

# Extending the Flexgrid Optical Core towards the Edges

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## ABSTRACT

National IP/MPLS network have being designed on top of fixed-grid DWDM optical networks so to spread out covering large areas. Besides, multilayer IP/MPLS-over-DWDM networks take advantage from grooming to achieve high spectrum efficiency, filling the gap between users' flows and wavelength channels' capacity. The advent of the flexgrid technology providing a finer granularity makes possible to perform grooming also at the optical layer. We propose to flatten previous multilayer approaches and advance towards single layer networks consisting in a number of IP/MPLS areas connected through a flexgrid-based core network. A two-step procedure to design such flexgrid-based IP/MPLS national networks is proposed. In this paper, a future large flexgrid core network inter-connecting small areas is shown.

**Keywords:** Multilayer Network Planning, IP/MPLS networks, Flexgrid-based networks.

## 1. INTRODUCTION

National IP/MPLS networks typically receive client flows from access networks and perform flow aggregation and routing. The problem of designing IP/MPLS networks consists of finding the configurations of the whole set of routers and links so as to transport a given traffic matrix whilst minimizing capital expenditure (CAPEX). To minimize the number of ports a router hierarchy consisting of *metro* routers performing client flow aggregation and *transit* routers providing routing flexibility, is typically created.

As a consequence of link lengths, national IP/MPLS networks have been designed on top of fixed-grid dense wavelength division multiplexing (DWDM) optical networks, and thus the design problem has been typically addressed through a multilayer IP/MPLS-over-optical approach where transit routers are placed alongside optical cross-connects (OXC) [1]. Besides, multilayer IP/MPLS-over-DWDM networks take advantage of grooming to achieve high spectrum efficiency, filling the gap between users' flows and wavelength channels' capacity.

The advent of the flexgrid technology [2] providing a finer granularity makes possible to perform grooming also at the optical layer. Flexgrid optical networks divide the available optical spectrum into a set of frequency slots of a fixed spectral width; optical connections (*lightpaths*) are assigned a number of slots according to their requested bit-rate, the selected modulation technique and the considered grid. The key technologies that are paving the way to devise novel network architectures are: *i*) the availability of flexgrid ready Wavelength Selective Switches (WSS) to build Bandwidth-Variable Optical Cross-Connects (BV-OXC) [3]; *ii*) the development of advance modulation formats to increase efficiency and being capable of extending the reach of optical signals avoiding really expensive electronic regeneration (3R); *iii*) Multi-Flow Transponders (MF-TP) able to deal with several flows in parallel, thus adding even more flexibility and reducing costs [4].

Authors in [5] analysed the CAPEX needed to deploy a multi-layer IP/MPLS-over-Flexgrid architecture as a function of the frequency slot width used in the flexgrid network. They used three different traffic profiles in the same range as above. In line with [6], results showed that investments in optical equipment capable of operating under slot widths of 6.25 GHz are more appropriate when lightpaths' capacity is low, whereas 12.5 GHz, or even 25 GHz, work better when lightpaths' capacity increases.

In this paper we summarize the main conclusions from our previous work [7]-[9] where we proposed to flatten previous multilayer approaches and advance towards single layer networks consisting of a number of IP/MPLS areas connected through a flexgrid-based core network.

## 2. NETWORK DESIGN PROPOSED PROCEDURE

Given a national network with several hundreds of Central Offices, a full, single step network optimization is clearly impossible. Hence, a two-step procedure is proposed to design such IP/MPLS national networks and investigate its optimal size so as to minimize CAPEX: 1) area partitioning and 2) networks design.

Starting from a given set of locations, where some of them are also candidate core locations (based on location and good node connectivity), and from a traffic matrix for the entire network, the first step, finds the optimal set of areas, each consisting of a subset of locations, one of them belonging to both that area and the core network. Figure 1 illustrates the proposed design procedure where some data needs to be pre-computed: a) candidates for

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core nodes can be limited to those nodes with sufficient connectivity degree and b) the limited subset of potential core nodes (*e.g.* based on distance) each location can belong to.

The performance of several slot widths so as to obtain the highest spectral efficiency is investigated. Spectral efficiency is defined in eq. (1), where  $b_{aa'}$  represents the bitrate between locations  $a$  and  $a'$  belonging to two different areas in the set of areas  $A$ ,  $\Delta f$  is the considered slot width, and  $B_{mod}$  is the spectral efficiency (b/s/Hz) of the chosen modulation format. Note that the ceiling operation computes the amount of slots to convey the requested data flow under the chosen slot width. The use of spectral efficiency links the two proposed steps so that the final network design eventually minimizes CAPEX.

$$\sum_{a \in A} \sum_{\substack{a' \in A \\ a' \neq a}} \frac{b_{aa'}}{\Delta f \cdot B_{mod}} \left\lceil \frac{b_{aa'}}{\Delta f \cdot B_{mod}} \right\rceil \quad (1)$$

In the subsequent design step, each of the IP/MPLS areas and optical core networks are designed separately given its particular traffic matrix, so as to minimize CAPEX (Figure 2). Regarding IP/MPLS area networks design, we assume that underlying transmission capabilities to connect IP/MPLS routers among them are available and no cost is considered for them. For each area, its optimal IP/MPLS design and dimensioning, including router, cards, and ports types is obtained. As for the flexgrid-based core network, the optimal design and dimensioning to serve the aggregated demands between areas is found.

### 3. ILLUSTRATIVE NUMERICAL RESULTS

This section presents the results obtained from solving a close-to-real problem instance consisting of 1113 locations, based on the BT network. Those locations (323) with a connectivity degree of 4 or above were selected as potential core locations. A 3.22 Pb/s traffic matrix was obtained by considering the number of residential and business premises in the proximity of each location. Locations could only be parented to a potential area if they were within a 100 km radius. Finally, four slot widths (50, 25, 12.5 and 6.25 GHz) were considered.

#### 3.1. Area Partitioning

Figure 3 plots the amount of aggregated traffic for each solution from solving the heuristic algorithm when the number of areas is fixed. The relationship between the amount of aggregated traffic and the number of areas is clearly shown: more areas entail higher aggregated traffic to be exchanged because less traffic is retained within an area, since the areas are smaller. On the contrary, it is worth noting that the amount of aggregated traffic does not depend on the slot width.

In order to understand the behaviour of the core network spectral efficiency, this has been included as part of the objective function to be maximized. Therefore, plots in Figure 3 show the maximum spectral efficiency of the solutions as a function of the slot width and the number of areas selected. As illustrated, network spectral efficiency decreases sharply when the number of areas is increased since more flows with lower amount of traffic are needed to be transported over the core network. Note that the traffic matrix to be transported by the core network has  $|A| \cdot (|A| - 1)$  unidirectional flows. Let us consider a threshold for spectral efficiency of 80% (horizontal red line in Figure 3). Then, the largest number of areas is 116, 165, 216, or 295 when the 50, 25, 12.5 and 6.25 GHz slot width, respectively, is selected. Obviously, the coarser the grid granularity chosen for the optical network, the larger the areas have to be for the spectral efficiency threshold selected and thus the lower the number of areas opened.

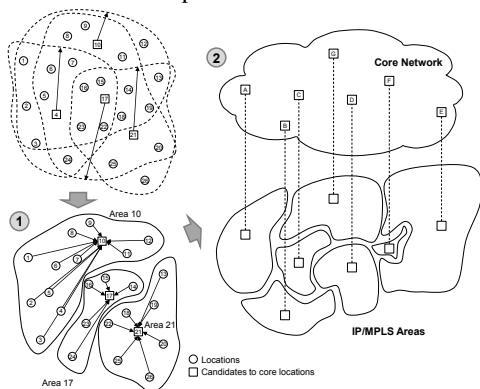


Figure 1. Two-step procedure for network design: 1) Locations are grouped into areas. 2) Each IP/MPLS areas and the core network are designed.

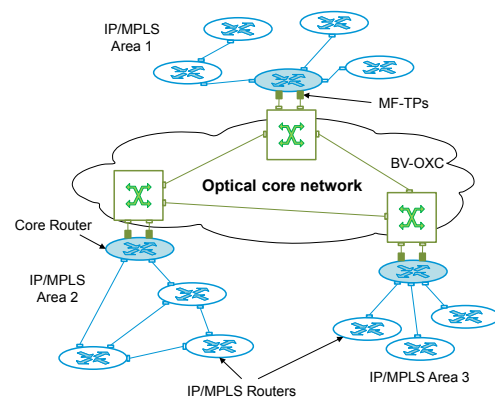


Figure 2. Each network is designed independently given its particular traffic matrix.

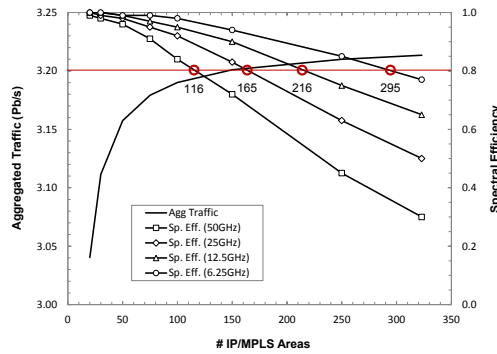


Figure 3. Aggregated traffic and spectral efficiency.

Figure 4 presents the details of the solutions as functions of the number of areas. Note that plots in Figure 4 are valid irrespective of the slot width used, since no spectral efficiency threshold was required.

In Figure 4a, the size of the areas is represented. Note that in the reference interval [116, 295] the average number of locations in each area is lower than 10, being lower than 20 for the largest area. This limited area size simplifies the design of those IP/MPLS networks. Besides, switching capacity of core IP/MPLS routers is proportional to the size of the areas as shown in Figure 4b. They require capacities of up to 58 Tb/s (28.5 Tb/s on average) when the 50 GHz slot width is used, decreasing to 28.5 Tb/s (11 Tb/s on average) for 6.25 GHz. Hence, finer slot widths might keep routers to single chassis size – far more efficient and cost effective.

Figure 4c surveys the size of the area internal data flows (flows where at least one end router is in a given area). In the reference interval, the size of the internal flows is up to 72 Gb/s, 32 Gb/s on average, when the 50 GHz slot width is used, decreasing to 38 Gb/s, 15 Gb/s on average, when the 6.25 GHz slot width is used. The average size of the areas traffic matrix is small as a result of the size of the areas: lower than 300 unidirectional flows.

Finally, Figure 4d examines the size of the aggregated data flows in the optical core network. When the number of areas is low, the size of the aggregated flows is quite large but the overall size of the traffic matrix is quite small: the largest flow conveys 19 Tb/s although there are only 380 aggregated data flows. In comparison, when the number of areas is large, the size of the largest flow is smaller but the size of the core network traffic matrix is very large: the largest flow conveys 203 Gb/s but there are as many as 104,000 aggregated data flows.

In the reference interval, the size of the aggregated flows is up to 989 Gb/s, 264 Gb/s on average, when the 50 GHz slot width is used, decreasing to 223 Gb/s, 39 Gb/s on average, when the 6.25 GHz slot width is used. The size of the optical core network traffic matrix increases from 14,000 to 48,000 unidirectional flows when the 50 and 12.5 GHz slots widths are selected.

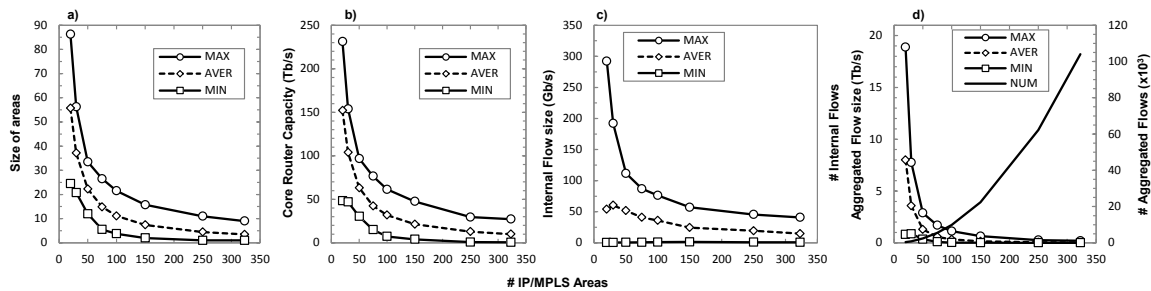


Figure 4. Details of the solutions against the number of IP/MPLS areas. Max, min, and average plots are shown.

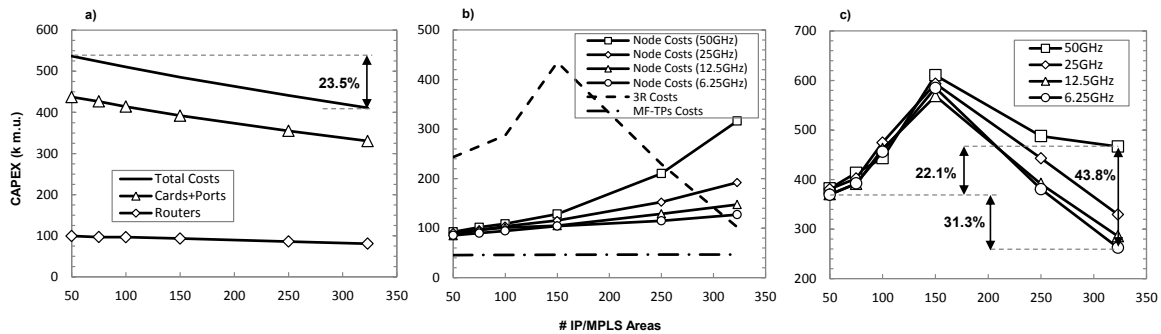


Figure 5. CAPEX vs. amount of opened IP/MPLS areas. a) Aggregated and breakdown IP/MPLS CAPEX. b) Flexgrid core network CAPEX for each considered slot width. c) Core network costs breakdown.

### 3.2. Networks Design

Having few IP/MPLS areas results in several parallel BV-OXC to be installed in each location, since the capacity of BV-OXCs to source traffic it is limited by its architecture [3]. We limited the number of parallel BV-OXC per location to only two, which resulted in ranging the number of areas to open from 50 to 323. Each of the resulting 24 (6 different number of areas and 4 slot widths) scenarios was designed.

As for the costs, we used the cost model produced in the STRONGEST project [3]: Ten IP/MPLS router types were considered, their capacity ranging from 4 to 57.6 Tb/s and the number of slots where cards are plugged in ranging from 10 to 144. Different cards for access (48×1, 14×10, 3×40 and 1×100 Gb/s), internal (14×10, 3×40 and 1×100 Gb/s), and 400 Gb/s MF-TP ports were considered. Two types of WSSs (1×9 and 1×20) were used to build BV-OXCs. Finally, four types of 3Rs (up to 10, 40, 100, 400 Gb/s) were taken into consideration.

Figure 5 presents CAPEX results as a function of the number of opened IP/MPLS areas. Figure 5a reports aggregated costs of the IP/MPLS areas, including IP/MPLS routers, cards, and ports (excluding MF-TPs which have been considered part of core networks) costs. Briefly, costs decrease as much as 23.5% with the number of opened IP/MPLS as a consequence of cards and ports costs decrement.

Figure 5b shows disaggregated costs for the flexgrid core network as a function of the slot width considered. We found that MF-TPs and 3Rs costs are almost the same irrespective of the slot width. Notwithstanding, MF-TPs costs remain constant regardless the number of opened IP/MPLS areas whereas 3R costs first increase exponentially with the number of areas up to a point where they decline significantly. The sharp increment is as a result of that in the number of aggregated flows in the core network to connect an increasing number of areas while their on-average capacity is still high enough so to need the highest capacity 3Rs (and shortest reach). Once the on-average capacity of the aggregated flows decreases optical signals reach increases significantly and 3Rs are seldom needed. In contrast, BV-OXC costs depend remarkably from the used slot width; starting from the same values, all costs show an upwards trend being those for the 50GHz slot steeper.

When all costs are aggregated (Figure 5c) we observe 31.3% savings when all areas were opened and the finer slot width was used, comparing to the case where only 50 areas were opened and 50GHz slots were used. Note that the latter represents the case where just super-channels are added to fixed-grid DWDM-based networks. Saving climb to 43.8% compared to the case where all areas are opened and 50GHz slots are used.

## 4. CONCLUDING REMARKS

A new architecture to design national IP/MPLS networks consisting of a set of areas interconnected through a flexgrid optical core has been proposed. A two-step procedure to design those networks was presented: the first step consist in partitioning the network into areas. Each IP/MPLS area and the flexgrid core networks can be designed separately. Results showed that simpler and smaller areas containing 10 – 15 locations are enough to obtain good spectral efficiency in the flexgrid-base core network when 12.5 or even 6.25 GHz slot widths are used. Significant savings at the flexgrid core network (31%) as well as the IP/MPLS area networks (23%) can be obtained when the core network extends towards the edges increasing the number of areas that are connected.

The resulting flexgrid core network need to use finer slots (12.5 or even 6.25 GHz) so grooming is done, in part, at the optical layer considerably reducing that done at the IP/MPLS one. In such scenarios, both the capacity and the number of IP/MPLS routers and ports can be reduced. From the side of the flexgrid core network, 3R regeneration as a result of using super-channels, *e.g.* 400 Gb/s, is an issue that might be mitigated by using inverse multiplexing, *e.g.* 4×100 Gb/s, increasing thus the reach of the optical signals.

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