How National IP/MPLS Networks can benefit from Flexgrid Optical Technology?

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Abstract: We design a 1113-node network and show that the optimum is a large Flexgrid core serving small metro areas. Cost savings of about 31% in the core and 23% in the metro are shown.

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1. Introduction

National IP/MPLS network have traditionally been designed on top of fixed-grid DWDM optical networks to allow them to cover large areas. Multilayer IP/MPLS-over-DWDM networks [1] take advantage of grooming to achieve high spectrum efficiency, filling the gaps between users' flows and wavelength channels' capacity.

However, with the advent of the Flexgrid technology [2], [3] providing a finer wavelength granularity it is now also possible to perform grooming at the optical layer. The key technologies that are paving the way to devise these novel network architectures are: *i*) the availability of Flexgrid ready Wavelength Selective Switches (WSS) to build Bandwidth-Variable Optical Cross-Connects (BV-OXC); *ii*) the development of advanced modulation formats to increase efficiency and being capable of extending the reach of optical signals avoiding expensive electronic regeneration (3R); *iii*) Multi-Flow Transponders (MF-TP) that are able to deal with several flows in parallel, thus adding even more flexibility and reducing costs [4].

In our previous work [5] we proposed to directly connect routers to the optical network and advance towards single layer networks consisting of 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 was proposed: starting from a given set of locations, where some of them are also candidate core locations, and from a traffic matrix for the entire network, the first step in the area partitioning problem finds the optimal set of areas, each consisting of a set of locations and a core location that belong to both that area and the interconnection network (Fig. 1). Optimal results showed a future large Flexgrid core network interconnecting small areas. In this work we report the results of the subsequent design step, where each of the areas and the core is designed separately, given its particular traffic matrix, so as to minimize Capital Expenditure (CAPEX) (Fig. 2).

2. IP/MPLS Area Network DEsign (MANDE) and COre Network DEsign (CONDE) problems

To design each IP/MPLS area network and the Flexgrid core network, MANDE and CONDE problems need to be solved. The MANDE problem statement is as follows (recall that it must be solved separately for each IP/MPLS area):

Given: (1) a network topology represented by a graph $G_A(N_A, E_A)$, with N_A the set of area locations, where one of them is the designated core location, and E_A the set of links connecting two locations; (2) a set D_A of IP/MPLS demands to be transported; (3) IP/MPLS equipment cost, specified by a fixed cost for every type of IP/MPLS router, pluggable card and port. Three types of ports are specified: access ports that are used by incoming demands, internal ports used to connect two IP/MPLS routers in the area, and MF-TPs used to connect IP/MPLS router(s) to BV-OXC(s) in the core location.

Output: the IP/MPLS network, including router types, cards, and ports.

Objective: Minimize the expected CAPEX for the IP/MPLS area network designed for the given set of demands.

In addition, the CONDE problem statement is as follows:

Given: (1) a network topology represented by a graph $G_C(N_C, E_C)$, with N_C the set of core locations and E_C the set of fiber links connecting two locations; (2) a set S of available slots of a given spectral width for each link in E_C; (3) a set D_C of IP/MPLS demands to be transported; (4) BV-OXC cost, which includes a fixed cost for common hardware and a variable cost which depends on the nodal degree and the number of local ports (see [2]) (patch panels can be used to connect optical fibers provided that no local signals are dropped); a cost for every optical amplifier (OA) to be equipped in the used fiber links; a cost of every 3R needed to electronically

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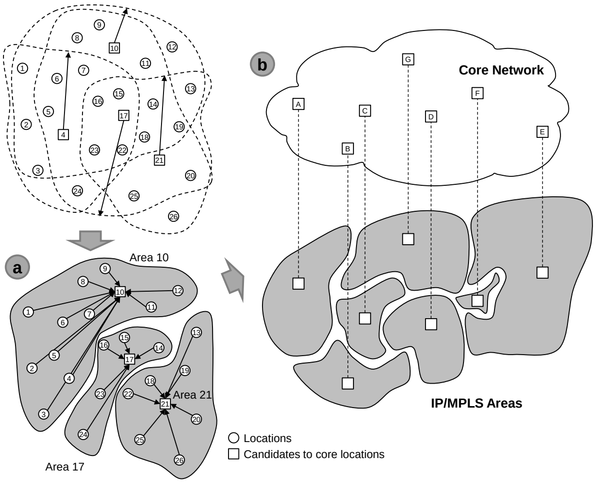

Fig. 1 Two-step procedure for network design: a) Locations are grouped into areas. b) Core locations belong to the core network.

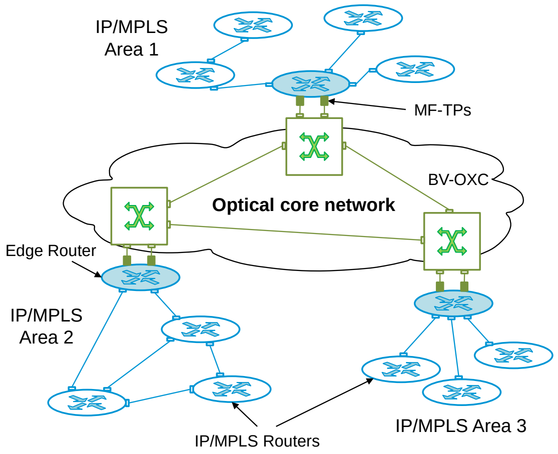

Fig. 2 Each network is designed independently given its particular traffic matrix. The core network is based on the Flexgrid technology whereas the areas are equipped with IP/MPLS routers.

regenerate optical signals at intermediate nodes. Different types of 3Rs may exist differing in their capacity and reach.

Output: (1) the optical network, including patch panels, BV-OXCs and its configuration, OA and fibers; (2) the location and capacity of each of the 3Rs needed.

Objective: Minimize the expected CAPEX for the core network designed for the given set of demands.

Both the MANDE and CONDE problems were modeled by means of integer linear programming (ILP) formulations, with the ILP formulation for the CONDE problem based on [6]. Since their exact solutions become impractical when real-sized network and traffic instances are considered, we developed heuristic algorithms which provide a much better trade-off between optimality and complexity.

3. Illustrative numerical results

In this section we present the results obtained from solving a close-to-real problem instance consisting of 1113 locations based on the BT network. Those locations which had a connectivity degree of 4 or more were selected as the 323 possible core locations. Locations could only be parented to a potential core location provided that they were within a 100 km radius. A 3.22 Pb/s traffic matrix was obtained by considering the number of residential and business premises in the proximity of each location. We considered six different sized core networks (with 50, 75, 100, 150, 250 and 323 separate IP/MPLS areas) and four Flexgrid slot widths (50, 25, 12.5 and 6.25 GHz). After running the heuristic algorithm presented in [5] for each combination of number of areas and slot width we obtained the optimal area partitioning together with the specific traffic matrix for every resulting IP/MPLS area and for the core network.

Each of the 24 resulting scenarios (six different core network sizes and four slot widths) were designed by running the CONDE and MANDE heuristics. Each result reported in the following comes from running the heuristics 168 hours (1 week) for the whole scenario, which includes the IP/MPLS areas and the core network. For the costs, we used the cost model produced in the STRONGEST project [7]. Ten types of IP/MPLS router were considered with capacities ranging from 4 to 57.6 Tb/s and slot counts varying between 10 and 144. Different cards for access (48x1, 14x10, 3x40 and 1x100 Gb/s), internal (14x10, 3x40 and 1x100 Gb/s) and 400 Gb/s MF-TP ports were considered. Two types of WSSs (1x9 and 1x20) were used to build BV-OXCs. Finally, four types of 3Rs (up to 10, 40, 100 and 400 Gb/s) were taken into consideration.

Fig. 3 presents the CAPEX results as a function of the number of opened IP/MPLS areas. Fig. 3a reports the aggregated costs of the IP/MPLS areas which include the costs of the IP/MPLS routers, cards and ports, but excludes the costs of the MF-TPs which have been considered part of the core network. Costs decrease by as much as 23.5% as the number of IP/MPLS areas increase as a result of the decreasing card and port costs.

Fig. 3b shows non-aggregated costs for the Flexgrid core network for each Flexgrid slot width considered. We found that MF-TPs and 3Rs costs are almost the same for all four slot widths. Also MF-TPs costs remain constant regardless of the number of IP/MPLS areas whereas 3R costs initially increase exponentially with the number of areas to a maximum before declining significantly. The sharp cost increase is due to the fact that additional aggregated flows in the core network are required to connect the increasing number of areas, but the on-average capacity of these flows is still large enough to require high capacity 3Rs (with short reach) [5]. Once the on-average capacity of the aggregated flows decrease, the optical signal reach increases significantly and 3Rs are seldom needed. In contrast, BV-OXC costs depend heavily on the slot width used; starting from

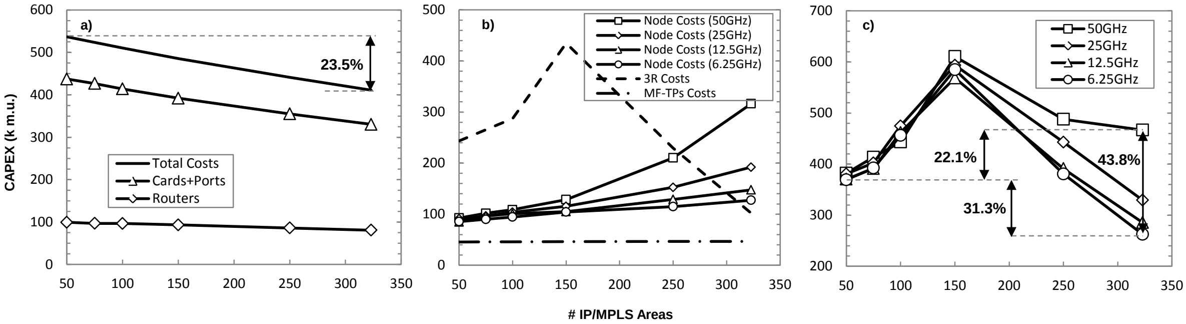

Fig. 3. CAPEX vs. number of IP/MPLS areas. a) Aggregated and breakdown of IP/MPLS CAPEX. b) Flexgrid core network CAPEX for each considered slot width. c) Core network cost breakdown.

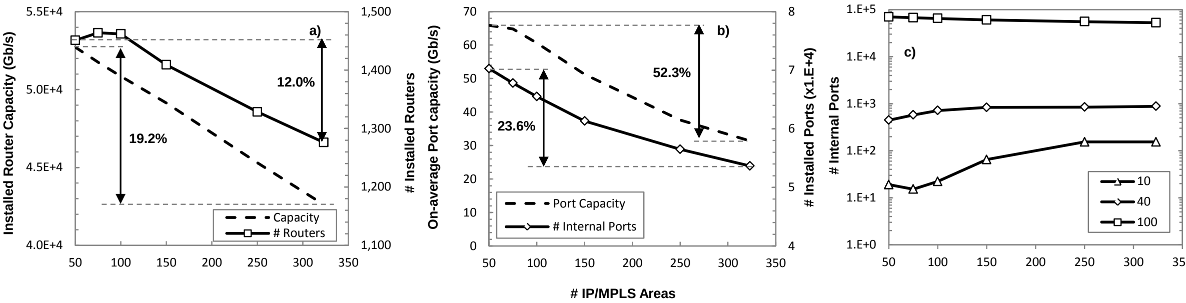

Fig. 4. Details of the solutions against the number of IP/MPLS areas. a) Installed capacity and number of IP/MPLS routers. b) On-average capacity and aggregated number of area internal ports. c) Number of area internal ports.

the same values, all costs show an upwards trend with the 50GHz slot width showing the most significant cost increases. When all costs are aggregated (Fig. 3c) we observe 31.3% savings for the largest core network size and using the finest slot width compared to the case for a 50 node core network and 50 GHz slots were used. Note that the latter represents the case where just super-channels are added to a fixed-grid DWDM-based network. Savings climb to 43.8% compared to the case where all areas are opened and 50 GHz slots are used.

Fig. 4 gives insight on the solutions for the IP/MPLS areas. Fig. 4a illustrates the switching capacity and the number of IP/MPLS routers installed on all the areas of each network as a function of the number of IP/MPLS areas. A significant decrease of up to 19.2% in switching capacity and 12.0% in terms of number of routers is shown. Fig. 4b focuses on the number and on-average capacity of internal ports while Fig. 4c provides disaggregated values for 10, 40 and 100 Gb/s internal ports. A noticeable reduction in the on-average port capacity with the number of IP/MPLS areas is shown, reaching 52.3% for the largest core network size. In terms of the number of internal ports, the reduction is as high as 23.6% as a result of a decreasing number of 100 Gb/s ports which are gradually substituted by 10 and 40 Gb/s ports as the number of IP/MPLS areas increases.

4. Conclusions

National IP/MPLS networks consisting of a number of areas connected through a Flexgrid-based core network have been designed. Results show that significant savings in the Flexgrid core network (31%) as well as the IP/MPLS area networks (23%) can be obtained when the core network is extended towards the edges increasing the number of areas connected. The resulting Flexgrid core network needs finer slots (12.5 or even 6.25 GHz) to allow efficient optical layer grooming to take place, considerably reducing grooming done at the IP/MPLS layer. In such scenarios, both the capacity and the number of IP/MPLS routers/ports can be reduced. In the Flexgrid core network, 3R regeneration as a result of using 400 Gb/s super-channels is an issue that might be mitigated by using inverse-multiplexing (e.g. 4x100 Gb/s) and thus increasing the optical signal reach.

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