OTN Switching for Improved Energy and Spectral Efficiency in WDM MLR Networks

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Abstract: The application of OTN switching on top of a WDM layer is evaluated in terms of energy and spectral efficiency (SE). Significant improvements in energy-efficiency-per-GHz and SE are demonstrated with respect to conventional WDM architectures.

OCIS codes: (060.4251) Networks, assignment and routing algorithms; (060.4256) Networks, network optimization.

1. Introduction

The exponential traffic growth experienced by communications networks is pushing operators to continuously increase the capacity of their telecommunications infrastructure. A network capacity upgrade entails additional capital and operational expenditures that may come, among others, by increased energy consumption. In this regard, telecom operators are becoming one of the largest energy consumers in the world. Therefore, energy-efficient and green networking techniques are becoming increasingly important to ensure the development of the Internet Society in a cost-effective manner while preserving the natural environment.

In the core network, traffic grooming techniques are essential to maximize the channel bandwidth utilization and to economically justify the deployment of higher-speed systems such as 400 Gbps. The Optical Transport Network (OTN) technology [1] is emerging as a promising optical transport architecture that enables sub-wavelength grooming and switching by means of optical data unit-cross connect (ODU-XC) boards. This functionality allows the clients to be decoupled from the wavelength division multiplexing (WDM) transport interface, which permits reductions of the service over-provisioning levels and smooth upgrades (without hardware modifications) at the tributary side. The benefits that OTN switching can bring have been investigated in the literature, mainly from an economical point of view. For instance, Takita et al. define an analytical model to determine in which traffic conditions this functionality can be advantageous to reduce cost in [2], while Bertollini et al. evaluate the cost savings that OTN switching can provide over conventional WDM architectures in [3]. In [4], Melle et al. also study the cost benefits based on the potential reduction of the number of client ports. In this paper, we aim at evaluating the potential energy and spectral efficiency that the application of the OTN switching functionality can offer to WDM networks, which is a topic that, to the best of authors' knowledge, has not been addressed so far. Our study is carried out considering two node architectures (i.e., with and without OTN switching) and a realistic core network scenario with mixed-line-rate (MLR) transmission (40/100/200/400 Gbps) and different traffic conditions.

2. OTN switching

The architecture of a node with OTN switching functionality differs from that of a conventional node by the presence of an OTN switching matrix (composed of ODU-XC boards) between the OTN tributary ports and the line boards as shown in Fig. 1. OTN switching enables easy sub-wavelength grooming, which is in contrast with the functionalities of a conventional WDM node (where sub-wavelength grooming would require the de-multiplexing of the wavelengths into client signals before). In fact, the application of OTN switching may favor an enhanced utilization of the network resources as lightpaths (LPs) do not have to be dedicated to a particular optical layer

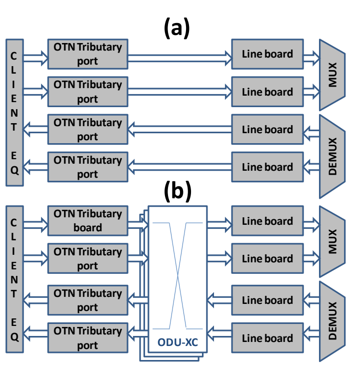


Fig. 1. Node architecture: (a) Conventional WDM; (b) WDM with OTN switching matrix.

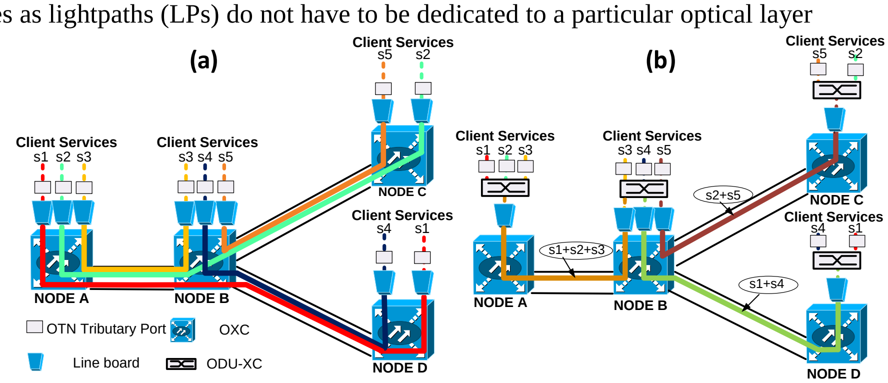
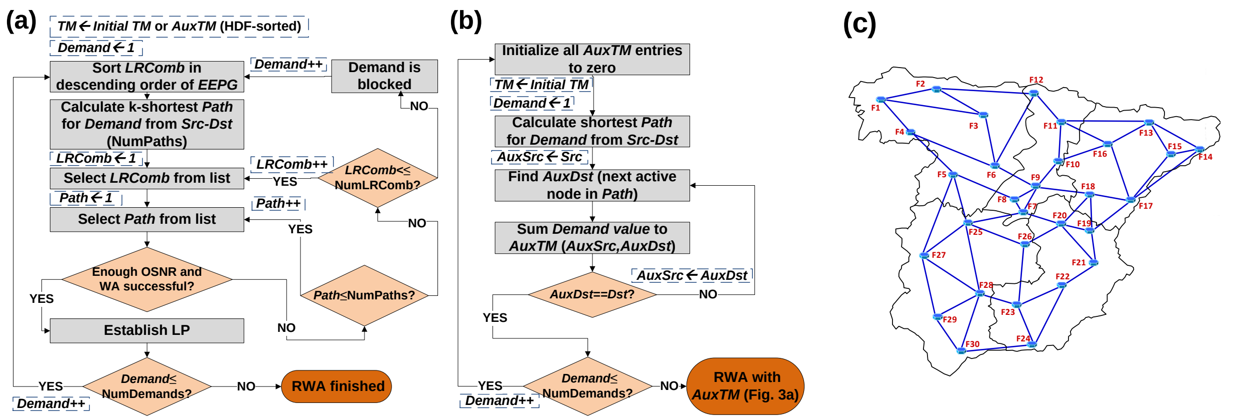


Fig. 2. Provisioning of 5 end-to-end services in network architectures: (a) Conventional WDM; (b) WDM with OTN switching functionality.



Initial TM: Reference traffic matrix (TM)
Demand: Traffic demand
Src: Initial source node of the demand
Dst: Initial destination node of the demand
Path: Candidate path from *Src* to *Dst*
NumPaths: Num. of candidate paths
LRComb: Line rate combination
NumLRComb: Num. of possible *LRComb*
NumDemands: Num. of demands in initial TM
AuxTM: Auxiliary TM for OTN switching sc.
AuxSrc: Auxiliary source node for OTN switching sc.
AuxDst: Auxiliary destination node for OTN switching sc.

Fig. 3. (a) RWA flow diagram; (b) Traffic matrix generation for OTN switching application; (c) Telefónica's Spanish core network model.

service from source (Src) to destination (Dst), but can carry several client signals aimed to different nodes instead. For instance, Fig. 2 presents the provisioning of 5 end-to-end services in a network architecture without and with the OTN switching functionality. In the conventional architecture (Fig. 2a), each service is mapped to a fixed-rate ODU and transmitted in a dedicated LP to its destination. In the OTN switching case (Fig. 2b), *s1*, *s2* and *s3* are multiplexed together at Node A and transmitted onto the same LP to Node B, where *s3* is terminated. At Node B, *s1* is groomed with *s4* onto the same LP to Node D, whereas *s2* is groomed with *s5* and transmitted on a different LP to Node C. As shown, the number of established LPs can be significantly reduced.

3. Network and power consumption model

An International Telecommunications Union-Telecommunications (ITU-T) grid WDM optical mesh with a total number of 80 wavelengths (per link) over the C-band, and MLR transmission with 40 Gbps, 100 Gbps, 200 Gbps and 400 Gbps (occupying two ITU-T grid slots) are considered. Four energy-consuming network elements are taken into account: Transponders (TSPs), optical amplifiers (OAs), optical cross connects (OXCs) and OTN switching matrices. The TSPs, which include the tributary and line boards, with line rates of 40, 100, 200 and 400 Gbps consume 173.8, 243.4, 280 and 481.9 W, respectively [5]. Then, the in-line OAs (i.e., erbium-doped-fiber-amplifiers) consume 30 W per direction with an overhead of 140 W per location [5]. The power consumption (PC) of an OXC depends on the node degree (*N*) and the add/drop degree (*a*) as follows: ($PC = N * 85 + a * 100 + 150$), where 150W is the node overhead [5]. Finally, the PC of an OTN switching matrix depends on the number of required ODU-XC boards, assuming that each board consumes 96 W and provides a maximum switching capacity of 1 Tbps (nodes dealing with higher traffic volumes require more than one ODU-XC board).

4. Methodology

An energy-aware routing and wavelength assignment (RWA) heuristic algorithm is used to compare both network architectures (i.e., without and with OTN switching functionality). The RWA algorithm attempts to allocate the maximum traffic in the network while jointly optimizing the overall energy and spectral efficiency. For this purpose, an energy-efficiency-per-GHz (EEPG) metric (i.e., traffic demand [kbps]/PC at the TSPs[W]/spectrum occupancy [GHz]) is adopted to select the most suitable route and line rate combination (*LRComb*).

- *Initial scenario- without OTN switching functionality- (Fig. 3a):* The demands of the initial traffic matrix (*Initial TM*) are first sorted in descending order of value (i.e., highest demand first-*HDF*-). Then, for each demand, the possible *LRComb* are calculated and listed in descending order of *EEPG metric*. After that, the WA is evaluated for the first *LRComb* in the candidate paths (*k*-shortest paths). For a successful service provisioning, the wavelength continuity and the physical constraints must be fulfilled. The transparent reach feasibility is evaluated according to the OSNR model in [5], assuming that no regenerator is available at the nodes. If both constraints cannot be fulfilled with the first *LRComb* in any candidate path, the following *LRComb* of the list are evaluated until reaching a feasible solution, or until concluding that the demand is blocked if no solution is found with any *LRComb* over any path.
- *OTN switching scenario (Fig. 3b):* The availability of OTN switching functionalities at some nodes allows the demands of the *Initial TM* to be segmented into shorter-distance LPs that end at intermediate nodes and can carry together signals aimed to different destinations. It is assumed that ODU-XC boards are only available at *active nodes* (i.e., those which are source and/or destination of at least one traffic demand of the *Initial TM*), whereas the

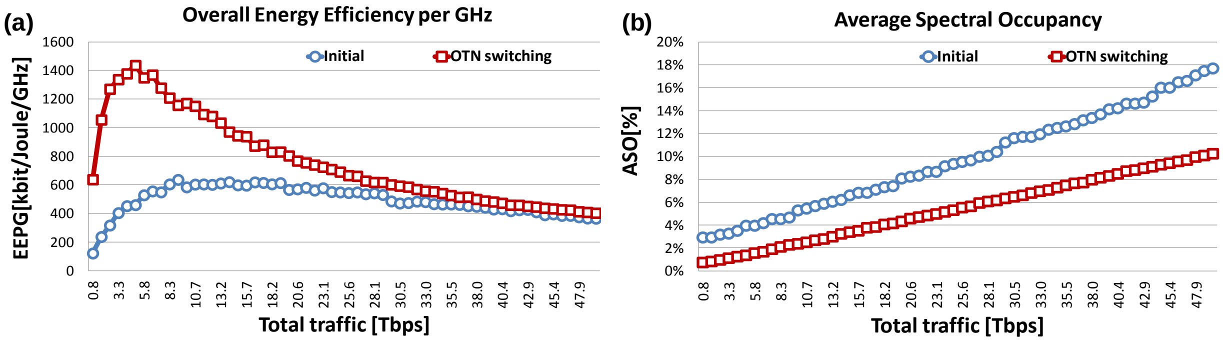


Fig. 4. Simulation results: (a) Initial EEPG (without OTN switching capabilities) and final EEPG with OTN switching; (b) Initial ASO (without OTN switching capabilities) and final ASO with OTN switching.

remaining nodes are considered as mere transit nodes where optical bypass is applied. In order to simulate this scenario, a new TM is generated (*AuxTM*) as shown in Fig. 3b. First, the shortest path (*Path*) is calculated for each demand of the *Initial TM* from *Src* to *Dst*. Then, *Path* is divided into different segments by finding the next *active node* in the link sequence (e.g., in Fig. 2, *s1* would result in two "sub-demands": one from A to B and another from B to D). Next, the *Demand* value is summed up to the existing traffic values of the corresponding Src-Dst entries of the *AuxTM* (initially set to zero). Once the previous process is carried out for all the demands in *Initial TM*, the RWA algorithm (Fig. 3a) is run using *AuxTM* as TM. In this scenario, it is also required to account for the total traffic switched by the OTN matrix in each node as this value determines the number of required ODU-XC boards.

The total *EEPG* of the network is obtained in Eq. (1) by the ratio of the energy efficiency (*EE*) measure and the average spectral occupancy (*ASO*) of the links. *EE* is the ratio of the *TotalTraf* and *TotalPC*, where *TotalTraf* is the summation of all the demands in *Initial TM*, and *TotalPC* is the power consumed by all the equipment deployed in the network, i.e., TSPs, OAs, OXCs, and ODU-XC (only used in the OTN switching scenario).

$$EEPG\left[\frac{\text{kb/J}}{\text{GHz}}\right] = \frac{EE\,[\frac{kb}{J}]}{ASO[\text{GHz}]} = \frac{TotalTraf[\text{kbps}]/TotalPC[\text{W}]}{ASO[\text{GHz}]} = \frac{\sum TrafficDemand/(\sum PC_{TSP}+\sum PC_{OA}+\sum PC_{OXC}+\sum PC_{ODU-XC})}{ASO} \quad (1)$$

5. Simulation results and discussion

The study considers the Spanish core network model of Telefónica I+D, composed of 30 nodes and 56 bi-directional links with a total of 66 amplifier locations (Fig. 3c). An *Initial TM* with 46 bi-directional demands and an overall traffic of 825 Gbps is adopted as a reference and scaled up to 47.85 Tbps [5] to emulate different traffic conditions.

As shown in Fig. 4a, at low traffic, OTN switching can significantly enhance the overall EEPG with respect to the initial scenario. In fact, when traffic is low, the application of grooming strategies can greatly improve EEPG since the capacity of TSPs is mostly underutilized (the reference average traffic demand is 9 Gbps). However, as traffic grows and the over-provisioning levels are reduced (i.e., the capacity of the TSPS gets more efficiently utilized), grooming strategies become less advantageous. At high traffic, the application of OTN switching requires the installation of ODU-XC boards and a greater number of TSPs (i.e., more end-to-end traffic demands) which entail a substantial increase in PC. Nevertheless, OTN switching shows superior energy efficiency than the initial scenario at any evaluated traffic load, since it permits to transmit more bits per GHz with one Joule of energy (i.e., higher EEPG). These EEPG improvements range from 422 percent (low traffic) to 9 percent (high traffic).

Regarding spectral efficiency (SE), Fig. 4b shows that the application of OTN switching can significantly reduce the ASO of the network. The SE improvements are remarkable at low traffic (up to 288 percent), but also remain notably advantageous at high traffic with enhancements of around 70 percent over the initial scenario.

6. Conclusions

The application of OTN switching can bring significant improvements in the resource utilization to WDM networks. This functionality can notably decrease the ASO, while also increase the energy-efficiency-per-GHz (EEPG). OTN switching can be especially beneficial at low traffic loads, where the spectral efficiency and the EEPG can be improved over 280 and 400 percent with respect to conventional WDM architectures, respectively.

7. References

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