Paper

On effectiveness of conditional admission control for IP QoS network services with REM scheme

Marek Dąbrowski, Wojciech Burakowski, and Andrzej Bęben

Abstract — Future IP QoS (quality of service) networks are aiming at differentiating transfer quality of packets belonging to different flows. For this purpose, a set of network services (NS) with different QoS objectives is defined and implemented in the network. To a NS a certain amount of network resources, i.e. dedicated link capacity with associated buffer size, is allocated. Moreover, the resources dedicated for one NS are not available for other NSs. Traditional approach for admission control algorithm corresponding to given NS takes into account current traffic conditions inside considered NS. This can lead to the situation, due to traffic fluctuations, that temporary overloaded NS cannot use the spare bandwidth from underloaded in this time other NSs. This paper describes a conditional admission control algorithm (C-AC), allowing us to admit new packet flow conditionally in the case where no available capacity inside a given NS. For conditionally accepted flow currently unused capacity, dedicated to other NS, is allocated. This can be done only in the case when QoS requirements for both the conditionally accepted flow and the flows in progress are satisfied. The conditions for effective using of C-AC algorithm are discussed in the paper, like characteristics of NS borrowing and lending capacity and their current traffic load. To show potential benefits of the approach, exemplary numerical results are included, corresponding to hypothetical NSs using REM (rate envelope multiplexing) scheme.

Keywords — QoS IP network, conditional admission control.

1. Introduction

For the development of the future IP-based network, called IP QoS, two network architectures are discussed by the IETF: IntServ [4] and DiffServ [2, 3]. Despite that these architectures differ in many points, each of them offers a possibility for defining a set of network services with different QoS objectives. The NSs can be similar to these supported by ATM, like CBR (constant bit rate) and VBR (variable bit rate), or can be arranged for transferring packet stream associated with specific application (like WWW – world wide web). Implementation of a NS is possible thanks to QoS mechanisms available in IP routers. These mechanisms correspond to classification, policing, scheduling and buffer management. The excellent example of a new NS for IP network is the premium service for transmitting voice traffic [6].

Each NS is designed to offer specific QoS objectives, usually expressed in terms of maximum allowed packet transfer delay, packet transfer delay variation, packet loss ratio, etc. A certain amount of network resources, i.e. dedicated link capacity with associated buffer size, is assigned for each NS. Access to this capacity can be assured e.g. by setting appropriate weight value in the WFQ (weighted fair queuing) packet scheduler in the output port of the router. The maximum volume of traffic allowed inside a given NS is controlled by appropriate admission algorithm. In the case when there is not enough capacity available inside a given NS, new flow request is simply blocked. Let us remark that strict partitioning of network resources between NSs limits multiplexing gain only to the capacity dedicated for a single NS.

This paper describes a conditional admission control algorithm (C-AC), allowing us to admit new packet flow conditionally in the case where no available capacity inside a given NS. For conditionally accepted flow currently unused capacity, dedicated to other NS, is allocated. This can be done only in the case when QoS requirements for both the conditionally accepted flow and the flows in progress are satisfied. The conditions for effective using of C-AC algorithm are discussed in the paper, like characteristics of NS borrowing and lending capacity and current traffic load. To show potential benefits of the approach, exemplary numerical results are included, corresponding to hypothetical NSs using REM multiplexing scheme.

The paper is organized as follows. Section 2 discusses the implementation of differentiated NSs in IP networks. Section 3 describes the proposed C-AC algorithm and discusses its application and implementation aspects. Numerical examples are included in Section 4. Finally, Section 5 summarizes the paper.

2. Supporting differentiated NSs in IP networks

Conditional admission control algorithm can be engaged in the case when capacity of transmission link is strictly partitioned among a number of NSs. Each NS supports different QoS requirements corresponding to the packet transfer characteristics. The studied system with n NS is depicted in Fig. 1a. Dedicated capacity in the link is assigned for each NS, adequate to the fixed value of the weight in the WFQ scheduler. Exemplary link partitioning is shown in Fig. 1b, where the ith NS has dedicated capacity equal to $C_i = w_i C$ (w_i – value of the weight for the ith NS, $i = 1, \ldots, n$, C-link capacity). The maximum allowed carried traffic inside the ith NS is limited by the C_i value (and the length of the associated buffer) and is controlled by appropriate admission algorithm. The type of applied admission rules directly depends on the type of multiplexing scheme assumed for the considered NS.

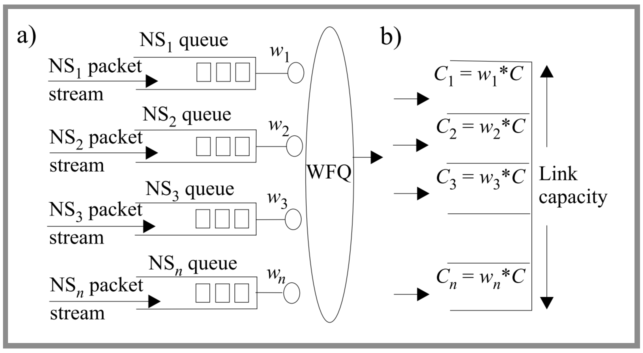

Fig. 1. Exemplary structure of the output port in the IP router supporting N different NSs: (a) studies system; (b) exemplary link partitioning.

We distinguish two types of multiplexing which are REM and RSM (rate sharing multiplexing). Let us recall that the REM scheme is dedicated for traffic with rigorous requirements with respect to packet delay characteristics. Usually, for this scheme a small buffer is dedicated for absorbing packets arriving to the system in the same time. On the contrary, the RSM multiplexing scheme is for bursty traffic and it requires relatively large buffer for absorbing traffic fluctuations in time. The differences between these schemes are important in the case of the discussed conditional admission.

The above system is in fact partitioned into N subsystems, each corresponding to different NS. High overall link utilization is reached only in the case the traffic load submitted to each NS is heavy at the same time. However, assuming that fluctuations in time of the traffic submitted for a given NS follow a stochastic process, there is a chance that a high percentage of new flows is blocked despite of spare capacity on the link. Better link utilization (lower flow request blocking) can be achieved by "borrowing" the resources from the NS that is temporarily under-utilized to the one that is actually overloaded. This requires changing the WFQ weights on the link, which has two serious drawbacks:

- Updating the values of weights in the WFQ scheduler in a dynamic way can cause uncontrolled traffic oscillations [5].
- Repartitioning of link resources may require adequate changes on all the subsequent links in the network (see Fig. 3). In a network based on the DiffServ architecture [2], this affects the scalability of AC mechanism. In an ideal case AC can be applied locally, taking into account traffic conditions in a particular Edge Router [6].

Therefore, changing WFQ weights is an operation, which can be performed in rather long time scale (e.g. hours). Repartitioning of resources between the NSs in the whole network can be done for example as a result of a long-term analysis of the traffic demands. New weights can be calculated in an off-line process of network reprovisioning, based on the observed changes of the traffic matrix.

If the network should be able to react quickly to traffic fluctuations in a shorter time scale, e.g. minutes, changing WFQ weights is not a reasonable solution. Therefore, we propose, so called conditional admission as a mechanism, which could significantly decrease the probability of call blocking in the case of short-time fluctuations of traffic offered to the network.

3. Conditional admission control

The proposed C-AC assumes that in the case of blocking, new flow can be accepted and submitted to other NS guaranteeing requested by this flow packet transfer quality. This is illustrated in Fig. 2. The conditionally accepted flow is submitted to the queue associated to other NS. It can take place only when this NS is under light load and available capacity is sufficient. It is obvious that the volume of available capacity limits the number of conditionally accepted flows. The flow is turned back to its own NS when capacity will be sufficient for its service. Anyway, the service of the considered flow can be terminated successfully even if the conditional status of this flow will not be changed. Of course, the service of the conditionally admitted flows is not always finished with success. This is due to the fact that new flows from the NS lending the capacity can arrive to the system. These flows are admitted with the highest priority and, as a consequence, can interrupt the service of the conditionally accepted flows.

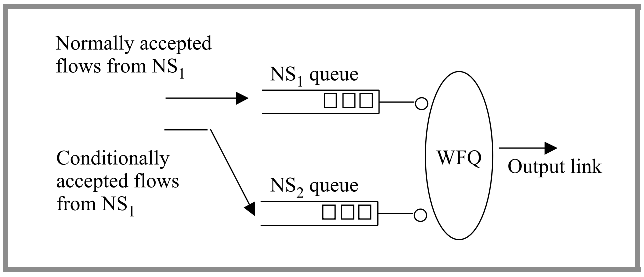

Fig. 2. Illustration of the conditional admission. Conditionally accepted new flow from the NS_1 borrows the capacity originally dedicated to the NS_2.

Effective application of the proposed C-AC scheme requires satisfactory solutions for the following questions:

- What about co-operation level of different NSs? It means, which NS can lend/borrow capacity to/from other NSs?
- When co-operation of the NSs can give expected profit?
- What about the implementation complexity level?
- What is the level of risk that the conditionally accepted flow will be terminated before the proper time?

3.1. Co-operating NSs

Basic requirement for co-operating NSs is that a flow "belonging" to a given NS can efficiently transfer its packets inside co-operating NS. Let us consider two NSs both working under REM (or RSM) scheme. Furthermore, let us assume that the first NS provides stronger QoS guarantees than the second. In order to assure appropriate QoS, the first NS has potential to lend the capacity to the second NS without essential limitations. On the contrary, the second NS can lend its resources only when it is currently under very light traffic conditions. In the next section, an example of co-operation between two NSs, both using REM multiplexing scheme, is more deeply discussed.
The rules of the co-operation between two NSs with different multiplexing schemes, i.e. REM and RSM, are not so clear. We can deduce that one NS can lend a limited volume of its capacity only when current traffic load conditions are rather low. Anyway, the detailed studies for specific NSs are required.

3.2. Expected profit

The potential profit that we can reach from the application of C-AC depends on the degree of the flow level (not the packet level) traffic fluctuations inside the co-operated NSs. It is obvious that no profit is possible when these NSs are overloaded at the same time. Otherwise, one can expect better traffic service when the traffic submitted to the considered NSs will alternate in time.

3.3. Risk assessment

The fundamental question is *when conditional admission of a new flow is reasonable?* Let us recall that a flow admitted in such a way can be terminated before the proper time. Note, that the probability of such event depends on the flow level traffic conditions and the current system state. The decision whether a new flow is conditionally accepted or not, should take into account the above probability. It is reasonable to admit a new flow conditionally only when this probability is relatively low, e.g. on the level comparable to the flow blocking probability.

3.4. Complexity level

Two essential factors influence the complexity of C-AC schema, which are:

- Modifications to the packet handling mechanisms in edge and core routers.
- Additional complexity of AC and user-network signaling.

A comparison of the proposed scheme with the method based on changing the WFQ weights is presented in Fig. 3. Consider a simple network, consisting of 2 links. Both links are equally partitioned between NS_1 and NS_2. Let us assume, that NS_1 is temporary overloaded (marked as light grey area) while NS_2 is at the same time underloaded. Then, the call blocking is observed in NS_1 despite there are unused resources in NS_2.

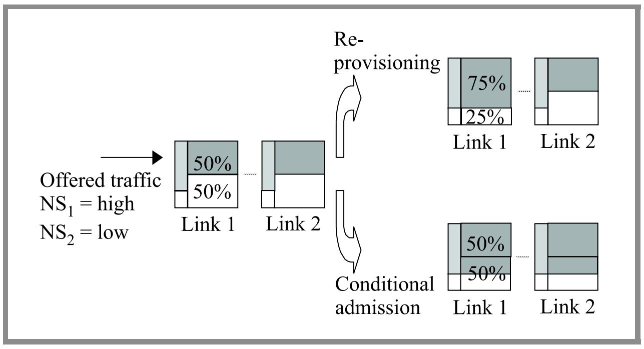

Fig. 3. Comparison of two methods of adapting network resources to fluctuating traffic load: changing WFQ weights (reprovisioning) and conditional admission.

As it was stated before, two solutions are possible for increasing the network utilization. One of them is to update the WFQ weights for NS_1 to serve the higher load. These weights must be adequately changed on all the consecutive links. Otherwise, as it is depicted in the Fig. 3, the NS_1 capacity on the first link (dark-grey area) is sufficient for serving the submitted higher load (light-grey area), while in the case of unchanged weights on the second link, an overload for NS_1 is still observed. If we admit the excess traffic from NS_1 conditionally, it must be served within capacity allocated for NS_2 on both links. In the framework of DiffServ architecture, conditional acceptance requires only marking the packets in the edge router with the code point corresponding to the PHB (per-hop behaviour) associated with NS_2. Then, packets are served in the same way on all subsequent routers in a given domain. Therefore, one can conclude that WFQ weights can be changed as a result of re-calculation process taking into account all links in the network. This imposes a significant complexity level and can be done only in a long time scale. On the contrary, conditional admission applies modifications to the packet marking locally at the edge router, not requiring changes in the core network.

Anyway, introducing conditional admission increases complexity of the control algorithm and user-network signaling implementation. This is caused by:

- Conditionally accepted flow should submit its traffic to another queue in the WFQ scheduler. If sufficient capacity will become available to accept this flow in the original NS, this flow should be switched to the proper WFQ queue, loosing its status of a conditionally accepted flow.
- Conditionally accepted flow may be terminated before the proper time by the new flows arriving to the NS, which lends its capacity to conditionally accepted flows.

4. Numerical example

In this section, the effectiveness of the proposed C-AC algorithm will be illustrated by considering an exemplary system with two NSs, say NS_1 and NS_2, both working under the REM multiplexing scheme.

Example 1. Co-operation of NSs designed for CBR traffic

Consider a system with NS_1 and NS_2, both designed for serving CBR traffic and working under typical AC algorithm (not C-AC). Guaranteed packet loss ratio (PLR) by NS_1 is 10^{-4} and by NS_2 is 10^{-2}. The associated buffer sizes, say B_1 and B_2, for NS_1 and NS_2 are of 10 packets each. The maximum allowed value of the link utilization for the NS_1, say ρ_1, can be calculated by [1, 5]:

$$\rho_1 = \frac{2B_1}{2B_1 - \ln\left(PLR_1\right)} . \quad (1)$$

The value of $\rho_1 = 0.68$. Similarly, for NS_2 we calculate $\rho_2 = 0.81$. (Notice that ρ_1 and ρ_2 do not depend on the link capacity). The traffic submitted to the NS_1 (NS_2) and corresponding to the flow (call) level follows Poissonian process with parameter λ_1 (λ_2) while the holding times are negative-exponentially distributed with parameter μ_1 (μ_2). Additionally, each flow submitted to NS_1 or NS_2 requests for the same amount of bandwidth, fixed to 1. The total link capacity is 100.

Three scenarios are considered, which differ in link partitioning between NS_1 and NS_2. They are the following:

Scenario 1: $NS_1 = 50$, $NS_2 = 50$.
Scenario 2: $NS_1 = 70$, $NS_2 = 30$.
Scenario 3: $NS_1 = 30$, $NS_2 = 70$.

Furthermore, we investigate the system assuming that the offered traffic (at the call/flow level) is such that the resulting call/flow blocking probabilities for both NS_1 and NS_2 are 10^{-2}. Therefore, the corresponding to the considered scenarios values of the offered traffic to NS_1 and NS_2 (calculated from Erlang formula), in the case when flow holding times are 1 ($1/\mu_1 = 1/\mu_2 = 1$), are:

Scenario 1: $\lambda_1 = 23.8$, $\lambda_2 = 29.5$.
Scenario 2: $\lambda_1 = 35.2$, $\lambda_2 = 15.3$.
Scenario 3: $\lambda_1 = 12.0$, $\lambda_2 = 43$.

The admission regions for scenario 1 are depicted in Fig. 4. The curve corresponding to typical AC shows that the maximum number of admitted flows from the NS_1 and NS_2

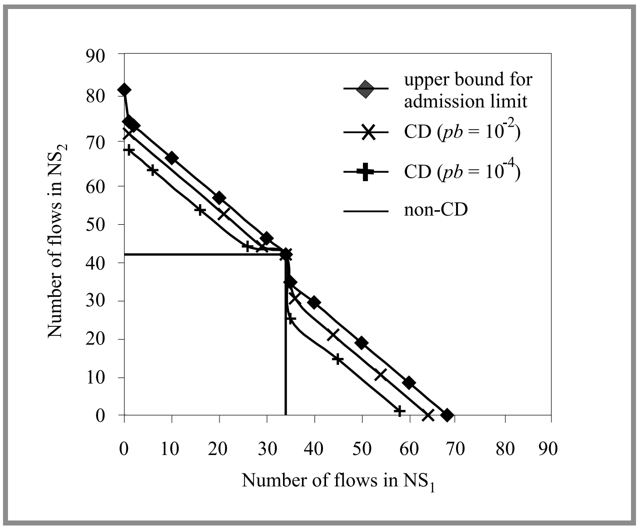

Fig. 4. Scenario 1: admission regions for the C-AC and typical AC for CBR traffic (CD – conditional admission; non-CD – typical admission, *pb* – level of risk).

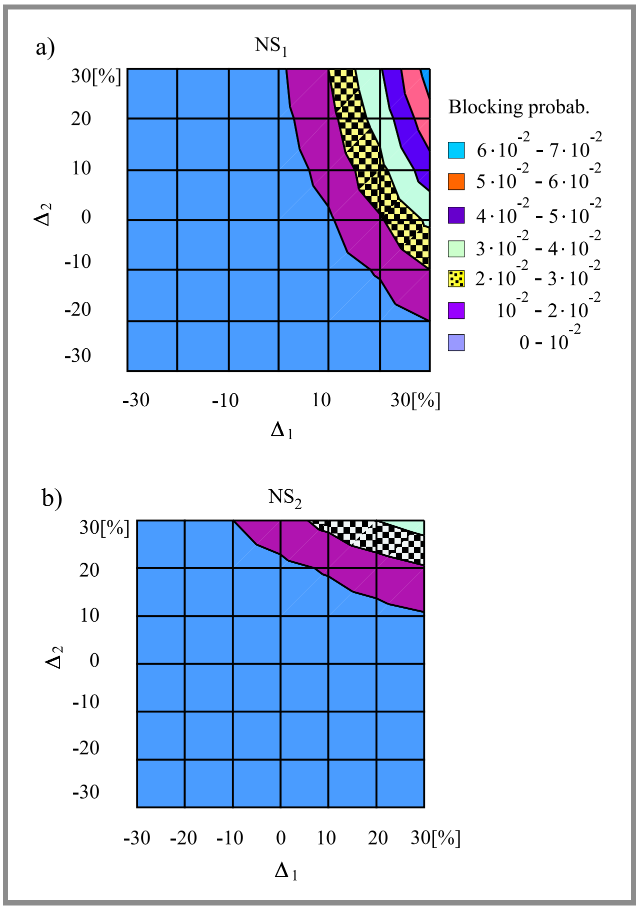

Fig. 5. Scenario 1: blocking probability in NS_1 (a) and NS_2 (b) versus the fluctuations of traffic offered to NS_1 and NS_2 for CBR traffic.

is 34 and 40, respectively (non-CD curve). Note that the upper bounds with applied the C-AC algorithm are in this case significantly greater. Now, the admission region is limited by 68 flows for NS_1 and 80 flows for NS_2 (!). Anyway, this result is too optimistic since this curve does not take into account any level of risk, expressed by the probability, say pb ($pb > 0$), that a conditionally admitted flow can be terminated before its proper finish time. The remaining two curves from Fig. 4 (CD curves) show the resulting admission regions in the cases when $pb = 10^{-2}$ and 10^{-4}. One can observe that the curve corresponding to $pb = 10^{-2}$ is very close to the upper bound curve. For the case of $pb = 10^{-4}$, we observe smaller admission region, but still significantly greater than this obtained by typical AC. Summarizing, we can conclude that the C-AC scheme can radically improve the admission region.

Figure 5 illustrates the effectiveness of the C-AC algorithm when the offered traffic to the NS_1 and NS_2 deviates from the assumed. Now, the call/flow arrival rates are $\lambda_1 = \lambda_1 + \Delta_1 \cdot \lambda_1$ and $\lambda_2 = \lambda_2 + \Delta_2 \cdot \lambda_2$. The factor Δ_1 (Δ_2) expresses a bias coefficient of the offered traffic to NS_1 (NS_2).

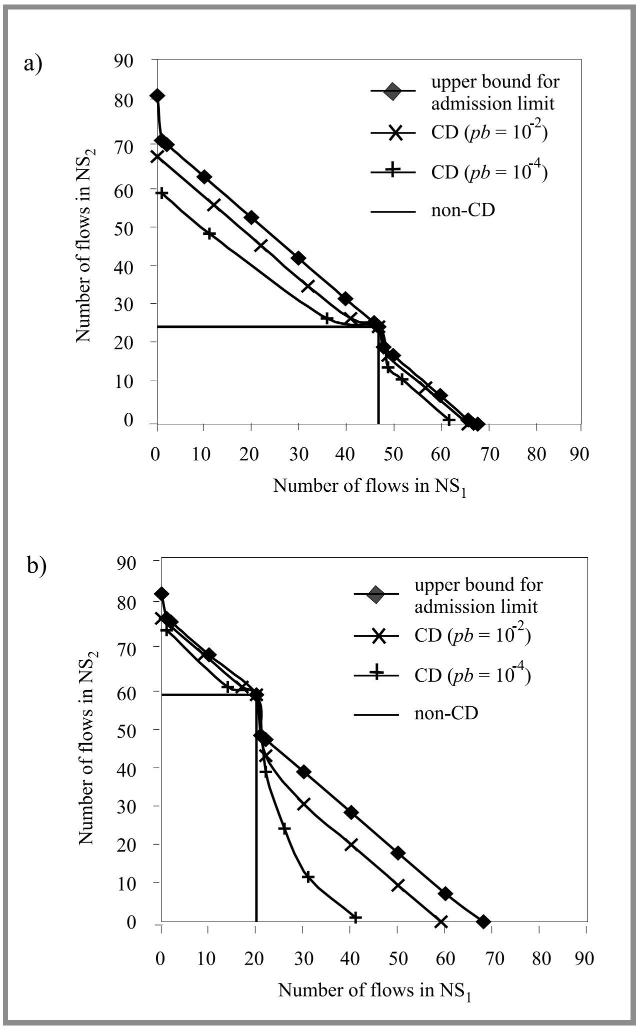

Fig. 6. Scenario 2 (a) and scenario 3 (b): admission regions for the C-AC and typical AC for CBR traffic (explanations – see Fig. 4).

Let us recall that, when $\Delta_1 = 0\%$ and $\Delta_2 = 0\%$, the assumed blocking probabilities (with typical AC) for NS_1 and NS_2 are 10^{-2}. The curves from Fig. 5 show that, thanks to the C-AC algorithm, the call/flow blocking probabilities for NS_1 are still below 10^{-2} even when $\Delta_1 = 10\%$ and $\Delta_2 = 0\%$. As it was expected, more profit of using C-AC is observed when $\Delta_2 < 0$. For instance, when $\Delta_2 = -20\%$ and $\Delta_1 = 30\%$, call/flow blocking probability in NS_1 is still below 10^{-2}.

Figure 6 shows the obtained admission regions in scenario 2 and 3. One can observe that for scenario 2 the C-AC algorithm is more effective for flows submitted to NS_2 than NS_1. This is caused by the fact that in this case the capacity allocated for NS_2 is smaller than for NS_1. Therefore, one can expect that more NS_2 flows can be conditionally accepted within NS_1 than in reverse.

In scenario 3 more capacity is allocated to NS_2 than NS_1. The obtained upper bound for admission region in the case of NS_1 with the C-AC algorithm is now essentially larger comparing to the system with typical AC. However, the gained profit is now much less than expected. This is caused by the fact that NS_1 provides more rigorous QoS (at the packet level) than NS_2. When NS_1 flow is conditionally accepted to the capacity assigned for NS_2, the maximum link utilization in NS_2 must be decreased from 0.81 to 0.68.

Example 2. Co-operation of NSs designed for VBR and CBR traffic

Co-operating NSs from example 1 were both designed for CBR traffic, although with different target PLR. In this example we consider the case when NS_1 and NS_2 serve VBR and CBR traffic, respectively. Both NSs guarantee PLR value not greater than 10^{-4}. VBR flows are characterized by parameters of dual token bucket, e.g. peak bit rate (PBR) and sustainable bit rate (SBR). For non-conditionally accepted flows, we use the AC algorithm based on calculation of, so called, effective bandwidth, following Lindeberger formula [1, 5]. Therefore, new flow can be admitted only if the sum of effective bandwidths of all multiplexed flows is not greater than the capacity assigned for NS_1. In the NS_2 case, AC is performed as in the example 1. Maximum link utilization factor for NS_2 is $\rho = 0.68$. For conditionally accepted flows, the rules for AC differ for both NS_1 and NS_2 class. In the case when a flow originally submitted to NS_1 is rejected and as a consequence is re-submitted to NS_2, the admission control takes into account only PBR values of the flow in question as well as the flows being in progress and served by NS_2. The same rule is kept when flows are conditionally accepted in NS_1. The above algorithm seems to be a bit restrictive, since at least theoretically more flows could be admitted conditionally when effective bandwidth for VBR flows instead of PBR was taken into account.

In the considered example, CBR flows submitted to NS_2 request for 1 unit of link capacity, while VBR flows submitted to NS_1 request for a certain amount of effective bandwidth (EB), calculated assuming PBR= 2, SBR= 1. The total link capacity is 100. Three network scenarios are again considered, with the link partitioning as in example 1. Therefore, a single VBR flow requires 1.6, 1.45 and 1.9 units of EB, in scenario 1, 2 and 3, respectively.

Furthermore, we investigate the system assuming that the offered traffic (at the call/flow level) is such that the resulting call/flow blocking probabilities for both NS_1 and NS_2 are 10^{-2}. Therefore, the corresponding to the considered scenarios values of the offered traffic to NS_1 and NS_2 (calculated from Erlang formula), in the case when flow holding times are 1 ($1/\mu_1 = 1/\mu_2 = 1$), are:

Scenario 1: $\lambda_1 = 20$, $\lambda_2 = 23.8$.
Scenario 2: $\lambda_1 = 31.6$, $\lambda_2 = 12$.
Scenario 3: $\lambda_1 = 8.7$, $\lambda_2 = 35.7$.

The admission regions for scenario 1 are depicted in Fig. 7. The curve corresponding to typical AC shows that the maximum number of admitted flows from the NS_1 and NS_2

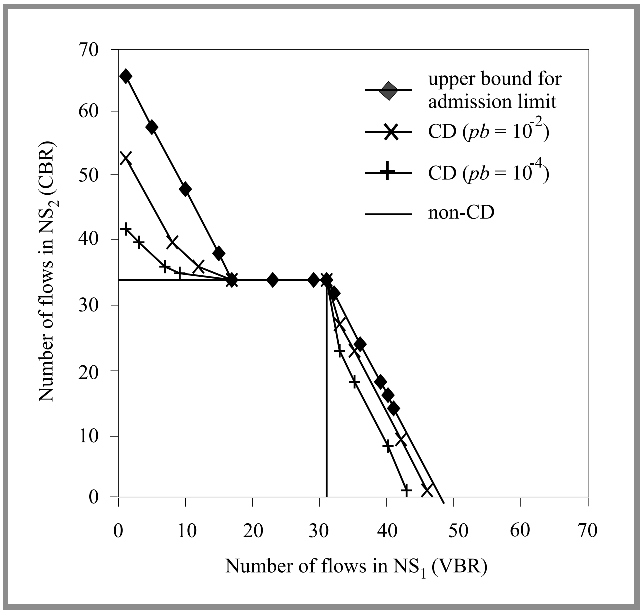

Fig. 7. Scenario 1: admission regions for the C-AC and typical AC for VBR and CBR traffic (explanations – see Fig. 4).

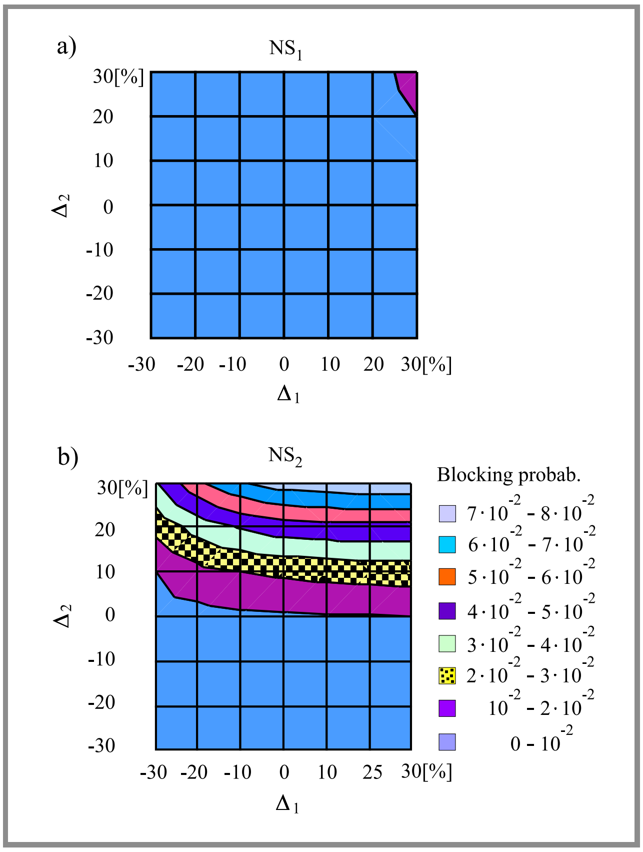

Fig. 8. Scenario 1: blocking probability in NS_1 (a) and NS_2 (b) versus the fluctuations of traffic offered to NS_1 and NS_2 for VBR and CBR traffic.

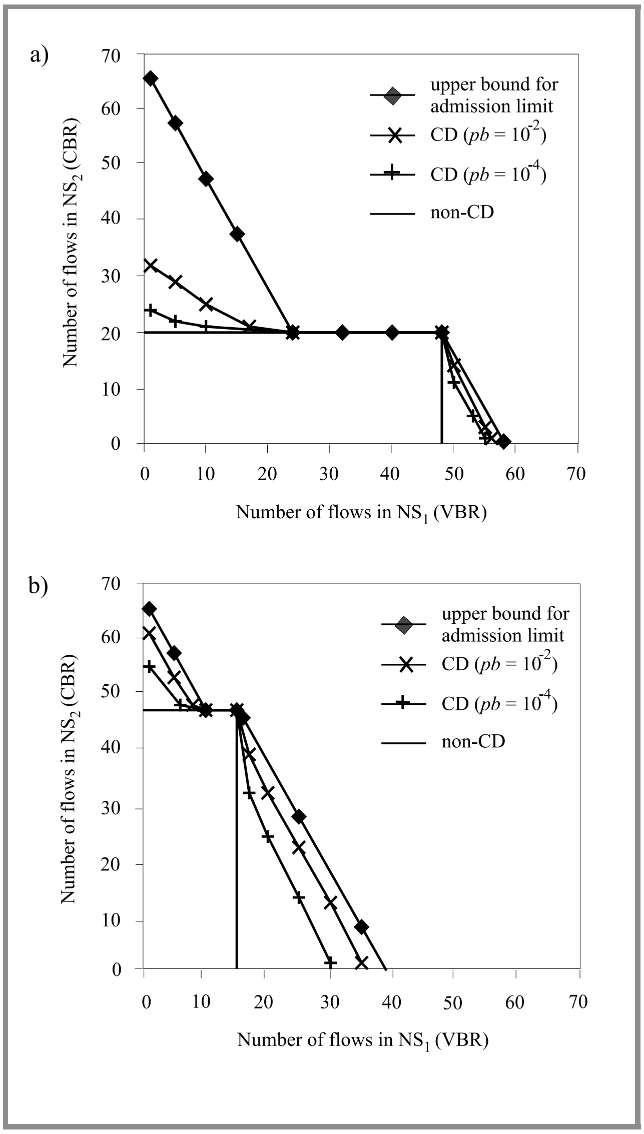

Fig. 9. Scenario 2 (a) and scenario 3 (b): admission regions for the C-AC and typical AC for VBR and CBR traffic (explanations – see Fig. 4).

is 31 and 34, respectively (non-CD curve). Note that, as in example 1, the upper bounds with applied the C-AC algorithm are in this case significantly greater. Now, the admission region is limited by 48 flows for NS_1 and 66 flows for NS_2. One can observe that, comparing to the scenario 1, the possibility of shifting resources between NSs is now limited. This is caused by the fact, that when CBR and VBR flows are mixed, the admission rules take into account only values of PBR of submitted flows, which does not allow for a multiplexing gain within VBR service. As a consequence, CBR flows can be conditionally admitted to the NS_1 only when it is under very low traffic conditions.

Figure 8 illustrates the effectiveness of the C-AC algorithm when the offered traffic to the NS_1 and NS_2 deviates from the assumed. The presented curves show that, thanks to the C-AC algorithm, the call/flow blocking probabilities for NS_1 are still below 10^{-2} even when $\Delta_1 = 25\%$ and $\Delta_2 = 25\%$. As it was expected, much less profit of using C-AC is observed in the case of NS_2. Now, Δ_2 can be increased only when $\Delta_1 = -30\%$ and below.

Admission regions obtained in the case of scenario 2 and scenario 3 are depicted in Fig. 9. One can observe, that the risk related with conditional admission of CBR flows within the capacity allocated for NS_1 is quite high in scenario 2. This is caused by the fact that in this case the conditional admission is allowed only when the current traffic load carried by NS_1 is very low.

5. Conclusions

The concept of conditional admission of new calls/flows was presented and discussed in the paper. The proposed approach assumes that new flows, which would normally be blocked, are conditionally accepted. This is possible by using spare at this moment capacity dedicated for other NSs. The preliminary numerical results confirm that the proposed approach is reasonable, leading to admitting larger number of flows and higher overall resource utilization, with a low probability that conditionally accepted flows will be terminated before the proper finish time. The admission regions for particular NSs can be, in some cases, radically extended. The proposed conditional admission can be especially attractive for the QoS IP networks where network resources are strictly partitioned between supported NSs.

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Marek Dąbrowski – for biography, see this issue, p. 13.