Resource allocation strategies for new connections in QoS multi-domain networks with signaling capabilities

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Abstract — **Before accepting a new connection in QoS networks we need to check if the amount of required resources is available on the path from the source to the destination. In the case of QoS multi-domain networks, we need to make resource reservations in each domain on that path, as it has a place e.g. in EuQoS[1] system. Choosing optimal strategy for resource reservations in such a network is a very important issue since it has great impact on the system effectiveness.**

In this paper we are going to present, evaluate and compare three strategies for resource allocations for new connections that are based on: (1) *per flow* treatment by each domain, (2) *per flow* treatment only by ending domains while using resource pre-reservations in transit domains, and (3) an intermediate approach that is based on partitioning the resources in transit domains into two separate pools - each pool is fully booked for the connections that are handled according to (1) and (2), respectively. For comparative studies of the above-mentioned strategies we are going to present the simulation results corresponding to such parameters as link utilization, probability of call blocking as well as required signaling in transit domains. Finally, we argue that the strategy (3) overcomes the strategies (1) and (2).

Keywords - QoS multi-domain networks, resource reservation strategies, EuQoS system, signaling

I. INTRODUCTION

New demands for using multimedia applications over the Internet, such as IP telephony, video, tele-medicine, tele-engineering, tele-education, etc., have spurred the emergence of several research topics aimed at providing customers with the required QoS. One of these research topics deals with the problem of providing adequate resource allocation for a new connection over multi-domain network to satisfy QoS constraints at the packet level.

A user (by QoS-aware application) who wants to establish the QoS connection via the network needs to send his/her request for required resources to the network. For this purpose, we need to add signaling capabilities, similarly as it is done in PSTN network. Following this approach, a request sending by the calling user is transferred via the signaling system and it is submitted for allocating the resources to each domain along *a priori* defined path to the called user. In the response to this request, the domain checks, by the Connection Admission Control (CAC), whether the required resources are available and, if the answer is positive, they are allocated. On the contrary, if there are no available resources, the request is rejected and this happens when the network is just loaded and no more connections can be accepted. Finally, in this way we guarantee the absolute QoS requirements at the packet level for accepted connections.

The example of such connection-oriented network is the solution developed by the EuQoS project [1][2][3]. EuQoS is an European research project aimed at building an entire QoS framework, addressing all the relevant network layers, protocols and technologies. This framework, which includes the most common access networks (xDSL, UMTS, WiFi, and LAN) is being prototyped and tested in a multi-domain Pan European scenario, composing what we call the EuQoS system. The EuQoS system offers the capabilities for transferring signaling messages across the multi-domain heterogeneous network and its architecture is depicted on Figure 1. One can distinguish between two different behavioral subsystems, i.e. the application layer and the (virtual) network layer, where we again have two sub-layers: Technology Independent (TI) sub-layer and Technology Dependent (TD) sub-layer. The application layer is responsible for the user-user communication signaling and is aimed at making agreement corresponding to the setting of the same set of multimedia devices, i.e. on a set of compatible codecs. This upper layer signaling can be performed twofold: by EQ-SIP, enhanced version of SIP (Session Initiation Protocol [4]) protocol developed in the EuQoS project, or by any legacy signaling protocol (e.g. SIP or H.323 [5]). Furthermore, the TI sub-layer is responsible for the QoS negotiation and resource reservation along the QoS-path between communicating terminals. So, after successful signaling at the application layer, the request for the resource allocation is submitted to the network layer. In the TI layer, the key elements are RMs (Resource Managers),

[1] EuQoS system is the QoS multi-domain system that is being developed and tested inside 6FR European project "End-to-end Quality of Service support over heterogeneous networks"

that are in charge of handling the requests per domain (including inter-domain link). It means that they are responsible for the multi-domain routing (as in [6]) and sending requests for resource reservation to the TD layer. Again, in the TD layer the key elements are RAs (Resource Allocators) that perform CAC function and communicate to the network elements (e.g. routers) for setting for this connection the appropriate mechanisms (as policers, schedulers, markers etc.). The signaling transmission between RMs is supported by NSIS (Next Step in Signaling [7]), while between RM and RA by COPS (Common Open Policy Service [8]) protocols.

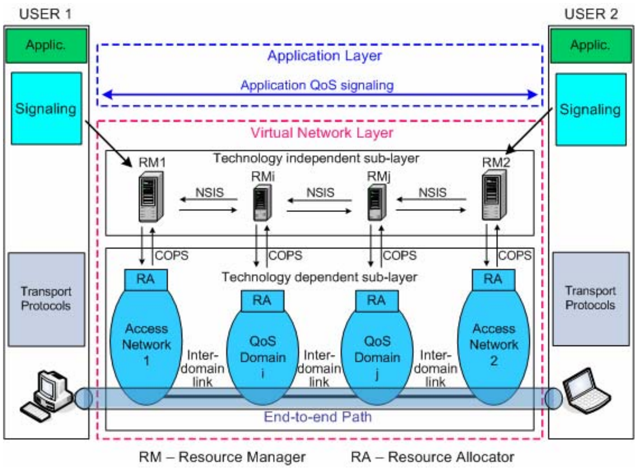

Figure 1. The EuQoS system architecture.

In this paper we present, evaluate and compare three strategies for handling new connection requests that are based on: (1) only per flow treatment by each domain and it means that all resources are allocated on a new connection demand only, (2) per flow treatment only by ending domains while using resource pre-reservations in transit domains, and (3) an intermediate approach that is based on partitioning the resources in transit domains into two parts – one fully reserved for the connections that are admitted only by handling in the ending domains and use pre-reservations in transit domains and one that is dedicated to the requests that are handled in transit domains as well. The approaches mentioned above are examined from the point of view of the link utilization, call blocking probabilities and involving of the signaling system.

The organization of the paper is as follows. Section 2 provides us with the details about the considered strategies for handling new connection requests. The numerical results are shown in section 3. Finally, we conclude the paper.

II. STRATEGIES TO ALLOCATE RESOURCES FOR NEW REQUESTS

A path between ending domains consist of a number of parts in multi-domain network that are related to intra- and inter-domains areas. Therefore, for setting resources for a new connection request along such a path we can consider some options, depending on the solution we chose for the resource pre-reservations.

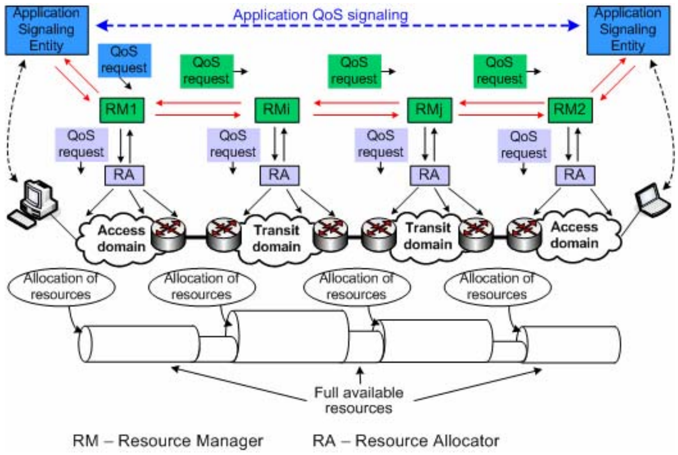

Figure 2. The Per-Flow strategy for resource reservation.

The first considered option that is currently implemented in EuQoS system is to make the status of all resources in each part of the network as fully available for all new connection requests. As a consequence, for allocating the resources to a new request we transfer the signaling message from the domain to peering domain along the path and perform per flow operation in each domain for allocating resources in intra- and inter-domain areas (see Figure 2). It means that the network resources in each part of the multi-domain network are allocated on a new connection request demands only, similarly as it is done in the IntServ architecture [9] with the remark that now we speak about reservations in domains, while the IntServ deals with the nodes. In the further part of the paper we will call this strategy PF (Per-Flow) strategy.

In general, the solution based on per flow call handling provides better resource utilization and a strict QoS assurance, but it affects the network scalability [10]. Since the PF strategy requires involving all EuQoS system elements in each domain to handle every call request, its complexity increases as a function of the number of flows.

The above-mentioned disadvantage does not apply to the second investigated approach of the resource allocation for new connections. It relies on making a priori pre-reservations in chosen parts of the path for given pair of ending domains. More precisely, we do pre-reservations in all transit domains, where huge amount of served flows leads to large load of RMs due to necessity of handling signaling messages as well as maintaining the state of each call. As a consequence, we can handle new requests only in the ending domains, which usually are access domains, where the number of flows is relatively small. By allocating resources RM element at ingress domain knows how much resource is available on a path towards egress domain and the CAC algorithm can be performed merely at the entrance of the pre-reserved tunnel. The pre-reservations can be done in the pre-provisioning process and can be updated, in long time scale, by re-provisioning procedure, depending e.g. on the load in the network. Notice, that in this approach we make partitioning of all available capacity in transit domains into all pairs of ending domains which use this domain on the path to the destination domain. In fact, in the considered example we create a logical mesh topology in multi-domain network. Such a solution can be attractive since it has a potentiality for decreasing of connection set-up time due to limiting the resource reservation procedure to be made in the ending domains only. In particular, the pre-reservations can be related to the establishing MPLS tunnels and their dimensioning. The discussed approach, we call PR (Pre-Reservation) strategy, is illustrated on Figure 3. In the PR strategy we do not involve in transit domains the RM and RA elements. At most, when the information about RM entity at the domain which is situated on the "end" of pre-reserved tunnel cannot be reached directly by the RM at the beginning domain, RM elements play the role of transit signaling nodes only, since each RM "knows" the RMs of adjacent domains (see Figure 3).

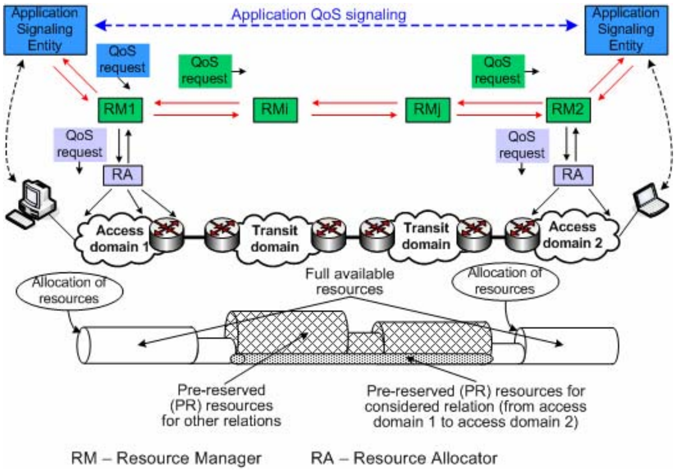

Figure 3. The Pre-Reservation strategy for resource reservation.

However, notice that in PR scheme we loose the potential profits we can get from the multiplexing as we expect to have from using the PF strategy [11]. Another point is that in some cases the logical mesh network structure cannot be scaled when the number of ending domains increases. In this case, we can modify the concept of PR strategy by making resource pre-reservations only in some network areas while keeping fully available capacities in other areas. However, this extended option is not considered in this paper.

There are many others than PR strategies copy with the lack of scalability resulted from per flow management on each part of the network. The most popular seems to be the aggregation of flows into classes of flows, and then handling them instead of individual flows. This approach is the base of the DiffServ architecture [12], therefore, it does not require any per flow operations in the core of the network. However, the lack of per flow information causes that DiffServ cannot provide strict QoS guarantees [13]. Another way to eliminate signaling load is to make an admission control decision by the host (or by the ingress node) taking into account only results obtained from probing the path on which data will be transferred [14][15]. Although this approach requires no signaling, the problem causes relatively long call set up delay, since gathering the adequate information about the network resources needs appropriate period of probing before sending the data. The next issue is the necessity of using suitable traffic generators, which can produce the probe traffic with the same profile as will be send during data transmission phase. It applies particularly to the real-time video applications (e.g. video teleconferencing), which generate VBR flows. As far as so-called *endpoint admission control* is concerned [11][16], though this approach does not require per flow handling in the core, in multi-domain environment, as e.g. the EuQoS system, it needs to exploit the admission control decision at egress router of each domain, also transit, for every new call request. Per flow handling in the transit domain is what we want to avoid by applying the PR strategy.

The last strategy discussed in this paper is an intermediate approach between the PF and PR strategies. The main idea is based on *partial sharing* policy proposed for satellite systems [17][18] and B-ISDN [19]. It relies on dividing the resources in transit domains into two main parts, when one part is for pre-reservations, the rest of capacity is fully available and is allocated on the basis of the new connection request. Therefore, the basic resource allocation scheme is to use pre-reservations and to limit per flow operations to the ending domains, as it is in the PR approach. However, if there is no available capacity in the pre-reserved area then the new connection request is handled on the PF basis and allocates the resources from the fully available part. As a consequence, we expect that the majority of the new requests will be handled on the PR scheme while by keeping functionality of using PF scheme we will be able to get better resource utilization and improve the number of successful allocations. The latter relates to e.g. situations when the offered load temporarily exceeds the expected value for which pre-reserved resources were provisioned. Since re-computation of allocated tunnels constitutes rather complex process in terms of computation time as well as required distribution of the information about the new configuration for the ingress/egress nodes, we assume that pre-reservations in PR strategy should not be updated dynamically, to cover above-mentioned traffic growth, but only in long time scale, at provisioning procedure.

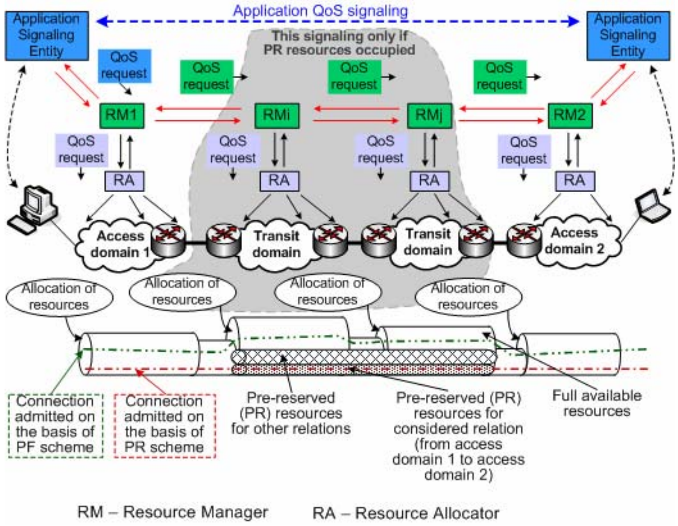

Figure 4. The SomeTimes Per-Flow strategy for resource reservation.

The discussed strategy is illustrated on Figure 4, and in further part of the paper we will call it STPF (SomeTimes Per Flow) since we expect that a new connection request will be handled on the basis of PF strategy only sporadically. This means that all EuQoS system elements in transit domains will be used only sporadically, too.

Because STPF assumes that RM elements in transit networks have the same functionality as RMs in ending domains, there is no necessity of pre-allocating resources in transit domains as e.g. MPLS or GRE tunnels. The standard procedure, as during arrival of new call request, can be exploited, with appropriate amount of requested resources. To work properly, RM elements in ending domains need to use a *get_next_RM()* function, which returns "address" of RM in egress domain of the pre-reserved tunnel (if new call is admitted to pre-reserved pool of resources) or RM in adjacent transit domain (if there is no available capacity in pre-reserved part).

III. Numerical Results

In this section we are going to show the basic numerical evaluation results comparing the presented approaches for resource allocation strategies for new connection requests. We evaluate these strategies from the viewpoint of the resource utilization, call blocking probabilities and involvement of the signaling system. To obtain the numerical results we built a flow-level simulator emulating a chain of M/M/N/N queues. Arrival of a new call is noted along with its bandwidth requirement and duration time. There is no packet level details, as we assume that the packet level statistical properties of generated traffic are taking into account during provisioning phase, when appropriate CAC limits are calculated.

The experiments are performed for the sinking tree multi-domain scenario. For example, one of the studied network scenario is depicted in Figure 5, in which we have 10 domains and among them the domains labeled as n10 ... n15 are the source domains that generate traffic to the destination domain n4 via the transit domains n21/n22 and n3. Each of these domains is described by an amount of available resources, represented by the link capacity counted by the number of homogenous channels. So, a single domain represents the whole intra-domain or the outgoing link from border routers when we deal with inter-domain area. In each domain we can perform CAC function, when we use PF or STPF strategies. For PR strategy the CAC is performed only in the source domains. In this example, the whole capacity of domain n*x* is denoted as *N_x* while the pre-reserved capacity is denoted by *NR_x*. Furthermore, we assume that at the second stage where the traffic from the source domains is aggregated, the capacity N_21 (N_22) is half of merged capacities N_10, N_11 and N_12 (N_13, N_14 and N_15 respectively). Similarly, the capacity of link N_3 is half of merged capacities N_21 and N_22. As a consequence, link N_3 constitutes the bottleneck of the system.

The experiments were performed assuming that call input process is Poissonian process with exponential service time distributions (normalized to 1, $\mu = 1$). The calls arrive to each source domain with the same arrival rate λ. Arriving calls request the same amount of bandwidth that is equal 1 channel. So, the capacity of each link, expressed in number of channels, indicates the maximum number of connections they can run simultaneously. A call which cannot be accepted by the system is blocked and cleared.

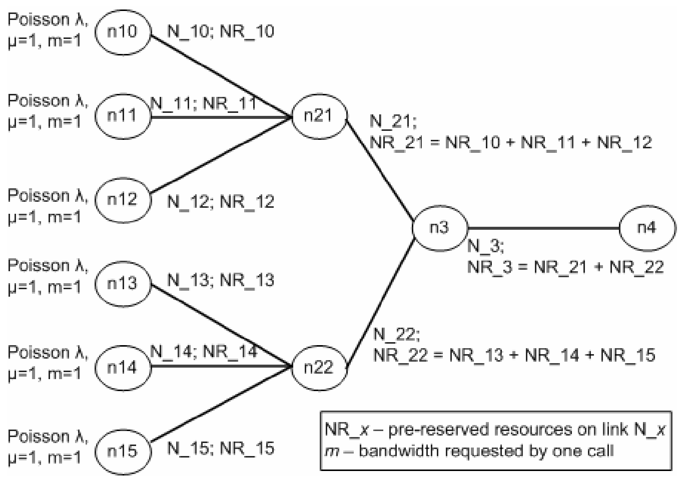

Figure 5. Studied multi-domain topology.

The reported simulation results correspond to three cases. In case#1 we assume 6 source domains (as shown on Figure 5) and relatively low level of multiplexing, i.e. capacities of links, where traffic is aggregated, are 100 times bigger than capacity demanded by a single connection request. This case can be representative for handling e.g. VoD (Video on Demand) connections where each connection requires, for instance, 2 Mbps. On the contrary, in case#2 we assume relatively high level of multiplexing where link capacities are of 1000 times bigger than bandwidth requested by a single call. Such situation can take place when we handle e.g. VoIP (Voice over IP) connection each requiring for instance 64 Kbps. For the case#2 we consider two scenarios, with 6 and 10 source domains (3 or 5 source domains connected to each of transit domains: n21 and n22). Finally, in case#3 we compare traffic load in link N_3 for the PF, PR, and STPF strategies as a function of the number of attached source domains (number of pre-reserved tunnels established on the link N_3). For STPF we assume that 20% of link N_3 capacity is dedicated for per-flow connection request handling.

Each link has the reservation pool, described as *NR_x*, which indicates the amount of capacity units designated to handle arriving calls according to the PR strategy. During each simulation, reservation pools in the links between source domains and domains n21/n22 were the same. It is worth mentioning that when these reservation pools are 0 (no resources reserved) we consider the PF strategy. On the other hand, when the reservation pool amounts to e.g. 25 units for case#1, we consider the PR strategy – reservation of 25 units on links N_10 … N_15 means that the whole capacity of the link N_3 is reserved ($6 \cdot 25 = 150$) and there is no free capacity to handle QoS requests in per-flow manner.

The measured parameters are: (1) blocking probability, (2) signaling ratio (sig_ratio) defined as the ratio of number of calls handled in a per flow manner, i.e. complete reservation process in each node is performed, to the total number of calls handled during simulation, and (3) link N_3 load which indicates the average load of bottleneck link between domains n3 and n4, where flows are aggregated.

For case#1 and #2 we study the impact of reservation pool size on signaling ratio, blocking probability and link N_3 utilization, assuming load offered to the network appropriate to achieve fixed blocking probability equals 10^{-2}.

The simulations were performed respecting the following rules: (1) during each simulation at least 10^6 calls arrived to each source nodes, (2) each simulations were repeated 12 times to account for the random nature of the experiment. All results are represented without 95% confidence intervals as these intervals were negligible.

A. Simulation Results

Table 1 shows the numerical results that correspond to the case#1 for the network with 6 source domains, where N_10= N_11= N_12= N_13= N_14= N_15= 100, N_21= N_22= 150 and N_3= 150. The PR, STPF and PF strategies are examined for different traffic conditions but guarantying that the call blocking probability is kept in all studied systems on the level of 0.01. For the STPF strategy we have assumed different percentage of resources dedicated from the N_3 link for allocation to the new connection requests handled on per flow basis. The results say that by employing the STPF strategy we can: (1) comparing to the PR strategy, we can considerably improve link utilization even when the percentage of the calls handled on per flow basis is not more than 10%, (2) comparing to the PF strategy, we can radically decrease the percentage of calls handled on the per flow basis while keeping similar level of link utilization. Concluding, the STPF strategy seems to be very attractive since it can take advantages from both the PR and PF strategies while eliminates theirs drawbacks.

TABLE I. CASE#1: SIMULATION RESULTS FOR PR, STPF, PF STRATEGIES UNDER CONDITION THAT CALL BLOCKING PROBABILITY IS 0.01.

Strategy	% of link N_3 capacity dedicated for per flow call handling	sig_ratio	Load of link N_3
PR	0.0%	0.000	0.639
STPF	6.7%	0.056	0.743
STPF	10.0%	0.083	0.767
STPF	13.3%	0.111	0.785
STPF	16.7%	0.140	0.799
STPF	20.0%	0.169	0.808
PF	100.0%	1.000	0.869

Table 2 shows the results that correspond to the case#2 for the network with 6 source domains, where N_10= N_11= N_12= N_13= N_14= N_15= 1000, N_21= N_22= 1500 and N_3= 1500. Comparing to the case#1, now we examine the PR, STPF and PF strategies assuming the high level of multiplexing. The presented results say that in this case the differences between link utilization are not so visible as in the previous case, due to multiplexing gain appears inside pre-reserved tunnels. Notwithstanding, by using the STPF strategy, we still get benefits of keeping high level of link utilization by allowing per flow allocation.

TABLE II. CASE#2 FOR 6 SOURCE DOMAINS: SIMULATION RESULTS FOR PR, STPF, PF STRATEGIES UNDER CONDITION THAT CALL BLOCKING PROBABILITY IS 0.01.

Strategy	% of link N_3 capacity dedicated for per flow call handling	sig_ratio	Load of link N_3
PR	0.0%	0.000	0.905
STPF	6.7%	0.066	0.949
STPF	10.0%	0.098	0.955
STPF	13.3%	0.129	0.959
STPF	16.7%	0.161	0.961
STPF	20.0%	0.194	0.963
PF	100.0%	1.000	0.972

Table 3 shows the results that correspond to the case#2 for the network with 10 source domains, where N_10= N_11= N_12= N_13= N_14= N_15= N_16= N_17= N_18= N_19= 1000, N_21=N_22= 1500 and N_3= 1500. One can observe that by increasing the number of source domains from 6 to 10 (i.e. decreasing a single pre-reserved tunnel capacity), we again observe the more visible benefits of using the STPF strategy comparing to the PR and PF strategies.

TABLE III. CASE#2 FOR 10 SOURCE DOMAINS: SIMULATION RESULTS FOR PR, STPF, PF STRATEGIES UNDER CONDITION THAT CALL BLOCKING PROBABILITY IS 0.01.

Strategy	% of link N_3 capacity dedicated for per flow call handling	sig_ratio	Load of link N_3
PR	0.0%	0.000	0.869
STPF	6.7%	0.070	0.933
STPF	10.0%	0.101	0.943
STPF	13.3%	0.132	0.948
STPF	16.7%	0.164	0.953
STPF	20.0%	0.197	0.956
PF	100.0%	1.000	0.972

Finally, in the Figure 6 we show the characteristic of N_3 link load utilization as a number of tunnels that are pre-reserved, under the assumption that for the STPF strategy we have 20% of this link capacity for per flow resource allocation. The rest of the assumption is as for the case#2. The presented results say that by increasing the number of tunnels in this link its utilization decrease when we apply the PR strategy. On the other hand, by using the STPF we do not observe this drawback and comparing to the PF strategy, the difference in link utilization is not so significant while we have still only not more than 20% of new requests handled on per flow basis, what significantly reduces signaling load in transit domains.

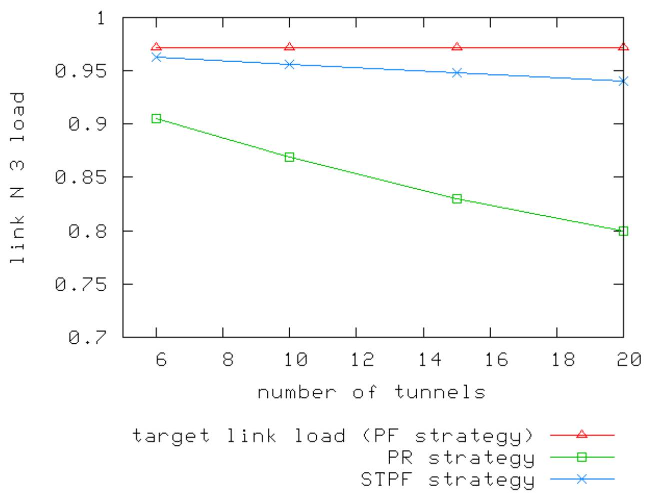

Figure 6. Utilization of the Link N_3 as a function of number of pre-reserved tunnels for the PR and STPF strategies (for STPF 20% of link N_3 capacity is dedicated for per flow resource allocation).

IV. CONCLUSIONS

In this paper we have presented and evaluated the approaches to allocate resources for the new connection requests in QoS multi-domain networks with signaling capabilities. The investigated approaches were: (1) PF, only per flow treatment by each domain, (2) PR, per flow treatment only by ending domains while using the resource pre-reservations in transient domains, and (3) STPF that is an inter-mediate approach and assumes to use PF scheme only if there is no available pre-reserved resources. The reported numerical results show that the STPF strategy can be a very attractive solution since it guarantees high link utilization, similarly as by using PF strategy, simultaneously handling majority of new connection requests with PR strategy. As a consequence, the new requests will be handled on per-flow basis only sporadically, thanks to it we can radically reduce, comparing to the PF strategy, signaling load in the transit domains.

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