Simplified Framework for Optimal Support of 40Gb/s and 100Gb/s Services over OTN Exploiting Grooming and VCAT

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Abstract: We propose a simplified framework that exploits grooming and virtual concatenation to minimize the optical transport network cost for supporting 40Gb/s and 100Gb/s services. The impact of transceiver cost and maximum optical reach is assessed.

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1. Introduction

Faced with a tremendous traffic demand growth caused by widespread adoption of broadband connectivity (e.g. VDSL, xPONs, HSPA) and intensive use of IP applications (e.g. on-line gamming, IPTV, web browsing), network operators are obliged to upgrade or renovate their core network infrastructure. With the advent of 100 Gb/s (100G) technology, equipment vendors will have a solution to augment the capacity per wavelength, satisfying the increased packet flows. However, since most carriers are not willing to drastically change the existing optical facilities, the 100 Gb/s transmission must be able to fit into 10 Gb/s and 40 Gb/s (40G) -designed channels. Therefore, 100 Gb/s must be deployed using advanced modulation formats (e.g. PM-DQPSK) characterized by their robustness to physical impairments and capability to raise the spectral efficiency of the optical signal. Currently, this is leading to the development of novel, and rather complex, transceiver equipment whose cost-effectiveness cannot be fully predicted. Given the immaturity and cost uncertainty of serial 100 Gb/s technology, parallel approaches based on off-the-shelf and reliable optical components at 40 Gb/s may be seen as a more attractive solution to cope with the capacity improvement dilemma, at least in the sorter term. Conversely, if the price points are suitable, operators may prefer to migrate to 100 Gb/s technology, using the higher capacity channels to also aggregate and carry lower capacity services (10 Gb/s, 40 Gb/s), sharing the equipment expenses by several clients. The adoption of a solution comprising serial, parallel, or a mixture of both transmission schemes will ultimately depend on the final cost of the network, which is mainly determined by the transceiver and regenerator expenditures [1].

In order to cost-effectively supply emerging 100G and 40G services over optical transport networks (OTN), the network planner must account for the properties of the referred equipment elements. For instance, it is expected that the cost of a single 100 Gb/s transceiver surpasses that of one, two, or more 40 Gb/s transceivers. Furthermore, the number of required regenerators is a function of the optical transmission performance obtained with the selected technology. In principle, albeit depending on the modulation formats used, 40 G/s should be able to be transmitted over longer distances without 3R regeneration, when compared with 100 Gb/s. Hence, to systematically take these characteristics under consideration, we propose a simplified optimization framework to enable the cost-effective planning of OTN networks supporting 100G and 40G services. Importantly, the novel framework exploits the traffic engineering capabilities of OTN, such as grooming and virtual concatenation (VCAT), to determine the transceiver type and routing paths, for each traffic demand, that lead to the lowest capital expenditures. The design method is evaluated in the NSFNET topology for traffic demands comprising mixed line-rate service demands of 100G and 40G. Moreover, the impact on the optimal solution of the cost ratio between 100G and 40G equipment and of the relative physical transmission performance (maximum transparent optical reach) of these technologies is analyzed.

2. OTN Transport Schemes for 100G and 40G Services

OTN systems [2] provide an extensive set of traffic engineering capabilities adequate for increased operational efficiency. Within this set, grooming and VCAT emerge as the most suitable for handing next-generation services in the 40 Gb/s and 100 Gb/s granularity, as depicted in Fig. 1(a). The VCAT protocol allows for the transport of higher capacity traffic flows over lower capacity optical transmission channels. In particular, 100G service streams can be carried over three optical channel data unit (ODU) containers of 40 Gb/s each. Furthermore, the combination of VCAT with multipath (MP) ODU routing (see Fig. 1(b)) enables the exploitation of load balancing techniques that avoid earlier link congestion when compared with single-path (SP) approaches [3]. The application of grooming at the OTN level consists of multiplexing lower capacity flows into a higher capacity channel. With this functionality, several individual services are conveyed over the same lightpath enabling a more efficient use of the available bandwidth [4]. In order to benefit from such capabilities, our framework explores the grooming of one or two 40G streams in 100G channels and the virtual concatenation of 100G flows over three 40G channels.

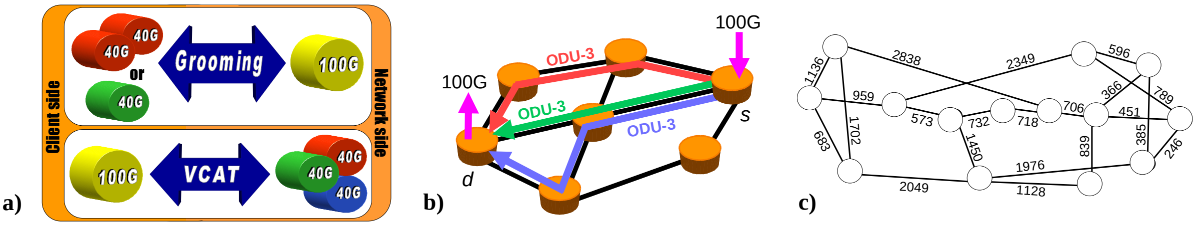

Fig. 1. (a) VCAT and grooming applications; (b) Multipath ODU routing; (c) NSFNET topology (link distances in km).

3. Cost Model and Mathematical Formulation

As mentioned, our framework aims at minimizing the cost of the network while resorting to both 40G and 100G optical technology. To differentiate the expenditures related with each option we define a cost model based in the transceiver cost ratio (6), identified as α, and the maximum optical distance without regeneration ratio (7), denoted as β. The maximum optical reach of each transceiver type, D^{max}, is used to calculate the minimum number of regenerators, $Reg^{sd,k}$, required in the k-th candidate path between source node s and destination node d (8). For simplicity, it is assumed that the cost of one regenerator corresponds to that of two transceivers, C^{TxRx}.

The optimization framework developed consists of an integer linear programming (ILP) model. The model uses as input the transceiver cost ratio, a set of K candidate paths per node pair, the number of regenerators per candidate path, and the traffic demand t^{sd}. For 100G demands, the traffic demand of each sd pair is divided into N multiples of 100G, (9), whereas for 40G requests, the traffic demand is divided into multiples of two 40G flows, (10), to enable grooming into 100G channels. The model returns the routing of all 100G and 40G demands using variables x and y, respectively. The 100G demands are sent over a single 100G channel, x_{100}, or via three 40G channels, x_{40}, exploiting VCAT. The 40G demands are directly transmitted over 40G channels, y_{40}, or groomed into 100G channels, y_{100}. The objective function, (1), minimizes the total cost associated to the transceivers and regenerators required to satisfy all traffic demands, (2). Constraint (3) guarantees that the maximum number of optical channels per link, W, is not exceeded. The use of VCAT for 100G and grooming for 40G is considered in (4) and (5), respectively. Note that (4) enables the model to select if the virtually concatenated ODUs should follow the same route or be diversely routed.

Objective: Minimize z (1)

Subject to:

$$z = \sum_{sd}\sum_{k}\sum_{n}\left[C_{40}^{TxRx}\left(x_{40,n}^{sd,k} + y_{40,n}^{sd,k}\right)\cdot\left(Reg_{40}^{sd,k}+1\right)\right] + \sum_{sd}\sum_{k}\sum_{n}\left[C_{100}^{TxRx}\left(x_{100,n}^{sd,k} + y_{100,n}^{sd,k}\right)\cdot\left(Reg_{100}^{sd,k}+1\right)\right] \quad (2)$$

$$\sum_{sd}\sum_{k}\sum_{n}\left(x_{40,n}^{sd,k} + x_{100,n}^{sd,k} + y_{40,n}^{sd,k} + y_{100,n}^{sd,k}\right)\cdot\delta_{ij}^{sd,k} \le W, \quad \forall_{ij} \quad (3)$$

$$\frac{1}{3}\sum_{k} x_{40,n}^{sd,k} + \sum_{k} x_{100,n}^{sd,k} = t_{100,n}^{sd}, \quad \forall_n \forall_{sd}$$
$$x_{40,n}^{sd,k} = \left\{0,..,3t_{100,n}^{sd}\right\}, \quad x_{100,n}^{sd,k} = \left\{0,..,t_{100,n}^{sd}\right\} \quad (4)$$

$$\sum_{k} y_{40,n}^{sd,k} + \sum_{k}\left(t_{40,n}^{sd}\cdot y_{100,n}^{sd,k}\right) = t_{40,n}^{sd}, \quad \forall_n \forall_{sd}$$
$$y_{40,n}^{sd,k} = \left\{0,..,t_{40,n}^{sd}\right\}, \quad y_{100,n}^{sd,k} = \left\{0,1\right\} \quad (5)$$

Constants:

$$C_{100}^{TxRx} = \alpha\cdot C_{40}^{TxRx} \quad (6)$$

$$D_{40}^{\max} = \beta\cdot D_{100}^{\max} \quad (7)$$

$$Reg_{40}^{sd,k} = \left\lfloor \frac{D^{sd,k}}{D_{40}^{\max}} \right\rfloor, \quad Reg_{100}^{sd,k} = \left\lfloor \frac{D^{sd,k}}{D_{100}^{\max}} \right\rfloor \quad (8)$$

$$t_{100,n}^{sd} = \begin{cases} 1, & \text{if } n <= t_{100}^{sd} \\ 0, & \text{otherwise} \end{cases} \quad (9)$$

$$t_{40,n}^{sd} = \begin{cases} 2, & \text{if } \left(\text{mod}_2\left(t_{40}^{sd}\right) = 1 \wedge n < \left\lceil t_{40}^{sd}/2 \right\rceil\right) \vee \\ & \vee\left(\text{mod}_2\left(t_{40}^{sd}\right) = 0 \wedge n <= \left\lceil t_{40}^{sd}/2 \right\rceil\right) \\ 1, & \text{if } \text{mod}_2\left(t_{40}^{sd}\right) = 1 \wedge n = \left\lceil t_{40}^{sd}/2 \right\rceil \\ 0, & \text{otherwise} \end{cases} \quad (10)$$

4. Results and Discussion

The proposed design framework is evaluated using the NSFNET topology depicted in Fig. 1(c). The model uses as input 10 candidate paths for each sd pair, pre-computed with a k-shortest path algorithm. A unitary cost is given to 100G transceivers and α is varied between 1 and 4. The maximum optical reach for 100G is fixed in 1000 km, while β takes the value 1 or 1.4. The static demand matrices have 80% of the total node pairs active, each exchanging one 100G and four 40G signals in each direction. The network has 40 or 60 wavelength channels per fiber link.

Fig. 2 and Fig. 3 express the type of equipment selected when grooming and VCAT are enabled for 40 and 60 wavelengths per link, respectively. With W=60, the use of 40G channels is preferred for both 100G (through VCAT) and 40G services when $\alpha \geq 2$, for β=1.4, and $\alpha \geq 2.5$, for β=1. Note that a larger β benefits 40G-based solutions due to a reduced number of regenerators per path. However, for W=40, 100G channels are more intensively used for supporting 100G and 40G (via grooming) requests, restricting the adoption of 40G equipment only for higher cost ratios. This trend is attributed to the fact that the utilization of 40G channelization strongly depends on the available number of channels per fiber, even when price points are favorable to 40G. Such behavior is evident from Fig. 2(a) where MP routing is applied in 40G channels via VCAT for relieving the more congested links and comply with W.

In Fig. 4, the influence of disabling VCAT or grooming on network cost is evaluated, but only for W=60, since for W=40 inhibiting grooming yields unfeasible solutions due to insufficient link capacity. This outcome reinforces the importance of this functionality to fully exploit the available capacity. The results confirm that the minimum cost solution is always obtained when both VCAT and grooming are available. Particularly, for α below 2, most savings (up to 40% of the total cost) come from grooming, which benefits from price points favorable to 100G. For α above 3.5 (for β=1) or 2.5 (for β=1.4), most cost reductions (reaching 20%) are attained with VCAT, which relies on 40G.

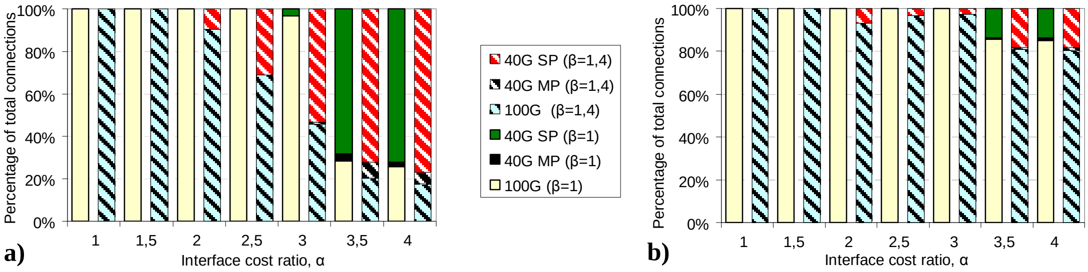

Fig. 2. Connection type for (a) 100 Gb/s and (b) 40 Gb/s services with 40 wavelength channels per link.

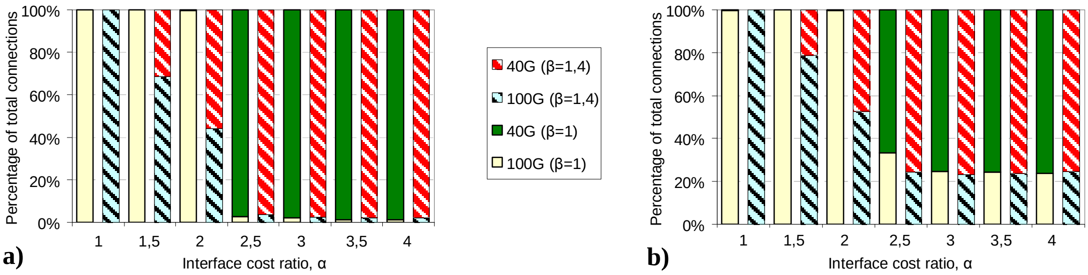

Fig. 3. Connection type for (a) 100 Gb/s and (b) 40 Gb/s services with 60 wavelength channels per link.

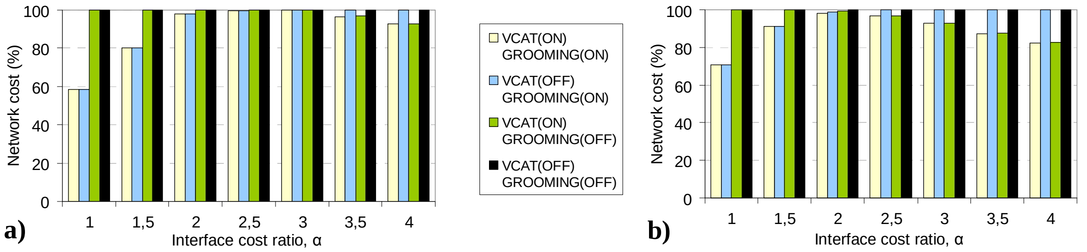

Fig. 4. Total network cost for (a) β = 1 and (b) β = 1.4 with 60 wavelengths channels per link.

5. Conclusion

This work proposed a simplified framework for minimizing the capital expenditures of supporting 40G and 100G services over OTN networks using grooming and virtual concatenation functionalities. The exploitation of both functionalities is shown to always provide the most cost-effective solution. In addition, the range of the cost savings is shown to vary with the equipment cost ratio, maximum optical reach, and number of wavelengths per link.

6. References

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