Hands-on Demonstration of Open-Source Filterless-Aware Offline Planning and Analysis Tool for WDM Networks

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Abstract: We demonstrate an open-source filterless-aware multilayer WDM-network planning tool, that allows hands-on creation of mixed filterless/ed topologies and the application of built-in or user-developed algorithms and analysis tools for line engineering, spectrum and cost planning.

1. Introduction

Telecom operators are constantly forced to pursue cost-effective solutions for their network infrastructure to face the ever-growing traffic demand [1]. In this context, *filterless networks* are getting increased interest, exploiting the utilization of extremely simplified OADMs, where expensive programmable spectrum-selective devices are replaced by cheaper optical splitters [2,3]. However, the absence of filters causes wasted spectrum from signal propagating into *undesired* output fibers, which results in added constraints to Route and Spectrum Allocation (RSA) [4].

Offline network planning and optimization is crucial to support mid-to-long term decision-making by efficiently employing network resources [5]. A recent study [6], concluded that Net2Plan [7] represents the most prominent open-source network planning and optimization tool as it embraces the multiple features required in the optimization of transport network resources. Net2Plan has also been extended to handle NFV over IP-WDM (NIW) networks, i.e. an open-source framework for modeling and optimizing Network Function Virtualization (**N**FV) in **I**P over **W**DM networks [8], which recently enabled a thorough techno-economic study of a network comprising 5G NR characteristics, dynamic control-plane capabilities and filterless optical data-plane nodes [9].

Here, we demonstrate on the most recent evolution of open-source Net2Plan-NIW that specifically includes filterless-aware network planning and analysis framework showing the following functionalities: (i) (filterless) node and network modeling, (ii) algorithms for the allocation of amplifiers and transponders, and RSA, and (iii) analysis tools for spectrum inspection, line engineering and cost/energy consumption analyses. Attendees will be able to download and use the software in their laptops, create hybrid filterless/ed network from scratch, use the proposed functionalities and observe/analyze the results.

2. Demo overview

2.1 Filterless-enabled network model

The new filterless-aware version of the NIW model incorporates several changes to enable the planning and analysis of hybrid networks mixing filterless and non-filterless nodes in arbitrary form. Table I summarizes a subset of key parameters of the enhanced network model, that will be briefly presented below. The model comprises other relevant parameters beyond those listed in Table I, like system margin (typically 1-3 dB), spectrum margins for roll-off for transmitters, or fiber margin and lumped attenuations caused by e.g. connectors. Similarly, Fig. 1 illustrates the novel filterless extension of the Optical Add/Drop Multiplexer (OADM) model, that now can represent a large range of optical switching architectures, including both WSS-based ROADM variants and extremely simplified filterless architectures. Each *in* degree may have a pre-amplifier, and each *out* degree may have a booster amplifier. As for the switching matrix itself, three architectures are considered in the model:

(i) Filterless architectures, where each *in* and *out* degree is realized with splitters/couplers.
(ii) Broadcast-and-Select (B&S), where *out* degrees are implemented with WSSs.
(iii) Route-and-Select (R&S) where *in* and *out* degrees are WSS-based.

Table I. Configurable parameters in filterless-aware NIW.

Fibers	Optical amplifiers	OADMs	Transponders
Type (e.g. G.652-B) Length (km) Attenuation (dB/km) CD coeff. (ps/nm/km) PMD param (ps/sqrt(km)) Nonlinear coeff.	Type (EDFA, Raman) Gain (dB) CD compensation (ps/nm) PMD (ps) Max/min gain (dB) Max/min in/out power (dBm) Noise factor (dB)	Arq.: Filterless, B&S R&S Directionless: yes/no #Add/Drop modules (dirless. case) Type Add/Drop: Mux, WSS WSS: Loss (dB), PMD (ps) (De)Mux: Loss (dB), PMD (ps)	Modulation format Linerate (Gbps) Sensitivity [max/min] (dBm) CD tolerance (ps/nm) PMD tolerance (ps) OSNR tolerance (dB)

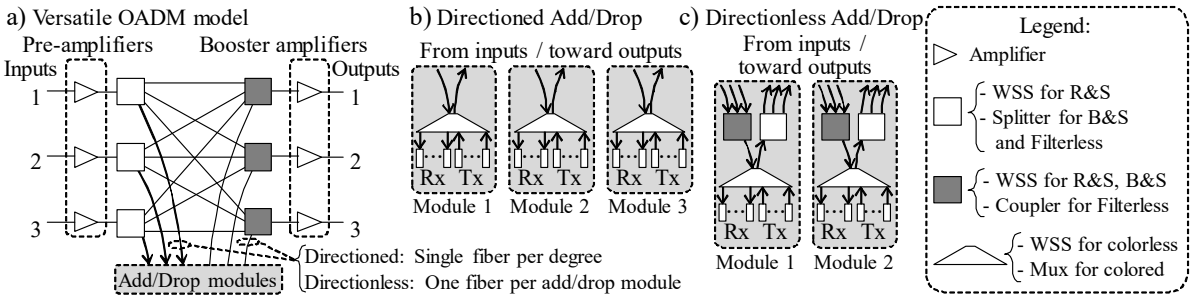

Fig. 1. a) Example of versatile Optical Add/Drop Multiplexer (OADM) model of degree 3, b) Three directioned add/drop modules and c) Two directionless add/drop modules. By construction, directioned OADMs have one Add/Drop module per degree whereas directionless OADMs can have an arbitrary number of add/drop modules.

The Add/Drop modules can be realized with passive Mux/DeMux, or with WSSs (the latter being colorless). Finally, the architecture may be directionless or directioned. In the former case, each Add/Drop module is like a new degree, using WSSs and splitter/coupler depending on the architecture type. In the latter case, one Add/Drop module is attached to each degree with a hard-wired fiber connection. Parameters in Table I are used to compute the signal degradation effect of traversing each OADM. In filterless cases, the tool automatically characterizes the *undesired* propagation of the input signals, as *waste* spectrum occupation in out degrees. This information is used to validate the designs against wavelength clashing: no two lightpaths with overlapping spectrum can use the same fiber. Note that interestingly, the node model is able to capture the classical blocking situation [5] caused by resource contention in directionless Add/Drop modules: no two lightpaths can be added or dropped in the same add/drop module, with the same wavelength.

The model incorporates enough information to compute four key signal performance parameters anywhere in the network: lightpath power, accumulated CD, PMD, and OSNR. Net2Plan algorithm plug-ins can also be used to calculate the nonlinear fiber transmission contribution to OSNR. Optical amplifiers with or without dispersion compensation are characterized with information describing how they modify these four aspects, and transponders include aspects like bandwidth, sensitivity, CD, PMD and OSNR tolerances. In all the cases, cost and energy consumption figures are included in the model, which will enable the application of network-wide analysis tools described below.

2.2 Filterless-aware algorithmic tools

Two key algorithms have been implemented specifically devoted to plan hybrid filterless/ed networks under the model described above. Firstly, an algorithm is available that permits solving the routing, spectrum and transponder type assignment, for a given set of available transponder types. The algorithm is filterless-aware, and accounts for the spectrum occupied by legitimate signals and by the waste spectrum that may be produced by the filterless nodes. The user can tune the algorithm to put emphasis in searching for a lower cost solution, or a solution with better spectrum efficiency. The algorithm is a variant of the multilayer IP over WDM algorithm developed in [9], and its code is publicly accessible within Net2Plan [7].

Secondly, we demonstrate an amplifier placement algorithm specific to networks where filterless nodes are restricted to degree 1 or 2, a sweet spot application for filterless architectures [9]. The algorithm first partitions the WDM plant into filterless components (i.e. topologies composed of sequence of fibers and filterless nodes). Then, for each component, pre-amplifiers and boosters are placed in the nodes minimizing its number according to a heuristic technique. The algorithm is suitable for metro networks, where minimizing the number of amplifiers is the target and the limiting factor is the optical power.

Altogether, the two algorithms compute the need for amplifiers, and the allocation of transponders, as well as route and spectrum allocation for arbitrary demands, which opens the door for strategic comparisons of different technological alternatives.

2.3 Filterless-aware analysis tools

Filterless capabilities added to Net2Plan NIW framework enable addressing some of the open questions related to this technology. These tools can easily analyze full network designs with potentially hundreds of nodes and fibers.

- Route & Spectrum occupation analysis. The tool analyzes the spectrum occupation of the lightpaths, warning about clashes and/or internal blocking events, considering the propagation of the legitimate and waste signals in the fiber. In addition, it can identify *lasing loops* that can appear in filterless topologies (see Fig. 2 a) and c)). These are cycles of fibers and filterless nodes, that result in continuous propagation of waste signals, and that compromise the entire network performance (see Fig. 2 e)).

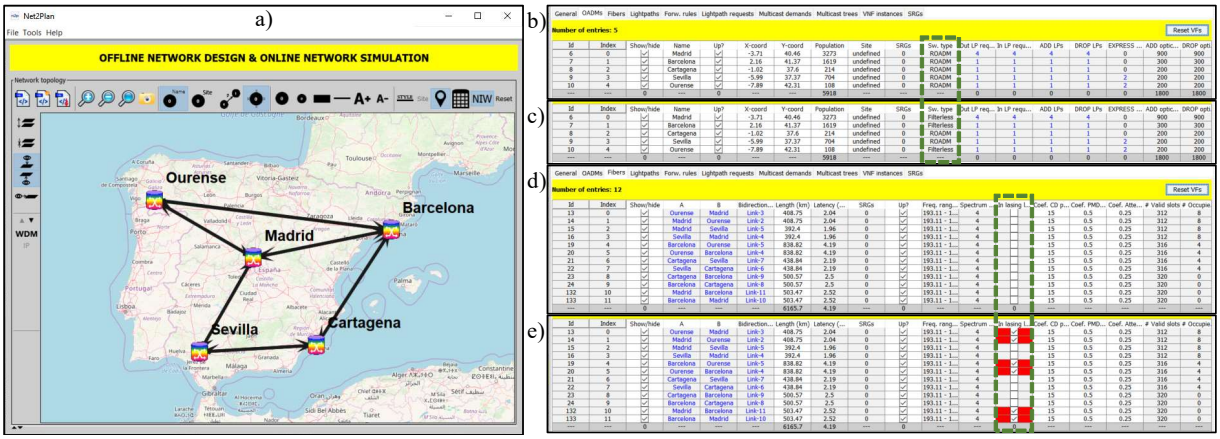

Fig. 2. a) Geographical view of an illustrative 5-node topology. b) and c) list of OADMs. d) and e) list of fibers. Note that in b) all OADMs are B&S nodes and thus fibers in d) do not form lasing loops. Instead, in c) OADMs in Madrid, Barcelona and Ourense are Filterless nodes which create a lasing loop in e) fibers that interconnect them.

- WDM line engineering analysis: Power, CD, PMD and OSNR are estimated using conventional models in all parts of the network. The user can explore this information in the graphical interface, and the tool automatically warns of e.g. unmet transponder tolerances or saturation situations at the optical amplifiers.
- Cost & Energy consumption analysis: Based on the per-component information in the network model, the tool generates a report summarizing total CAPEX, as well as energy consumption information, suitable for techno-economic analyses.

3. Innovation

We demonstrate and give hands-on access to novel filterless-aware planning resources like optical amplifier placement and RSA in flexi-grid networks. The analysis tools provided are unprecedented in the open-source community to gain insights in the filterless/ed networks WDM line engineering, spectrum efficiency, cost and energy consumption analysis. According to the Net2Plan NIW philosophy, an open and extensible software, new algorithms and reports can be developed and plugged in, extending, enhancing and customizing the built-in ones.

The filterless-aware planning and analysis innovations are of interest to e.g. decision making of network carriers to better evaluate filterless techno-economic impact. As an example, the demonstrated framework recently permitted us to identify filterless technologies as a sweet spot option when limiting its use to replace degree 1 and 2 OADMs in regional metro networks (e.g. 200 km of diameter) [9].

4. OFC relevance

Attendees will be able to download and run the software in our, or their laptops, create hybrid filterless/ed networks from scratch, and plan and analyze them in a hands-on experience, using solely the graphical user interface. No programming skills are needed.

Acknowledgments

This work was supported in part by the Spanish Government: ONOFRE-2 project under Grant TEC2017-84423-C3-2-P (MINECO/AEI/FEDER, UE) and the Go2Edge project under Grant RED2018-102585-T; and by the European Commission: METRO-HAUL project (G.A. 761727) and INSPIRING-SNI project (G.A. 750611).

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