NORMA: Network Operator Revenues Maximization

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ABSTRACT
A great part of core network operators' gross profit comes from the provisioned connectivity services. In this work, we analyze the provisioning of differentiated services in current Shared Path Protection (SPP) environments. This analysis concludes that, with current resource assignment policies, only a very poor grade of service can be provided to the carried best effort traffic. Hence, we propose *diff-WS*, a resource partitioning scheme that differentiates those wavelengths supporting each class of service in the network. The benefits of *diff-WS* in front of current resource assignment policies are afterwards evaluated from an economic perspective. To this goal, we define the NORMA problem as a revenue maximization problem. To solve NORMA, we introduce statistical models to obtain, for a given grade of service, the highest traffic intensity for each supported class of service and resource assignment scheme. From the numerical results, we show that *diff-WS* maximizes resource utilization in the network and, thus, network operator's profit.
Keywords: Optical Networks, Resource Differentiation, Shared Path Protection.

1. INTRODUCTION

Service differentiation allows network operators to meet a wider range of client necessities. For instance, many companies do not consider the Internet access as a critical service. Therefore, the price they are willing to pay for it is generally low. On the contrary, business data traffic is usually associated with strict Service Level Agreements (SLAs), which makes this service significantly more expensive.

Typically, SLA contracts contain, among other parameters, the connection availability, that is, the probability that a connection will be operative at a random point in time. The way to improve this connection availability in Dense Wavelength Division Multiplexing (DWDM) networks is by means of protection and restoration schemes. Particularly, Shared-Path Protection (SPP) has received much research attention, as it provides the best balance among availability, recovery time and resource utilization (e.g., see [1]-[3]).

Essentially, SPP consists on providing two disjoint paths between source and destination nodes, where the working path is replaced by the backup path upon a failure affecting the former. The same backup resource (i.e., wavelength channel) may be shared so as to provide protection to multiple working paths, as long as they are mutually diverse. In fact, backup paths are configured to recover working paths from failures, but not used in normal conditions. Hence, this unused backup capacity can be used for supporting extra-traffic, which would be preempted in case of working path failure.

In this paper we propose a novel scheme to maximize network operator revenues resulting from the provisioning of differentiated services in DWDM networks. To this end, two classes of service are defined: the SPP-based protected class (SP) and the best effort preemptable class (BE). Although two classes of service are only considered in this work, the ideas here introduced can be easily extended to a higher number of classes. Our approach for revenue maximization consists on partitioning the set of available wavelengths per link, leading to differentiated sets of resources for each class of service and decoupling traffic dependences.

2. PROBLEM STATEMENT

The topology of an optical network can be represented by a graph $G(N, E, WL)$, where N represents the set of nodes, E the set of links, and WL the set of wavelengths available in each link, with size W. Assuming that wavelength conversion is not available in the network, we can split the graph G into W independent subgraphs $G^i(N, E, i)$, one per wavelength. Each subgraph G^i represents the network connectivity through wavelength i.

An interesting property of SPP is its resource efficiency resulting from backup paths sharing. This resource sharing is attained by reserving the backup resources, but postponing their allocation until the working path fails. In order to assign a wavelength to both working and backup paths, enough resources must exist for them. Then, working and backup paths might interfere between them, as they might compete for the same resources.

BE connections are established using those resources reserved for the backup paths. Consequently, BE traffic is subordinated to the SP traffic. In other words, while for SP traffic the blocking probability (Pb) depends on the network topology G and the offered load, for BE traffic it also depends on the amount of resources loaned by the currently established SP connections. Furthermore, since BE connections are borne on reserved backup resources, as soon as any of the resources conveying a BE connection is left to be reserved, the BE connection is torn down even if its requested holding time (ht) has not yet expired. In this context, let us define the billable

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time (bt) of a connection as the total time being operative. Thus, $bt=\rho \cdot ht$, where ρ is the proportion of consumed ht over the total. Note that $\rho_{BE} \leq 1$, as a consequence of this anticipated connection release, whereas $\rho_{SP} = 1$.

Aiming to quantify Pb for BE traffic, let us consider that a certain number of SP connections have been established in the network. In this case, we denote G^i_{SP} (N, E^i_{SP}, i) as the subgraph representing the resources available for BE traffic at wavelength i. Thus, $G_{SP}(N, E_{SP}, WL) = \{G^i_{SP} \mid i \in WL\}$. In fact, Pb can be described as the contribution of two different factors: the connectivity of the graph and the offered load to the network. For the ongoing analysis, let R_{BE} be the set of BE connection requests and $R^i_{BE}(G^i_{SP})$ the subset of R_{BE} having a feasible route over G^i_{SP}. Then, the set of BE connection requests with a feasible route on G_{SP} is given by:

$$R^*_{BE} = \bigcup_{\forall i \in WL} R^i_{BE}\left(G^i_{SP}\right). \tag{1}$$

We define $P(R_{BE}, G_{SP})$ as the probability that a BE connection request can be established according to current G_{SP} connectivity, which can be expressed as:

$$P\left(R_{BE}, G_{SP}\right) = \frac{\left|R^*_{BE}\right|}{\left|R_{BE}\right|}. \tag{2}$$

We can express Pb_{BE} as the sum of two terms: a) the number of BE connection requests without feasible route on G_{SP} over the size of R_{BE}; b) the number of BE connection requests with feasible route on G_{SP} weighted by a probability function that depends on G and the intensities of SP (I_{SP}) and BE (I_{BE}) traffics. Therefore, $P(R_{BE}, G_{SP})$ provides a lower bound for the BE blocking probability, as shown in eq. (3). Then, the BE traffic GoS will generally be very poor due to the BE traffic coupling to the SP one, leading to very low BE traffic revenues.

$$Pb_{BE} = \frac{\left|R_{BE}\right| - \left|R^*_{BE}\right|}{\left|R_{BE}\right|} + f(G, I_{SP}, I_{BE}) \cdot \frac{\left|R^*_{BE}\right|}{\left|R_{BE}\right|} \geq 1 - P\left(R_{BE}, G_{SP}\right). \tag{3}$$

In view of the above, we propose a novel partitioning scheme for provisioning differentiated traffic in the network. This scheme drastically improves the BE traffic GoS, maximizing the expected revenues from serving both SP and BE traffic classes. The main idea is to split the complete set of wavelengths into two different subsets of size $W/2$, namely, WL_{WORK} and WL_{BUP}, dedicated to SP working and backup path reservations, respectively. The wavelengths in both sets are rigidly related as follows. Being an SP working path assigned to wavelength i, its backup path is assigned to wavelength $W - i$. We call this partitioning scheme as differentiated set (*diff-WS*), in contrast to the traditional unpartitioned set where all resources are shared (*sh-WS*) [1], [2].

Since the whole WL_{BUP} set is dedicated for backup path reservations in *diff-WS*, it can be all used to support BE traffic, thus being more beneficial than *sh-WS*, where only those resources already reserved for backup SP paths can be used for carrying it. This new approach provides optimum GoS for BE traffic. In fact, even though a slightly lower amount of SP traffic can be served in certain network topologies, the total revenues from serving both SP and BE traffic classes are maximized when *diff-WS* is applied.

Then, the Network Operator Revenues Maximization (NORMA) problem can be formulated as follows:

- *Given*: a) The physical topology of a network represented by a graph $G(N, E, W)$; b) a set S of classes of service to be provided; c) the network operator's pricing structure, specified by a fixed fee c_j charged to the customers per time unit of class of service j; d) a set of connection requests for every class of service (R_j), where each request is identified by the source-destination node pair (s, d) and the requested ht; e) the blocking probability threshold Pb_j^{max} allowed for each class of service j; f) a set K of partitioning schemes.
- *Output*: A partitioning scheme k among the available ones and the intensity I_j^k of every class of service j.
- *Objective*: Maximize the network operator's revenues from serving traffic belonging to the defined classes. We define bt_j^k as the billable time of service class j during a certain time interval Δt (e.g., one year) and using the wavelength partitioning scheme k. Thus, the NORMA objective function can be expressed as:

$$\text{(NORMA)} \quad \underset{\forall k \in K}{Maximize} \quad Z^k = \sum_{\forall i \in S} c_j \cdot bt_j^k. \tag{4}$$

Here, bt_j^k can be computed as the amount of expected arrivals during Δt multiplied by the average connection ht. Therefore, defining iat_j^k as the average inter-arrival time, bt_j^k can be formulated as:

$$bt_j^k = \left[|N| \cdot \frac{\Delta t}{iat_j^k} \cdot \left(1 - Pb_j^k\right) \right] \cdot \left(ht_j^k \cdot \rho_j^k\right) = |N| \cdot I_j^k \cdot \rho_j^k \cdot \left(1 - Pb_j^k\right) \cdot \Delta t, \tag{5}$$

where $I_j^k = ht_j^k / iat_j^k$ is the intensity per node of the class of service j when the partitioning scheme k is used.

We face the NORMA problem from a statistical perspective. Specifically, a statistical model to predict, for each wavelength partitioning scheme, the maximum offered load to the network meeting each service class GoS requirements is proposed in the next section.

3. STATISTICAL MODEL

By eq. (5) inspection, two unknowns can be identified: the offered load and the actual proportion of provided *ht*. In this section, we focus on modeling these variables from a statistical point of view, referring to I_j^k and ρ_j^k as the *response variables* to be modeled. From eq. (4) and (5), maximize the billable time is equivalent to maximize the offered load while meeting the blocking probability threshold. Hence, we hereafter focus on predicting the offered load to the network by unleashing Pb_j^{max}.

Aiming to obtain likely values for the response variables, we have studied their behavior over a meaningful set of networks. These network scenarios were chosen from the set of real backbone optical transport networks presented in [4]. From the complete set, a subset of 16 bi-connected and planar networks was selected, representing a wide range of distinct topologies. Each network was identified by means of 12 topology-dependent characteristics (*independent variables*) candidates to be part of the model.

We conducted a large amount of simulations over the networks under study for every traffic class and partitioning scheme, where each DWDM link was equipped with 16 wavelengths. For *sh-WS*, the CAFES algorithm in [1] was adapted to compute feasible routes for the SP connections while satisfying the wavelength continuity constraint. In contrast, for *diff-WS*, a simpler shortest path algorithm was used. In this regard, Pb_{SP}^{max} = 1% was assumed for the SP class, a value commonly used in the literature. Alternatively, a significantly higher Pb_{BE}^{max} = 5% was assumed for the BE class.

Every simulation for a specific traffic class and wavelength structure scheme resulted in a tuple containing the offered load to the network, the blocking probability, and the proportion of *ht* provided. We chose those tuples with *Pb* equal to Pb_j^{max}. Then, together with the candidate set of independent variables, we applied a multiple linear regression to obtain statistical models for the response variables.

Assuming non-linear relations among the candidate independent variables, we used a logarithmic transformation for both response and independent variables, enabling a linear regression methodology. Moreover, aiming to avoid over-fitting, which could be a drawback in further predictions, we limit to two the number of independent variables in the models.

Regarding traffic intensity, four models are needed, one per I_j^k. From the results, we observed the best fit using $|E|$ and $\langle h \rangle$ as independent variables. The former provides the amount of network resources, whereas the latter gives information about the amount of resources per connection. We also concluded that a general parametrical formula with those independent variables can be used with specific linear coefficient values for each I_j^k model. Eq. (6) shows the prediction model where the logarithmic transformation has been reversed, so that the linear coefficients become exponents. Table 1 shows the values of the exponents for each I^i_k model.

$$I_j^k = \frac{10^{\alpha} \cdot |E|^{\beta}}{\langle h \rangle^{\gamma}} \pm \varepsilon \tag{6}$$

To provide a confidence interval to the statistical models, the parameter ε collecting the relative error has been also included. As shown in Table 1, these errors are close to 5%, except for the BE traffic class with *sh-WS*, where fewer networks were available for the model. Moreover, the values of the Pearson coefficient (R^2) are higher than 95% as shown in Table 1, thus giving a tight fit for the offered load models.

Table 1. Parameters and Observed Adjust for the Intensity Models.

Scheme (k)	Class (j)	α	β	γ	ε (%)	R^2(%)
sh-WS	SP	0.222	0.931	3.07	5.62	99.2
	BE	1.522	0	6.40	9.94	95.1
diff-WS	SP	0.334	0.724	2.72	5.44	99.3
	BE	0.548	0.603	2.56	5.48	99.1

Taking up again the blocking probability bound (1-*P*) defined in eq. (3); if that bound is higher than Pb_j^{max}, the traffic intensity must be set to zero since any traffic load would satisfy the requested GoS. However, there is only one case where this may happen, namely, the case where the BE traffic under *sh-WS* as a consequence of its subordination to the SP traffic. In view of this, the $I_{BE}^{sh\text{-}WS}$ model needs to be completed with an expression to predict whether $(1 - P) > Pb_{BE}^{max}$. We have computed *P* for every network under study, finding a tight relation between *P* and $\langle h \rangle$. We observed $(1 - P) > Pb_{BE}^{max}$ in every network with $\langle h \rangle > 2.5$.

Regarding ρ_j^k, by simple inspection of the simulation results, we concluded that $\rho_{BE}^{sh\text{-}WS} \sim 0.6$. In the rest of cases, the factor ρ_j^k is equal to 1, thus reflecting the independence of the different traffic classes.

4. ILLUSTRATIVE NUMERICAL RESULTS AND CONCLUSION

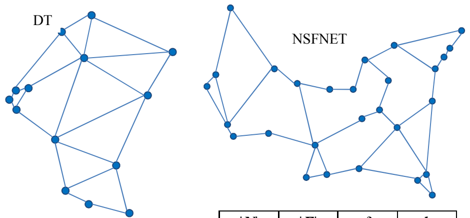
We solved the NORMA problem the moderately meshed 14-node DT and the quite sparse 28-node NSFNET topologies. Fig. 1 shows these topologies and their most relevant characteristics.

Aiming to compare the offered loads obtained under *sh-WS* and *diff-WS*, let us define their intensity ratio as $I_j^{sh\text{-}WS}{:}I_j^{diff\text{-}WS}$. An intensity ratio of one depicts a network that can carry the same amount of traffic under both wavelength partitioning schemes; a value greater (or lower) than one means more traffic being carried under *sh-WS* (or *diff-WS*). Fig. 2 shows this intensity ratio for SP and BE traffics.

Fig. 2a shows that the *sh-WS* scheme supports more traffic intensity when it is applied to moderately or highly meshed networks (low average path lengths). This is the case of the DT network, which can transport 10% additional traffic under *sh-WS* in contrast to *diff-WS*. On the contrary, *diff-WS* supports more traffic when applied to sparsely meshed networks. In particular, the NSFNET topology provides approximately the same amount of traffic under both schemes, since its intensity ratio becomes nearby 1.

A similar study can be done for the BE traffic (Fig. 2b). In this case, *diff-WS* allows more traffic than *sh-WS*, regardless of the average nodal degree value. As observed, *sh-WS* can carry at most 40% of the traffic carried by *diff-WS*. For instance, the *sh-WS* scheme can carry only 5% of the traffic carried under *diff-WS* over the DT network. In fact, since the great majority of the networks under study have $\langle h \rangle > 2.5$ hops, the BE traffic intensity becomes zero under the *sh-WS* scheme. This is the case also of the NSFNET network.

Similarly, we define the revenue ratio $Z^{sh\text{-}WS}:Z^{diff\text{-}WS}$. In this case, a ratio equal to 1 means that both schemes lead to the same revenues, whereas a ratio greater (or lower) than 1 means that more revenues are obtained under *sh-WS* (or *diff-WS*). Aiming to compare the prices of SP and BE services, we additionally define the price ratio $c_{SP}:c_{BE}$. Note that a fair price ratio could be 5:1, reflecting the amount of resources used by each service.



	|N|	|E|	δ	<h>
DT	14	23	3.29	2.34
NSFNET	28	37	2.64	4.07

Fig. 1. Network topologies used for evaluation with their most relevant characteristics.

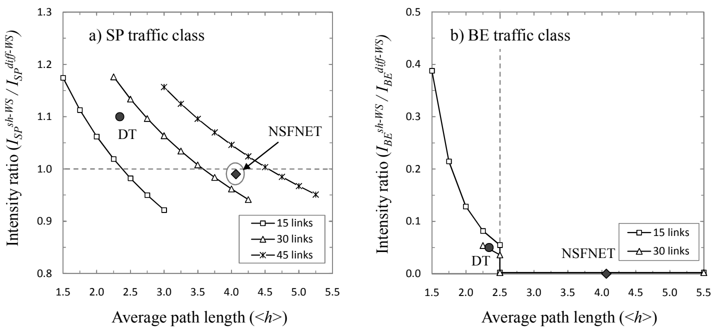


Fig. 2. Intensity ratio for (a) SP and (b) BE traffics. Networks with $|E|=45$ links have $\langle h \rangle > 2.5$.

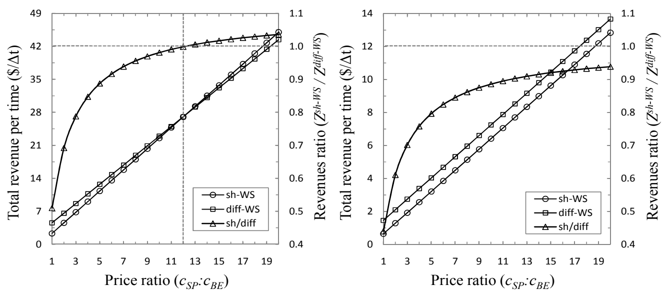


Fig. 3. Total revenues and revenue ratio against the price ratio for DT (left) and NSFNET (right) networks.

Fig. 3 plots the revenue ratio and the total revenues obtained by each partitioning scheme, as a function of the price ratio for the test networks. In the case of the DT network we observed the break-even price ratio near 12:1. If a 5:1 price ratio was applied, *diff-WS* would obtain 11.25% additional revenues than sh-*WS*. Although more SP traffic intensity can be carried under *sh-WS*, higher revenues are obtained with *diff-WS*. As a result, the revenues from operating the DT network would be higher in a wide range of price ratios when the *diff-WS* scheme is chosen. A similar analysis can be done on the NSFNET network. In this case, there is not break-even price ratio, since the *diff-WS* scheme already carries more SP traffic on this network. Then, the revenues from operating this network are always higher under the *diff-WS* scheme (20.36% higher with the price ratio 5:1).

In light of the results, we concluded that *diff-WS* maximizes the revenues from operating a large range of different backbone networks.

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