with inter-domain admission control based on user traffic declarations. The novelty of the proposed approach is that the traffic descriptors are recalculated in each domain taking into account the effect of traffic profile deformation. The proposed recalculation method is supported by measurements of packet delay variation introduced within each domain. The performance of the proposed method is illustrated by numerical results.*

## 1. Introduction

Currently, the lack of end-to-end QoS (Quality of Service) solution in the Internet is the main reason why new attractive applications cannot be deployed. While it can be regarded that there are some successful prototype implementations of single domain IP QoS networks, like in European projects GEANT [1], AQUILA [2], the solution for supporting end-to-end QoS in multi-domain network is still a challenging task. The main problems are related with performing Admission Control (AC), inter-networking between heterogeneous network technologies and developing appropriate signaling.

The paper focuses on issues related with AC in multi-domain network. We assume that each domain offers several network services, dedicated for handling specific type of traffic with adequate QoS objectives. This can be achieved by implementing in each domain a Resource Controller (RC) responsible for admitting flows and performing resource management within the single domain (see e.g. AQUILA approach [2]). The intra-domain AC function admits or rejects new flow requests based on the knowledge of available resources within the domain and flow requirements [3][8][9][10]. The recognized approaches assume calculating the effective bandwidth, which is a measure of the amount of resources needed for handling the flow, taking into account the Traffic Descriptor (TD) declared by a user, usually in form of the parameters of single or double token bucket mechanism.

However, for providing the end-to-end QoS in multi-domain network, effective mechanism for performing Inter-Domain Admission Control (IDAC) is required. Although some literature focused on designing a scalable protocol for end-to-end QoS signaling is known [11], the thorough analysis of QoS control issues in multi-domain environment seem to be missing.

The discussed IDAC approach assumes that the TD of the flow is successively submitted to RCs of the domains on the end-to-end path. The crucial point in performing IDAC is that the traffic submitted by a user may change inside the domain due to multiplexing with other packet streams and as a consequence, the original TD becomes inaccurate. The violation in traffic description can lead to the failures in AC decisions. In order to minimize the risk of improper decision, the IDAC has to evaluate traffic profile deformation and then recalculate the TD before submitting it to the next domain. The method for recalculation of TD based on measurements of packet delay variation is proposed for supporting the considered IDAC approach.

The structure of the paper is following. Section 2 introduces the inter-domain admission control approach and presents the general multi-domain network model. Section 3 discusses the method for TD recalculation. The numerical results illustrating effectiveness of the proposed IDAC method are presented in section 4. Finally, section 5 summarizes the paper.

## 2. Inter-Domain Admission Control

This section discusses the assumed approach for performing IDAC in multi-domain IP QoS network (see Fig.1).

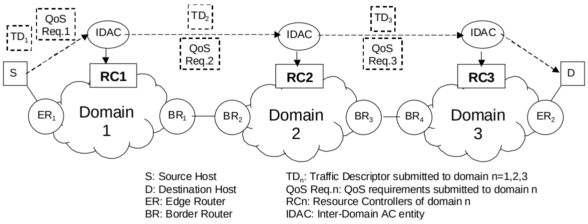

**Figure 1. Inter-domain admission control scenario**

The scenario for establishing the QoS enabled flow is as follows. A user submits the flow setup request, which contains TD and QoS requirements, to its home IDAC entity. The IDAC (see Fig.1) is performed in the additional layer, implemented on top of the RCs of the domains. It is responsible for handling the user signaling and communication with its local RC and IDAC entities in neighboring domains. The tasks performed by the IDAC are the following:

(1) Forwarding the flow setup request to the RC. The RC is responsible for flow admission and resource reservation inside its associated domain. Notice, that in the case when the connected domains use different schemes for specification of traffic profile and QoS requirements, the IDAC has to provide an adequate mapping in order to assure a consistent end-to-end service. If the RC successfully admits a flow within its domain, the IDAC receives a positive acknowledgment and continues with performing the next tasks.

(2) Evaluation of the traffic profile deformation and recalculation of TD. Traffic profile may change due to multiplexing with other traffic inside the domain. Note, that due to stochastic nature of this deformation, after passing the domain the traffic conforms to the recalculated TD only with a certain probability level. This probability should be related with the QoS level offered by a considered service.

(3) Assessment of the domain's contribution to the end-to-end QoS. The flow QoS requirements are expressed in terms of end-to-end parameters, thus they are not directly related with the QoS level offered within a single domain. Therefore, on each step on the end-to-end path the IDAC has to assess the QoS degradation level expected in particular domain and inform the next domain that it has to offer e.g. lower delay and packet loss ratio, taking into account the degradation introduced in all previously visited domains. This task may be realized with the help of so-called QoS assembling functions, which compose the end-to-end QoS values based on the contributions of consecutive domains. This is also quite complex problem due to variety of QoS parameters and their features. For example, the maximum packet delay is additive while the packet loss ratio is rather multiplicative.

(4) Forwarding the flow setup request, with possibly modified TD and information on the flow QoS requirements, to the IDAC entity in the successive domain. Notice, that this task may require some information about the inter-domain routing.

The above-described scheme is repeated until the destination domain is reached. A flow setup request can by blocked in any of the domains on the path if there are no available resources to fulfill the end-to-end QoS requirements.

For providing the IDAC with an abstract view of multi-domain heterogeneous network, the general model is proposed which assumes that each path going through a domain and terminating on a given domain egress link is represented by as a single queue, followed by a delay and loss function blocks. For example, the model depicted on Fig. 2 corresponds to two domains, Domain 1 and Domain 2. Domain 1, has three ingress links denoted as A,B,C and one egress link connected to Domain 2. Therefore inside domain 1 one can distinguish three paths, say A, B, C which are modeled as separated queues followed by delay and losses function boxes $F_A$,$F_B$, $F_C$, respectively. Domain 2 has one ingress and one egress link, therefore there exist a single path which is modeled as queue with function box $F_D$.

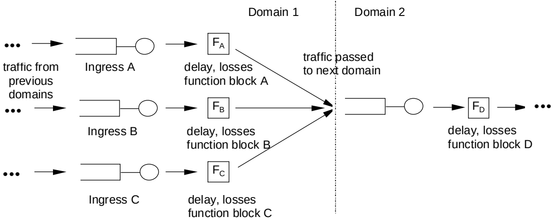

**Figure 2. General model of multi-domain network**

The motivation for representing the model as a network of queues is that the resources controlled by AC are always modeled as a link with associated buffer. Therefore, from a point of view of a single flow, the multi-domain network with AC performed in each domain (perhaps even using different algorithms) is always seen as a chain of queues.

The delay and loss function blocks (see Fig.3) describe the influence of the domain on the analyzed traffic stream. They contain the specification of: (1) the QoS assembling functions, and (2) the TD recalculation functions, which take as input the characteristics and current conditions (e.g. introduced packet delay and loss ratio) of the particular path within the domain. Notice, that since the traffic profile as well as QoS requirements may be expressed using different parameters, the set of functions present in particular function block is network- and service- dependent.

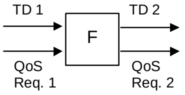

**Figure 3. Delay and loss function block**

This general model can be applied for any IP QoS network. For example, the DiffServ architecture assumes that the bottleneck is located at the domain ingress, while a core is over-dimensioned. Therefore the AC is preformed only on the ingress link, which is directly represented by the queue, while the impact of the core is reflected in functions blocks.

The proposed model can be helpful in designing the details of IDAC mechanism and analyzing its performances. For each edge-to-edge path within each domain, the adequate delay and loss functions have to be defined. That can be done analytically or with the support of measurements. In the following, we focus our attention to the delay function block. Remark that the loss function and QoS assembling issues are currently out of scope of this paper. Rather, we discuss how the IDAC can evaluate the traffic profile deformation and recalculate the TD.

## 3. Evaluation of traffic profile deformation and recalculation of TD

Fig. 4 provides the intuitive explanation of the effect of traffic profile deformation. It depicts exemplary periodic ON/OFF source when it has entered the network, Fig.4a, and when it leaves the domain, Fig.4b. The ON/OFF pattern is convenient for such analysis since it is precisely and tightly characterized by the token bucket TD, with two parameters: token accumulating rate, *r*, and token bucket size, *b*. As a consequence, such traffic pattern will be the mostly effected by the effect of traffic profile deformation. Assume, that at the network ingress point the flow was policed by the token bucket mechanism which was properly dimensioned, i.e. there were always enough tokens in it to accommodate the arriving packet. The time-plot of the token counter value is depicted in Fig.4a as the dotted line.

Now, observe how the traffic emitted within one of the ON periods, starting at time $t_1$ and ending at time $t_2$, has changed during passing the network. Suppose, that the transfer delays of the first and last packet of this ON period were $\tau_1$ and $\tau_2$ respectively, with $\tau_2 < \tau_1$. Assuming that no packets were lost, the total amount of bytes transmitted within the ON period has not changed. However, the burst duration, which at the entry to the network was equal to $(t_2 - t_1)$, got reduced to $(t_2\text{-}t_1) - (\tau_1\text{-}\tau_2)$. The dotted line at the Fig.4b is the time-plot of the token counter value of the hypothetical token bucket configured with the same parameters *(r,b)* and running at the entry of the next domain. Notice, that at some point it drops to zero and the shaded part of the burst would not be accommodated. Thus, we may conclude that due to the traffic profile deformation the resource requirements of the flow have increased and should now be expressed by updated token bucket parameters *(r,b')*, where $b' > b$. Notice, that the effect of increasing the duration of some of the bursts is also possible. This may happen if $\tau_2 < \tau_1$. However, since the deterministic token bucket TD has to assume the worst-case behavior of the flow, it should be dimensioned taking into account the maximum burst reduction.

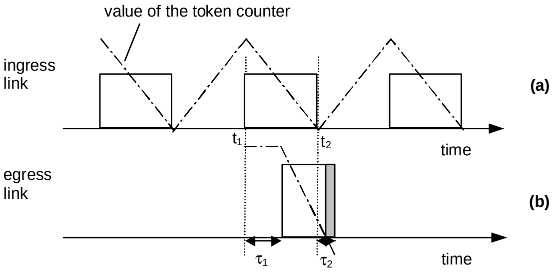

**Figure 4. Illustration of traffic profile deformation**

The related issue of traffic deformation within the access network was discussed in the context of *CBR (Constant Bit Rate)* connections in ATM networks. The recognized solution was to update the limit of the *GCRA (Generic Cell Rate Algorithm,* which is ATM equivalent of the token bucket) with the value of *CDVT (Cell Delay Variation Tolerance)*. A simple method for approximation of *CDVT* was to replace it by the maximum difference of cell transfer times experienced by two cells belonging to the same connection [3]. Some intuition on this approximation can be obtained from Fig.4: remark, that the greatest possible deformation occurs when $\tau_1$ is the maximum and $\tau_2$ is the minimum of observed delays. Thus, *CDVT* is approximated by $W_{max}–W_{min}$, where $W_{max}$ is the $1\text{-}\varepsilon$ quantile and $W_{min}$ is the minimum of the cell transfer times in the access network. As a “rule of thumb”, $1\text{-}\varepsilon$

should be equal to the target probability of transmitting non-conforming cell.

Below, we discuss the application of the simple approximation method for recalculation of TD inside the IP QoS domain. Remark, that the aim is to define the delay function block for the inter-domain network model introduced in section 2. Applying the functions specified in this block, the IDAC should be able to recalculate the TD of the flow before passing the request to the neighbor domain.

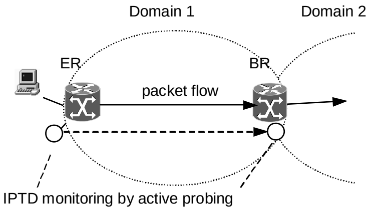

**Figure 5. Monitoring delay characteristics by active probing**

The quantile-based *IPDV (IP Packet Delay Variation)* [5] should be measured between the ingress Edge Router, and the egress Border Router (see Fig. 5). The network measurement and monitoring system (e.g. similar to the one described in [7]) collects a sample of *IPTD (IP Packet Transfer Delay)* values, experienced by probe packets emitted within a predefined observation window. The following statistical parameters should be obtained from the collected sample: $IPTD_{min}$, which is simply the minimum value, corresponding to the constant delay on a given path, and $IPTD_{upper}$, defined as $1\text{-}\varepsilon$ quantile (e.g. with $\varepsilon=10^{-3}$) of the distribution of random variable representing the *IPTD*. More specifically,

$$IPTD_{upper} = \sup\{w \mid \Pr\{IPTD \le w\} \le 1-\varepsilon\} \tag{1}$$

$IPTD_{upper}$ is the parameter of random variable and its credible measurement can be quite difficult. The problem of estimating with assumed precision the quantiles of the distribution from the sample (e.g. of size $n$) was discussed in [4]. Below we recall the simple and efficient procedure for estimating $IPTD_{upper}$ from measurements. It assumes ordering the set of the collected measured values, $IPTD_i$, $i=1,\ldots,n$, into a non-decreasing sequence $X_i$, $i=1,\ldots,n$. The values of $X_i$ are called the order statistics, and the estimate of the $1\text{-}\varepsilon$ quantile is $\hat{x}_{1-\varepsilon} = X_{\lceil n(1-\varepsilon)\rceil}$, where $\lceil y \rceil$ denotes the integer ceiling of the real number $y$. Notice, that according to the definition of sequence $X_i$, the proportion of values within the sample that are not greater than $\hat{x}_{1-\varepsilon}$, is exactly equal to $1\text{-}\varepsilon$. If the size of the sample, $n$, is at least:

$$n_\varepsilon = \left\lceil \frac{z_{1-\alpha/2}^2 \cdot \varepsilon \cdot (1-\varepsilon)}{\varepsilon'^2} \right\rceil \tag{2}$$

where $z_{1\text{-}\alpha/2}$ is the quantile of standard normal variable, the probability that the estimator $\hat{x}_{1-\varepsilon}$ is indeed between the $1\text{-}(\varepsilon+\varepsilon')$ and $1\text{-}(\varepsilon\text{-}\varepsilon')$ quantiles of the distribution is not smaller than $1\text{-}\alpha$ [4]. Thus, we can control the credibly of the measurement by setting an appropriate size of the sample as $n_\varepsilon$ (see the exemplary values in Table 1). Then we can replace $\hat{IPTD}_{upper}$ with the upper bound of the $1\text{-}\alpha$ confidence interval for the $1\text{-}\varepsilon$ quantile:

$$\hat{IPTD}_{upper} = X_{\lceil n(1-\varepsilon+\varepsilon')\rceil} \tag{3}$$

The *IPDV* estimate is then:

$$\hat{IPDV} = \hat{IPTD}_{upper} - IPTD_{\min} \tag{4}$$

In analogy with dimensioning GCRA in ATM networks [3], we can write the following expression for the recalculated value of token bucket size, $\hat{b}'$:

$$\hat{b}' = b + \hat{IPDV} \cdot r \tag{5}$$

where $b$ is the original declared bucket size and $r$ is the original token bucket rate. Notice, that this expression constitutes a part of the specification of the delay function block for the particular domain (see Fig.3).

**Table 1. Sample size required for estimating *1-ε* quantile with 95% and 90% confidence level**

| ε | ε' | $n_\varepsilon$ (1-α=0.95) | $n_\varepsilon$ (1-α=0.9) |
|---|---|---|---|
| $10^{-1}$ | $0.5 \cdot 10^{-2}$ | 139 | 98 |
| $10^{-2}$ | $0.5 \cdot 10^{-3}$ | 1522 | 1072 |
| $10^{-3}$ | $0.5 \cdot 10^{-4}$ | 15351 | 10812 |
| $10^{-4}$ | $0.5 \cdot 10^{-5}$ | 153643 | 108211 |

## 4. Numerical results

The effectiveness of IDAC approach is analyzed by simulations using NS-2 [6] in a simple network consisting of 2 domains, named Domain 1 and 2, as depicted on Fig. 6.

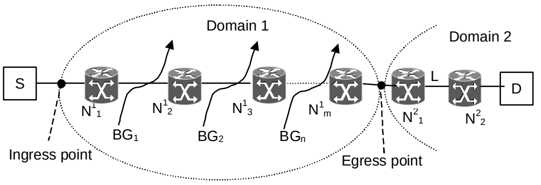

**Fig. 6. The studied system and the model for IDAC**

The flow considered for IDAC will be established between the source host (S) and the destination host (D) belonging to different domains. We assume that both domains offer an exemplary QoS network service, designed for handling variable bit rate traffic with negligible losses. The traffic submitted into this service is described by double token bucket with the following parameters: peak rate *P*, sustained rate *r* and corresponding bucket size *b*. For such defined service, the admission decisions inside each domain may be performed based on the following formula for effective bandwidth [3]:

$$eff(.) = \max\left( \frac{P}{1 + B/(C \cdot b)(P - r)}, r \right) \tag{6}$$

where P, *r* and *b* are TD parameters, while *C* and *B* are the link capacity and associated buffer size, respectively.

In the IDAC approach, as it was presented in section 2, the admission to domain 1 is performed based on $TD_1$ with *(r,b)* originally declared by a user, while in domain 2, based on re-calculated $TD_2$ $(r, \hat{b}')$, taking into account the assessment of traffic profile deformation introduced inside domain 1.

Below, we focus on evaluation of the traffic deformation introduced inside the domain 1 and then we show its impact on performing AC in the domain 2.

## 4.1. Evaluation of traffic profile deformation

In this section, we study the effectiveness of the proposed TD recalculation method. For that purpose, we assume that Domain 1 consist of a chain of *m-1* routers, $N^1_i$, $i=1,\ldots,m-1$ connected by links with capacities *C*=2Mbit/s. Within each router, the analyzed foreground flow is multiplexed with the background flow, $BG_i$, $i=1,\ldots,m$, injected independently on each link, as depicted on Fig. 6a. Assuming large degree of possible aggregation of individual flows, the background traffic can be modeled as a Poisson process.

Fig. 7 shows how the traffic profile deformation accumulates with the number of routers in a chain. In this case we assume that foreground traffic is deterministic ON/OFF flow with *P*=200kbit/s, *r*=100kbit/s, MTU=500B and corresponding value of *b* was fixed between 1 and 100 MTUs, which reflects different length of ON and OFF periods. The background traffic load on each link was fixed at $\rho=0.8$.

The traffic profile deformation is expressed as the value of *b'* in relation to *b*, where *b* is the parameter of the original token bucket TD and *b'* was obtained by simulations as the minimum size of the token bucket applied at the egress point of Domain 1, such that the probability of a non-confirming packet was negligible. Thus, value of *b'* represents the actually required update of original TD parameter, *b*. On the other hand the value of $\hat{b}'$ was obtained by formula (5) from measurement of $\overset{\wedge}{IPTD}$ estimated taking into account IPTD of all packets belonging to the foreground flow. Notice, that $\hat{b}'$ constitutes a conservative upper bound for the true required *b'* in all evaluated traffic scenarios. The level of overestimation depends on the characteristics of the particular traffic source.

The effect of traffic deformation is especially visible in the case of flows characterized by rather small values of *b*, original bucket size. For flows with large values of *b*, the deformation has a maximum in certain value of *m* and then it diminishes. The widths of 95% confidence intervals are indicated on all plots.

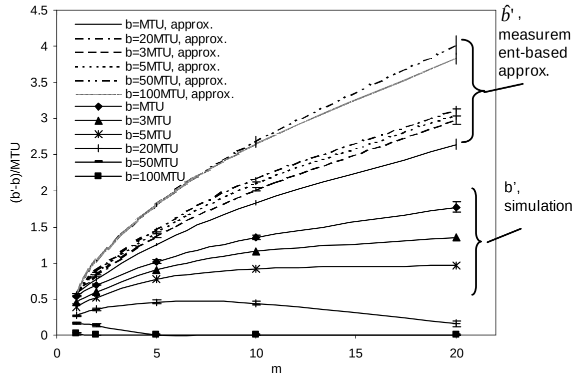

**Figure 7. Difference between *b'* and *b* vs. the number of routers in a chain, *m***

The next experiment was carried out in a network with *m*=10 routers and with foreground flows characterized by different values of peak rate, *P*. The mean rate was always *r=P/2* and the durations of ON and OFF periods were fixed in such way, that the corresponding value of *b* was equal to 5 MTU. Simulations were repeated under different background traffic load conditions, represented by the value of utilization coefficient, $\rho$. On Fig.8, the value of obtained *b'* normalized in relation to the original bucket size *b*, is depicted as a function of ratio of *P* to

*C*. Notice, that the traffic profile deformation effect increases with the relative “size” of the flow with respect to the total link capacity.

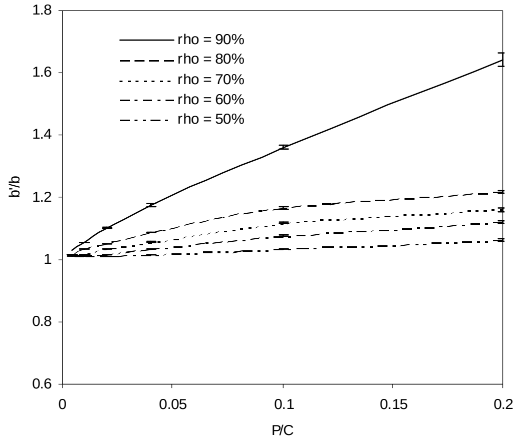

**Figure 8. Ratio of *b’/b* vs. the ratio of flow peak rate to the link capacity**

Based on the obtained results one can conclude that the traffic submitted by a user changes after passing the domain even significantly and that the original TD is inaccurate. Therefore, it has to be recalculated and the discussed measurement-based method can be effectively applied for that purpose. However, the proposed method overestimates the TD.

### 4.2. Evaluation of IDAC approach

Now, we investigate the impact of deformation of traffic profile in Domain 1 on the effectiveness of AC performed within the Domain 2 and, as a consequence, on end-to-end QoS offered to the user. For that purpose we analyze the impact of TD changes on the value of effective bandwidth calculated according to formula (6). In Fig. 9 we show the value of effective bandwidth, *e’*, calculated based on the modified TD obtained in the experiments described in section 4.1, in relation to *e*, the effective bandwidth calculated using the original TD.

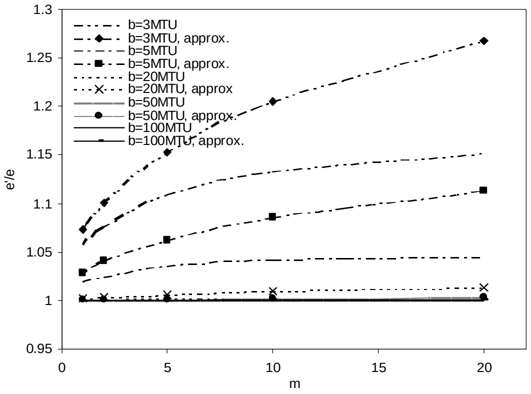

**Figure 9. Ratio of *e’/e* vs. the number of routers in a chain, *m***

One can observe, that the level of TD deformation will have impact on the number of admitted flows. In order to practically verify that performing inter-domain AC without taking into account the effect of traffic deformation may lead to QoS failures, we performed the following simulation experiment. Let us assume, that the capacity of the bottleneck link L in Domain 2 (see Fig. 6) is *C*=2Mbit/s, while the size of the associated buffer, *B*=22000Bytes. Further, assume that a flow (denoted as flow type #1) has TD parameters: *r*=100kbit/s and *B*=22000bits. According to formula (6), the maximum admissible number of type #1 flows on link L is 14.

Simulation experiment, carried out with 14 simultaneous flows, generated between nodes $N^2_1$ and $N^2_2$ exactly according to the ON/OFF profile determined by TD of flow type #1, confirms that the packet loss ratio measured on link L is equal to 0 (see Table 2, row 1).

Then, assume that one of the flows passing link L has arrived from the Domain 1. Its traffic profile would be deformed, and the correct TD value for this flow is *b’*=25670bits (obtained in simulation scenario 1). In the experiment, one of the flows on link L was exchanged with flow type #2, generated according to profile determined by the modified TD with parameters *(r,b’)*. Now (see Table 2, row 2), one can observe packet losses on link L. This suggests, that the effective bandwidth of flow #2 submitted to link L should be calculated not based on original TD *(r,b)*, but based on recalculated TD *(r,b’)*. The admissible set would than be reduced to 12 flows of type #1 and 1 flow of type #2, but target packet loss ratio equal to 0 is kept (see Table 2 raw 3). The result presented in the last row of Table 2 was obtained with the effective bandwidth of flow #2 calculated based on the TD estimated with the help of measurements, represented by $(r,\hat{b}')$. The admissible set is here also equal to 12 flows of type #1 and 1 flow of #2.

**Table 2. Packet loss ratio experienced by flows submitted to link L, assuming unmodified and recalculated TDs of flow #2**

| **TD of flow #2** | **Flow #2 TD bucket size** | **Flow #2 real bucket size** | **N. of flows #1** | **N. of flows #2** | $P_{loss}$ |
|---|---|---|---|---|---|
| $(r,b)$ | 22000 | 22000 | 14 | 0 | 0 |
| $(r,b)$ | 22000 | 25670 | 13 | 1 | $3.8\cdot10^{-2}$ |
| $(r,b')$ | 25670 | 25670 | 12 | 1 | 0 |
| $(r,\hat{b}')$ | 30400 | 25670 | 12 | 1 | 0 |

The results of this simulations confirm, that recalculation of TD is desired for the IDAC in order to keep stringent QoS guarantees. However, the exhaustive evaluation of impact of traffic deformation needs more experiments with different traffic loads and real IP QoS network topologies.

## 5. Summary

The paper discussed the issues related with performing admission control in multi-domain IP QoS network. For that purpose, the general model of multi-domain network was introduced. This model constitutes a base for designing and performance analysis of inter-domain admission control. The discussed declaration based admission control approach is enhanced by a method for recalculation of traffic descriptors. The motivation for performing recalculation is that the traffic after passing a domain may have worse properties than the originally declared profile. The discussed TD recalculation method is based on measurements of packet delay variation.

The simulation experiments confirm that the effect of traffic profile deformation can be quite important and neglecting it may lead to degradation of end-to-end QoS. This effect is especially critical for the tight AC algorithms, which give the exact boundary and even small inaccuracies in TD lead to QoS degradation. The proposed measurement-based approximation can be effectively applied for recalculation of TD. Notice, that the proposed method is only one of the possible approaches for assessment of traffic deformation. Another approaches giving lower over-dimensioning of TD should be considered.

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