A Techno-Economic Comparison of Filterless and Wavelength-Switched Optical Metro Networks

Oleg Karandin, Omran Ayoub, Francesco Musumeci, Massimo Tornatore
Department of Electronics, Information and Bioengineering, Politecnico di Milano, Italy
E-mails: {firstname.lastname}@polimi.it

ABSTRACT

We model the cost of Filterless Optical Networks (FONs) and compare FONs with state-of-the-art Wavelength-Switched Optical Networks (WSON) in core and metro-aggregation networks considering traffic evolution over a multi-year time period. Results show that, due to the energy savings allowed by passive devices, FONs achieve up to 4-6% cost savings with respect to WSON.

Keywords: Filterless Optical Networks, Network architectures, Metro-Aggregation Networks, Cost Analysis

1. INTRODUCTION

Network operators (NOs) must constantly upgrade the capacity of their optical networks to accommodate a continuous traffic growth, which is fuelled, as of today, mostly by the expected bandwidth requirements of 5G communications. However, simply scaling the network capacity in conventional Wavelength-Switched Optical Networks (WSONs) is not an economically-viable long-term solution, due especially to the high linear costs associated with switching equipment. Therefore, NOs have started investigating new architectures to increase network capacity while keeping capital (CAPEX) and operational (OPEX) expenditures under control. Filterless Optical Networks (FON) [1] offer a promising alternative to maintain network costs under control by replacing costly active switching devices, such as Reconfigurable Optical Add-Drop multiplexers (ROADMs) based on Wavelength Selective Switch (WSS), with passive optical splitters/combiners that operate on the entire fiber spectrum, thus employing a broadcast-and-select approach.

However, due to their broadcasting nature, in FONs optical signals propagate to all the outgoing ports of the nodes encountered along a path, causing a significant increase in spectrum consumption with respect to state-of-the-art WSONs. Despite this, FONs are considered a promising solution due to their relatively low equipment cost and energy consumption, and as well due to the high mean-time-between-failure of passive components. FONs, originally investigated mostly for core meshed networks [2], have recently gained momentum in the context of metro networks, especially for metro architecture where nodes are organized in horseshoe (ring) topologies.

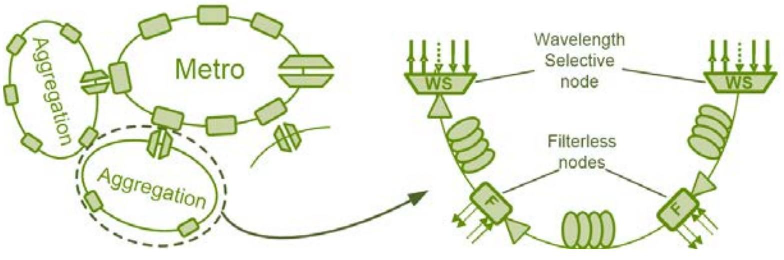


***Figure 1**. Metro network composed of interconnected horseshoes*

Fig. 1 shows how a metro ring can be implemented over a horseshoe filterless topology. Note that, when a FON is deployed in mesh networks, node interconnections, i.e., splitters and combiners, must be configured so that the network is divided into separate fiber trees (this process is known as "fiber tree establishment") to avoid laser-loop effects. Instead, in a simple horseshoe topology, fiber tree establishment is not necessary as no closed loop is possible.

Some network design issues in FONs have been already investigated. Ref. [2] studied the problems of fiber-tree establishment, routing and wavelength assignment. Ref. [3] compared the equipment cost of FON and WSON network deployment in metropolitan networks over different time periods, showing that FONs can yield some cost savings (around 5%). Ref. [4] expanded the analysis by including semi-filterless networks, however still considering only equipment cost. Ref. [5] compared filtered and filterless architectures in hub-and-spoke network topologies while Ref. [6] analysed equipment cost savings for FON equipped with reconfigurable passive switches. Although in the mentioned papers energy efficiency is claimed among one of the main advantages provided by FONs, to the best of our knowledge, there is no study which quantitatively incorporates this aspect.

In this work, we provide a techno-economic comparison between FON and WSON in both meshed core and in metro-aggregation networks. We adopt a cost model accounting for the capital (equipment cost) and operational (energy consumption) costs of network equipment over a 5-year time period. Results show that cost savings are in the order of 4-6% (in accordance with previous works), confirming economic convenience of FON over WSON in specific network conditions.

2. FILTERLESS OPTICAL NETWORK DESIGN AND COST MODEL

2.1 Node Architecture and Cost Model

An exemplificative structure of a WSON (and required modification to turn into a FON) degree-2 node is represented in **Fig. 2**. The only difference is that at each output port there is either a WSS (WSON architecture) or an optical combiner (FON architecture). The number of input ports of the WSS (or of the combiner) must be no less than the node degree. In both architectures, there is a pair of a multiplexer-demultiplexer for every pair of input-output ports and an optical splitter at every input port. The number of output ports of the splitter must be no less than the node degree. There is an optical preamplifier before each input port and a booster optical amplifier (OA) after each output port. One or multiple transponders are needed to establish a unicast connection with another node, depending on the traffic requirements.

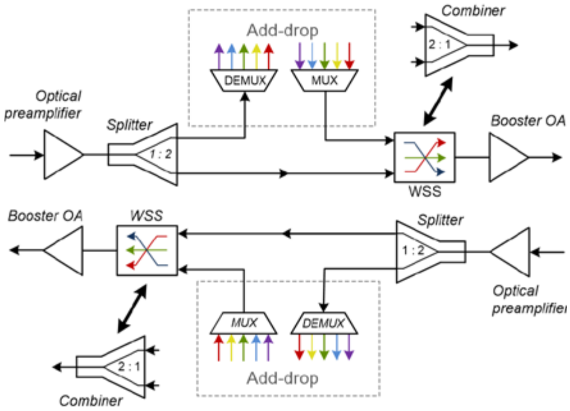


Figure 2. *Structure of WSON and FON node*

In this paper, we evaluate the cost difference between WSON and FON architectures by considering both CAPEX and OPEX, i.e.,

$$\mathrm{CAPEX}_{WSON} = N_{WSS} \times Pr_{WSS} + N_{OA} \times Pr_{OA} + N_{MUX/DEMUX} \times Pr_{MUX/DEMUX} + N_{Split} \times Pr_{Split} + N_T \times Pr_T$$

$$\mathrm{OPEX}_{WSON} = \left(N_{WSS} \times P_{Av.WSS} + N_{OA} \times P_{Av.OA} + N_T \times P_{Av.T} \right) \times Pr_{Energy}$$

$$\mathrm{CAPEX}_{FON} = N_{Comb} \times Pr_{Comb} + N_{OA} \times Pr_{OA} + N_{MUX/DEMUX} \times Pr_{MUX/DEMUX} + N_{Split} \times Pr_{Split} + N_T \times Pr_T$$

$$\mathrm{OPEX}_{FON} = \left(N_{OA} \times P_{Av.OA} + N_T \times P_{Av.T} \right) \times Pr_{Energy}$$

where $Pr_{Component}$ is the price of the component; $N_{Component}$ is the number of these components in each node, $P_{Av.Component}$ is the average power of these components and Pr_{Energy} is the price of electricity.

2.2 Filterless Optical Network Design

Given the node architecture above, the absence of filters (i.e., WSS's) in meshed FONs would results in laser loop effects, making reliable transmission of information impossible due to the accumulation of the amplified spontaneous emission (ASE) noise of EDFA amplifiers. To avoid that, FONs must be divided into separate fiber trees. Within a fiber tree, wavelengths are assigned to lightpaths to serve the traffic demands between network nodes. Wavelength occupied by propagating signals cannot be reused, hence spectrum resources in a fiber-tree-based FON can be exhausted by a smaller number of traffic demands than in the equivalent WSON. Therefore, managing unfiltered channels (i.e., unnecessary signal broadcasting) in FONs is important, to avoid waste of spectrum resources and to establish a larger number of connections. In addition to laser-loop and spectrum constraints, no path in the fiber tree should exceed the maximum reach, defined by the QoT (Quality of Transmission) constraint. To perform fiber trees establishment in meshed FONs, considering the three described constraints, we used a Genetic Algorithm (GA) as suggested in [2], with the objective of minimizing spectrum consumption. **Fig. 3** shows an example of a fiber tree establishment.

3. NUMERICAL RESULTS AND DISCUSSION

3.1 Evaluation Settings

For the techno-economic analysis in core networks we consider the 7-node German [9] and 10-node Italian (**Fig. 3**) network topologies. Two fiber trees are established in both cases. Traffic matrix is full mesh with the initial traffic of 400 Gb/s for each connection and 30% increase each year. 400G transponders are used in core networks. For the analysis of metro-aggregation networks, we consider the 60-node Metro-HAUL topology (**Fig. 4**) and the 52-node TIM topology in [8]. Note that the core nodes and core backbone nodes are ROADM-based while the aggregation nodes are filterless. Traffic matrix for metro topologies consists of a mesh among the core nodes and among the aggregation nodes of each fiber tree.

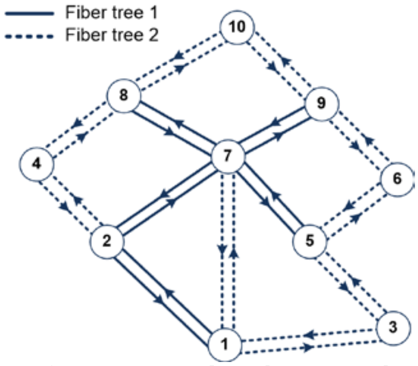


Figure 3. *10-node Italian optical network showing 2 fiber trees*

For TIM topology the initial traffic among the core nodes is 200 Gb/s for each connection with 30% increase each year, and among the aggregation nodes it is 100 Gb/s with a 20% yearly increase. Traffic is served with 400G transponders. For Metro-HAUL topology we differentiate the traffic inside the horseshoes based on the geotype [8]. Connections in the dense urban segment start with 250Gb/s, urban – 200Gb/s, suburban – 100Gb/s, rural – 50Gb/s with the 20% increase every year for all geotypes. Traffic is served with 100G transponders in suburban and rural segments, and with 400G ones in dense urban and urban segments as well as in the core-nodes [8]. The cost and power consumption of the considered components are listed in **Table 1**. We also consider a CAPEX depreciation factor of 10% per year that refers to the percentage of cost decrease for network equipment from one period to the next one. Price of energy is estimated to be 0.001 CU/kWh.

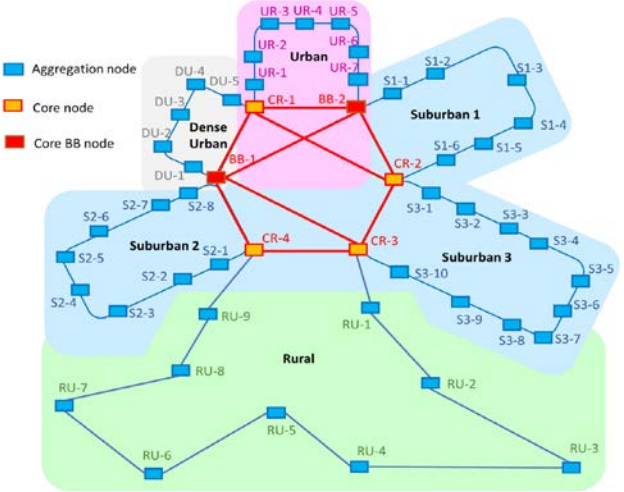


Figure 4. *60-node Metro-HAUL optical network*

3.2 Numerical Results: FON in Core Networks

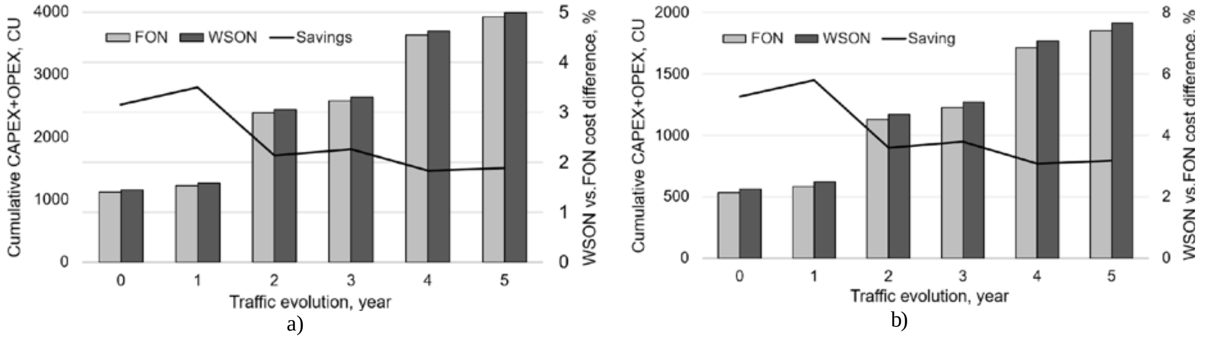
Table 1. Cost and power consumption of the components [8]

Network component	Cost, CU	Typical power consumption, W
Splitter (combiner) 1x2; 1x4; 1x8	0.004; 0.01; 0.02	0
WSS 1x4; 1x9	1.1; 2.2	30; 40
Multiplexer/demultiplexer	0.8	0
Booster + preamplifier	0.6	27
Transponder 100G; 400G	5; 12	110; 120

Figure 5 shows the overall cost of FON and WSON and the percentage of cost savings of FON over a period of 5 years for the Italian and the German core networks. In terms of CAPEX (year 0), results show that FON architecture exhibits around 3% and 5% of savings for the Italian network and the German network, respectively. From year 1 we start adding OPEX and, after a peak at year 1, due to the annual growth of traffic, the increase in the transponders' cost prevails over the energy savings (by year 5 transponders constitute 70% of total cost in both architectures), hence percentage of cost savings decreases.

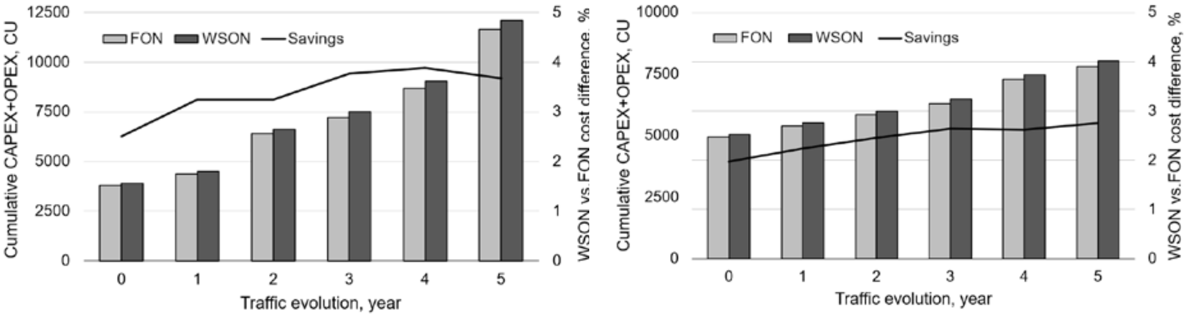
3.3 Numerical Results: FON in Metro Networks

Figure 6 shows the overall cost of FON and WSON and the percentage of cost savings of FON over a period of 5 years considering the Metro-Haul and the TIM metro-area networks. In terms of CAPEX (year 0), results show that FON architecture exhibits around 2.5% and 2% of savings for the Metro-Haul and the TIM network, respectively. Relative savings slightly increase during the whole period due to the low rate of traffic growth that leads to energy savings not being dominated by the increasing cost of transponders. Moreover, in **Fig. 7** we focus on the source of cost savings, the cost of switching equipment, i.e., WSS, splitters/combiners and multiplexers/demultiplexers, for both architectures. Results show that the overall cost savings of FON considering the switching devices range between 40% and 50% for the Metro-HAUL network topology. Finally, in **Fig. 8** we specify the distribution of these savings between CAPEX and OPEX. Contribution of OPEX increases from 35% on year 1 to 70% on year 5. Before concluding we remark that, despite FON's cost savings, scarce reconfigurability of FON might limit its adoption in scenarios with high traffic variability.



a) b)

Figure 5. *Overall cost of FON and WSON and FON's cost savings (%) for the (a) 10-node Italian network and the (b) 7-node German network over a 5 years period*



a) b)

Figure 6. *Overall cost of FON and WSON and FONs' cost savings (%) for (a) 60-node Metro-Haul network and the (b) 52-node TIM network over a 5 years period*

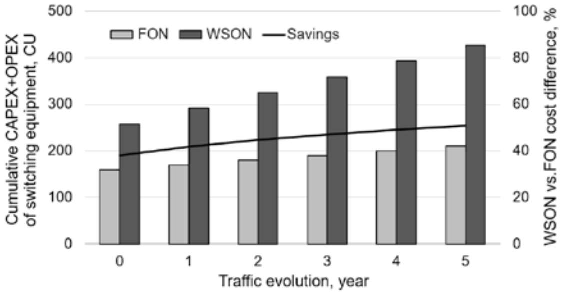


Figure 7. *Overall cost of switching components of FON and WSON and FON's cost savings (%) for the 60-node Metro-Haul network*

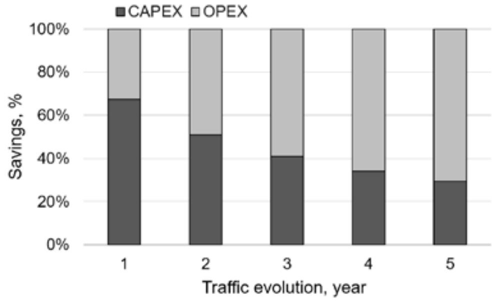


Figure 8. *Distribution of savings between CAPEX and OPEX for the 60-node Metro-Haul network*

4. CONCLUSION

We performed techno-economic evaluation of FONs in core and metro-aggregation networks over a 5-year period, considering both equipment cost and energy cost. Numerical evaluations show that the maximum achievable cost savings of FONs are in the order of 4% in metro and 6% in core networks. Interestingly, results show that the cost savings in core networks slightly diminish over time while they show a small increase in metro-aggregation networks. It should be noted, that FONs provide further operational savings due to higher reliability of passive components, reduced cooling and space requirements. Also, FONs allow the adoption of flex-grid operation and the consequent advantages in spectrum utilization at no additional cost compared to conventional architectures.

ACKNOWLEDGEMENTS

The work leading to these results has been supported by the European Community under grant agreement no. 761727 Metro-HAUL project funding.

REFERENCES

[1] C. Tremblay, et al, "Filterless optical networks: a unique and novel passive WAN network solution," in Proceedings of Opto-Electronics and Communications Conf., Japan, 2007.

[2] E. Archambault, et al. "Design and simulation of filterless optical networks: Problem definition and performance evaluation." IEEE/OSA Journal of Optical Communication and Networking 2(8) (2010): 496-501.

[3] C. Tremblay, et al. "Agile Optical Networking: Beyond Filtered Solutions." in Proceedings of Optical Fiber Communication Conference., 2018

[4] O. Ayoub, et al. "Filterless and semi-filterless solutions in a metro-haul network architecture." in Proceedings of IEEE International Conference on Transparent Optical Networks (ICTON), July 2018.

[5] J. Pedro, A. Eira and N. Costa, "Metro Transport Architectures for Reliable and Ubiquitous Service Provisioning," in Proceedings of *Asia Communications and Photonics Conference (ACP)*, 2018.

[6] O. Ayoub, F. Fatima, A. Boyio, F. Musumeci, M. Tornatore, "Traffic-Adaptive Re-Configuration of Programmable Filterless Optical Networks." in Proceedings of IEEE International Conference on Communications (ICC), June 2020.

[7] A. Betker, et al, "Reference transport network scenarios," Tech. Rep. BMBF MultiTeraNetProject, July 2003

[8] Metro-HAUL project Deliverable D2.4: Techno-economic Analysis and Network Architecture Refinement.