MPLS versus IP for Interworking of Wide Area Subsystems with QoS Guarantees

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Abstract

The paper analyzes two solutions (IP and MPLS) for interworking of network portions implementing different QoS technologies and belonging to diverse Autonomous Systems (ASes). While the implementation of QoS is a AS's concern, three topical problems should be solved at the interworking points (called Relay Points, RPs, in the paper): 1) the definition of the RP convergence technology, 2) the signalling between the RPs, 3) the bandwidth pipes dimensioning for flows traversing the heterogeneous network. The paper investigates these points and proposes a description of the Service Level Agreements available in the heterogeneous network as function of the RP protocol architecture.

The RP stack proposed needs to interact with ASes QoS-solutions. It means that the RP QoS must be "mapped" on alternative technologies (DiffServ, IntServ, ATM and so on), implemented locally. This leads to the analysis of the traffic aggregation effect on the performance, e.g., if traffic requiring different performance is joined in one flow for technological reasons. The results reported, obtained through simulations, investigate this topic and allow providing operative solutions applicable in the field.

1. Introduction

The support of *end-to-end* (e2e) QoS over heterogeneous networks, composed of different wide area subsystems (also called *Autonomous Systems*, ASes, in this paper), is a hot topic of research. The main point is to build an overall e2e architecture that offers full support to QoS, independently of the single solution (ATM, IP-DiffServ, IP-IntServ, and, more recentely, MPLS and DVB) part of the heterogeneous network. The connection point interconnecting two ASes is defined as *Relay Point* (RP). The role of RP is **1)** to establish a proper interface between two ASes; **2)** to transfer the QoS needs for each e2e connection across them. **3)** Once transferred the QoS requests among the ASes, it is topical to map the performance requests over the peculiar technology implemented within each AS.

In this view, the paper highlights the advantages of the MPLS interworking solution (firstly proposed in [1]), by focusing both on inter-domain signalling and on other IP-centric approaches. It also generalizes the results presented in [1] by considering real VoIP and video traces with a large range of QoS metrics.

The paper is organized as follows. The following section summarizes the IP solution for RP. Section 3 deals with the proposed MPLS architecture. Performance evaluation is the subject of section 4. Conclusions and future work are summarized in section 5.

2. IP-centric QoS Architecture

The first solution for QoS interworking that can be suggested is IP-centric. It means that the common e2e language is IP both concerning QoS definition and interworking architecture. The architecture of IP-centric RP protocol stack is detailed in Fig. 1.

It means that RP acts as an IP router concerning all the aspects (routing, encapsulation, processing). The IP-DiffServ paradigm is chosen for scalability purposes. A proper definition of the *DiffServ Code Point* (DSCP) is thus necessary to cover the entire

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network with a common set of *Service Level Agreements* (SLAs) (the *extended QoS class* concept, in [2] terminology).

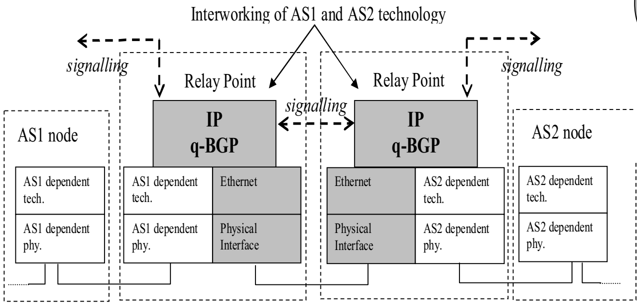


Fig. 1. IP-centric Relay Point.

According to the DiffServ paradigm, to define a common set of SLAs among the ASes, there are 14 traffic classes characterized by a common assignation of the DSCP field. Each of the mentioned classes deserves its specific SLA, expressed in terms of: **1)** traffic description, **2)** conformance testing parameters and **3)** required performance guarantees (e.g., loss rate, delay and delay jitter of the packets) and, when needed, priority preemption and connection protection [3] levels.

The coordination of resource allocation to guarantee the SLAs in the heterogeneous network implies the presence of a signalling protocol to transfer the QoS needs and possible feedback about the congestion of the network. Fig. 2 shows a possible abstraction of the IP e2e architecture at management plane. The way to transport QoS requirements between RPs relies on QoS-*Border Gateway Protocol* (q-BGP) and its architectural improvements [2]. Each single network portion implements a *Bandwidth Broker* (BB) that negotiates SLA with neighbour ASes, implements *Call Admission Control* (CAC) and QoS management. Management and data planes are completely decoupled: there is one centralized BB for each domain, which communicates with the RPs separating the different network domains. The SLA agent is responsible for the contract between neighbour domains. On the basis of the contract, the SLA agent controls the configuration agent to set the forwarding path in the RP and the related controls (such as classifier, marker, and scheduler). The relation with the RP is immediate: SLA agent and resource control agent may be part of the RP, while the check about the status of the single portions may be left to the BBs responsible for the ASes themselves.

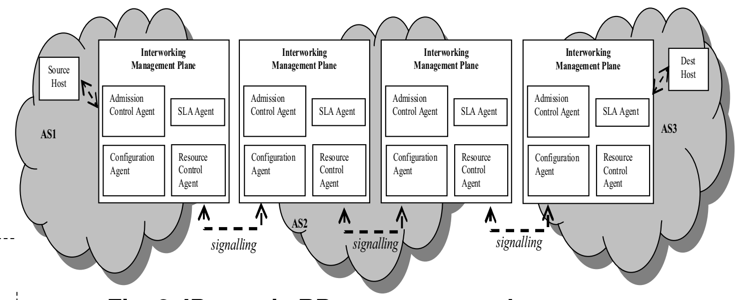


Fig. 2. IP centric RP management plane.

3. MPLS-Centric QoS Approach

Actually, the solution presented in section 2 offers *loose guarantees* QoS [2], which do not support *traffic engineering* (TE). Anyway, also generally speaking and considering a *hard guarantees* QoS [2] supported by signalling (RSVP-like) over the IP architecture, the key point is that the exclusive application of the DiffServ paradigm may not be completely satisfying. **i)** It looses the reference to the single connection and **ii)** does not guarantee sufficient SLA flexibility. As should be clear also from the results of this paper, no bandwidth optimization can be reached. Concerning point **i)**, no guarantee may be provided to the single user; MLPP and recovery management are applicable by using complex solutions (some good examples are reported in [4]). Concerning point **ii)**, if the number of traffic classes increases (for example if enlarging the granularity of QoS constraints is necessary due to novel applications), or MLPP and connection protection classification is required, the 8-bits of the DSCP may be unsufficient for SLA categorization, especially if some parts of the DSCP itself are used for control purposes [4]. As a result, the adoption of an alternative technology matching the previous points reveals to be much more effective, especially from the TE viewpoint. This is the rationale of the following MPLS-based architecture.

The MPLS-based RP protocol architecture is reported in Fig. 3. MPLS acts as a layer 2.5. The traffic flows of the ASes come from the hosts plus the MPLS shim header (the MPLS label) added at the first RP. The labelled packets are tunnelled along the ASes (not necessarily MPLS capable) and forwarded. MPLS is used at RPs to classify packets of each traffic class, thus inferring the guaranteed bandwidth, the class-related scheduling, the packet discarding treatment, and, in general, the SLA treatment of the packet. The encapsulation solution recalls the principle of MPLS-based *Virtual Private Networks* (VPNs) (both concerning VPNs at Layer 2 and 3) where the MPLS label is incapsulated within the core of the Service Provider (offering VPN service) and is used at the border routers to infer the correct routing information. In brief, the overall e2e is seen as full MPLS by RPs (see [1] for further details).

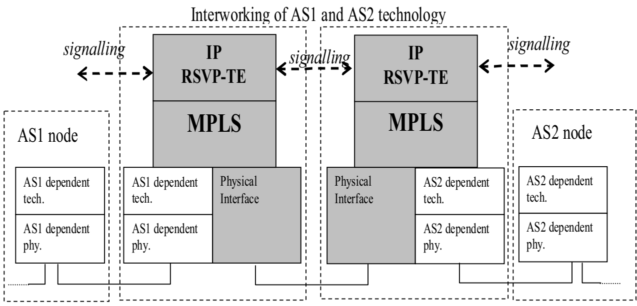


Fig. 3. MPLS-centric Relay Point.

Regular RSVP-TE is used to set the labels over the RPs e2e path and to signal QoS requirements among the RPs. It is assumed that an IP address plane is available in each RP for signalling. RSVP-TE guarantees a common format for service requests flowing through RPs and carrying information about the flows entering the network. The management of the bandwidth within each single AS is left to the AS itself. RSVP-TE transports QoS requests from one RP up to the next RP along the path. The IP-centric architecture of BBs described in section 2 may be similarly used to map the SLA over a single AS (if IP-based AS is taken as an example), so getting a properly dimensioned "bandwidth pipe" to guarantee SLA up to the next RP. The advantage is that ASes need to have in common only the definition of the RSVP-TE.

More specifically, the choice of MPLS as interworking technology allows obtaining:

1. QoS with single connection granularity if needed (e.g., for specific mission critical applications is a mandatory requirement, even if it might affect scalability);
2. the definition of a large set of SLAs: the mentioned 14 DiffServ classes may be extended with respect to larger granularity of QoS contraints, MLPP and connection protection classification;
3. MLPP management (the RSVP-TE "Session_Attribute" field is dedicated to it, see [5] for recent IETF results);
4. re-routing to guarantee connection protection [3]: the "loose" option, make before break, route pinning and crankback techniques may be applied through RSVP-TE;
5. inter-ASes TE [2].

4. Performance Evaluation

Special attention is devoted in this paper to point 2 above (the adoption of a large set of SLAs). The flexibility of service differentiation may allow significant bandwidth saving during the traffic aggregation process. If a specific technology does not offer the possibility of separating the required number of SLAs, there is the need to aggregate together traffic flows that not only can be characterized by different source models, but also by performance requirements. If traffic requiring different performance is joined in one flow, it is necessary to investigate the bandwidth required to keep the performance levels required by each flow. Many studies confirm the efficiency of aggregating homogeneous traffic, but the performance of non-homogeneous trunks (from the statistical behaviour and QoS requirement viewpoints) is still an open issue.

The RP is modelled through buffers. The allocated bandwidth is the service rate assigned to buffers. Two types of SLAs are considered for performance evaluation: VoIP and video. VoIP SLA considers sources modeled as an exponentially modulated on-off process, with mean on and off times (as in the ITU P.59 recommendation) equal to 1.008 s and 1.587 s, respectively. When in the active state, they are 16.0 kbps flows over RTP/UDP/IP. The VoIP packet size is 80 bytes. As far as the video service is concerned, real traces (taken from [6]) have been used. Data are H.263 encoded and have an average bit rate of 260 kbps and a peak bit rate ranging from 1.3 to 1.5 Mbps, depending on the specific trace. Each video trace lasts about 1 hour. QoS constraint of both SLAs is *Packet Loss Probability* (Ploss).

If traffic needs to be aggregated (i.e., conveyed to a single buffer), the choice of the bandwidth to be assigned to guarantee the fixed SLA is topical. The relevant metric, in this case, is the measure of the addition (or reduction) of bandwidth necessary to keep the same level of service when SLAs are aggregated with reference to a complete separation (i.e., where VoIP and video are conveyed to separate buffers and receive a dedicated bandwidth).

An ad-hoc simulator in C++ has been used to get the results. The width of the confidence interval over the performance measures is less than 1% for the 95% of the cases. To achieve low Ploss values (e.g., below 10^{-5}, referring to most literature), not obtainable by ordinary simulation analysis for computational reasons, the well-known *equivalent bandwidth* (EqB) formula:

$$C = m + a \cdot \sigma$$

is used to compute the bandwidth provision C of a given trunk for all results. The quantities m and σ

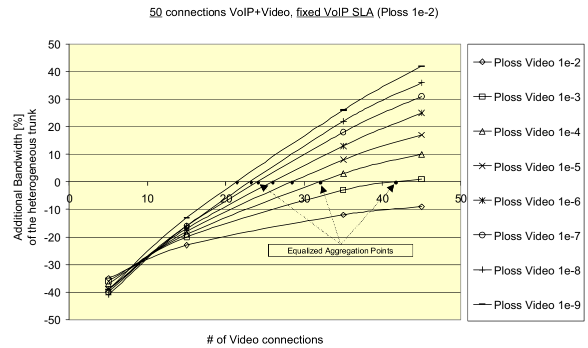
denote the *mean* and the *standard deviation*, respectively, of the input process of the buffer; and $a = \sqrt{-2\ln(\mathrm{PLP}^*) - \ln(2\pi)}$ being PLP^* the upper bound on the allowed PLP (the most stringent PLP in the heterogeneous case). The mentioned statistics are estimated by simulation inspection for each traffic composition.

Fig. 4 shows the additional bandwidth of the aggregated trunk necessary to satisfy both the SLAs, with respect to the resource allocation corresponding to the traffic separation case. Fig. 4.(a) and (b) is obtained by aggregating 50 connections globally. Fig. 4.(c) and (d) by aggregating 150 connections. VoIP SLA is fixed and video SLA is changed within the range $[10^{-2}, 10^{-9}]$ in Fig. 4.(a) and (c), viceversa in Fig. 4.(b) and (d).

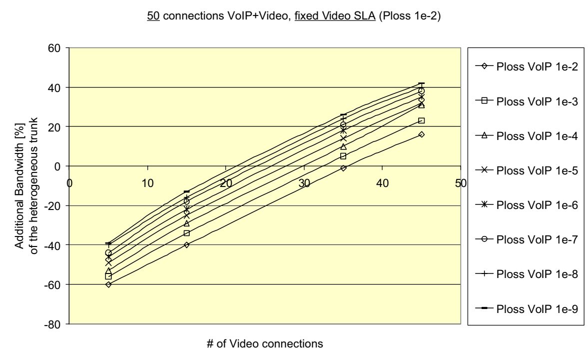
The results highlight that provisioning in heterogeneous conditions is not a straigthforward matter. Due to the multiplexing gain in presence of bursty sources, below a given threshold (the intersection point of each curve with the x-axis), aggregating is always convenient (the gain is negative), despite QoS heterogeneity. Above the threshold, a portion of bandwidth is wasted if the traffic classes are not kept separated. Such a threshold is defined as *Equalized Aggregation Point* (EAP) in this paper, because it represents the equilibrium point where aggregating and separating is indifferent for bandwidth allocation.

It is worth noting that Fig. 4.(a) and (b) has the same trend of Fig. 4.(c) and (d), respectively. The position of EAPs is almost invariant if the number of total connections is scaled up. For instance, the curve of 'Ploss video 1e-3' meets the x-axis of 42 video connections point in Fig. 4.(a) and of 130 video connections point in Fig. 4.(c). Both cases correspond to the 85% of video connections in the aggregated trunk.

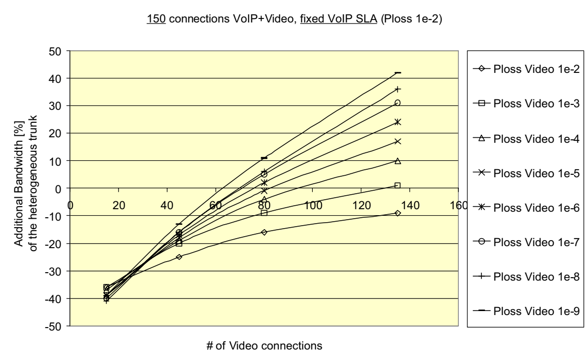
Summarizing and trying to generalize: it must be noted that above a given EAP, separating the traffic classes through MPLS (as proposed for the RP solution), should allow bandwidth saving. The performance evaluation is not only significant for resource allocation at RPs, but also for internal ASes provisioning, having therefore an effect for the entire e2e path within the heterogeneous network.



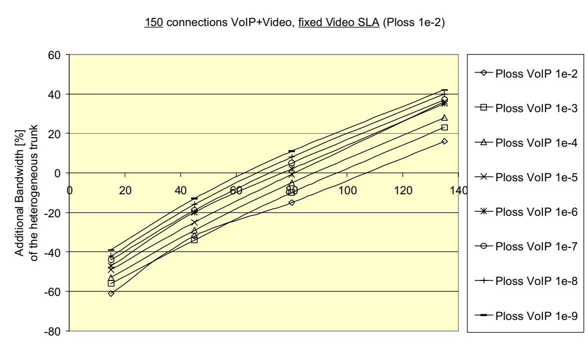
(a). 50 connections, fixing the VoIP SLA.



(b). 50 connections, fixing the Video SLA.



(c). 150 connections, fixing the VoIP SLA.



(d). 150 connections, fixing the Video SLA.

Fig. 4. Traffic aggregation performance.

7. Conclusions and Future Work

The paper has presented and compared IP-centric and MPLS-centric solutions for the protocol stack interconnecting network portions implementing different QoS technologies. The proposals are investigated in detail specifying the data flow along the end-to-end paths both for data and signalling. The advantages of the MPLS architecture are highlighted, with emphasis on the effect of traffic aggregation. The results reported concern this topic and try providing operative indications possibly applicable in the field. A future extension may concern the possible migration from MPLS to IPv6-centric approach by using extended features of IPv6 concerning label switching [7] and QoS management through the Flow Label-20 bits field.

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