IP SWITCHING ENHANCEMENTS OVER IP DIFFERENTIATED SERVICES FOR QOS INTERWORKING

Mario Marchese♣, Annamaria Raviola♦, Maurizio Mongelli♣, Vincenzo Gesmundo♦

♣*DIST - Department of Communication, Computer and System Sciences*
University of Genoa, Via Opera Pia 13 - 16145 Genoa, Italy

{ *Mario.Marchese, Maurizio.Mongelli* }*@unige.it*

♦*Selex Communications S.p.A., a Finmeccanica Company*
Via Pieragostini 80 - 16151 Genoa, Italy

{ *Annamaria.Raviola, Vincenzo.Gesmundo* }*@selex-comms.com*

ABSTRACT

In the last decades, the explosive growth of the Internet gave rise to the development of several telecommunication technologies, aimed at satisfying the increasing users needs with different degrees of Quality of Service (QoS). Together with the development of QoS technologies, an increasing number of Service Providers and networking companies developed their specific architectural and implementation choices. As a consequence, nested, heterogeneous infrastructures compose today's Internet. End-to-end QoS provisioning in such kind of infrastructures requires proper mapping operations among different protocols and united architectures to interconnect different QoS solutions. In this perspective, the paper analyzes QoS interworking architectures. Two solutions are considered: IP DiffServ and IP switching. They are compared with respect to recent results of standardization bodies and of scientific literature.

I. Introduction

The support of end-to-end (e2e) QoS over heterogeneous networks, composed of different portions (also called Autonomous Systems, ASes), 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 part of the heterogeneous network. Possible QoS technologies are: ATM, IP Differentiated Services (DiffServ), IP Integrated Services (IntServ), and, more recentely, MPLS. The problem involves a common language for QoS definition, interworking solutions, signalling, and control mechanism implementations. Having in mind tactical hazardous and challenging environments as in military and civil protection world [1, 2], it is often recommendable to have QoS for each user considering Multi Level Priority Pre-emption (MLPP). It means to identify each single e2e connection having a specific Service Level Agreement (SLA).

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 AS technology (see, e.g., subsection 5.2 of [3], [4, 5, 6] and references therein).

The current state of the art of QoS interworking at RPs is based on the DiffServ paradigm (see, e.g., [1-3] and references therein). Such a solution not always solves the main objectives listed above, even if it represents a reasonable solution and an important reference. So, it is important to investigate alternative solutions to match advanced QoS delivery over inter-domain environments. The aim of the paper is to exploit the features of IP switching architectures (e.g., MPLS, IPv6) to match points 1)-3) above.

The work is part of a scientific project between Selex Communications S.p.A, Italy, and the Department of Communication, Computer and System Sciences of the University of Genoa. Some material of the work was partially used by Selex Communications within the framework of the TACOMS Post 2000 project [1].

II. IP Diffserv-centric QoS architecture

As mentioned above, the first solution for QoS interworking that can be suggested is IP DiffServ-centric. It means that the common e2e language is DiffServ, both concerning QoS definition and interworking architecture.

A good example related to a specific military inter-domain environment is [1, 2].

A. A common set of Service Level Agreements

The architecture of the IP DiffServ-centric RP protocol stack is shown in Fig. 1. A proper definition of the DiffServ Code Point (DSCP) is necessary to have a common SLA for the entire network. See, for instance, tables 1 and 2. They contain some examples of applications (table 1) and of performance constrains (table 2). Each single data packet arriving at RP IP layer is treated in conformance with the DSCP assignation. From the QoS viewpoint, the adoption of either IPv4 or IPv6 has no impact because there is no difference after fixing the use of DiffServ.

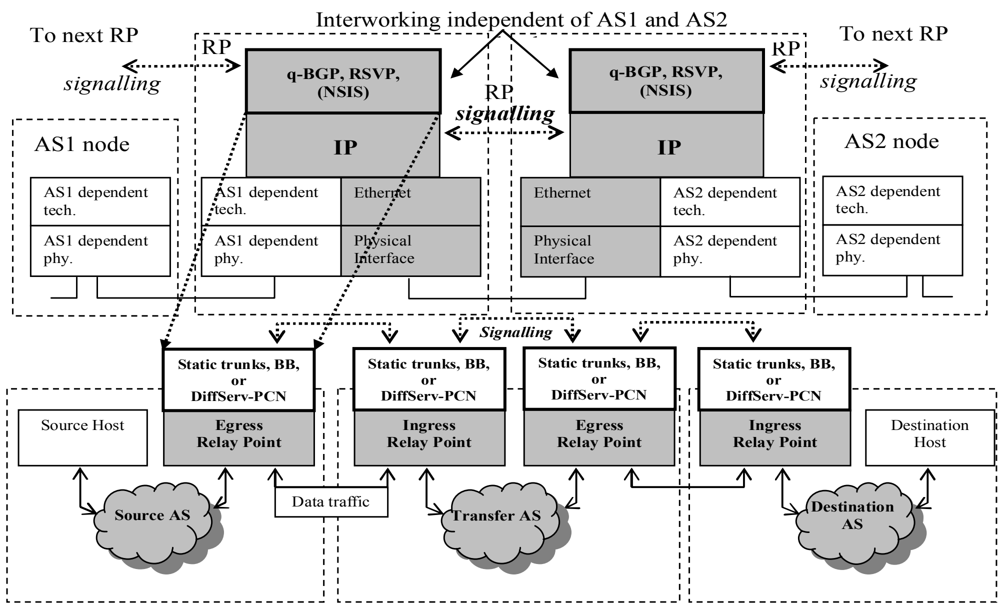

Fig. 1. IP-centric Relay Point: protocol stack and control plane (in bold).

B. IP end-to-end signaling architecture

QoS implementation implies the presence of a signaling protocol to transfer the content of inter-domain SLAs. The signaling protocol triggers resource allocation for incoming connections. Resource reservations are managed through proper signaling actions, private to each single AS.

One of the most recent signalling solutions for IP RP is QoS-Border Gateway Protocol (q-BGP) [3]. q-BGP-based RPs communicate the reachability of specific destinations with a fixed degree of service (the established SLA), associated to each DSCP value. The key point is that no assurance is given on the guaranteed QoS along the e2e path. q-BGP communicates reachability after the QoS has been installed within the ASes. Another important signalling is RSVP. In particular with respect to some recent modifications made on the protocol to support information about CAC (RSVP - Pre Congestion Notification, PCN) and priority of the calls (Emergency RSVP) [9]. It allows resource control in tactical environments as detailed below at point 2). The IETF Next Steps in Signalling (NSIS) working group (RFC 4080) is considering protocols for signalling information about data flow along its path in the network.

Resource control reveals to be the ultimate key to assure QoS. Three approaches may be implemented within IP DiffServ-centric RPs: **1)** static trunks, **2)** DiffServ PCN or **3)** Bandwidth Brokers. It is true for every IP network, including the network portions that implement IP.

1) *Static trunks.* No specification to dynamically reserve resources or to receive indications of network resource availability is implemented. The term static denotes the manual management of network resources over large time scales. For instance, the pre-allocation of a bandwidth trunk for a specific traffic class. Neither traffic prediction nor real time reaction to congestion including Call Admission Control (CAC) is provided. For this reason, static trunks are typically overprovisioned.

Service	Traffic class	DSCP assignation	Example of applications
Telephony	EF	101110	IP Telephony bearer
Multimedia conference	AF41	100010	Video-conference
	AF42	100100	
	AF43	100110	
Multimedia streaming	AF31	011010	Streaming video and audio
	AF32	011100	
	AF33	011110	
Data of low latency transactions	AF21	010010	Client/server web-based transactions
	AF22	010100	
	AF23	010110	
High Throughput Data	AF11	001010	Client/server web-based transactions
	AF12	001100	
	AF13	001110	
Standard Data	Default	000000	Not specified
Low Priority Data	CS1	001000	Best Effort
Broadcast Video Events	CS3	011000	Broadcast TV
Real-time interaction	CS4	100000	Interactive applications and gaming
Operation and Management (OAM)	CS2	010000	OAM
Signalling	CS5	101000	IP telephony signalling
Network Control	CS6	110000	Routing and control information
Administrative	CS7	111000	Routing and control information

Table 1. Possible DSCP assignation within RP.

Service	Traffic class	DSCP assignation	IP-D Delay	IP-DV Delay Variation (Jitter)	IPLR Loss Rate
Continuous Bit Rate CBR	EF	101111, 101110, 101101, 101011, 101001,10100	100-400 ms	30-50 ms	10^{-2}-10^{-3}
Variable Bit Rate VBR	AF41	100010	100-400 ms	30-50 ms	10^{-2}-10^{-3}
	AF42	100100			
	AF43	100110 100000			
Multimedia	AF31	011010	5-10 s	Not applicable	10^{-2}-10^{-3}
	AF32	011100			
	AF33	011110			
Mission Critical	AF21	010010	20ms-100ms	1ms-50 ms	0
	AF22	010100			
	AF23	010110			
Mission Critical	AF11	001010	1ms – 50 ms	Not applicable	0-10^{-3}
	AF12	001100			
	AF13	001110			
Best Effort	Default	000000, 001000, 101000, 011000	Unspecified	Unspecified	Unspecified
Control and Management	CS7	111000	50 ms – 1 s	Not applicable	0-10^{-3}
Control and Management	CS6	110000	1s – 10 s	Not applicable	10^{-2}-10^{-3}

Table 2. DoD SLAs DSCP assignment.

2) *DiffServ-PCN* (see [9] and the upcoming PCN IETF working group). It supports both CAC and MLPP within the IntServ over DiffServ framework. Each RP is responsible of the QoS maintenance in the AS. It receives specific alerts concerning the congestion state of the traffic classes within the AS. AS interior devices generate the alerts by properly setting the 2-bits Explicit Congestion Notification (ECN) field of IP packets. Two alerting states are defined: one for updating CAC and one for triggering MLPP. No RP centralized monitoring is needed. The congestion information is reported to the RP in order to shape the incoming traffic from the other ASes. In turn, the first RP alerted about congestion may perform its specific CAC and MLPP decisions or may automatically forward the congestion state to the upstream RP of the path. The mentioned RSVP-PCN and Emergency RSVP protocols must be installed within each RP to carry information about the actual rate of a given traffic class and about the priority of the calls. The key idea of the control structure is fixing sustainable rate limits for each traffic class, whose violation is reported towards the closest RP before uncontrollable congestion could generate QoS degradation. A continuous monitoring of rate fluctuations must be reported from internal devices to the RP, without explicit AS internal signaling. The monitoring information is embedded in regular traffic packets, properly ECN marked.

DiffServ-PCN contains some drawbacks that affect its QoS provision. a) The mentioned sustainable rate limits are statically configured, unless a signaling scheme is used within DiffServ, for instance considering future NSIS results. b) In case the RSVP-PCN and Emergency RSVP messages build by RPs traverse a connectionless core, the time interval necessary to implement control reactions cannot be dimensioned precisely. c) The mentioned monitoring mechanism needs a continuous real time estimation of the actual rate of each traffic class. It is implemented for each couple of RPs along the path. It may be computationally expensive and requires some time to reach convergence. If CAC, MLPP and regular IP fault tolerant re-routing must guarantee QoS with tight time constraints, such disadvantages make the planning of the network very difficult. It is intuitive that these services cannot be fast enough if unexpected congestion takes place.

3) Bandwidth Brokers (BBs) [10]. A BB defines an entity responsible for the resource control of a network portion. Specific protocols may be used to monitor congestion (e.g., OSPF-TE, IS-IS-TE) and to allocate resources (e.g., RSVP, NSIS). Each single RP may implement a centralized BB by receiving information by the network managing entity, e.g., the local BB of that domain. The BB negotiates traffic contracts to support SLAs with neighbour ASes. BBs also implement CAC and QoS management. Traffic contracts may be renegotiated following predefined time scales. The signalling used by local BBs and RP BBs may be RSVP-PCN, Emergency – PCN or some evolution taken from the NSIS suite.

III. "Hard" guarantees versus "loose" guarantees QoS

Except for the possible evolution of the BB approach, the solutions presented in section II offers loose guarantees QoS, following the terminology in [3], or Controlled Load QoS, as in [9] terminology. It means they support neither dynamic control of network resources nor traffic engineering (TE). Dynamic control implies real time management of network resources to follow traffic variations and topology changes. TE means resource optimization to minimize network deployment and maintenance costs. Together they can be considered the key support elements for hard guarantees QoS [3], i.e. QoS delivery with tight constraints.

Hard guarantees QoS can be approximated within the mentioned IP architectures through appropriate planning and accurate resource tuning, often together with overprovision. In any case, the topical point is that the exclusive application of the DiffServ paradigm may not be completely satisfying. i) It looses the reference to the single connection, ii) does not guarantee sufficient SLA flexibility, iii) does not implement any signalling to perform dynamic control and TE. Actually, point i) and ii) are true also including the BB solution.

Concerning point ii), and recalling attention to the services reported in tables 1 and 2, it is remarkable that each SLA is expressed in terms of: 1) traffic description, 2) conformance testing parameters, 3) required performance guarantees (e.g., loss rate, delay and delay jitter of the packets) [11] and, when needed, 4) priority preemption and 5) connection protection [12] levels. The proposed composition of the SLA derives from different standards and literature sources, each of which emphasizing different objective parameters for inter-AS QoS definition [1, 2, 3, 11, 12]. All this information should be encoded in the DSCP of the packets. Subsection 5.4 of [9] contains some simple examples concerning the need of encoding the priority level in the DSCP because it simplifies the MLPP implementation.

Moreover, in the future, customer needs may increase due to new applications. Enlarging the granularity of QoS constraints may be a mandatory choice for SLAs. If also MLPP and connection protection classification is required, the 6-bits of the DSCP may reveal to be unsufficient for SLA categorization, especially if some parts of the DSCP itself are used for control purposes (as in tables 1 and 2 or in [9]).

The adoption of an alternative technology matching the previous points and supporting both intra-TE [13] and inter-TE [14] may be of great interest. This is the rationale behind the proposal of the IP Switching (IPS)-based architecture.

IV. IP switching-centric QoS approach

The IPS-based RP protocol architecture is reported in Fig. 2 together with the e2e network and the control action. IPS can be realized using MPLS or IPv6 switching. Label switching can be introduced in the IPv6 paradigm (in place of regular IP routing) as function of the Flow Label (FL) of the IPv6 header. The resulting architecture (called IPv6 Label Switching Architecture [16]), follows the guidelines of regular MPLS switching rules.

The traffic flows at the RPs encapsulate the IP host traffic with the IPS frame. The IPS (MPLS or IPv6) shim header is added at the first RP of the e2e path in order to classify packets and differentiate the SLAs. The first RP met along the e2e path acts as a regular Label Edge Router by identifying the flow, classifying the SLA and applying the label. The opposite operation is implemented at the last RP before the destination. Intermediate RPs act as conventional Label Switch Routers. Since the ASes are not necessarily IPS capable, the labelled packets will be tunnelled within proprietary technologies and forwarded to the next RP.

A. IPS integrated Relay Point solution

The IPS-based RP solution may be structured into two consecutive steps. Firstly, it can be seen as a support for QoS provision offered to IP DiffServ framework. In this case, IPS is used for packet switching and for the establishment of intra-AS and inter-ASes explicit routed tunnels (see, e.g., [3]). The information concerning routing is inferred from the IPS label and the traffic class (i.e., scheduling and drop precedence or packet discarding, in the DiffServ terminology) is inferred from the 3-bits of the Experimental (EXP) field of IPS header. The approach is called EXP-inferred Label Switch Path (LSP). Another option is also possible, called label-inferred LSP, where the drop precedence is inferred from the EXP field, and both routing and scheduling treatments are inferred from the label. In this case, the IPS layer is added to IP DiffServ so that hard guarantees QoS may be offered without the adoption of IP non standard solutions based on BBs.

B. Full IPS Relay Point

The evolution of IPS integrated RP implies a full use of IPS. The inference of the SLA is based on the label (MPLS label or IPv6 FL) value. The SLA includes MLPP and fault tolerance guarantees. In this view, IPS RP defines a generalized version of regular label-inferred LSPs. Only IPS packets have QoS meaning for the RPs.

C. IPS end-to-end signaling architecture

In both integrated and full IPS solutions, regular RSVP-TE (Fig. 2) is used to set the labels over the RPs e2e path and to signal QoS requirements among the RPs. q-BGP may be again used for announcements of destinations reachable with a specific SLA, but, differing from the IP DiffServ RP control plane, resource allocation along the e2e path is controlled by RSVP-TE and its embedded dynamic control tools, such as bandwidth allocation, CAC, MLPP, re-routing and TE modules.

D. IPS Relay Point control plane

As summarized in Fig. 2, the Path Computation Element (PCE) architecture can be used at the control plane level to implement inter-domain TE (see [14] and the other documents of the related IETF working group). The key feature of the PCE paradigm is to let ingress-egress RPs to communicate each other in order to trigger the establishment of optimized e2e paths, even if the local composition of internal paths is hidden to the inter-AS routing level.

RSVP-TE guarantees a common format for service requests flowing between RPs and carrying information about QoS indications and network congestion. The management of the bandwidth within each single AS is left to the AS itself. To summarize, the choice of IPS as interworking technology allows obtaining:

1) Full technological support to hard guarantees QoS by using components available in the market;

2) MLPP management (the RSVP-TE "Session_Attribute" field is dedicated to MLPP, see [15] for recent IETF results);

3) re-routing to guarantee connection protection [12]: make before break and crankback techniques may be applied through RSVP-TE;

4) inter-ASes TE (see, e.g., subsection 4.3 of [3] or [14]);

Additionally the Full IPS solution allows:

5) QoS with single connection granularity if needed (e.g., for specific mission critical applications is a mandatory requirement; however, due to scalability limitations, per-customer SLA classification may be hardly applied in the Internet and in large enterprise networks);

6) the definition of a large set of SLAs: tables 1 and 2 may be extended with respect to larger granularity of QoS contraints, MLPP and connection protection classification;

7) bandwidth optimization at the traffic aggregation level (see, e.g., section 4 of [17]).

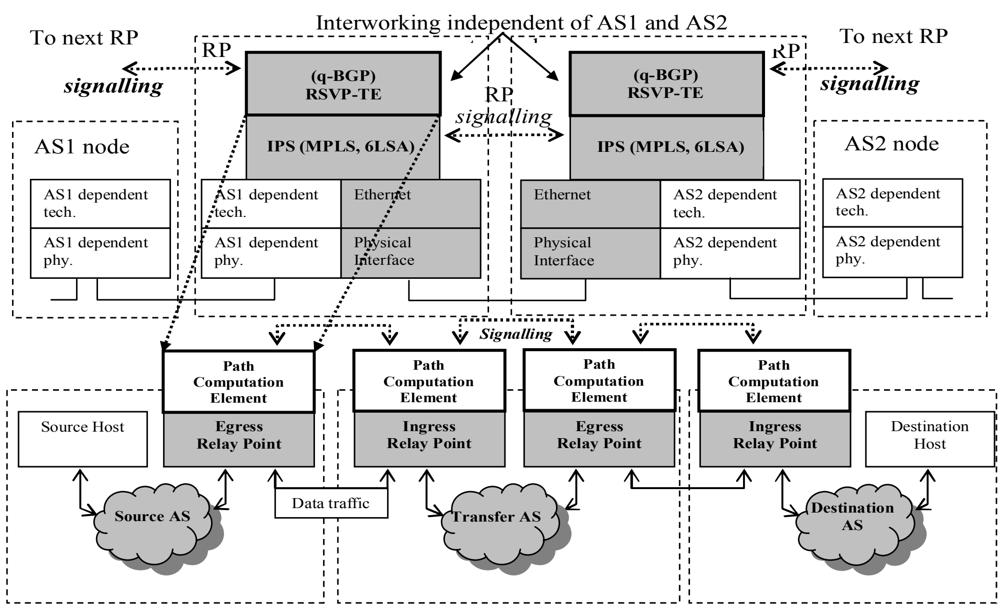

Fig. 2 IPS-centric Relay Point: protocol stack and control plane (in bold).

IV. IP versus IPS inter-domain QoS delivery

Table 3 reports a comparison between IP DiffServ and IPS as RP solutions for all the presented alternatives. Both MPLS and IPv6 are independently considered within IPS solution. Emphasis is put on: traffic management, bandwidth optimization, CAC, MLPP, network planning and fault tolerance. The analysis may support network operators to choose the most suitable technology for their specific needs. The level of consolidation (may be null, low, medium, and high) considers: standards, scientific literature and device availability in the market. For instance, it is remarkable that despite intra-domain TE in MPLS is a consolidated technology, inter-domain TE is currently under study in standardization bodies and scientific community.

Actually, deploying, emulating, or even simulating the entire system at the different levels of responsibility constitutes an impracticable task for computational and monetary costs. Independent investigations are usually performed for each topic, e.g., traffic management [3] and classification [1], bandwidth control [4, 5, 6], fault tolerance [12].

To summarize the results of table 3, it must be noted that the IPS RP solution in general reveals to be more flexible in managing resources. The presence of a powerful signalling, like RSVP-TE, is essential elements to optimize resource allocation and to support timely fault countermeasure. The IPS support of hard guarantees QoS is also more consolidated than DiffServ one. The IP environment results to be less flexible if static schemes are considered. Concerning the DiffServ-PCN paradigm, more satisfying results are guaranteed, even if the intrinsic imprecision of the applied bandwidth estimation and the signalling scheme overlying connectionless IP introduce a lower precision level than the IPS case.

It is remarkable that even using the IPS RP solution, the presence of loose guarantee QoS along the ASes chain can destroy the support of hard guarantees QoS. Fault tolerance is not guaranteed if the RP of a given AS is not able to trigger re-routing decisions within the required time interval. For example if the local AS does not support any internal signalling. The same concept applies if CAC and MLPP are considered.

No specific solution reveals to be the best one. For instance, if overprovision may be applied because bandwidth is not a scarce resource, the IP centric solution based on DiffServ paradigm may reveal more than sufficient, also with static resource allocation. This condition may be satisfied in specific wired environments, but it is hardly applicable for terrestrial wireless and satellite links. If there are no signalling schemes to manage resources dynamically, the SLAs support is left to the experience of network operators at network planning level.

V. Conclusions and Future Work

The paper presents and compares IP DiffServ and IPS protocols as solutions for interconnecting network portions implementing different QoS technologies. The advantages of the IPS architecture are highlighted, with respect to the technology requirements necessary to implement QoS with tight guarantees. Future extensions concern the specifications of the IPv6-centric approach within the IPS RP framework.

References

[1] Tacoms Post 2000 Project (TACOMS), TACOMS STANAG 4637, "TACOMS HEAD STANAG" (draft ed. 1), NATO Steering Committee, http://www.tacomspost2000.org, NSA, 2005.

[2] I. Sorteberg, O. Kure, "The Use of Service Level Agreements in Tactical Military Coalition Force Networks," *IEEE Comm. Mag.*, vol. 43, no. 11, Nov. 2005, pp. 107-114.

[3] M. P. Howarth, M. Boucadair, P. Flegkas, N. Wang, G. Pavlou, P. Morand, T. Coadic, D. Griffin, H. Asgari, P. Georgatsos, "End-to-end Quality of Service Provisioning Through Inter-provider Traffic Engineering," *Comp. Commun.*, vol. 29, no. 6, March 2006, pp. 683-702.

[4] J. Schmitt, "Translation of specification units between IP and ATM quality of service declarations," *Internat. J. Comm. Sys.*, vol. 16, no. 4, 2003, pp. 291-310.

[5] M. Marchese, M. Mongelli, "On-line Bandwidth Control for Quality of Service Mapping over Satellite Independent Service Access Points," *Computer Networks*, vol. 50, no. 12, Aug. 2006, pp. 1885-2126.

[6] S. Georgoulas, P. Trimintzios, G. Pavlou, K. Ho, "Heterogeneous Real-time Traffic Admission Control in Differentiated Services Domains," Proc. of IEEE Global Telecommunications Conference 2005 (*Globecom 2005*), St. Louis, USA, 28 Nov.-2 Dec. 2005, pp. 523-528.

[7] Satellite Earth Stations and Systems, Broadband Satellite Multimedia Services and Architectures: Interworking with DiffServ QoS, TS 102 464 V0.4.1, Sept. 2006.

[8] J. Babiarz, K. Chan, F. Baker, "Configuration Guidelines for DiffServ Service Classes", IETF RFC4594, Aug. 2006.

[9] B. Briscoe, P. Eardley, D. Songhurst, F. Le Faucheur, A. Charny, J. Babiarz, K. Chan, S. Dudley, G. Karagiannis, A. Bader, L. Westberg, "An edge-to-edge Deployment Model for Pre-Congestion Notification: Admission Control over a DiffServ Region," <draft-briscoe-tsvwg-cl-architecture-03.txt>, IETF Internet Draft, 26 June, 2006, work in progress.

[10] Y. Jia, M. Chen, "A new architecture of providing end-to-end quality-of-service for differentiated services network," Proc. of IEEE Military Communication Conference 2001(*Milcom 2001*), Washington, D.C., USA, 28-31 Oct. 2001, no. 1, pp. 1451-14568.

[11] J. Gozdecki, A. Jajszczyk, R. Stankiewicz, "Quality of Service Terminology in IP Networks," *IEEE Comm. Mag.*, vol. 41, no. 3, Mar. 2003, pp. 153-159.

[12] P. Pongpaibool, H. S. Kim, "Providing End-to-End Service Level Agreements across Multiple ISP Networks," *Computer Networks*, vol. 46, no. 1, Sept. 16, 2004, pp. 3-18.

[13] D. O. Awduche, "MPLS and Traffic Engineering in IP Networks," *IEEE Comm. Mag.*, vol. 37, no. 12, Dec. 1999, pp.42-47.

[14] A. Farrel, J.-P. Vasseur, J. Ash, "A Path Computation Element (PCE)-Based Architecture," IETF RFC 4655, Aug. 2006.

[15] M. R. Meyer, J.-P. Vasseur, D. Maddux, C. Villamizar, A. Birjandi, "MPLS Traffic Engineering Soft Preemption," <draft-ietf-mpls-soft-preemption-08.txt>, IETF Internet Draft, Oct. 2006, work in progress.

[16] S. Chakravorty, "IPv6 Label Switching Architecture (6LSA)," <draft-chakravorty-6lsa-01.txt>, IETF Internet Draft, Feb. 2005.

[17] M. Marchese, A. Raviola, M. Mongelli, A. Garibbo, V. Gesmundo, "IPv4 versus IPv6 Interworking with QoS Guarantees," Proc. 25th IEEE Military Communications Conference 2006 (*Milcom 2006*), Washington D.C., 23-25 Oct. 2006.

Technological features	IP DiffServ [Static trunks, PCN, BB] (level of consolidation)	MPLS [Integrated, Full] (level of consolidation)	IPv6 [Integrated, Full] (level of consolidation)
	Traffic Management		
Additional headers to IP stack	No (-)	Yes (high)	No (-)
Explicit Routed Label Switching Paths (LSPs)	No (-)	Yes (high)	Limited - Integrated (high) Huge - Full (null)
SLA classification	Limited (high)	Limited - Integrated (high) Huge - Full (null)	Limited - Integrated (high) Huge - Full (null)
Traffic Engineering	No - Static trunks (-) No - PCN (-) Yes - BB (null)	Yes (high)	Yes (high)
Resource assignment procedure	Manual - Static trunks (high) Manual/automatic - PCN (low) Automatic - BB (null)	Automatic (high)	Automatic (low)
	Bandwidth Optimization		
Bandwidth allocation scheme	Overprovision - Static trunks (high) Static - PCN (low) Dynamic - BB (null)	Dynamic (high)	Dynamic (Integrated - high, Full - null)
Resource allocation control	Planning level - Static trunks (high) Planning level - PCN (low) Call level - BB (null)	Call level (high)	Call level (high)
Bandwidth wasting with heterogeneous SLAs (e.g., [17])	Large waste - Static trunks (high) Medium waste - PCN (low) Medium waste - BB (null)	Medium waste - Integrated (high) No waste - Full (low)	Medium waste - Integrated (high) No waste - Full (low)
	Call Admission Control (CAC)		
CAC	No - Static trunks (-) Yes - PCN (low) Yes - BB (null)	Yes - Integrated (high) Yes (fine granularity) - Full (null)	Yes - Integrated (low) Yes (fine granularity) - Full (null)
Precision of bandwidth computation during CAC	Not applicable - Static trunks (-) Limited - PCN (low) High - BB (null)	High - Integrated (high) High (fine granularity) - Full (null)	High - Integrated (low) High (fine granularity) - Full (null)
Preemption during CAC	Not applicable - Static trunks (-) Yes - PCN (low) Yes - BB (null)	Yes - Integrated (high) Yes (fine granularity) - Full (null)	Yes - Integrated (low) Yes (fine granularity) - Full (null)
	Multi Level Precedence and Pre-emption (MLPP)		
MLPP	No - Static trunks (-) Yes PCN (low) Yes - BB (null)	Yes (medium)	Yes (low)
Precision of bandwidth computation during MLPP	Not applicable - Static trunks (-) Limited - PCN (low) High - BB (null)	High - Integrated (high) High (fine granularity) - Full (null)	High - Integrated (low) High (fine granularity) - Full (null)
Time interval before preemption completed	Not applicable - Static trunks (-) Not controlled - PCN (low) Controlled - BB (null)	Controlled (high)	Controlled (low)
	Network Planning		
Mandatory a priori LSPs overprovision	Yes - Static trunks (high) Partial - PCN (low) Partial - BB (null)	No (-)	No (-)
Planning phase development	Simple - Static trunks (-) Average difficulty - PCN (-) Difficult - BB (-)	Difficult (-)	Difficult (-)
	Fault Tolerance		
Backup paths	No - Static trunks (-) No - PCN (-) Yes - BB (null)	Yes (high)	Yes (null)
Re-routing methodology	Regular connectionless IP (high)	Customized (high)	Customized (null)
Graceful restart for ingress/egress RP	No - Static trunks (-) No - PCN (-) Yes - BB (null)	Yes (high)	Yes (null)
Time interval control to alert ingress RP of e2e path	No - Static trunks (-) Yes - PCN (low) Yes - BB (null)	Yes (high)	Yes (null)
Time interval control to trigger backup path	No - Static trunks (-) Yes - PCN (low), Yes - BB (null)	Yes (high)	Yes (null)

Table 3. IP DiffServ versus IPS RP solutions.