HYBRID MODEL OF TRAFFIC CHARACTERIZATION FOR OPTIMIZATION IN GMPLS OPTICAL NETWORKS

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Abstract—This paper presents a hybrid traffic model for GMPLS (Generalized Multi-protocol Label Switched) optical networks. The model is focused in multi-service traffic characterized as self-similar and is used to produce more accurate QoS (Quality of Service) metrics which influence the different hierarchies of the network topology. Also, the model is used to implement an optimization procedure with a genetic algorithm for the establishment of link capacities in different physical mediums. The extensions of the model for the hierarchies of LSPs (Label Switched Paths) in the GMPLS suite are also analyzed.

Index Terms—GMPLS, lightpaths, LSP, QoS, self-similar traffic, traffic engineering, genetic algorithm.

I. INTRODUCTION

The rapid growth of services and applications driven by the IP (Internet Protocol) trends to the packet switched network as the natural choose for the future of communications. This results in the need to provide fast provisioning and scalability in order to offer multi-service capabilities [1].

In recent years, MPLS (Multiprotocol Label Switching Protocol) appears as a solution to implement traffic-engineering (TE) mechanisms, which will allow a major integration between the different planes of the layers in the network reference model. The MPLS works with label switching. On each network element, called of LSR (Label Switching Router), the packets are switched based on the label value [2]. Each LSP has an associated FEC (Forward Equivalence Class) that describes the type of traffic requirements.

In order to facilitate the traffic engineering capabilities of the network, nowadays there is a trend to migrate to MPLS, and integrate the synchronous digital hierarchy (SDH) and wavelength division multiplexing (WDM) in an unique operational model.

The TE procedure has the task to optimize the network resources for different traffic fluctuations. Within an integrate reference model, this should be performed considering the different network layers and technologies, and with this goal in mind, extensions to MPLS have been made resulting in the GMPLS suite [1].

By the other hand, the self-similar nature of Internet traffic has been demonstrated with high quality measures [3],[4]. Observations in the electronic domain and in the optical packet switching networks have confirmed that the performance of optical network is seriously degraded because of the self-similarity of the traffic [5].

This work presents the problematic of network optimization for GMPLS networks focused in an accurate model of traffic characterization and the optimization of network capacities. In Section II, the theoretical concepts of TE with GMPLS and hierarchical LSPs are introduced. The traffic characterization procedure for converged networks is presented in Section III and the accuracy of the proposed hybrid model is also analyzed. In section IV, the traffic model with a genetic algorithm is used to optimize link capacities. In Section V, the results of the analytical model are discussed as well as the implications of the optimization procedure in GMPLS paradigm as part of future works.

II. TRAFFIC ENGINEERING AND GMPLS

The GMPLS presents a gradual and future approach toward converged networks. The extension provides a control plane (signaling and routing) for devices that switch in domains such as packets, time, wavelength and fiber [6].

The GMPLS approach intends to simplify network operation and management by automating end-to-end provisioning of connections with all the related tasks involved. One of the expected results of this integration is to find an optimal path based on user traffic requirements for a flow that potentially starts on an IP network, is transported by SDH and then is switched through a specific wavelength on a specific physical fiber. So, the maintenance of end-to-end service quality as usage data travels through dissimilar network types is essential and appears as a main research topic [6].

The LSP establishment through different networks is shown in Fig. 1. The LSP-λ is established between OXC1 and OXC2, capable of deliver STM-16 wavelength to tunnel in TDM LSPs. A packet switched network is connected via a TDM network, which establishes an LSP-TDM tunnel. The LSP-tdi should carry various LSPs of the higher hierarchy if the sum of traffic permits its accommodation. This shows that the traffic grooming in upper hierarchy influences the whole network topology.
The internetworking between the IP/MPLS and optical layers can be in two ways: i) the overlay model, which uses a client-server structure, where the optical layer acts as a server of the IP/MPLS layer, and ii) the peer model, with a single control plane that manages the whole network and both the IP/MPLS and optical components act as peers, sharing the same topological view.

Each of these approaches changes the routing strategy in that GMPLS can be of two types: the single layer approach and the multilayer approach. For the first, the LSPs are aggregated by edge LSRs into lightpaths, the connections requests are composed based on the number of wavelengths requested by each pair of optical nodes and the optical layer is responsible for finding the routes for the optical LSPs (routing and wavelength assignment – RWA). In the second type, aggregation and routing are performed together, which may produce the routing of a LSP on a concatenation of lightpaths in a single routing instance, procedure that improves efficient use of network resources. The multilayer reference model is shown in Fig. 2.

The routing and signaling protocols of the MPLS based network may be extended to suite the development of GMPLS. The whole number of links in an optical network can be several orders of magnitude bigger than in a MPLS network. The concept of link bundling has been introduced which permits that, several and similar optical parallel links may be aggregated to form a bundle for routing purposes, in which the LMP (Link Management Protocol) performs the links management task.

The potential of GMPLS control plane for QoS handling will allow that bandwidth reservation may occur for individual LSPs at any hierarchical level. This procedure relies on accurate traffic models and optimization procedures that work over the whole network topology.

### III. Traffic Characterization in Converged Networks

While the transmission capacity of multi-wavelength (WDM) links may be scalable, the switching capacity of an optical router may be limited by the processing capacity of electronic control and signaling [7].

For a TE procedure in GMPLS, it is convenient to adopt a multilayer approach, which permits optimization of network resources. It depends on appropriate QoS measurements, which are still problematic issues even for IP/MPLS networks, due to the nature of Internet traffic, which appears to have asymmetry of flows of data, and has a self-similar nature [3].

The optimization implies that the number of lightpaths must be minimized in order to optimize data flow aggregation and the LSPs spanning during its travel throughout the network to reduce the number of times of electronic processing inside the nodes. For the above purposes, limiting the bandwidth of each wavelength constituting the lightpaths is necessary [6].

This procedure implies in a bandwidth control of LSPs in the IP/MPLS level, where each LSP is expressed in terms of source-destination node and the mapped FECs. Each FEC has a QoS need, so a method for mapping flows into FECs to keep the QoS measures and the bandwidth allocation of the LSP is necessary in order to promote the limit of bandwidth assigned to each wavelength, before the bundling task.

The above procedures need an accurate traffic model, which based on a traffic matrix can produce realistic QoS values for a logical topology which reflects the LSP mapping on the physical network. Also, the traffic model can allow the optimization of network capacities for a certain traffic load that within the GMPLS protocol can be extended to the optimization in terms of localization, capacity and configuration of the optical network elements.

#### A. The hybrid model for traffic characterization

 Nowadays, is broadly accepted that network traffic exhibits the features of long-range dependence and self-similarity. This approach, broadly discussed in the last decade, represents a major change in network analysis, since network traffic was for a long time treated as Poisson [4]. The Poisson traffic exhibits short range dependence and treats network elements as M/M/1 queues, according to Kendall’s notation [10]. The implications in QoS metrics of each type of traffic are very different. The treatment of traffic as self-similar in data networks was one of the major influences in the last
decade regarding the network area and should persist for the new converged networks.

Let \( Y(t) \) be a stochastic process for \( t \in \mathbb{R} \). \( Y(t) \) is a self-similar process, denoted by \( H \)-ss, with Hurst parameter \( \frac{1}{2} \leq H \leq 1 \), if (1) is satisfied for \( a > 0 \) and \( t \geq 0 \). The equality is in a statistical sense, so it appears that \( Y(t) \) is a scaled version of \( Y(at) \), normalized by \( a^{-H} \), with the same distribution.

\[
Y(t) = a^{-H} Y(at)
\]  

Considering an original temporal series \( Y, Y_i \) is the number of bits, bytes or packets in the \( i \)-th interval. Let \( Y(m) \) denote the new process obtained by averaging the original series \( Y \) in non-overlapping sub blocks of size \( m \). For each \( m \), \( Y(m) \) defines a wide-sense stationary random process. Let \( \rho^m(k) \) be the autocorrelation function of \( Y(m) \). As \( k \to \infty \), the function varies very slowly which characterizes long range dependence with hyperbolically decays as \( k \) increases.

The Hurst parameter is the key for the measure of self-similarity. Its value influences the QoS measures of the network, such as delay and packet losses. Also, it is known that the aggregation of different flows preserves the self-similar nature of traffic [4].

The QoS metrics calculus for self-similar traffic can use the approach of fBm (fractional Brownian motion) envelope process of a traffic trace [7]. The definition of the traffic fBm envelope process is

\[
\hat{A}_H(t) = at + k \sigma^H
\]  

where \( \hat{A}(t) \) is the envelope process of a cumulative second order self similar process \( A(t) \), the \( k \) parameter indicates the probability that \( A(t) \) will overpass \( \hat{A}(t) \) on time \( t \) and. \( \sigma \) is the standard deviation of the traffic trace. With (2), an expression, for end-to-end delay can be induced and used for the calculus of QoS metrics in multimedia applications [8]-[9].

Observations showed that for a higher degree of self-similarity and channel load the M/M/1 model gets even more inaccurate, but for light loads it has an acceptable behavior. The proposal of this work is shown in (3). A hybrid model, with two different windows: for channel load lower than 0.3 the M/M/1 model is applied and for loads equal or higher than 0.3 the model based on self-similar traffic is applied, where \( T \) is the delay in a node for certain flow. The variables \( c \) and \( a \) are the capacity of the channel and the mean rate respectively. The channel load is \( \rho \), with \( \rho < 0.8 \). The delay for M/M/1 corresponds to the Kleinrock equations for data networks [10].

\[
T = \begin{cases} 
\frac{(c-a)^H}{c(1-H)} (k \sigma)^{1-H} \left\{ \begin{array}{l}
\rho \geq 0.3 \\
M/M/1 \end{array} \right. & \rho \geq 0.3 \\
\frac{1}{c} H^{-1} (1-H) & \rho < 0.3
\end{cases}
\]  

In Table 1, it is shown a comparison of delay metrics in a hypothetical network with 12 nodes and 10 traffic flows (Fig.3). The flows identifiers are in column 1. The simulations were made in the NS-Network Simulator [11]. The F3, F5, F7 and F9 are CBR (Constant Bit Rate) flows with \( a=1000 \) kbps and the others are self similar flows with \( H=0.8, \sigma=1250 \) and \( a=8000 \) kbps. For this problem, 3 different networks were projected and optimized based on M/M/1, self-similar [9] and the proposed hybrid model. The third column shows the delays calculated with the hybrid model (the analytical results of the other models are not shown). Columns 4-6 show the simulations with the capacities established through calculation with each of above mentioned analytical models, restricted to the value of column 2 which contains the maximum delay admissible for each flow.

The novelty of this approach is to obtain a closer to reality value of delay for multimedia traffic network, which should promote a more accurate calculus of network capacities, and consequently, influence the several hierarchies of the network topology in the GMPLS proposal.

### Table 1. Delay calculus of network simulations with different networks and the hybrid model.

<table>
<thead>
<tr>
<th>F</th>
<th>Max Delay</th>
<th>Hybrid model</th>
<th>Simulations in NS</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>F1</td>
<td>0.050</td>
<td>0.020</td>
<td>0.020</td>
</tr>
<tr>
<td>F2</td>
<td>0.150</td>
<td>0.070</td>
<td>0.068</td>
</tr>
<tr>
<td>F3</td>
<td>0.050</td>
<td>0.020</td>
<td>0.030</td>
</tr>
<tr>
<td>F4</td>
<td>0.200</td>
<td>0.070</td>
<td>0.066</td>
</tr>
<tr>
<td>F5</td>
<td>0.050</td>
<td>0.040</td>
<td>0.043</td>
</tr>
<tr>
<td>F6</td>
<td>0.080</td>
<td>0.040</td>
<td>0.027</td>
</tr>
<tr>
<td>F7</td>
<td>0.180</td>
<td>0.110</td>
<td>0.104</td>
</tr>
<tr>
<td>F8</td>
<td>0.090</td>
<td>0.070</td>
<td>0.046</td>
</tr>
<tr>
<td>F9</td>
<td>0.060</td>
<td>0.040</td>
<td>0.048</td>
</tr>
<tr>
<td>F1</td>
<td>0.100</td>
<td>0.030</td>
<td>0.026</td>
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</tbody>
</table>

### IV. NETWORK CAPACITIES OPTIMIZATION

In this section, the optimization problem of link capacity assignment is solved using a genetic algorithm. The objective function is the cost of the network, which considers a linear function based on the capacity units of the link, which may be generalized for different physical mediums. The restrictions considered in the heuristic are the delay as a function of the traffic characterization as shown in the hybrid traffic model shown in (4).

A hypothetical topology is used, with routes and LSPs fixed manually, as shown in Fig. 3 with the same flows used in Table 1. This is an IP/MPLS environment that could be mapped as shown earlier in Fig. 2.

Initially, the routes are established such that the traffic is distributed on the MPLS layer with bundling of LSPs onto the lightpaths and the available wavelengths.

The optimization procedure should produce a set \( \{ C_{ij} \} \) of capacities, with \( i \) and \( j \) being the origin and destination node respectively, which in the hypothetical network topology produce the desired QoS metrics with a lower cost. In order to ease the simulation task in NS, the capacities and flows used are extremely reduced in terms of rate, since our main goal is to show the potentiality of the method.
aggregations have values of capacities are sub estimated in the cases where the traffic models are shown. For the M/M/1 model the other layers within the GMPLS approach.

The link capacities are optimized based on a linear cost function that can be extended to consider a variety of physical mediums. The hybrid model shows satisfactory results and could be the primary element of a TE procedure that will promote network stability and resource optimization.

The final goal is to optimize the localization, capacity and configuration of optical network elements through the different hierarchies of the GMPLS suite. The optimization results in a lower introduction of unnecessary LSPs and consequently, the creation of new wavelengths that should increase the OXC processing and the creation of new lightpaths.

The extensions of the model for different LSPs hierarchies and its integration in a complete TE framework for GMPLS are future tasks of this research.

REFERENCES


V. CONCLUSIONS

In this paper, was discussed the potentiality of a traffic characterization procedure for TE in converged networks with the GMPLS paradigm.

Simulation results were shown for an IP/MPLS core, based in a heuristic with genetic algorithms and a hybrid QoS model for traffic characterization.

In Table 2, the capacities obtained with three different traffic models are shown. For the M/M/1 model the capacities are sub estimated in the cases where the traffic aggregations have values of $H>0.5$ and higher channel loads. For the self-similar case as shown in [9], the capacities are very sub estimated and over estimated for light and heavy channel loads respectively. For the hybrid model, the capacities are the most accurate to comply with the delay limits established and the simulation results, shown before through the calculations in Table 1. The simulations with the capacities of column 1 and 3 of Table 2 reported QoS values higher than the required limits, and even packet losses for F2, F4 and F8. So, the above results show that the optimization method produces a closer to reality topology that benefits the network planning and stability, which is extensible to the other layers within the GMPLS approach.

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