Bandwidth Sharing in SLA Negotiation Process

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Abstract

In this paper we propose efficient resource management technique to predict sufficient bandwidth resources for traffic caused by contracting of SLAs (Service Level Agreement). Such bandwidth expansion and bandwidth sharing technique can be a part of TEQUILA architecture based on autonomic computing and could be an important part of negotiation process in SLA creation (DiffServ/MPLS networks). The problem is seen as an expansion problem of link capacities (bandwidth) that can be done dynamically from NP (network provider). Also, it helps to avoid the creation of bottleneck links on the path and maintains high network resource utilization efficiency.

Index Terms - dynamic bandwidth sharing, admission control in DiffServ/MPLS networks, SLA creation, end-to-end QoS routing, traffic routing of aggregate flows.

1. Introduction

In DiffServ networks the classification of the aggregated flows is performed according to the SLA (Service Level Agreement) signed between a customer and the network operator. Multi-protocol label switching (MPLS) has gained popularity as a technology for managing network resources and providing of performance guarantees. In this paper we are looking for optimal path provisioning for all existing SLAs participating in the same time period (former contracted SLAs); see fig. 1. The main condition is: the sufficient network resources must be available at any moment of that period. In the worse case it must be sufficient for the first service class (full satisfied). Expansions of link resources in any virtual network (VN) can be made dynamically from the transport network provider (NP). If it is possible to predict sufficient link resources (without shortages), the possibility of traffic congestions will be significantly reduced in the moment of service invocation.

The network operator (e.g. ISP) wants to accept new SLA (traffic flow) that generates the traffic flow between edge routers. In DiffServ/MPLS architecture we call them LER (Label Edge Router). Traffic demand on exit of LER represents the sum of all ingress and egress flows. Interior routers in core network, capable to forward traffic in equivalent classes (FEC), are called LSR (Label Switching Routers). The network that is shown in fig. 2. can be a representation of such architecture. Such aggregated flow is coming to LSR and has to be routed to destination (egress router). Packets of the same FEC are assigned the same label and generally traverse trough the same path across the MPLS network. A FEC may consist of packets that have common ingress and egress nodes, or the same service class and same ingress/egress nodes or any other combination. In this case, the FEC of appropriate service class aggregates traffic demands (new SLA and former contracted SLAs) of the same QoS level. A path traversed by an FEC is called a label switching path (LSP). In that sense network operator has to find optimal path for the FEC but without any congestion in the network. Possibility of congestion on some links (with nominal bandwidth) exists, specially for definite period of time; see fig. 1. For each communication link in the network given traffic demands can be satisfied on three different QoS levels (different bandwidth). At the SLA level, the transport network resources are shared by set of per-class, per ingress/egress-pair SLAs. Traffic can be satisfied on appropriate QoS level or higher, but not on lower QoS level.

In fact, we use different LSP for different service class. But we don't want that physical network be divided into multiple virtual networks, one per service class. The

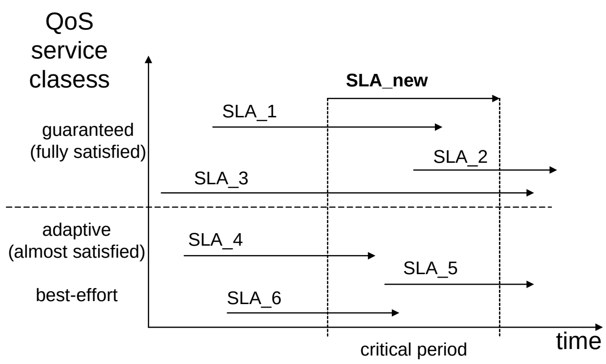

Figure 1. An example of number of SLAs that participate in the same period of time. The bandwidth sharing and the congestion control has to be done, specially for critical period for new SLA.

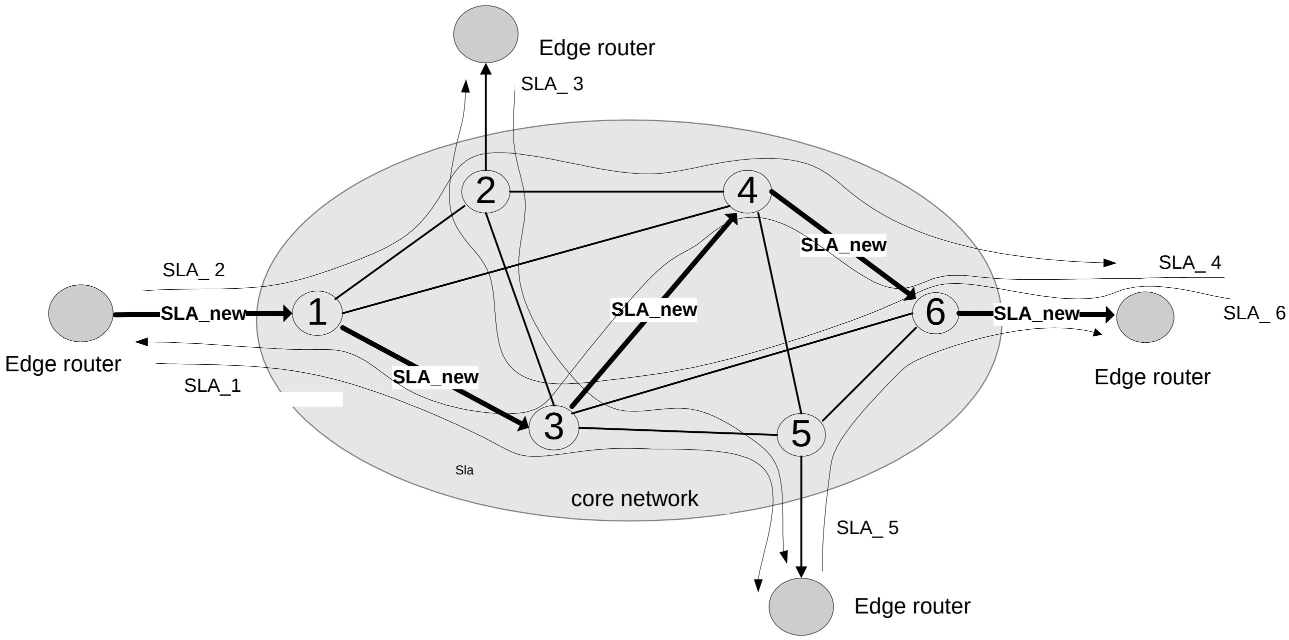

Figure 2. An example of number of SLAs in context of network configuration. They share bandwidth on the links in the same period of time; see fig. 1. New SLA can be accepted only if we can find optimal path from end-to-end with enough free capacity.

end effect is that we want to give to premium traffic more resources, but exactly that is necessary, no less no more. In the same time we strongly need the optimal utilization of limited capacity and to minimize the bandwidth expansion.

So we need congestion control/expansion algorithm related on limited link resources and predicted traffic (caused with accepted SLAs). We need very effective tool to optimize network bandwidth dynamically. The optimal resource management problem can be seen as the link capacity expansion problem (CEP) from the common source with expansion values in allowed limits; see [4] and [6]. If the optimal routing sequence has any link expansion with value that exceeds allowed limits, it means that link capacity on the path cannot be sufficient for such traffic. It means that new SLA cannot be accepted and must be redefined through negotiation process. For example, the customer can decide to take the adaptive QoS service class instead of fully satisfied (guaranteed) service class.

In the next discussion the problems of dynamic bandwidth sharing technique between SLAs are investigated. Explanation of the mathematical model and heuristic approach for link bandwidth expansion technique is given in section II. Numerical examples, testing results and algorithm application are discussed in section III.

Some important papers about that problem are [1], [2] and [3]. In paper [1] such bandwidth sharing technique is a part of TEQUILA architecture based on autonomic computing. In the paper [5] such algorithm is the part of service management architecture. In paper [8] similar network engineering technique is related on path provisioning.

2. Algorithm Development

The problem of the optimal bandwidth sharing for given traffic with different service classes can be seen as the *Minimum Cost Multi-Commodity Flow Problem* (*MCMCF*) in the single (common) source multiple destination network. It is very complex problem (*N*-complete). Instead of nonlinear convex optimization method we divided problem into two-level network optimization, looking for objective function. For the first optimization level we are calculating the minimal link weight between any pair of capacity points. We call it: sub-problem. Algorithm is looking for the best expansion solution among all possible (minimal cost). On the second optimization level we are looking for shortest path in the network with calculated link weights between node pairs.

Such problem can be solved as the capacity expansion problem (CEP) without shortages. Partially expansions for each link are made from common source in given limits (existing link capacity). Transmission link capacities (bandwidth) on the path between routers are capable to serve traffic demands for N different QoS levels (service class) for $i = 1,2, ..., N$. Fig. 2. gives an example of possible path for new SLA that consists of M internal (core) routers included in the path.

Link capacity that is capable to serve traffic demands of service class i we call *facility.* It is used primarily to serve demands for QoS level i, but it can be used to satisfy traffic demands for QoS level j ($j > i$). Rerouting of traffic demands towards higher QoS level is the same thing as facility conversion to lower QoS level. In this model conversion of traffic demand is permitted only in the direction toward higher QoS level. It means that almost satisfied service class (adaptive or best effort) can be treated as fully satisfied (guaranteed) service class, but not vice versa.

In formulation (1) and (2) α_m denotes the vector of capacities $I_{i,m}$ for all QoS levels (facility types) on link m. Generalizing the concept of the capacity states for each quality level of transmission link m in which the capacity states of each link are known within defined limits we define *a capacity point* - α_m.

$$\alpha_m = (I_{1,m}, I_{2,m}, \dots, I_{N,m}) \quad (1)$$

$$\alpha_1 = \alpha_{M+1} = (0, 0, \dots, 0) \quad (2)$$

Formulation (2) implies that idle capacities or capacity shortages are not allowed on the link between edge and interior router (first and last link on diagram on figures). Link capacity values are positive only and shortages are not allowed.

If the link expansion cost corresponds to weight of used capacity, the objective is to find optimal routing policy that minimizes the total cost incurred over the whole path between edge routers (M interior routers and M + 1 transmission links) and to satisfy given traffic demands. The flow theory enables separation of these extreme flows, which can be a part of an optimal expansion solution, from those which cannot be. With such heuristic approach we can obtain the optimal result with significant computational savings; see [4].

Let the value $d_{u,v}(\alpha_u, \alpha_{v+1})$ represents the minimum cost between two capacity points. Calculation of that value is denoted as CES (*Capacity Expansion Sub-problem*). In the CEP we have to find many cost values $d_{u,v}(\alpha_u, \alpha_{v+1})$ that emanate two capacity points, from each node (u, α_u) to node $(v+1, \alpha_{v+1})$ for $v \geq u$.

The approach described in [7] requires solving repeatedly a certain single location expansion problem (SLEP). Many different expansion and conversion solutions (rerouting) can be derived. Lot of expansion solutions are not acceptable and they are not part of the optimal sequence, that is the key of the heuristic approach. Most of the computational effort is spent on computing the sub-problem values. Any of them, if it cannot be a part of the optimal sequence, is set to infinity.

Suppose that all links are known, the optimal solution for CEP can be found by searching for the optimal sequence of capacity points and their associated link state values for each time period. On that network optimization level problem can be seen as a shortest path problem for an acyclic network in which the nodes represent all possible values of capacity points. It has to be noted that the optimal routing sequence for traffic flow (included new SLA) between edge routers need not to be the shortest path solution. On this level of algorithm calculation it is very easy to introduce delay limits on the path. The number of all possible $d_{u,v}$ values depends on the total number of capacity points. It is very important to reduce that number and that can be done through imposing of appropriate capacity bounds or by introduction of adding constraints.

The required effort for one sub-problem is $O(N^2M)$. The number of all possible $d_{u,v}$ values depends on the total number of capacity points. If there are no limitations on capacity state ($I_{i,m}$) and expansion amount the complexity of such heuristic approach is pretty large and increases

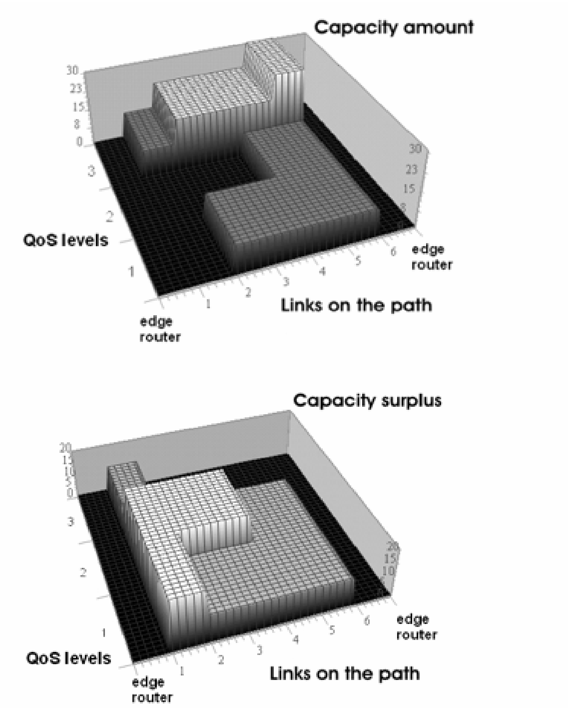

Figure 3. In this numerical test-example link capacities are sufficient to satisfy traffic demands.

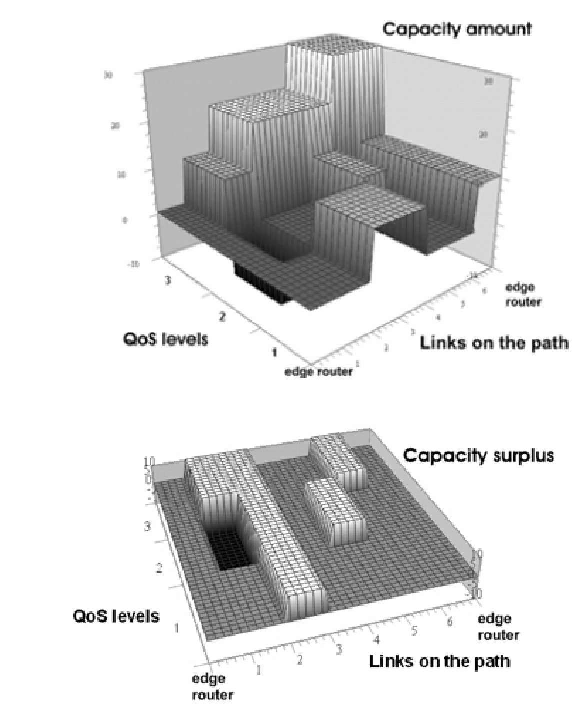

Figure 4. In this numerical test-example the lack of capacity on the link is obvious and acceptance of new SLA is critical. An arrangement of adding capacity is possible.

exponentially with N. Problem requires the computation effort of $O(M^3N^4R_i^{2(N-1)})$. In real application we normally apply definite granularity of capacity values. It reduces the number of the capacity points significantly.

3. Testing Results

We tested our algorithm on many numerical test-examples, looking for optimal routing sequence on the path. Between edge routers there are maximum six LSR (core routers) and they are connected with seven links. Traffic demands (SLAs) are overlapping in time. The heuristic algorithm in all test-examples can achieve near-optimal expansion sequence with minimal total cost, with equal or very close value to that one we can get with algorithm based on exact approach.

If the expansions of link capacities are possible (in allowed limits) or the capacity surplus is obvious, the traffic demands can be satisfied. In example from figure 3. we can see that traffic demands can be fully satisfied and capacity surplus for all links are positive or zero. There are no negative values; see diagram in fig 3.

In example from figure 4. we can notice the lack of capacity on the second link (for second QoS level). It means that traffic demands cannot be fully satisfied although the surplus is obvious on third (lower) QoS level. There is no free capacity on the first QoS level (for the premium service class) to be used instead. It means that adding capacity is not possible to arrange from NP. In that case new SLA cannot be accepted or must be redefined through negotiation process. With such management tool we can predict sufficient bandwidth on the link and possible congestions on the path very efficiently. Also,

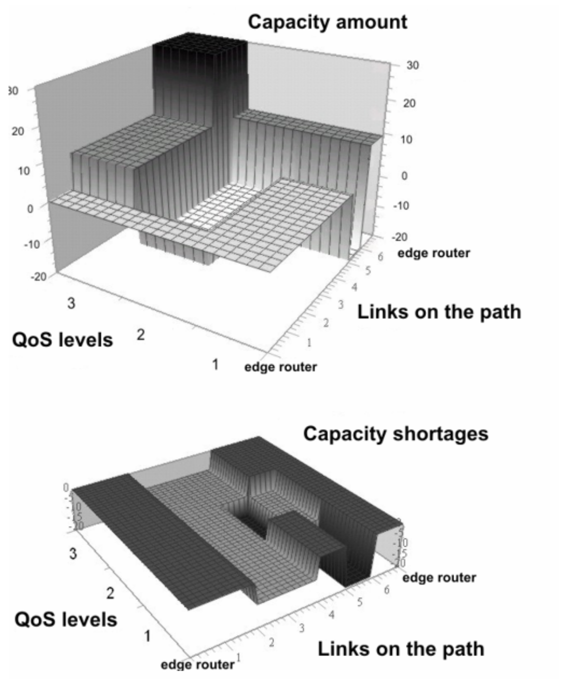

Figure 5. Shortages exist on many links and for such SLAs could be very hard to ensure enough capacity.

with such tool we can introduce new link capacity resources (bandwidth) in optimal way. Bandwidth sharing between SLAs can be done dynamically. Such explicit traffic engineering technique provides the possibility to intelligently tailor the route foe each SLA traffic flow such that different parts of the network remain equally loaded. Also, it helps to avoid the creation of bottleneck links on the path and ensures optimal network resource utilization.

4. Conclusions

In the process of SLA management in DiffServ/MPLS network the bandwidth sharing between traffic demands of existing SLAs has to be done and it could be done dynamically. It is the important part of SLA negotiation process and it can be done with proposed heuristic algorithm. Such optimization technique can predict situation on the link (sufficient bandwidth) in the moment of service invocation and can significantly reduce the possibility of traffic congestions. Algorithm is based on mathematical model for the capacity expansion problem (CEP). The first aspect of algorithm is that load balancing leads to minimal cost for used bandwidth and to higher resource usage efficiency.

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