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A Unified Model for Bandwidth Adaptation in Next Generation Transport Networks

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Abstract— In this paper we propose a unified model for dynamic bandwidth adaptation in future transport networks. It acts as an umbrella for both next generation SONET/SDH (NG-SONET/SDH) and even more general, networks with a GMPLS control plane. We adapt bandwidth in discrete steps by exploiting features of virtual concatenation and bundled links, respectively. Applying our model, we demonstrate its advantage in providing improved service quality in comparison to a scheduled provisioning scheme. We evaluate the adaptation granularity to provide a required quality of service for typical IP network traffic behavior in the access network. Furthermore we quantify in depth the impact of increasing access bandwidth at the network edge on signaling load in a transport network.

I. INTRODUCTION

A. Motivation

In current public transport network infrastructure, connectivity between two nodes in the core is still realized by provisioned point-to-point connections. Common transport technology deployed is SONET/SDH. In the future, more general GMPLS Label Switched Paths (LSP) will provide node interconnection. In this case several transport technologies (e. g. Ethernet, SONET/SDH, OTN, ...) may be used in parallel controlled by a single or multiple control plane instances. These technology aspects may be transparent, providing a single unified interface to the upper client layers.

On the other hand, emerging applications, e.g. high-bandwidth multi-media applications, increase IP traffic, which typically shows bursty and may have self-similar characteristics [1].

As information about the client layer demands is usually uncertain and as transport networks have to cope with them, link capacity in the transport network is usually provided with enough spare capacity. As a

consequence, the connection transporting IP traffic is underloaded for long time intervals and thus connection capacity is wasted. This approach is usually called a static approach, keeping the resource capacity constant in the network for long time intervals. As this is the worst case regarding network efficiency, we do not consider this case here, but focus more dynamic approaches.

The common vision of network engineering is to avoid underloaded, inefficient links by dynamically adapting capacity in the network, i. e. to put bandwidth where the traffic is. If network capacity is distributed in the network according to the current traffic demands, network resources are used in the most efficient way and spare capacity remains available for other demands or simply does not generate maintaining costs.

Besides this dynamic approach a scheduled approach is also feasible. As transport networks usually show a diurnal traffic profile, capacity adaptation may be provided by a predefined scheduling mechanism. Applying this idea, at a definite time based on pre-planned capacity estimations, connections are automatically established or removed.

In this paper, we structure the problem of dynamic bandwidth adaptation in next generation transport networks and discuss the specific constraints of both, SONET/SDH as well as GMPLS controlled networks. Further we compare the dynamic provisioning scheme and the scheduled provisioning scheme and show the advantage of our dynamic approach.

B. Dynamic bandwidth adaptation in next generation transport networks

We assume a layered network architecture as present in current networks. The client layer is an IP layer optionally with MPLS capabilities. Transport service is provided by an electrical layer, e. g. SONET/SDH or

OTN. The optical server layer commonly uses wavelength division multiplexing (WDM) technique.

As there are tendencies to reduce network complexity and to leave out the electronic switching layer, we also consider the scenario of IP/WDM. The Generic Framing Procedure [2] may be used as an adaptation layer between the remaining layers. Both studies are interconnected by our investigation on resource adaptation of the evolutionary steps in between.

Next generation SONET/SDH supports Virtual Concatenation (survey in [3]). Virtual concatenation features the aggregation of several Virtual Containers (VC) to a VC group (VCG). Thereby each Virtual Container may be routed in the network on a diverse path. One advantage of Virtual Concatenation is the finer bandwidth granularity it offers and the other advantage is the enhanced protection mechanism, which is exploited e. g. in [4]. The number of VCs within a VCG is adapted by the Link Capacity Adjustment Scheme (LCAS). By using LCAS, it is possible for any trigger mechanism either on the user network interface side or automatically within the node to dynamically adjust the capacity of a connection. This idea has also been proposed as an OIF UNI application in [5].

The functionality of the intermediate transport layer SONET/SDH can be abstracted by GMPLS LSPs. Considering GMPLS, a similar aggregating mechanism has been proposed in [6]. Parallel links between two nodes are aggregated in Bundled Links (equivalent to a VCG). The member of a bundled link is referred a component link (equivalent to a VC). Applying the GMPLS protocol suite [7]–[9], the number of components per bundled link is alterable equivalent to LCAS.

In the GMPLS framework LSPs are maintained by soft-states in the intermediate nodes. Refresh messages are used to keep alive the state of an LSP or may be used to update the capacity. In LCAS, the information about the state of each component is contained in the SONET/SDH frame itself. There is no need of an additional protocol or frame. Thus both transport technologies, GMPLS LSPs and SONET/SDH VCs show similarities, which are the basis of our unified model described in section II.

C. Related work

In our previous studies [10], we evaluated timing constraints and compared different controlling schemes for dynamically adapted transport networks. While this work assumed a next generation SONET/SDH environment, the work presented here has a much broader scope introducing a unified model for resource adaptation.
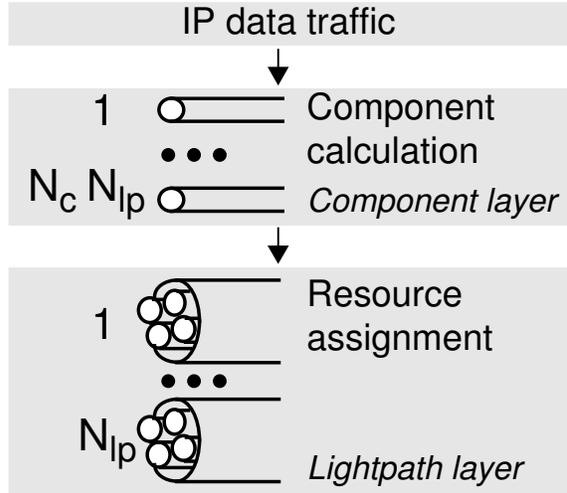
Fig. 1. Unified model for dynamic bandwidth provisioning

We already studied the feasibility of dynamic bandwidth adaptation with lightpath granularity in ASON networks using a diurnal traffic profile scenario in [11]. Here, we extend, amongst others, the traffic model to a general profile to receive more meaningful results.

Other publications on optimization strategies in WDM networks deal with rerouting of lightpaths or GMPLS label switched paths to optimize virtual topologies [12]–[16]. In these studies on a network wide perspective entire topologies are reconfigured. This is in general not desirable from an operators point of view. We restrict ourselves to a local reconfiguration and exploit NG-SONET/SDH networks and GMPLS controlled network features.

Most similar to our work is the study by H. A. Mantar et al. in [17], where bandwidth is managed by a bandwidth broker and offered to autonomous systems. They assume a general Diffserv environment, but they do not consider real transport technologies and technical feasibility.

The remainder of this paper is organized as follows. Section II introduces our unified model and describes the bandwidth adaptation process. Section III presents the traffic model and explains parameters and constraints of the simulation study presented in section IV. The paper is summarized in the concluding section V.

II. UNIFIED MODEL FOR BANDWIDTH ADAPTATION

We model NG-SONET/SDH as well as GMPLS features in a common model, to allow a joint evaluation and more generally applicable results. Figure 1 depicts our unified model.

Based on measurement samples enforced by an estimation step the equivalent capacity of incoming IP data traffic is calculated and mapped onto a discrete number of components. The current available capacity depends on the number of active components, which is adjusted according to an autonomous or manual provisioning scheme. In this paper we enhance the unified model by a measurement based provisioning scheme.

These components are set-up, mapped on dynamically established lightpaths and participate active in traffic transfer. If the number of requested components is higher than the number of components a single lightpath is able to transport, a new lightpath is established.

On the other side, if the number of components is decreased, a lightpath is torn down, if it is not transporting any components anymore. If a requested lightpath/component can not be established due to resource shortage, traffic destined for that lightpath will be lost. The functional blocks involved in this adaptation scheme are described in detail in the following paragraphs.

Measurement entity: It is assumed that each node is able to measure the traffic directed to a certain outgoing link. These measurement samples usually represent the traffic mean value over a small time interval.

Estimation: Based on measurement samples the equivalent capacity $\hat{e}$ is calculated by the formula according to Guerins approximation [18]. It is calculated by

$$\hat{e}_i = m_{\{i-(n-1),i\}} + \alpha' \cdot \sigma_{\{i-(n-1),i\}}$$

and it is based on the traffic mean m and the standard deviation σ, which are calculated over the last n samples. α' is chosen not to exceed a certain overload probability and is given by Guerins approximation. This estimator is known to be conservative, so we apply it even when traffic characteristics do not meet Gaussian assumptions [19]. It is a straightforward one, because our previous studies [10] have shown that even complexer estimators do not improve the results much.

Component calculation: Based on the bandwidth estimation value $\hat{e}$, the number of required components is calculated by $N_c' = \lceil \hat{e}/C_c \rceil$, where C_c represents the capacity of a single component

Resource assignment: Two nodes are interconnected at a maximum of N_{lp} unidirectional lightpaths. Each lightpath is able to transport a maximum of N_c components. The capacity of a single lightpath is equal to C_{lp}. The necessary minimum number of lightpaths to transport all requested components is given by $N_{lp}' = \min\left(\lceil N_c'/N_c \rceil, N_{lp}\right)$. The calculated number of components are mapped onto these lightpaths.

Resource sharing: With respect to service differentiation we introduce a gold and a best effort traffic class (GO and BE respectively). Lightpaths are either dedicated to a certain traffic class (e. g. to realize different protection schemes) or the lightpath is shared by both service classes. In case of a dedicated lightpath its components belong to the same traffic class the lightpath belongs to. In case of a shared lightpath its components may belong to either of both traffic classes.

The gold class is defined to have stricter resource requirements than the best effort class. If there are still components to add by the gold class and if there is no spare capacity available, components of the best effort service class are replaced by components of the gold class. In case of dedicated resources this leads to a re-dedication of lightpath service class and a loss of transport capacity of the best effort service class.

III. PERFORMANCE EVALUATION

A. Traffic modeling

For a realistic traffic scenario, we consider a diurnal traffic behavior super-positioned by a stationary process, showing bursty traffic characteristics. The diurnal traffic profile rate $r(t)$ is given by

$$r(t) = s \sin\left(2\pi\,\frac{t}{T}\right) + \frac{s}{2} \cos\left(4\pi\,\frac{t}{T}\right) + \Delta + \eta(t)$$

Herein the sine and cosine functions model the daily fluctuations, with two busy periods representing the traffic of business and residential users. The traffic model has been adapted from the traces measured at UPC [11]. The analytical form has been chosen, not to rely only on measured traces, but on random traffic data, with given properties.

The period T corresponds to 1 day, s is a scaling factor and Δ is an offset to achieve minimum load. $\eta(t)$ models the bursty and self-similar behavior of broadband IP traffic.

We assume a link occupancy without $\eta(t)$ during the maximum busy time of 75% and in the minimum busy time of 10%. The amount of broadband IP traffic ($\eta(t)$) is assumed to be 10% of the maximum link capacity.

The IP traffic $\eta(t)$ is modeled as proposed by Neame in [20] by an aggregate M/Pareto fluid flow process, with a Poisson flow arrival process and a Pareto-distributed flow length. The flow rate, i. e. the height of the flow, is kept constant and may be the result of aggregated user or inter-machine message flows. Then, the flow rate may be interpreted as the rate of the access circuit. With respect to different access rates, we consider different flow rates.

The mean value of $\eta(t)$ is given by $\bar{\eta} = \lambda\,k\,\frac{\alpha}{\alpha-1}$ where λ represents the mean inter-arrival time of flows, k the minimum flow size and α the shape parameter of the Pareto distribution. The shape parameter is set to 1.3

(H=0.85). The mean flow inter-arrival time is constant at 1 sec. The minimum flow size is expressed by $k = \frac{\bar{\eta}(\alpha-1)}{\lambda\alpha}$.

B. Simulation set-up and metrics

We consider two connected nodes. Both nodes are interconnected by a maximum of 4 lightpaths. Each lightpath has a total capacity of 2.5 Gbps with coarsest granularity of 1 component per lightpath and the finest granularity of 16 components per lightpath. The maximum link capacity is therefore 10 Gbps.

We assume 25% of the total traffic to be gold class, even at night for special gold services, e. g. movie data distribution.

Traffic is measured periodically every 2 minutes. It is motivated by our findings, that even larger intervals up to 15 minutes do not change our results significantly, while smaller time scales have already been investigated in [10].

We further assume, that the time to establish a new component or lightpath is significantly smaller than the measurement time scales of minutes. Any path computation is assumed to be done in parallel before requesting a new lightpath or component.

Our provisioning scheme is quantified by the metric of traffic volume lost on IP layer. It measures the amount of lost traffic related to the total traffic which is dropped due to capacity shortage or bandwidth estimation errors. Our results are also backuped by the metric of the mean number of lightpath requests per day to evaluate the impact on the control plane.

IV. SIMULATION RESULTS

As introduced in section II, the number of intermediate connection-oriented components is dynamically changed. We refer to this scenario as IP/dynCO(n)/WDM, where n represents the maximum number of components per lightpath, thus the granularity of adaptation. In case of only 1 component per lightpath, the scenario degenerates to IP/WDM.

A. Implications of increasing flow rate

As mentioned before, the flow rate in our analysis may be seen as a measure of access connectivity. In figure 2 the volume lost is given for different flow rates ranging from 1 Mbps to 1 Gbps. The sets of 1 component (IP/WDM) and 16 components per lightpath are plotted. The graphs are given for dedicated and shared resources as well as for both service classes.

First the IP/WDM scenario with 1 component is considered. The results are represented by the top most graph and the single point on the bottom right. In this
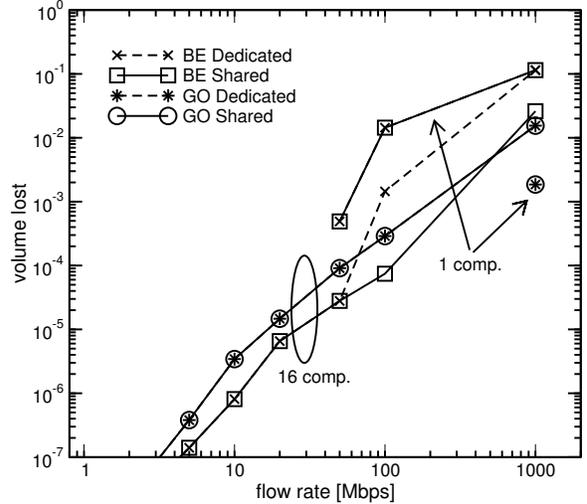
Fig. 2. Dynamic provisioning: volume lost in two selected IP/dynCO(16)/WDM scenarios

scenario traffic loss occurs for the best effort class (BE) only on high flow rates of 50 Mbps and more (no distinction between shared and dedicated lightpaths as there is only 1 component per lightpath). Flow rates of 50 Mbps and more cause high burstiness, that both service classes require additional lightpaths but only the gold class (GO) will succeed and thus inflicts huge losses to the best effort class. When traffic is less bursty, lightpath granularity guarantees enough spare capacity for these variations and no measurable loss occurs for both service classes.

In the IP/dynCO(16)/WDM scenario the granularity of adaptation is much smaller. Even at smaller flow rates traffic of both service classes is lost. And even more remarkable, gold class suffers from higher loss although its predominant resource assignment. This behavior is directly related to the granularity of adaptation. The estimation error in absolute values of both classes ranges in the same order of magnitude, while the relative error regarding the overall volume per class differs by the relation of both classes in traffic volume.

The figure also shows, that for flow rates greater than 50 Mbps shared resources perform better for the best effort class than dedicated resources. High bursty traffic requests a large number of components for the gold class, while the best effort class suffers from resource shortage.

B. Implications of adaptation granularity

Another important question is, which granularity is suitable for a given access rate to provide a certain quality of service at which costs. In figure 3 the volume lost is shown for different granularities. The graph

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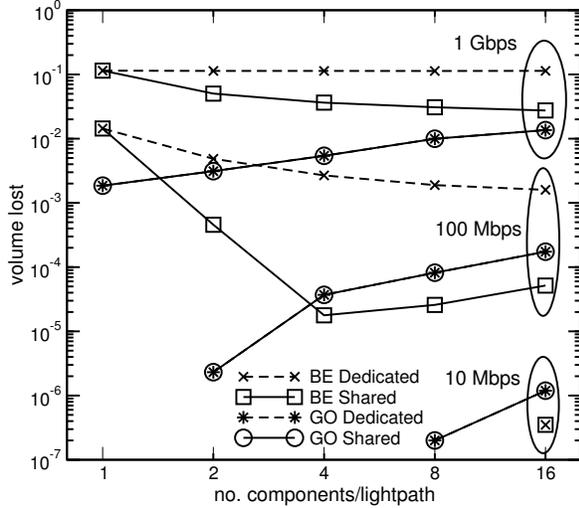
Fig. 3. Dynamic provisioning: volume lost for different granularities

Fig. 4. Dynamic provisioning: Number of lightpaths requests for different granularities

includes results for both service classes in both resource provisioning schemes for three distinguished flow rates.

If the flow rate is rather small compared to the capacity of an individual component, i. e. 10 Mbps, there are only measurable losses when granularity is even finer than 8 components per lightpath. If the components capacity becomes smaller the amount of extra bandwidth per component is reduced and in consequence the estimation error is amplified. Again, the behavior is the same for both service classes with both provisioning schemes, shared and dedicated, because lightpath resources do not become scarce.

If the flow rate is increased by the factor of 10, i. e. 100 Mbps, the volume lost is increased by a factor of about 100 for both service classes for both provisioning schemes. If granularity of adaptation is done roughly with only 1 or 2 components per lightpath the best effort class suffers from resource shortage, while the gold class has hardly any traffic loss. The difference between shared and dedicated resources is recognizable in bursty traffic scenarios, with high flow rates. Here shared resources are advantageous, because the highly bursty traffic causes the gold class to request high amounts of bandwidth. If resources are shared, only individual components are requested, unlike whole lightpaths like in the scenario of dedicated resources.

Further increasing the flow rate up to 1 Gbps flips the performance of gold and best effort class. Because of the large number of component requests due to high burstiness, the best effort class suffers from resource shortage all the time, also in scenario of shared re-

sources. Therefore applicability of dynamic bandwidth provisioning is limited to small and medium flow rates compared to the capacity of a single component.

C. Impact on signaling

An issue in dynamic transport networks is the amount of signaling messages exchanged. We quantify the amount of signaling in number of lightpath requests per day (lightpath signaling is to be presumed much more costly than component signaling). In figure 4 the mean number of lightpath requests per day is shown in dependence of the granularity of adaptation.

Lightpath requests for both resource provisioning modes and for three different flow rates are given. Apart from very coarse granularity of 1 or 2 components per lightpath, the mean number of requests per day is nearly constant, irrespective of the resource provisioning scheme. If resources are shared, the number of requests is slightly higher than in the dedicated mode. Because both service classes share the sparse capacity of a shared lightpath, probability increases for additional lightpath requests.

In the special scenario of very high flow rates of 1 Gbps either the best effort or the gold class requests additional lightpaths. In case of dedicated resources this large number of requests is shown in the dashed line in the figure on the very top. In case of shared resources these lightpath requests are multiplexed and most of the time all lightpaths are in operation, which causes the relatively small number of requests.

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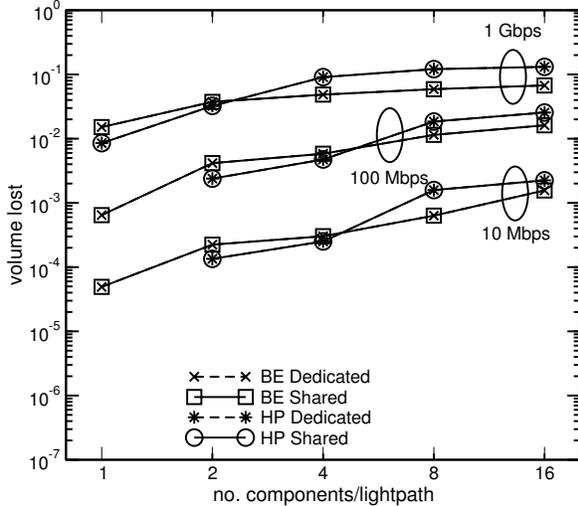
Fig. 5.   Scheduled provisioning: volume lost for different flow rates
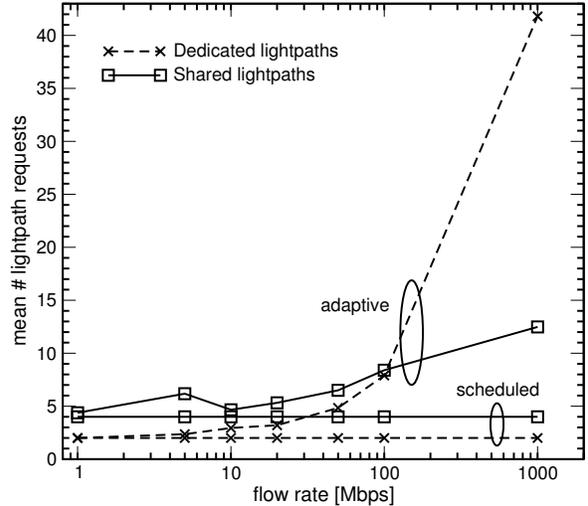
Fig. 6.   Scheduled provisioning: Number of lightpaths requests for different flow rates

D. Comparison to scheduled provisioning scheme

In the scheduled provisioning scheme, the traffic mean value is sampled every 2 minutes and assigned a pre-calculated number of components. This bandwidth provisioning schedule is applied on the same diurnal traffic model as in the dynamic provisioning scheme.

In figure 5 the impact of flow rates on loss performance is given for different granularities in the scheduled provisioning scenario. Comparing this figure with figure 3 the difference in service quality is obvious. In the scenario of 10 Mbps, scheduled provisioning performs 100 times worse than dynamic provisioning. Scheduled provisioning suffers from mean traffic value assumptions, without the possibility for any short-term reaction. With increasing flow rate both approaches converge, because bandwidth provisioning in highly bursty traffic is only tractable with a huge amount of overprovisioning.

In general, scheduled provisioning should perform best, when the traffic characteristics are less bursty and it is not likely that traffic characteristics will suddenly change completely. But when the network has to react to fast traffic changes, than scheduled provisioning is highly error-prone as we have shown.

Also, when considering signaling load, we compared in figure 6 signaling load of the scheduled with our adaptive provisioning scheme. In general, the amount of signaling of our adaptive scheme is higher than in scheduled mode, but up to 100 Mbps flow rate the number of lightpath requests is increased only slightly. A very high access bandwidth of 1 Gbps results in frequent changes of lightpaths due to the very bursty traffic.

V. Conclusion

We proposed a unified model for bandwidth adaptation in next generation transport networks. Our model covers NG-SONET/SDH as well as ASON/GMPLS networks. In the underlying transport network, capacity is partitioned in components of equal size. Our studies suggest an IP/dynCO(n)/WDM network architecture with suited partitioning for a limited number of lightpath requests per day.

We studied the impact of traffic burstiness using a M/Pareto fluid flow traffic model overlaid with a diurnal traffic profile on transport service quality in metrics of volume lost and signaling load. We further evaluated the impact of different adaptation granularities and quantified the flow rate dependent optimal granularity.

We demonstrated the advantage of our dynamic adaptation model in comparison to a scheduled provisioning scheme. We found that our dynamic adaptation model is economically feasible, because signaling is only increased slightly and QoS is substantially higher.

We also showed that service differentiation in the core in conjunction with dynamic bandwidth adaptation is not beneficial for the gold class, so we suggest to abandon service differentiation in the core. The result will be an efficient network exploitation, with an adequate quality of service for the remaining single service class.

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REFERENCES

[1] W. Willinger, M. S. Taqqu, R. Sherman, and D. V. Wilson, "Self-similarity through high-variability: statistical analysis of Ethernet LAN traffic at the source level," *IEEE/ACM Transactions on Networking*, vol. 5, no. 1, pp. 71–86, February 1997.

[2] ITU, "Rec. G.7041/Y.1303: Generic Framing Procedure (GFP)," International Telecommunication Union, ITU-T, Dec. 2001.

[3] L. Choy, "Virtual concatenation tutorial: enhancing SONET/SDH networks for data transport," *Journal of Optical Networking*, vol. 1, no. 1, pp. 18 – 29, Jan 2001. [Online]. Available: http://www.osa-jon.org/abstract.cfm?URI=JON-1-1-18

[4] C. Ou, L. H. Sahasrabuddhe, K. Zhu, C. U. Martel, and B. Mukherjee, "Survivable virtual concatenation for data over SONET/SDH in optical transport networks," *IEEE/ACM Trans. Netw.*, vol. 14, no. 1, pp. 218–231, 2006.

[5] B. R. Greg Bernstein and D. Spears, "OIF UNI 1.0 - Controlling Optical Networks," *Optical Internet Forum*, 2001.

[6] E. Mannie, "Generalized Multi-Protocol Label Switching (GMPLS) Architecture," RFC 3945 (Proposed Standard), Oct. 2004. [Online]. Available: http://www.ietf.org/rfc/rfc3945.txt

[7] E. Mannie and D. Papadimitriou, "Generalized Multi-Protocol Label Switching (GMPLS) Extensions for Synchronous Optical Network (SONET) and Synchronous Digital Hierarchy (SDH) Control," RFC 3946 (Proposed Standard), Oct. 2004. [Online]. Available: http://www.ietf.org/rfc/rfc3946.txt

[8] K. Kompella, Y. Rekhter, and Ed., "Routing Extensions in Support of Generalized Multi-Protocol Label Switching (GMPLS)," RFC 4202 (Proposed Standard), Oct. 2005. [Online]. Available: http://www.ietf.org/rfc/rfc4202.txt

[9] L. Berger, "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Resource ReserVation Protocol-Traffic Engineering (RSVP-TE) Extensions," RFC 3473 (Proposed Standard), Jan. 2003, updated by RFCs 4003, 4201, 4420. [Online]. Available: http://www.ietf.org/rfc/rfc3473.txt

[10] S. Gunreben and C. M. Gauger, "Dynamic bandwidth adaptation in NG SDH/WDM transport networks using LCAS," in *Proceedings of the Networks and Optical Conference (NOC)*, July 2005.

[11] S. Spadaro, A. D'Alessandro, A. Manzalini, and J. Sole-Pareta, "TRIDENT: An automated approach to traffic engineering in IP/MPLS over ASON/GMPLS networks," *Computer Networks*, vol. 51, pp. 207–223, Jan. 2007.

[12] B. Ramamurthy and A. Ramakrishnan, "Virtual topology re-configuration of wavelength-routed optical WDM networks," in *Proceedings of the IEEE Global Telecommunications Conference (Globecom)*, vol. 2, 2000, pp. 1269–1275.

[13] A. Guo, Z. Zhu, and Y. Chen, "Traffic engineering featuring dynamic lightpath provisioning in multilayer GMPLS optical networks," *Journal of Optical Networking*, vol. 4, pp. 533–548, 2005. [Online]. Available: http://www.opticsinfobase.org/abstract.cfm?URI=JON-4-9-533

[14] J. Comellas, R. Martinez, V. Sales, and G. Junyent, "Integrated IP/WDM routing in GMPLS-based optical networks," *IEEE Network*, Mar. 2003.

[15] A. Gencata and B. Mukherjee, "Virtual-topology adaptation for WDM mesh networks under dynamic traffic," *IEEE/ACM Transactions on Networking*, vol. 11, no. 2, pp. 236–247, 2003.

[16] A. Narula-Tam and E. Modiano, "Dynamic load balancing in WDM packet networks with and without wavelength constraints," *IEEE Journal on Selected Areas in Communications*, vol. 18, no. 10, pp. 1972–1979, 2000.

[17] H. Mantar, J. Hwang, I. Okumus, and S. Chapin, "A scalable model for interbandwidth broker resource reservation and provisioning," *IEEE Journal on Selected Areas in Communications*, vol. 22, no. 10, pp. 2019–2034, 2004.

[18] R. Guerin, H. Ahmadi, and M. Naghshineh, "Equivalent capacity and its application to bandwidth allocation in high-speed networks," *IEEE Journal on Selected Areas in Communications*, vol. 9, no. 7, pp. 968–981, Sept. 1991.

[19] S. Bodamer and J. Charzinski, "Evaluation of effective bandwidth schemes for self-similar traffic," in *Proceedings of the 13th ITC Specialist Seminar on IP Traffic Measurement, Modeling and Management*, Monterey, CA, September 2000, pp. 21.1–21.10.

[20] T. D. Neame, M. Zukerman, and R. G. Addie, "Modeling broadband traffic streams," in *Proceedings of the IEEE Global Telecommunications Conference (Globecom)*, 1999, p. 1048 1052.

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