

# Service Chaining in Filterless Optical Metro-Aggregation Networks

(Invited Paper)

Omran Ayoub<sup>(1)</sup>, Memedhe Ibrahim<sup>(2)</sup>, Oleg Karandin<sup>(2)</sup>, Leila Askari<sup>(2)</sup>, Francesco Musumeci<sup>(2)</sup>

<sup>(1)</sup>University of Applied Sciences of Southern Switzerland, Manno, Switzerland {[name.surname@supsi.ch](mailto:name.surname@supsi.ch)}

<sup>(2)</sup>Politecnico di Milano, Milano, Italy {[name.surname@polimi.it](mailto:name.surname@polimi.it)}

**Abstract:** We discuss the advantages and disadvantages of the deployment of Filterless Optical Networks (FONs) in metro-aggregation networks. In particular, we focus on the use case of service chaining under a filterless metro-aggregation network. © 2021 The Author(s)

## 1. Introduction

The telecom industry has been experiencing challenging times recently to satisfy the growth in Internet traffic fueled by the emerging 5G communications and by the world-wide shift to tele-working and tele-education as a part of the global measures to limit the Covid-19 pandemic [1]. Network operators must meet increasing capacity requirements while averting excessive costs. As optical networks, in particular in the metro-aggregation segment, represent the main transport platform for 5G communications, network operators are always seeking for low-cost architectures to scale up the capacity of their optical networks. Filterless Optical Networks (FONs), by replacing in switching nodes costly wavelength selective switches with passive optical power splitters/combiners, currently represent a prominent candidate for cost-effective optical-network deployment [2-3]. In this paper, we first compare the architecture and functionality of a filterless node to that of a WSON node. Then, we discuss the deployment of FON in metro-aggregation networks (MAN) highlighting the spectrum waste caused by the filterless architecture. Finally, we focus on the use case of service chaining under a filterless MAN.

## 2. Overview on FON

In FONs, switching nodes are not equipped with costly re-configurable filters (namely, the Wavelength Selective Switches, WSSs), which are instead replaced by splitters and combiners, building a broadcast-and-select node architecture, hence reducing the equipment cost in the Wavelength Division Multiplexing (WDM) layer. In addition to savings in equipment expenditures, FONs promise lower energy consumption (and in turn lower operational expenditure) with respect to WSS-based optical networks (or Wavelength Selective Optical Networks, WSON as they will be referred in the rest of the paper). On the other hand, the equipment cost savings in FONs come with a set of severe drawbacks, such as the spectrum waste and the signal-quality degradation caused by the elimination of filters [4].

Figure 1 (a) shows the architecture of a WSON node and a filterless node in the case of a simple degree-2 node. As shown in the figure, in filterless nodes passive splitters and combiners that operate on the entire frequency band substitute complex and costly active WSSs. Instead of filtering, signals are discriminated at the receiver using coherent detection. In this example, other components such as transponders, optical amplifiers at the input- and output-ports and multiplexors/demultiplexors are kept the same. Optical signals at the input ports of a filterless node are broadcasted to all its output ports. Hence, even if a signal reaches its destination, signal is not dropped, but it

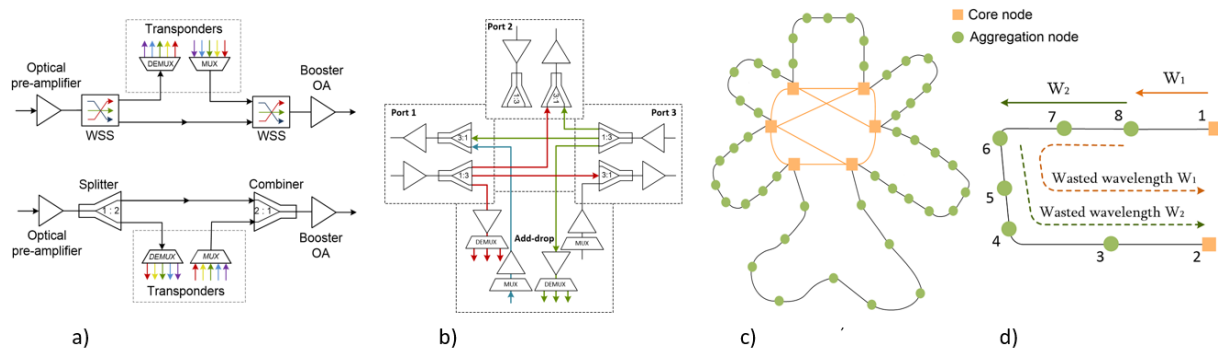


Figure 1 Architecture of degree-2 WSON and FON nodes (a), (b) architecture of degree-3 FON node, (c) practical deployment of a filterless metro-aggregation network and (d) horse-shoe filterless topology consisting of six FON nodes and two WSON nodes.

propagates further. As an example of unintended signal propagation, in Figure 1. we consider a more complex degree-3 filterless node, where the red signal entering through port 1 gets received, but it still propagates to ports 2 and 3. Same holds true for the green signal entering through port 3. Note, however, that blue signal, which originates at this node, gets propagated only to port 1, avoiding the broadcast. By removing WSSs from nodes, FON can achieve savings both in capital expenditure (CapEx) and operational expenditure (OpEx). In terms of CapEx, cost of passive optical splitters and combiners is negligible compared to the cost of a WSS; it must be noted, though, that cost of a WSS does not exceed (10-30) % of the cost of a single transponder, so removing WSS is beneficial only if that does not increase the expenses on transponders [3]. In terms of OpEx, passive switching leads to reduced energy consumption, lower cooling and space requirements. As splitters and combiners are drastically simpler than WSSs, maintenance and installation expenses decrease too. These economical savings come at cost of reduced networking capabilities, as FON nodes cannot route and drop optical signals. Moreover, removal of filters affects optical signal quality [4-5]. In fact, even though in FONs optical signals do not experience additional attenuation and crosstalk due to filtering, the unavoidable splitting in FON nodes makes node loss strongly dependent on the nodal degree, hence loss in a FON node can potentially exceed loss of a WSON node.

### 3. FON in Metro-Aggregation Networks

In MAN, filterless nodes are often deployed in horse-shoe topologies (rings) along with WSS-based ROADMs terminal nodes deployed at horse-shoe ends that terminate signal broadcasting and that also serve to connect the horseshoe to the rest of the metro network. Figure 1(c) shows a practical deployment of a metro network composed by several interconnected filterless branches, where each branch is constituted by a horseshoe. Figure 1(d) shows a horse-shoe topology consisting of two active terminal nodes (i.e., nodes 1 and 2) and six filterless nodes (i.e., nodes 3 to 8). Figure 1(d) shows also how two traffic demands (from node 1 to node 8 and from node 8 to node 6) are routed in the filterless horse-shoe network, and highlights signal propagation (signal waste) beyond destination due to broadcast in FON (respectively, wavelength W1 on links between nodes 8 and 2 and wavelength W2 on links between nodes 6 and 2). Note that W1 and W2 cannot be re-used on the horse-shoe to route traffic in the direction of node 2, a concept referred to as *no re-use* in FON, as re-using W1 or W2 will result in ‘clash’ of wavelengths in the horse-shoe. Note that, considering the broadcast nature of FONs, care must be taken to ensure that quality-of-transmission (QoT) of optical signals is satisfied for all traffic requests. Specifically, one must account that the absence of WSSs leads to propagation of Amplified Spontaneous Emission (ASE) noise generated by optical amplifiers beyond lightpath termination, and even to accumulation of ASE noise generated before a lightpath is initiated [4]. Despite spectrum waste, it has been shown that FON's design can be optimized to guarantee an acceptable performance in static traffic scenarios [6]. However, new services emerged in MAN, which require network operators to dynamically reconfigure network resource allocation to agilely provision new 5G services. To this end, Network Function Virtualization (NFV) as a new paradigm was introduced. NFV replaces hardware devices with software instances named Virtual Network Function (VNF), that can be run on commodity hardware and are connected in a specific sequence to form a Service Chain (SC), which provides a service to users. Therefore, to cope with the arrival of new highly dynamic 5G services, VNFs must be properly deployed, and the routing and wavelength must be optimized taking into consideration the characteristics of FONs to avoid excessive spectrum waste in presence of dynamic traffic. We refer to this problem as dynamic SC in filterless optical MAN.

### 4. Service Chianing in FON

The problem of dynamic SC in filterless optical MAN can be stated as follows. Given a filterless optical MAN, for each dynamically-arriving SC request, we decide the placement of its VNFs along with the SC traffic routing and wavelength assignment, with the objective of maximizing the total provisioned bandwidth in the network, subject to the no-re-use constraint in FONs. To provision a SC we need to place the VNFs on nodes equipped with computational capacity (referred to as NFV-nodes). However, due to frequency re-use restriction in FON, it may not always be possible to utilize all the NFV-nodes in the network. In other words, there might be a situation in which an NFV-node has enough computational capacity but is not accessible simply because all the wavelengths on the links connected to this NFV-node are occupied. Therefore, the mapping of VNFs to NFV-nodes should be done in a way to minimize the impact of frequency re-use restriction. To this end, it is decisive to consolidate all VNFs belonging to a SC on a single node as much as possible and preferably on the node where the SC is terminated (destination node of the SC). In this way, the SC request is provisioned by using as few as possible wavelengths.

Figure 2 shows an example of different provisioning strategies for a SC consisting of two VNFs, namely, VNF1 and VNF2, and the resulting wavelength utilization in an active network (subfigure a) and in a FON (subfigures b-d). In Figure 2(a), both VNF1 and VNF2 are placed at node 3 (the only NFV-node), resulting in wavelength W1 being used on links 4-3, 3-2 and 2-1, i.e., a total occupation of 3 units of capacity (one wavelength on three links). In Figure 2(b), the same VNF mapping as in Figure 2(a) is performed, but considering a FON; in this case, traffic

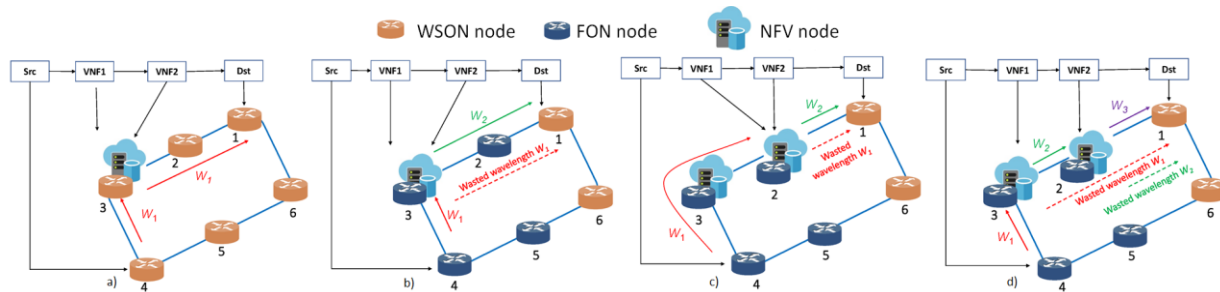


Figure 2. Example of different provisioning strategies for a SC consisting of two VNFs and the resulting wavelength utilization: (a) WSON with one NFV node and one used wavelength, (b) FON with one NFV node and two used wavelengths, (c) FON with two NFV nodes and two used wavelengths and (d) FON with two NFV nodes and three used wavelengths.

routed between node 4 and node 3 is transported using wavelength  $W_1$  (note that  $W_1$  is wasted on links 3-2 and 2-1, due to the broadcast nature of filterless nodes) and traffic routed between nodes 3 and 1 is assigned wavelength  $W_2$ , resulting in the usage of two wavelengths occupying a total of 5 units of capacity (2 of which are wasted) on all links. Moreover, Figure 2(c) shows how having more NFV-nodes (i.e., more possible locations to place VNFs) and optimizing the placement of VNFs allow to reduce the overall wavelength utilization in a FON (4 wavelengths are occupied on all links instead of 5 in Figure 2(b)). Note that, even if more NFV-nodes are present in the network, a non-optimized VNF placement, such as the case of Figure 2(d), might result in excessive spectrum utilization (total of 6 wavelengths occupied). This example shows that (1) additional investment in terms of computational resources (more NFV-nodes) and (2) a filterless-aware SC provisioning are required to avert excessive wavelength consumption in a FON. Note that deploying more NFV-nodes in a FON than that in a WSON does not necessarily translate into higher overall investment as FON provides significant cost savings at the WDM layer.

To investigate this, we consider two network scenarios: 1) a WSON with half the nodes serving as NFV nodes, 2) a FON with all the nodes serving as NFV nodes with filterless-aware algorithm for dynamic SC [7]. We perform dynamic simulations making use of a C++ discrete event-based driven simulator considering the topology depicted in Fig. 1(c) with each fiber supporting 12 wavelengths. The SC requests are generated according to Poisson distribution, and we consider two different traffic scenarios in our simulations, namely, *high dynamicity* and *low dynamicity*. In *high dynamicity*, SC requests arrive dynamically at each hour with an arrival rate  $\lambda$  and stay for a short amount of time in the network (5 seconds) and then leave. In *low dynamicity*, SC requests have higher holding time, e.g., 250 seconds, but with an arrival rate that is 50 times lower than that of the high dynamicity scenario ( $\lambda/50$ ), resulting in the same offered traffic for both traffic scenarios. Results show that in a traffic scenario with low traffic dynamicity, FON with all nodes functioning as NFV-nodes shows a comparable performance to WSON with only half of the network nodes acting as NFV-nodes in terms of provisioned bandwidth. In terms of average number of active NFV-nodes, FON solution shows a disadvantage as it requires almost double the number of active NFV-nodes of that of a WSON, which translates into OpEx of computational power and reduces the overall OpEx savings expected in FON due to the replacing WSS-based ROADMs by passive devices. In a traffic scenario with high dynamicity, FON shows an acceptable performance in terms of provisioned bandwidth however it is slightly outperformed by the WSON. In terms of NFV-nodes, the FON, despite having double the number of NFV-nodes deployed, has an average number of active NFV-nodes slightly higher than that of WSON, which promises overall savings in OpEx due to the use of passive optical devices instead of active devices in the WDM layer.

## References

- [1] Feldmann, Anja, et al. "A year in lockdown: how the waves of COVID-19 impact internet traffic." *Communications of the ACM* 64.7 (2021): 101-108.
- [2] Tremblay, Christine, et al. "Agile optical networking: Beyond filtered solutions." *Optical Fiber Communications conference and Exposition (OFC)*, 2018.
- [3] Karandin, Oleg, et al. "A techno-economic comparison of filterless and wavelength-switched optical metro networks." *International Conference of Transparent Optical Networks (ICTON)*, 2020.
- [4] Ibrahim, Memedhe, et al. "QoT-Aware Optical Amplifier Placement in Filterless Metro Networks." *IEEE Communications Letters* 25.3 (2020): 931-935.
- [5] Krannig, Simon, et al. "How to design an optimized set of fibre-trees for filterless optical networks-The elegance of a multi-goal evolutionary Pareto optimization versus." *Photonic Networks; 17. ITG-Symposium*, 2016.
- [6] Ayoub, Omran, et al. "Virtual network mapping vs embedding with link protection in filterless optical networks." *Global Communications Conference (Globecom)*. IEEE, 2020.
- [7] Askari, Leila, et al. "On Dynamic Service Chaining in Filterless Optical Metro-Aggregation Networks." *IEEE Access* 8 (2020): 222233-222241.