Multilayer Quality and Grade of Service Support for High Speed GMPLS IP/DWDM Networks

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Abstract. IP over optical networks controlled by the GMPLS control plane have become the common infrastructure for a variety of services, such as triple play and grid applications. The traffic aggregation requires the services to be differentiated in a multilayer fashion, so as to guarantee higher levels of GoS and QoS to 'gold' traffic. This means that the traditional DiffServ technology needs to be combined with differentiation mechanisms in the optical domain. This paper proposes a framework for multilayer QoS and GoS support in GMPLS based IP/WDM networks. The scheme is based on a multilayer strategy which combines two routing policies that optimize the resource utilization. The system also provides a lightpath differentiation which allows the operator to accommodate sensitive traffic on lightpaths able to guarantee a certain level of transmission quality. The benefits of the scheme are illustrated by a simulation study, discussing blocking probability and resource utilization.

Keywords: GMPLS, DiffServ, QoS, GoS, Multilayer Traffic Engineering, routing, grooming.

1 Introduction

Over the last few years the telecommunications world has considerably evolved towards new challenging scenarios. The increased adoption of broadband access technologies such as Digital Subscriber Line (DSL), cable modem and Ethernet passive optical networks, has lead to the migration of most services towards the Internet Protocol (IP).

Based on the type of application supported, Internet traffic can be roughly divided into two large groups. On the one hand, there is the so called triple play, being the bundle of voice, video, and data services [1, 12]. Due to the fast advance in Voice over IP (VoIP), video on demand, IPTV (IP television) and Web 2.0 technologies, triple play applications have become omnipresent in our daily lives. The second group is the set of the large-scale grid computing services such as e-science applications emerging on a variety of scientific fronts, including geosciences, biomedical informatics and nuclear physics [4]. These applications enhance the understanding of complex systems that share and process data distributed in geographically dispersed locations.

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The traffic change has given rise two phenomena that change the scenario of the telecommunication networks: the massive increase of the bandwidth needs and the migration of the traffic patterns from the predictable and stable behavior of the traditional voice traffic to a self-similar and asymmetric nature of data flows. Consequently, dynamic allocation of resources has become extremely important for the cost effectiveness of a network. In order to satisfy traffic's quantity and quality, network operators have to replace the traditional expensive and statically provisioned networks with dynamic and self adaptive infrastructures. Such networks provide traffic with time-depended application-driven communications paths established by means of near real time signaling.

The fast progress in optical networking and Dense Wavelength Division Multiplexing (DWDM) technologies has made available a huge amount of bandwidth at a lower cost and with predictable performance. DWDM mesh networks provide clients with all-optical high speed channels (i.e. lightpaths) up to 10 Gbps (OC-192) and 40Gbps (OC-768) rates. Lightpaths bypass the electronic switching at intermediate IP routers and improve the communication performance in terms of end-to-end delay, jitter and packet loss. In addition, there has been an effort in providing optical components with a certain grade of automation in order to facilitate intra/inter domain communication by means of an intelligent control plane – called Generalized Multi Protocol Label Switching (GMPLS) [5, 9, 10]. GMPLS eliminates the burden of the human manual intervention b erators need technologies for guaranteeing communications quality and increasing the Return on Investment (ROI). The preferred technology for scalable IP Quality of Service (QoS) deployments is Differentiation Service (DiffServ). DiffServ supports differentiated and assured delay, jitter and loss commitments on the same IP network for different Classes of Service (CoS). However, the massive traffic increase and the flexibility introduced by GMPLS and IP/DWDM networks have made IP layer QoS control mechanisms insufficient. Operators are required to implement new integrated techniques able to satisfy the communication quality on both IP and DWDM layer. The communication quality in IP/DWDM networks encloses two concepts: QoS and Grade of Service (QoS) [6]. The QoS concerns the transmission performance during the data communication phase, such as delay, jitter, Bit Error Rate (BER) and packet loss. The GoS is the set of parameters related to y using sophisticated signaling and routing mechanisms to set up on-demand high speed end-to-end connections in the order of milliseconds. In such a dynamic scenario, the network nodes become intelligent agents able to automatically react to the traffic changes in a multilayer way. This can be thought of as a cooperation between the IP layer (by means of traffic grooming) and the optical layer (by means of dynamic lightpath establishment) in traffic engineering the network and called Multilayer Traffic Engineering (MTE).

When aggregating different traffic types with different Service Level Agreements (SLAs) on the same infrastructure, op the connection establishment, such as blocking probability. Both aspects need to be considered by a network operator to guarantee higher quality communication to high priority sensitive traffic.

This paper proposes and analyzes a framework for multilayer QoS and GoS support in GMPLS based IP/WDM networks. In order to address both QoS and GoS issues, the system differentiates the traffic in two steps. In the first, the traffic differentiation is based on the required bandwidth. High bandwidth applications – likely grid computing services – are routed according to a policy preferring the installation of new lightpaths in order not to overload existing connections. Low bandwidth applications – likely triple play services – are first attempted to be groomed on existing lightpaths in order to optimize the bandwidth utilization while keeping physical resources available for high bandwidth connection requests. In the second step, the traffic differentiation is based on the priority assigned by the DiffServ domain and on an admission control accepting sensitive traffic only in case it can be accommodated on lightpaths providing a sufficient level of QoS. The simulation results show the improvements obtained by the proposed scheme in terms of resource utilization and blocking probability.

The paper is organized as follows. Section 2 describes the motivation and the related work. In Section 3 we give a detailed explanation of the proposed framework. In Section 4 the simulation results and their discussion are presented. Section 5 draws some conclusions.

2 Motivation and Related Work

In this section we first describe the related work found in the literature and then we present the twofold contribution of this paper.

The work in [6] focuses on the importance of the GoS in optical networks. The authors present three mechanisms for GoS differentiation in a DWDM network. The first policy is based on the resource preservation for high priority requests. The authors introduce a threshold that is used to decide on the amount of resources that should remain available for high priority requests at the expenses of low priority. The second mechanism is based on routing algorithms which assign a higher number of routes to high priority traffic. This policy results in a lower blocking probability for high priority requests but in a 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 preemption of low priority requests when the system is unable to find sufficient resources for high priority traffic.

The work presented in [1] proposes a multilayer routing solution based on a hybrid on-line/off-line approach. High priority traffic is accommodated by means of an off-line system that optimizes the route calculation based on a foreseen traffic matrix. Low priority 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 preemption module in order to guarantee a lower blocking probability to gold requests at the expense of the low priority traffic. According to our point of view, this system has several weaknesses. Firstly, it requires a high implementation complexity due to the need for an on-line and an off-line routing modules and a preemption module. Secondly, it relies on the assumption that high priority traffic is predictable.

In [4], an approach for service differentiation in a GMPLS grid infrastructure is proposed. The scheme is based on a mapping between the MPLS label and the lightpaths' quality. When traffic enters an optical network, the incoming label determines the received QoS treatment: high priority traffic is routed over lightpaths offering a lower signal degradation. This framework achieves a lower packet loss for high priority traffic with a slight increase of the total blocking probability. However, the GoS is not considered and therefore the author cannot guarantee lower blocking probability to high priority traffic.

In [10] and in [16] the authors propose two routing strategies. Either the system accommodates new traffic preferably on the existing virtual topology or it first tries to set up one or more lightpaths. The weakness of these schemes is that the system can only statically apply one routing policy therefore causing a non-optimal resource utilization level.

The analysis of the aforementioned studies suggests two considerations: GoS and QoS are typically considered individually and the routing/grooming strategies are always statically decided.

The contribution of this paper is twofold. Firstly, we propose a control scheme that differentiates the traffic considering both GoS and QoS. Secondly, the system accommodates requests according to bandwidth-depended multilayer routing policies.

3 A Scheme for Multilayer QoS and GoS in GMPLS Networks

In this section, we first recall some background information needed to understand the rest of the paper and then we describe (in paragraphs 3.1 and 3.2) the main building blocks.

In MPLS a connection is usually called Label Switched Path (LSP), indicating that a path between source and destination MPLS routers – called Label Edge Routers (LER) – is a set of links represented by a set of labels. The core routers along the LSP are called Label Switching Routers (LSRs). LSRs switch packets according to a forwarding table which associates an incoming link and label with an outgoing link and label. The counterpart of the LSP in GMPLS is called Optical LSP (OLSP), meaning that a source-destination connection is a set of wavelengths traversing one or more OXCs. Due to the non-packet nature of optical networks, the OXCs forward traffic by mapping an incoming fiber and wavelength on an outgoing fiber and wavelength.

In a DiffServ domain, IP packets are aggregated and marked using the DiffServ Code Point (DSCP) field in the packet, in order to identify the class of service. To guarantee the QoS to high priority traffic, the DiffServ paradigm defines three forwarding per-hop behaviors (PHB) to be applied to the traffic at each hop depending on the traffic classes: high sensitive traffic, bandwidth guaranteed traffic and best-effort traffic. These classes are respectively represented by the Expedited Forwarding (EF), the Assured Forwarding (AF) and the Default PHBs.

We suppose that a DiffServ/MPLS connection requires accommodation on a GMPLS optical network.

The scheme's architecture is described in figure 1. The modules implemented to build the proposed scheme are the GoS and the QoS modules. They are described in paragraph 3.1 and 3.2 respectively.

3.1 GoS Module

The GoS module gets input from the User Network Interface (UNI) module. The UNI is a set of protocols allowing the client network – in this case an MPLS/DiffServ domain – and the server domain (e.g. optical network) to communicate with each other. More precisely, by sending UNI request messages, the LSPs requests invoke the optical domain for the OLSPs setup, while the optical layer acknowledges the success or the failure of the OLSP establishment by sending UNI reply messages. The parameter passed by the UNI to the GoS module is the bandwidth required by the LSP. By looking at the required bandwidth, the GoS module decides on which multilayer routing policy to apply

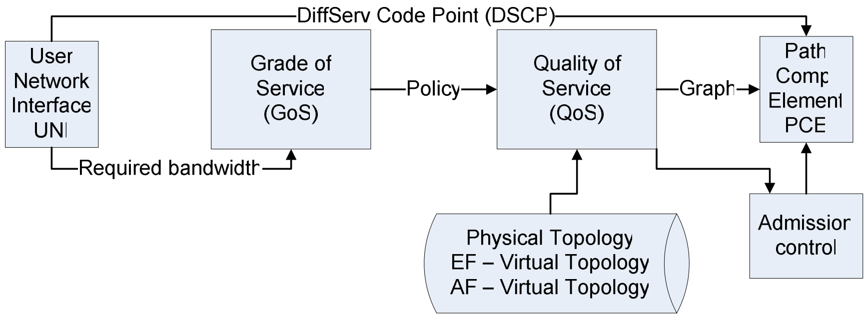

Fig. 1. Architecture of the proposed control scheme

The policy decision is taken by comparing the required bandwidth value with a fixed threshold: a high bandwidth LSP request is accommodated with the New Lightpath First (NLF) policy, while a low bandwidth LSP request is routed with the Grooming First (GF) policy. The two policies are described as follows:

- *NLF policy*. The system first attempts to establish a new direct OLSP between source and destination LERs. If a new OLSP cannot be established due to physical resource shortage (i.e. available wavelengths and ports) the system tries to aggregate the traffic over the existing virtual topology.
- *GF policy*. The system first attempts to groom the LSP request over the existing virtual topology. If there is not sufficient bandwidth and a path is not found, a new OLSP establishment is triggered.

The rationale for routing LSPs according to two different policies originates from empirical assessments and conceptual considerations concerning blocking probability and resource usage. On the one side, the NLF policy achieves a lower blocking probability at the expenses of a low bandwidth utilization level. The GF policy achieves a better bandwidth utilization level when the average LSP's required bandwidth is relatively low.

The previous considerations suggest that neither NLF nor GF are valid candidates as unique multilayer routing policy and that a higher grade of optimality can be achieved if the system suitably applies both strategies. In the system we propose, applications with massive bandwidth requirements (e.g. grid computations) are accommodated according to the NLF policy. Such applications likely have higher priority than low bandwidth applications and therefore require a lower blocking probability. Low bandwidth LSPs are routed according to the GF policy in order to improve the bandwidth utilization level at the expenses of a slightly higher blocking probability.

3.2 QoS Module

The output of the GoS module is a multilayer routing policy which is passed to the QoS block. Based on the LSP request's DSCP, the QoS module guarantees that sensitive traffic is routed on a single or multiple OLSPs whose performance degradation can be limited to a certain value. This implies the system awareness of the OLSP degradation and consequently of its fibers. For the sake of simplicity, we represent the fiber's transmission quality with a parameter – indicated as α_{fiber} - directly related to the fiber's BER, delay and jitter and assigned by the network operator on a monitoring basis. In our simulation the parameter α_{fiber} is uniformly distributed in the interval [0, 1], with 1 representing the highest fiber degradation value. As stated in [15] non linear physical parameters can be approximated with linear physical parameters. This suggests that the OLSP degradation – indicated as α_{OLSP} – is the sum of the degradation of all its constituent fibers.

The GoS module differentiates the created OLSPs according to a threshold – indicated as α_{max} – representing the maximum signal degradation an OLSP can support to provide a certain grade of transmission quality. Consequently, an OLSP is considered to be a high quality OLSP (HQ-LSP) if its signal degradation α_{OLSP} is lower than the threshold α_{max}, while an OLSP is considered to be a low quality OLSP (LQ-LSP) if its signal degradation α_{OLSP} is higher than α_{max}. By differentiating the OLSPs an operator can transmit sensitive traffic (EF-LSPs) by using only connections able to guarantee a deterministic performance in terms of BER, delay and jitter. In order to keep the HQ-OLSPs available in case sensitive traffic need to be transmitted, traffic requiring less tight QoS commitments (AF-LSPs) is accommodated on LQ-OLSPs.

4 Performance Evaluation and Results Analysis

The performance of the proposed multilayer QoS and GoS control scheme for IP/DWDM networks has been evaluated by means of simulation experiments under the OMNET++ simulation tool [16]. OMNET++ is an open source discrete event simulation system providing a component architecture based on reusable modules. The model topology is specified using the NED language while the modules are written in C++ programming language. We provided extensions for the basic OMNET++ package in order to model a GMPLS based IP over optical network.

The network under test is illustrated in figure 2. It consists of 21 nodes and 36 bidirectional optical fibers with the value of the signal degradation (α) uniformly distributed in the interval [0, 1]. The threshold for the OLSP differentiation – the maximum signal degradation α_{max} – has been chosen according to the formula $\alpha_{max} = (D + 1)\alpha_{av}$. D represents the network diameter, defined as the average minimum

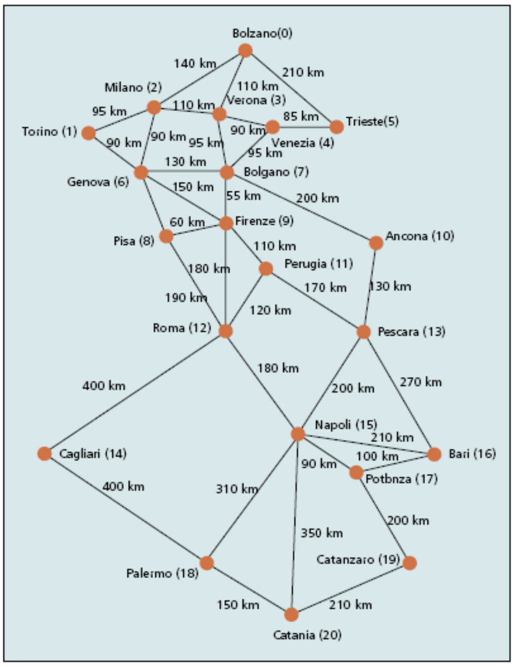

Fig. 2. Network topology under test

distance between any two nodes in the network. α_{av} is the mean value in the interval where α is generated. In our experiments $\alpha_{av} = 0.5$ and D = 2.78, therefore $\alpha_{max} = 1.89$.

Every fiber is equipped with 16 wavelengths each one supporting capacity values from 51.84 Mbps (OC-1) to 40 Gbps (OC-768).

The traffic sources are modeled with a Poisson process with an average rate λ and connection holding time exponentially distributed with mean $1/\mu$. The network load is given by $\gamma = \lambda/\mu$ Erlangs. The generators are set to generate 40% of Expedited Forwarding (EF) requests and 60% of Assured Forwarding (AF) requests. The connection requests have a bandwidth demand uniformly distributed among all the supported values, namely in the interval [OC-1, OC-768]. The threshold to differentiate a high bandwidth LSP (HB–LSP) from a low bandwidth LSP (LB-LSP) is set to OC-24. This means that all the connection requests with a bandwidth requirement lower than the threshold are considered as LB-LSP and are accommodated with the GF policy while connection from OC-24 till OC-768 are considered to be HB-LSP and are routed according to the NLF policy.

Each simulation run generates 10^6 requests with source and destination uniformly distributed among the entire set of nodes. In all the experiments the plotted results are the average values calculated over 10 outcomes for each value of the X-axis.

The performance is evaluated in terms of blocking probability, optical network resource utilization and bandwidth utilization. The blocking probability is defined as the average ratio between the number of rejected requests and generated requests. The optical network wavelength utilization is defined as the average ratio between the number of used wavelengths and available wavelengths at each link. The bandwidth utilization is defined as the average ratio between the used bandwidth and the total bandwidth of the OLSPs.

In figure 3, the average blocking probability is plotted against different values of the traffic load. In figure 3.a) we report the blocking probability undergone by the traffic in the GoS module, while figure 3.b) shows the blocking probability in the QoS module.

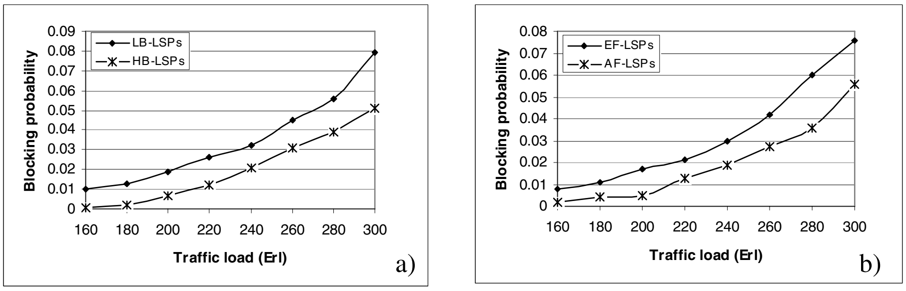

Fig. 3. Average blocking probability in the GoS module (a) and blocking probability in the QoS model (b)

As reported in figure 3.a), the combination of the NLF and GF policies gives rise to different values for the blocking probability suffered by high bandwidth and low bandwidth traffic. The number of blocked HB-LSPs is constantly lower than the one measured for LP-LSPs for every value of the traffic load. This is due to the fact that in the chosen network model, the system has more chances to find available wavelengths and ports to accommodate HB-LSPs on a new OLSP than to find available bandwidth to groom LB-LSPs on the existing virtual topology. Such a choice originates from the fact that only HB-LSPs have to undergo the QoS admission control because they imply a new OLSP establishment. However, the network operator can directly influence the performance by deploying a lower number of wavelengths and ports.

As shown in figure 3.b), sensitive traffic is penalized with a higher blocking probability for every traffic load condition. This is due to the QoS admission control that blocks EF-LSPs if the OLSPs do not provide a sufficiently low value of the signal degradation. It is straightforward that the threshold α_{max} directly affects the HP-LSP blocking probability. Consequently, the network operator can vary the network performance by changing the value of α_{max} according to the SLAs.

In figure 4, the resource utilization level is reported. In figure 4.a) we show the wavelengths utilization (optical layer), while figure 4.b) illustrates the bandwidth utilization (IP layer). In order to demonstrate the benefits of using a combination of the NLF and GF policies as multilayer routing strategy, the results obtained from the simulation of the proposed system are compared with the two cases in which either the NLF policy or the GF policy is used.

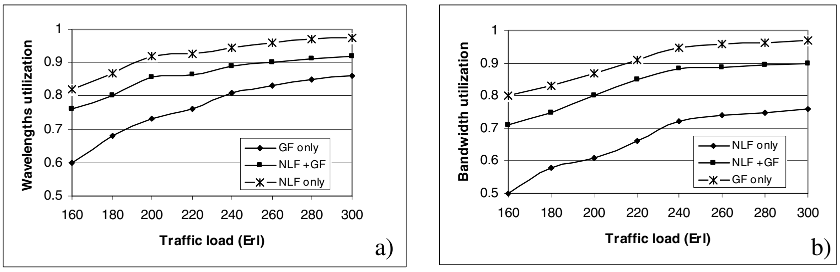

Fig. 4. Wavelength utilization (a) and bandwidth utilization level (b)

As expected, the use of only a static single policy as routing strategy leads to resource underutilization. The GF policy has a significantly low wavelengths usage (figure 4.a) while the NLF policy results in a very low bandwidth utilization level (figure 4.b). In both cases the curve representing the results obtained when using the proposed scheme (NLF + GF in the figure 4) is closer to the curve with the best performance. This explains that the combination of the two policies leads to a resource utilization compromise that combines the advantages of both policies.

5 Conclusions

Due to the migration of most services over the IP protocol, the service differentiation has become important not only in the IP layer, but also in the optical layer.

In this paper we proposed a framework for multilayer QoS and GoS support in GMPLS based IP/WDM networks. The system differentiates the traffic according to the required bandwidth and to the QoS needed. Under a first differentiation, high bandwidth connections are accommodated according to a routing policy that first tries to accommodate the request on a new direct lightpath and then tries to groom it on the existing virtual topology. Low bandwidth traffic is groomed on the existing virtual topology if possible, otherwise the systems considers a new lightpath set up. The second differentiation is based on the lightpath quality. Sensitive traffic is accommodated only on lightpaths with a signal degradation under a certain threshold. This admission control is not provided when accommodating traffic with less strict QoS requirements.

The benefits of the proposed system have been shown in terms of blocking probability and resource utilization level. The combination of the two multilayer routing policy leads to a compromise between optical resources utilization level and bandwidth utilization level.

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