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Service differentiation in IP/MPLS over ASON/GMPLS networks

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Abstract There is a general agreement that the future infrastructure for broadband communications will consist of Automatically Switched Optical Networks (ASONs) controlled by the Generalized Multi-Protocol Label Switching (GMPLS) control plane. Due to the convergence of most services on the Internet Protocol (IP) layer, ASON/GMPLS networks need to provide transport for a variety of applications having different Quality of Service (QoS) requirements. This implies that the Differentiated Service paradigm, which improves the QoS in pure IP networks, needs to be extended to the new underlying infrastructure. This article proposes and compares three schemes for the service differentiation in IP/MPLS over ASON/GMPLS networks. Simulation results demonstrate that a fair trade-off between QoS and resource utilization is achieved when combining *routing policy differentiation* (RPD), *virtual topology differentiation* (VTD), and *virtual topology sharing* (VTS) techniques. The RPD technique decides on the multilayer routing policy to apply depending on the Class of Service (CoS). The VTD technique transports different CoS over different independent virtual topologies. The VTS technique introduces a certain degree of resource sharing among the different virtual topologies.

Keywords Multilayer traffic engineering · Integrated routing · Service differentiation

1 Introduction

The future growth in network capacity will mostly support data traffic transmitted over the Internet Protocol (IP). IP networks will be the preferred infrastructure for the aggregation of diverse applications, ranging from real-time and streaming (such as voice, IPTV, telemedicine, digital cinema) to non-real-time but sensitive to bandwidth and packet loss (such as banking sector and grid applications), to traditional best effort applications (such as emails and web surfing) [1, 4].

The traffic diversity over IP networks has increased the need for Quality of Service (QoS). Operators have been forced to migrate towards a Differentiated Service (DiffServ) approach in order to increase the Return on Investment (ROI) [4]. DiffServ is a scalable technology for QoS deployments based on a Service Level Agreement that defines the operator's commitments in terms of parameters such as availability, delay, jitter and loss. DiffServ has also been integrated with the Multi Protocol Label Switching (MPLS) technology [9]. MPLS decouples routing from forwarding and creates connection oriented Label Switching Paths (LSPs) improving the IP layer Traffic Engineering (TE) [7, 3].

Besides MPLS and DiffServ that have significantly improved the QoS in IP networks, operators have also invested in optical technologies to face the increase in bandwidth demand. Dense Wavelength Division Multiplexing (DWDM) technology has made available a huge amount of bandwidth at a lower cost. DWDM networks provide clients with all-optical high-speed channels up to 10, 40 and 100 Gbps [1]. Lightpaths bypass electronic packet switching at intermediate nodes and improve communication

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performance in terms of end-to-end delay, jitter and packet loss. Initially deployed to merely provide end-to-end high capacity backbone pipes statically (which means manually) established, optical networks have recently experienced a fast evolution towards intelligent and self-adaptive infrastructures for metro and backbone segments. This evolution has resulted in the standardization of Automatically Switched Optical Networks (ASONs) by the International Telecommunication Union, Telecommunications Standardization Sector (ITU-T). ASONs are optical transport networks with dynamic connection capabilities [8]. Dynamic service provisioning is guaranteed by the Generalized Multi-Protocol Label Switching (GMPLS) signalling and routing protocols. GMPLS has been standardized by the Internet Engineering Task Force to extend the MPLS paradigm to a variety of technologies [10]. Specifically, in the case of optical networks, the MPLS protocols have been suitably adapted to deal with wavelengths and optical switches when creating Optical Label Switched Paths (OLSP). It has been demonstrated that the GMPLS control plane reduces OPerational EXpenditure (OPEX) [12].

The MPLS and GMPLS control plane similarity and the dynamic nature of ASONs have brought the IP and optical domains in a closer relationship. IP/MPLS over ASON/GMPLS networks can cooperate in an integrated manner and increase QoS [3]. Traditional TE that provides load balancing for IP/MPLS networks has been extended and integrated with the ASON/GMPLS layer. The result is the Multilayer TE (MTE) paradigm and integrated routing [5, 14, 11, 18]. These techniques allow the operator to accommodate services either in the IP/MPLS domain, by aggregating traffic on the existing capacity, or in the optical domain, by setting up new optical connections. In addition, it has been demonstrated that this cross-layer interaction optimizes the resource usage and consequently increases ROI. As a consequence, IP/MPLS over ASON/GMPLS networks are envisioned to be the preferred architecture for the future Internet [11].

In order to further improve QoS and make MTE more efficient, the DiffServ technique should also be extended and adapted to the integrated IP/MPLS over optical scenario. This article focuses on the introduction of the service differentiation in IP/MPLS over ASON/GMPLS and introduces three techniques:

1. *Routing Policy Differentiation* (RPD). This technique is a simple algorithm that decides on the multilayer routing policy according to the Class of service (CoS) the service request belongs to.
2. *Virtual Topology Differentiation* (VTD). This technique builds different virtual topologies used to accommodate traffic belonging to different CoS.
3. *Virtual Topology Sharing* (VTS). This technique allows different virtual topologies to share a limited amount of resources.

The goal of this study is to evaluate the impact of these techniques on the service differentiation in IP/MPLS over ASON/GMPLS networks. To asses the performance comparison, we designed three DiffServ schemes:

- *RPD Service (RP-Diff)*. This scheme is only based on the RPD technique.
- *Virtual Topology Hard Differentiation Service (VT-HardDiff)*. This technique implements the RPD and the VTD techniques.
- *Virtual Topology Soft Differentiation Service (VT-SoftDiff)*. This approach is a combination of the three techniques (RPD, VTD and VTS).

The simulation results show that the best performance in terms of blocking ratio and packet end-to-end delay as well as the desired service diversification are achieve by the VT-SoftDiff approach. This demonstrates that a combination of RPD, VTD and VTS is needed when providing service diversification in IP/MPLS over ASON/GMPLS.

The rest of the article is organized as follows. Section 2 reviews the related work and introduces the contribution of this article. Section 3 describes the system model, the traffic model and the simulation scenario considered in our study. Section 4 gives an overview of MTE in IP/MPLS over optical networks focusing on the integrated multilayer routing. Section 5 illustrates the three proposed schemes along with a discussion and comparison of the simulation results. Section 6 draws the conclusions.

2 Related work and contribution

Service differentiation in IP/MPLS over optical networks has recently received significant attention among the research communities.

The study in [16] focuses on the importance of Grade of Service (GoS) in optical networks. GoS is defined by the authors as the quality offered during the connection set up phase (such as connection set up time and blocking ratio), as opposite to QoS which is defined as the quality offered after the connection establishment (such as packet delay). The authors present three mechanisms for GoS differentiation in a DWDM network. The first policy is based on the resource preservation for high-priority (HP) requests. The authors introduce a threshold that is used to decide on the amount of resources that should remain available for HP requests at the expenses of low priority. The second mechanism is based on routing algorithms which assign a higher number of routes to HP traffic. This policy results in a lower blocking probability for HP requests but in a possible higher set up time due to the higher number of attempts the systems executes among the available paths. The last proposed GoS method is based on the pre-emption of low-priority (LP) requests when the system is unable to find sufficient resources for HP traffic.

The study in [7] proposes a multilayer routing solution based on a hybrid on-line/off-line approach. HP traffic is accommodated by means of an off-line system that optimizes the route calculation based on a foreseen traffic matrix. HP traffic is routed in a real-time fashion with an on-demand route computation based on the network state. The system needs to be equipped with a pre-emption module in order to guarantee a lower blocking probability to gold requests at the expense of the LP traffic.

Golmie et al. [6] formulate a differentiated optical service model which classifies the lightpaths according to a set of optical parameters that capture the wavelength's quality and reliability. The parameters are specified in quantitative terms (delay, average bit-error-rate (BER), jitter and bandwidth) or based on functional capabilities (monitoring, protection and security). Different CoS are mapped onto different lightpaths according to the required service quality.

Wei et al. [17] propose a hybrid and integrated QoS control scheme for IP over optical networks. The scheme combines an admission control algorithm at the IP flow level with a lightpath differentiation in the optical layer. IP traffic belonging to three CoS is mapped onto high-quality and low-quality lightpaths. The lightpaths are diversified according to the value of the BER and to some qualitative characteristics (survivable, secure, pre-emptible).

Puype et al. [15] present a proactive MTE strategy and evaluate its suitability to a multiservice environment. The MTE strategy consists of multiple cross-layer TE techniques. The first technique consists of (re)routing IP/MPLS flows through a shortest path algorithm. The algorithm is based on a cost function that increases the IP/MPLS link utilization while preventing congestions. The second technique is based on the IP/MPLS logical topology construction that integrates the aforementioned load-based cost function with a multiplicative optical metric [13]. The third technique is based on IP/MPLS link capacity up/downgrade that modifies the amount of offered capacity independent of the logical topology connectivity. To demonstrate the suitability of the proposed MTE strategy, the authors show how different optical cost metric and different provisioning modes impact the QoS parameters. This implies that in a multi-service environment the optical cost metrics and the provisioning modes have to be selected according to the CoS.

The analysis of the related work suggests that the introduction of the service differentiation in IP/MPLS over optical networks has recently received a significant attention among the research community.

This study addresses the service differentiation in integrated IP/MPLS over optical networks. It proposes and describes three DiffServ schemes. The first scheme is called RP-Diff and it is based on the *RPD* technique. The introduction of this technique is motivated by the fact that the choice of the MTE routing policy impacts the offered QoS as well as the resource utilization [2, 11]. As a consequence, the service differentiation in a multiservice infrastructure can be improved by deciding the routing policy according to the traffic requirements. However, we demonstrate that the RPD has no impact on the QoS differentiation because different services are aggregated on the same OLSPs. To make the RPD more effective, we propose a scheme called VT-HardDiff, based on the *VTD* technique. This technique is used to transmit different CoS over different virtual topologies. As a consequence of the resource virtualization in IP/MPLS over ASON/GMPLS networks, the different virtual topologies can be considered independent from each other. This independency improves the RPD and provides different CoS with different levels of QoS. Although achieving the desired service differentiation, the simulation results demonstrate that the VT-HardDiff approach deteriorates the performance with respect to the RP-Diff scheme. To overcome this problem, we introduce a heuristic called VT-SoftDiff, based on the *VTS* technique. This approach is a modification of the VT-HardDiff scheme and introduces a certain degree of resource sharing among the different virtual topologies.

The aim of the study is to demonstrate that a combination of RPD, VTD and VTS needs to be considered when designing a DiffServ scheme for integrated IP/MPLS over ASON/GMPLS networks. We do so by simulating and comparing the results of the three DiffServ schemes and by showing that VT-SoftDiff is the most effective approach. In fact, it achieves the best performance in terms of blocking ratio and packet end-to-end delay. In addition, it allows an operator to achieve the QoS diversification.

3 System model

3.1 Node and network model

It is a general trend for Service Providers to prefer a single network infrastructure with two different types of transportation: one being packet based (e.g. IP/MPLS) allowing packet flows to be efficiently multiplexed together and the other one being optical transport based (e.g. ASON/GMPLS) that provides encapsulation and flexible manageability for larger high-bandwidth circuit/tunnels. In our simulations, we consider a simplified model of integrated IP/MPLS over optical networks where every node has the architecture presented in [11]. This node model allows an operator to manage the packet and optical domains considering them as if they were a single layer. This scenario enables easier cross-layer designs which optimize the resource usage and decrease the OPEX/CAPEX [5].

Three topologies of different sizes have been simulated: a test topology with 7 nodes and 11 optical fibres, the NSFNET topology with 14 nodes and 21 optical fibres and the Italian topology consisting of 21 nodes and 33 optical fibres. In this article, we only report the outcomes obtained by simulating the Italian topology. Experiments on other topologies yield outcomes that are totally in line with the ones presented in this article. The nodes are equipped with 128 ports, whereas each fibre has 64 wavelengths each being able to set up 10 Gbps OLSPs.

3.2 Traffic model

We consider the traffic injected into the network as a set of connection requests (i.e. services sold by the operator). A service request is modelled with an LSP request belonging to certain CoS. Our case study considers two CoS: the HP traffic carrying services with stringent QoS requirements, such as real-time applications having strict service availability and end-to-end delay requirements; the LP traffic carrying services that have less stringent QoS requirements.

The LSP request module generates service requests according to a Poisson process with average rate λ and connection holding time exponentially distributed with mean $1/\mu$. The generated connection is characterized by the quadruple $\langle s, d, C_{\mathrm{req}}, c\rangle$, where "s" and "d" are the service request's source and destination IP/MPLS routers and are randomly chosen among all the network nodes; C_{req} is the capacity requested by the connection and it is randomly chosen according to a uniform distribution between 10 and 30% of the OLSP channel capacity; c is the CoS and it is set so that the 30% of the generated LSP requests belongs to the HP CoS, whereas the 70% belongs to the LP CoS. The packet generator module takes as its input the connection request's characteristics and generates packets according to a self-similar process.

To test the system under different load conditions, the traffic load is increased stepwise at constant intervals during the entire duration of the simulation. To increase the traffic load, the connection request interarrival time T_{ia} is fixed to 0.067 s, whereas the connection holding time T_{ht} is increased from a minimum of 100 s to a maximum of 300 s.

To calculate the connection blocking ratio, we run simulations with 2×10^6 requests, without considering the packet generation. When calculating the average packet end-to-end delay, the number of generated connection requests is lowered to 10^5.

3.3 Metrics for performance assessment

The metrics chosen for the performance evaluation are:

- *LSP request blocking ratio*. It evaluates the QoS at the connection level and it is calculated as the ratio between the number of rejected service requests belonging to a CoS and the total number of service requests of that CoS. We suppose that a call can only be blocked due to the lack of resources either on the IP/MPLS layer (lack of capacity) or on the optical layer (lack of wavelengths or ports). If a service cannot be accommodated, it is rejected and deleted from the system. The blocking ratio gives us indication about the service availability.
- *Average end-to-end packet delay*. This metric appears at the packet transmission level and therefore assesses the quality offered after the service has been accommodated. It is calculated as the average time for packets to be transmitted from the source to the destination IP/MPLS routers. In the calculation of the average end-to-end packet delay, we consider the queuing delay, the propagation delay and the Optical-Electro-Optical conversion delay.

4 MTE in integrated IP/MPLS over ASON/GMPLS networks

With an ASON being the underlying transport infrastructure, routing and TE can be executed in a multilayer fashion. The two basic multilayer routing policies in an integrated IP/MPLS over ASON/GMPLS network are the Virtual topology First (VTF) policy and the Physical Topology First (PTF) policy.

4.1 VTF policy

A system implementing the VTF policy first attempts to aggregate a new service request over the existing virtual topology. If there is insufficient bandwidth to find a path, a new OLSP establishment is triggered. This implies that the VTF policy exploits the available capacity as much as possible by aggregating sub-wavelength services on the existing virtual topology. The complete list of operations executed by the system is the following:

1. Check if there is an existing OLSP with sufficient capacity directly connecting source and destination node, and can accept the new service request. If yes go to step 4, else go to step 2.
2. Find a series of available existing OLSPs connecting source and destination node using a hop-based shortest path algorithm on the virtual topology. If a candidate exists go to step 4, else go to step 3.
3. Check whether a new OLSP can be set up using a hop-based shortest path algorithm on the physical topology. If yes go to step 4, else go to step 5.

4. Accept the service request.
5. Reject the service request.

4.2 PTF policy

When accommodating traffic by means of the PTF policy, the system first attempts to establish a new direct OLSP between source and destination nodes. If it cannot be established due to unavailability of wavelengths and ports, the system tries to aggregate the traffic over the existing virtual topology. This implies that the PTF policy exploits the physical resources as much as possible causing a high consumption in terms of ports and wavelengths. The complete list of operations executed by the system is the following:

1. Check if a new direct OLSP can be set up by means of a hop-based shortest path algorithm executed on the physical topology. If yes go to step 3, else go to step 2.
2. Check if there is a series of available existing OLSP that connect source and destination nodes using a hop-based shortest path algorithm on the virtual topology. If yes go to step 3, else go to step 4.
3. Accept the service request.
4. Reject the service request.

4.3 Comparison between PTF and VTF algorithms

The performance of an IP/MPLS over ASON/GMPLS network is considerably influenced by the choice of the routing policy [2, 3]. The main difference between PTF and VTF can be summarized into these two main points:

- *Resource optimization*. The VTF policy achieves high capacity utilization while saving physical resources as a consequence of a lower number of OLSP establishments. The PTF policy, instead, implies a high consumption of wavelengths and ports and less capacity optimization. In fact, the capacity created with the frequent OLSP installation is not efficiently used due to less aggregation of sub-wavelength services.
- *Offered QoS*. The PTF policy facilitates the traffic transmission over direct OLSPs while VTF aggregates traffic on the existing virtual topology. Therefore, LSPs accommodated with the VTF policy are more likely transmitted on paths containing more than one OLSP. It has been demonstrated that the PTF policy achieves a lower blocking probability, compared to the VTF policy [2]. In addition, the installation of more direct OLSPs avoids the possible bottleneck caused by electronic switching at intermediate routers and consequently PTF improves the end-to-end packet delay and packet loss.

5 DiffServ in IP/MPLS over ASON/GMPLS networks

This section describes and compares three schemes for the service differentiation in IP/MPLS over ASON/GMPLS networks.

5.1 Routing policy differentiation service (RP-Diff)

The comparison between the two multilayer routing policies previously illustrated highlights that VTF is an optimal policy from the operator's perspective (i.e. resource optimization) while PTF is the one that better meets the user's needs (i.e. QoS). This implies that the combination of these two policies should be considered when designing a DiffServ scheme in IP/MPLS over ASON/GMPLS networks. The RP-Diff scheme is based on a simple algorithm that decides on the multilayer routing policy according to the CoS the service request belongs to. More precisely, the system accommodates HP services by means of the PTF policy, whereas LP traffic is routed using the VTF policy. This decision is motivated by the comparison between VTF and PTF, which suggests that a combination of the two policies can achieve a compromise between QoS and resource utilization. In fact, the PTF policy provides HP traffic with a higher level of QoS, whereas VTF compensates the lack of resource optimization undergone by PTF. Since the VTF policy is only applied to LP traffic, the QoS deterioration introduced does not affect HP services. Figure 1 illustrates the simulation results of the

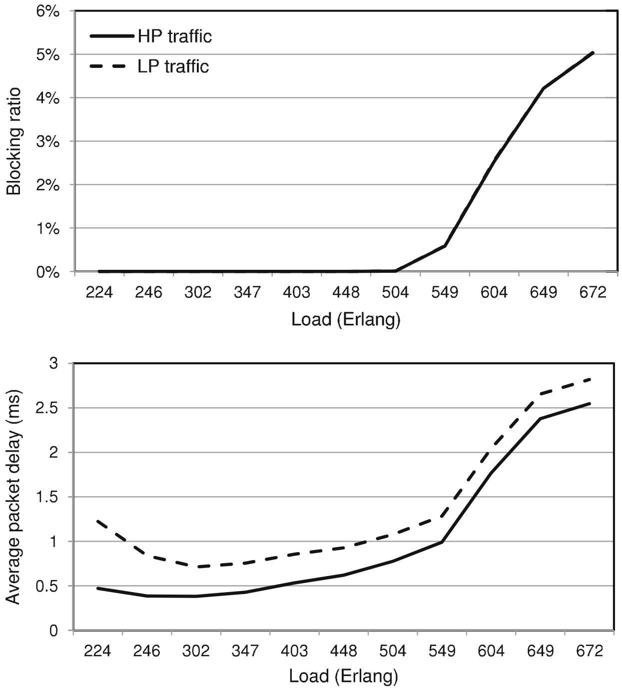

Fig. 1 Blocking ratio and average packet end-to-end delay of HP traffic and LP traffic in the RP-Diff scheme

RP-Diff scheme in terms of blocking ratio (upper part of the figure) and average packet end-to-end delay (lower part of the figure).

The upper part of Fig. 1 demonstrates that the a mere combination of VTF and PTF does not achieve the desired performance differentiation in terms of blocking probability. The two curves representing the blocking ratio of HP and LP traffic overlap even when the traffic load becomes higher (i.e. around 510 Erlang). This is due to the fact that the greedy PTF makes a heavy use of physical resources by installing a higher number of OLSPs without using them efficiently. When accommodating LP services, the VTF policy can easily find bandwidth available on the OLSPs installed by PTF.

The lower part of Fig. 1 shows a different behaviour in terms of average packet end-to-end delay. The RPD can diversify the offered QoS. In fact, the RP-Diff experiences a lower average end-to-end packet delay for the HP traffic compared to the LP traffic. However, from the blocking ratio behaviour, we can already conclude that the mere routing differentiation is not suitable for a multiservice platform.

5.2 Virtual topology hard differentiation service (VT-HardDiff)

The VT-HardDiff scheme combines the RPD of the RP-Diff scheme with the VTD technique. It transmits traffic belonging to different CoS onto different OLSPs. Every newly created OLSP is marked with the identifier of the CoS having triggered the OLSP installation. During its entire life cycle, the OLSP can only be used to aggregate traffic belonging to the CoS that has triggered the establishment. In practice, the system operates an OLSP differentiation that does not allow services belonging to different CoS to share resources on the virtual topology (i.e. bandwidth). This decision has been driven by the consideration that a traffic differentiation on the OLSP level (i.e. on the grooming level) in an IP/MPLS over ASON/GMPLS network allows an operator to build several independent virtual topologies. Each virtual topology is dedicated to the transmission of one CoS. As a consequence of the bandwidth virtualization, the different virtual topologies can be considered independent from each other and therefore can accommodate traffic by using different routing policies without sharing resources. An example of the VT-HardDiff approach is illustrated in Fig. 2, while its pseudo-code in Fig. 3.

Figure 2 highlights how the VT-HardDiff scheme allows an operator to map different CoS onto different virtual topologies built on top of the same physical infrastructure. When the system establishes a new OLSP, it is marked as HP-OLSP (HPO) or LP-OLSP (LPO) and will be used to aggregate only HP or LP traffic, respectively.

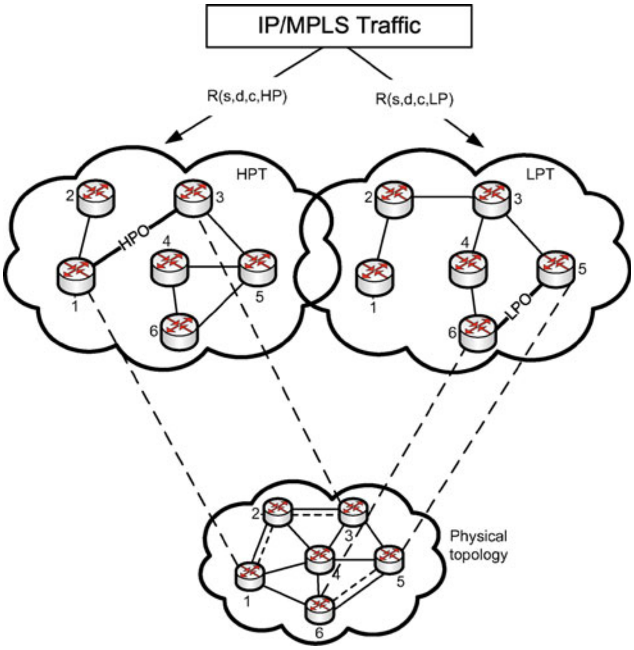

Fig. 2 Example of the VT-HardDiff scheme

```
$L_{LP} \equiv$ Low Priority Lightpath Set
                                            $\Rightarrow L_{LP} \cup L_{HP} = L$
$L_{HP} \equiv$ High Priority Lightpath Set
$G_v^{LP} \equiv G(n,m) : n \in N, m \in L_{LP}$   LP Virtual Topology Graph
$G_v^{HP} \equiv G(n,m) : n \in N, m \in L_{HP}$   HP Virtual Topology Graph
$G_v^{LP} \cup G_v^{HP} = G_v$

$L_{LP} \leftarrow \emptyset$
$L_{HP} \leftarrow \emptyset$
for each new connection request $R_i(s,d,c,p)$
    $route \leftarrow \emptyset$
    if ($R_i$ is HP Request) then
        $route \leftarrow PTF(G_p, G_v^{HP}, s, d, c)$
        if ($route \neq \emptyset$) then
            if (route is NEW LIGHTPATH) then
                $new\_lp \leftarrow route$
                $L_{HP} \leftarrow L_{HP} \cup \{new\_lp\}$
            accept $R_i$
        else
            reject $R_i$
    else
        $route \leftarrow VTF(G_p, G_v^{LP}, s, d, c)$
        if ($route \neq \emptyset$) then
            if (route is NEW LIGHTPATH) then
                $new\_lp \leftarrow route$
                $L_{LP} \leftarrow L_{LP} \cup \{new\_lp\}$
            accept $R_i$
        else
            reject $R_i$
endfor
```

Fig. 3 Pseudo-code of the VT-HardDiff scheme

The set of HPOs represents the HP Topology (HPT) and it is therefore dedicated to the transmission of HP services; the set of LPOs are grouped into the LP Topology (LPT) and it is used to aggregate LP services. The dashed lines between nodes 1 and 2 and between nodes 2 and 3 in the physical topology form an OLSP from nodes 1 to 3. In the virtual topology, that OLSP is marked as HPO, meaning that it is visible only in the HPT and used to only aggregate HP traffic. In the figure, the HPO between nodes 1 and 3 is indicated with the bold solid line in the HPT. If instead the dashed line between nodes 5 and 6 in the physical topology form an OLSP which is marked as LPO, it will be only included in the LPT and only used to transmit LP traffic (bold line between nodes 5 and 6 in the LPT). The marking operation is shown in lines 10 and 19, respectively, of the pseudo-code in Fig. 3. A new HP LSP request is accommodated on the HPT and routed by means of the PTF policy, whereas an LP LSP request is accommodated on the LPT and routed by means of the LPT. Note that in Fig. 2 the nodes in the physical topology and in the two virtual topologies are represented by the same symbol. This is motivated by the fact that we use an integrated IP/MPLS over optical network model, where every node integrates an optical switch and an IP/MPLS router. It is worth underlining that the decision to mark an OLSP as LPO or HPO does not take into consideration physical parameters of the optical layer. This decision is motivated by the fact that the aim of the VT-HardDiff scheme is to assess the impact of the VTD on a multiservice platform. However, the integration between IP/MPLS and ASON/GMPLS layers allows an operator to combine the VTD approach with thresholds that keep under control the physical structure of the OLSPs (maximum length, maximum number of amplifiers). This is outside the scope of this study.

Although using the same RPD approach as done in RP-Diff, the VT-HardDiff scheme achieves a sharp QoS differentiation. This is illustrated in Fig. 4.

The upper part of Fig. 4 visibly shows how the VT-HardDiff approach achieves a diversification between the blocking ratio offered to HP and LP traffic. Unlike the RP-Diff policy, the two curves representing the HP and LP blocking ratios of the VT-HardDiff policy never overlap. This result is a consequence of the fact that the VTD implies that the VTF policy has less bandwidth available to groom traffic. In fact, the LPT is more loosely connected compared to the HPT due to the lower number of established OLSPs. Moreover, the VTF policy finds less physical resources when needing to establish a new OLSP as a consequence of the high physical resource consumption of PTF. Note that the physical resources are not divided but can be used indifferently by HP or LP traffic when needed.

The lower part of Fig. 4 shows that the results of the average packet end-to-end delay are in line with the blocking probability. In fact, a significantly higher delay is experienced by LP services compared to HP ones.

Although achieving the desired QoS differentiation, the VT-HardDiff policy deteriorates the performance compared to the RP-Diff approach. The comparison between Figs. 1 and 4 highlights that both HP and LP traffics in the VT-HardDiff scheme result in unacceptably higher blocking probability and average packet end-to-end delay, compared to the ones achieved in the RP-Diff policy. This is a result to be expected if we consider that with the VTD technique the pool of physical resources is used to build two different virtual topologies. This implies that each CoS has a lower amount of capacity available for grooming compared to the RP-Diff scheme where HP and LP traffics are mixed over a unique virtual topology. The lack of capacity has a more significant impact on the LP traffic due to the use of the VTF policy in the LPT. In order to overcome this problem, an amount of capacity needs to be somehow shared between the two virtual topologies. This is the approach that has been used to design the heuristic described in the following section.

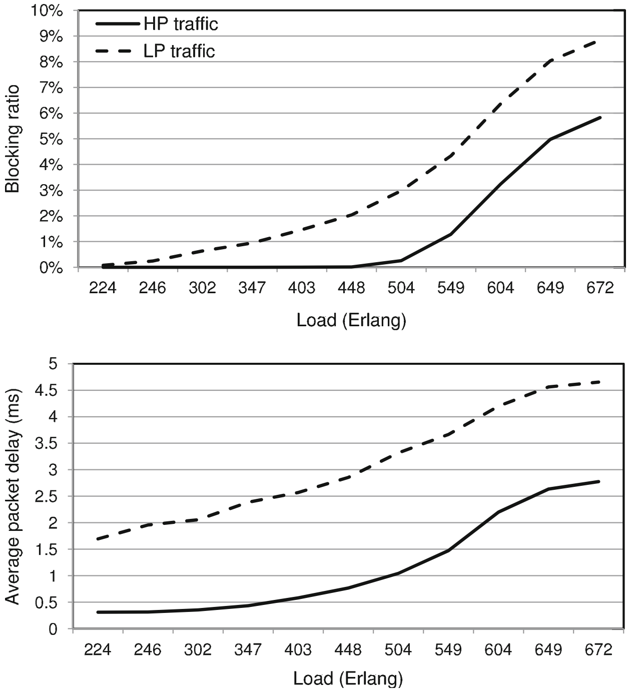

Fig. 4 Blocking ratio and average packet end-to-end delay of HP traffic and LP traffic in the VT-HardDiff scheme

5.3 Virtual topology soft differentiation service (VT-SoftDiff)

The VT-SoftDiff scheme combines the RPD, the VTD and the VTS. The VTS technique allows HPT and LPT to share a limited amount of resources.

The capacity sharing between HPT and LPT is enabled by a slight modification of the VTF policy in the LPT. When searching for a direct OLSP connecting source and destination of a new LP LSP request, the system considers both the HP-OLSPs and the LP-OLSPs. In practice, the LPT is allowed to use the capacity allocated to the HPT but only when needing a direct OLSP connecting the source and destination of the new connection. The VT-SoftDiff considers the resource sharing only in one direction. In fact, the LPT

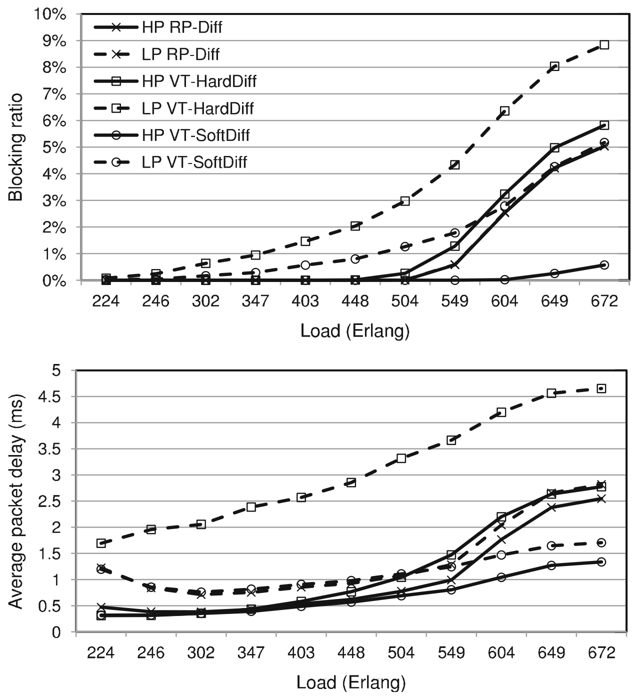

Fig. 5 Comparison of blocking ratio and average packet end-to-end delay of HP traffic and LP traffic in the RP-Diff, VT-HardDiff and VT-SoftDiff schemes

is allowed to use direct OLSPs of the HPT but not vice versa. This decision has been driven by a twofold motivation. Firstly, the LPT can undergo more instability because an operator might want to reconfigure the LPT more frequently than the HPT. This means that a HP service cannot be accommodated on the LPT otherwise would undergo more instability and therefore lower QoS. Secondly, the limited capacity availability experienced in the VT-HardDiff scheme is more significant for the LP traffic due to the use of VTF in the LPT. It is also worth underlining that the capacity sharing only considers OLSPs directly connecting source and destination (i.e. LSPs formed by only one OLSP). This decision has been driven by the consideration that the system uses the VTF routing policy to accommodate LP traffic and therefore LP LSPs will most likely be routed on multi-OLSP paths. If they were moved to the HPT, these multi-OLSP paths would spread the capacity used by the LP traffic through the HPT. By forcing the system to consider only OLSPs directly connecting source and destination, we limit the capacity utilization of the HPT and prevent the service degradation.

Figure 5 plots the comparison of the three approaches and demonstrates that the combination of RPD, VTD and VTS achieves the best performance.

As illustrated in the upper part of Fig. 5, for low- and medium-loaded networks (i.e. until about 500 Erlang), the RP-Diff policy experiences a non-significant blocking ratio for both HP and LP traffics. In the same load range, the VT-SoftDiff scheme results in slightly higher blocking ratio for LP services. We can conclude that for low- and medium-loaded networks the choice between the RP-Diff and VT-SoftDiff policy does not have a significant impact on the blocking ratio. The benefit of the VT-SoftDiff scheme can be appreciated when the traffic load increases. When the traffic load reaches 500 Erlang, the blocking ratio in the RP-Diff abruptly increases both for HP and LP traffics (as already observed in Fig. 1). This phenomenon does not affect the VT-SoftDiff scheme where the HP traffic blocking ratio remains insignificant (i.e. until about 630 Erlang), whereas the LP blocking ratio continues to increase but at a more stable pace. The difference between the two curves representing the HP blocking ratio of the two strategies highlights the gain obtained by the VT-SoftDiff heuristic. More specifically, the VT-SoftDiff scheme allows an operator to accommodate more HP traffic (more than 100 Erlang compared to the RP-Diff scheme) while keeping its blocking ratio under control.

The lower part of Fig. 5 demonstrates that the VT-SoftDiff heuristic achieves the best performance also in terms of packet end-to-end delay. Until a traffic load of around 510 Erlang, the VT-SoftDiff approach has similar performance as RP-Diff, both for HP and LP traffics. When the traffic load increases, the end-to-end packet delay offered by the RP-Diff policy starts not to be acceptable neither for the HP traffic nor for the LP traffic. This phenomenon is not noticed when using the VT-SoftDiff approach where the system can undergo the traffic increase without abruptly deteriorating the QoS.

6 Conclusions

This article addressed the problem of service differentiation in IP/MPLS over ASON/GMPLS networks. Three schemes were proposed and compared.

The first scheme, called RP-Diff, is based on the RPD technique. It is a simple algorithm that decides on the multilayer routing policy according to the CoS the service request belongs to. RP-Diff accommodates HP services by means of the PTF policy while LP traffic is routed using the VTF policy. The simulation results demonstrated that the RPD achieves the QoS differentiation only in terms of average packet end-to-end delay. In fact, HP and LP traffics result in the same blocking ratio which makes the RP-Diff scheme not useful for a multiservice platform.

The second scheme, called VT-HardDiff, combines the RPD of the RP-Diff scheme with the VTD technique. Besides using different multilayer routing policies for different CoS, the VT-HardDiff scheme transmits different CoS over dedicated virtual topologies. The simulation results showed a sharp service differentiation in terms of blocking ratio and average packet end-to-end delay but an unacceptable QoS degradation compared to the RP-Diff approach.

The third scheme, called VT-SoftDiff, is a combination of RPD, VTD and VTS techniques. The VTS technique allows HPT and LPT to share a limited amount of resources. Specifically, the LPT is allowed to use the capacity allocated to the HPT but only when needing a direct OLSP connecting source and destination of the new connection. The simulation results demonstrated that the VT-SoftDiff approach is the scheme achieving the best performance in terms of blocking ratio and average packet end-to-end delay. It not only achieves the desired service differentiation, but also improves the performance. We can conclude that in a multiservice IP/MPLS over ASON/GMPLS platform the combination of RPD, VTD and resource sharing needs to be considered when designing multilayer DiffServ schemes.

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