Joint Optimization of IT, IP and WDM Layers: From Theory to Practice

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***Abstract*—Softwarization of carrier networks is an unstoppable trend, driven by the possibility of instantiating Virtual Network Functions (VNFs) in carrier-owned data centers in their points-of-presence. In optical networks, VNF placement decisions are now intrinsically tight to IP and WDM resource allocations, e.g. in the metro, moving a VNF to a different central office changes the IP flows to carry, which then impacts the optical circuit footprint. In this paper, we review the efforts for a joint or cooperative optimization of the IT, IP and optical resources, both from the offline capacity planning and the online resource allocation points of view. The paper covers both theoretical results and practical implementation initiatives. Among them, we further elaborate on the Metro-Haul project approach, that proposes a common simulation framework for algorithm development and testing, which allows the application of those algorithms in demonstration prototypes.**

Keywords—IT, IP, Optical Networks, NFV, SDN, WDM.

I. Introduction

Software defined network (SDN) and network function virtualization (NFV) have shaken the telecommunication landscape in the last decade. SDN enables unprecedented network programmability by decoupling the logical decisions/policies in a centralized entity (i.e. SDN controller) from the data-plane forwarding actions [1]. NFV permits the deployment of virtualized network functions (VNFs) on commodity hardware appliances [2]. SDN and NFV are two complementary technologies that reorient the perspective in which telecom operators see their central offices (CO) and points-of-presence (PoPs) at the network edge [3]. In fact, both SDN and NFV are consolidated enablers for the "*scalable management framework enabling fast deployment of novel applications*" required for 5G [4][5], while also opening the door to numerous optimization opportunities [6].

In this context, the Metro-Haul project [7] brings NFV capabilities towards the edge of the metro network (i.e. close to the end user) by proposing a network and node architecture that encompasses compute and storage resources as well as network infrastructure. The open-source software Net2Plan [8] has been chosen by the Metro-Haul consortium as the planning tool for planning, optimization, and evaluation of networks that cover IT and multi-layer network resources, while fostering collaboration among partners.

In this paper, we review recent and ongoing efforts in Net2Plan for a joint or cooperative optimization of IT, IP and optical resources from two perspectives. On the one hand, we cover offline capacity planning and dimensioning studies. We refer to those works as *offline* initiatives because they commonly rely on non-real-time simulation studies, as we see in section II. On the other hand, we review recent experimental validations and demonstrations in which software modules interact for allocation of IT and network resources, namely *online* implementations that have real-time actions over infrastructure, as described in section III. Then, in section IV we dig into our proposal of an offline-online synergistic approach that uses Net2Plan from those two perspectives by employing algorithms suitable for capacity planning also in experimental tasks of resource allocation. Section V summarizes the paper and indicates future research directions.

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II. Offline Capacity Planning

This section reviews several works in the literaure for offline capacity planning. Then, we report our recently proposed NFV over IP over WDM (NIW) library, which is included in the Net2Plan tool.

A. Related Work

This section reviews state of the art for offline capacity planning. Specifically, we cover studies that model optical networks and NFV resources. In general terms, these works aim at dimensioning networks/resources by calculating blocking probabilities, network loads and/or similar network metrics. For instance, [9] reports an ILP formulation and two heuristics for provisioning VNF graphs in arbitrary elastic optical network topologies that are divided into public and private domains. Authors consider blocking probability and cost in terms of spectrum and IT resources, without considering the capabilities of the IP layer. Similarly, the reconfiguration cost due to VNF migration among multi-site COs on top of an elastic optical network infrastructure is considered in terms of cloud and bandwidth costs [10], however not including the characteristics of an IP layer. Authors in [11] propose an algorithm for allocating service chains in an optical metro-area network which jointly minimizes the average number of nodes required to host VNF. Specifically, [11] considers a dynamic scenario in which service chain requests arrive and departure according to certain rates, and report results in terms of blocking probability, number of active NFV-nodes and latency violation proportion.

B. Net2Plan and the NFV over IP over WDM (NIW) Library

NIW is a recent proposal elaborated in the contest of Metro-Haul to design, plan and optimize IP over WDM networks with IT resources in the nodes [12]. Specifically, NIW employs an abstract model that captures from optical fiber characteristics up to service chains defined as ordered sequences of VNFs.

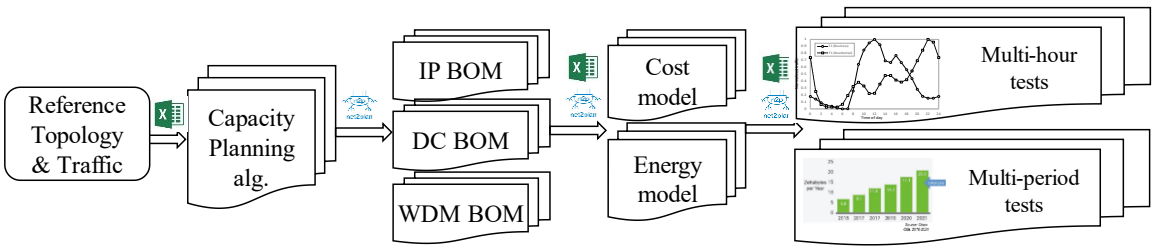

Fig 1. NIW library modular approach.

NIW library simplifies the development of Net2Plan algorithms and reports. It also includes import/export capabilities defined in an Excel-based template. NIW is open-source, publicly available and shipped with Net2Plan [8]. Its major principles are illustrated in Fig. 1, which follow a modular approach. In the following, we describe those modules considering as an example our recent tecno-economic results reported in [13] and [15].

- *Reference topology and traffic* module contains the characteristics of the network in terms of topology and traffic, e.g., in Excel format, and loads it in NIW format. The model has succeeded in representing real topology is some use cases. As an example, in [13] we dimension three reference topologies of Telecom Italia nation-wide infrastructure with diameter <200 km, and 52, 102, 159 nodes with anonymized nodes' position and with traffic types in agreement with the ones defined in [14]. In another recent work [15], we also consider a realistic topology based on COs and PoPs in the Murcia and Alicante Spanish regions, which comprise more than 3 million inhabitants in a 71-node and 102-link topology.

- *Capacity planning algorithms* module performs the joint capacity planning of IT and multi-layer network resources. Relevantly, the algorithmic subroutines for capacity planning have been reused for online resource allocation use cases in experimental validations (see section IV). This module has the potential to host algorithms from different partners for different problem variants / approaches. For instance, Metro-Haul considers machine-learning (ML) algorithms for resource allocation in dynamic traffic environments of both optical and VNFs [16]. Moreover, this module permits the reuse of code by leveraging on proven routines or other algorithms. In our recent studies, the main algorithm in [13] performs the NFV placement with IP topology optimization while considering static and dynamic control-plane capabilities, filtered and filterless optical nodes, and failure protection. Our proposal in [15] performs NFV placement with IP and optical considerations to account on latency requirements for the network capacity dimensioning.

- *Automatic scripts* module permits the creation of a series of bill of materials (BOM) reports, which include different CO architectures, capabilities of IP and optical equipment. Specifically, once the algorithms in the previous module perform the capacity planning/dimensioning, the network design permits the generation of BOM reports. Note that in the context of Net2Plan, we differentiate between *algorithms*, which consume a network status described as a `.n2p` file as input information and generate a potentially modified (`.n2p`) network design, and *reports* that analyze (i.e. perform calculations) on a network design (`.n2p`) and generate human-readable information in HTML format.

- *Cost and energy models* module leverage on the effort made in the Metro-Haul project and previous European projects [14] to perform an additional post-processing phase. Additional automatic reports can produce cost and energy figures from the BOMs and network designs.

- *Evaluation scenarios* can be conducted via scripts in bulk series, which can include multi-hour aspects that exploit knowledge of well-known traffic profile variation along day and/or multi-period, which consider traffic growth for future network evolution. For instance, our recent study [13] combines the cost and energy models with multi-hour and multi-period tests for reporting the benefits of a dynamic control plane in a long-term traffic scenario. Specifically, CAPEX in terms of number of transponders are reduced in a 7-13% and IT resources are reduced in 10%-13% by decreasing the amount of Tbps processed by the VNFs. OPEX reductions are achieved deactivating transponders and IT resources by a 30%. Additionally, [13] highlights optical nodes of degree 1 and 2 as a sweet spot for filterless architectures.

Note that the specific studies carried out in [13] and [15] represent practical applications of capacity planning algorithms because the proposed approaches are applied in realistic networks (in terms of topology and traffic) so that the required infrastructural resources are dimensioned. Finally, it is worthwhile mentioning that NIW library has been recently demonstrated at OFC 2020, in which attendees of the demo were able to download the software, create hybrid filterless/filtered networks from scratch, and plan and analyze them in a hands-on experience, using solely the graphical user interface [17].

III. Online Resource Allocation

This section reviews state of the art for online resource allocation. Then reports our usage of specific Net2Plan developments in recent demonstrations.

A. Related Work

Relevant works in the literature provide the technological solutions (e.g. architectures, software modules and interfaces) to exploit the benefits of the SDN and NFV technologies by combining the decision of IT, IP and optical resources [18], also in unified control-plane solutions [19]. In this context, [20] focuses on SDN/NFV-enabled wide-area networks (WANs), hence enabling the IT-network plus multi-layer networks resource allocation with latency considerations leveraging on an extension of PCEP in the ADRENALINE testbed. Relevantly, a specific extension of the ETSI-based open-source management and orchestration (OSM) framework is described in [21] to allocate a service chain across multiple PoPs interconnected with an IP-over-WDM network.

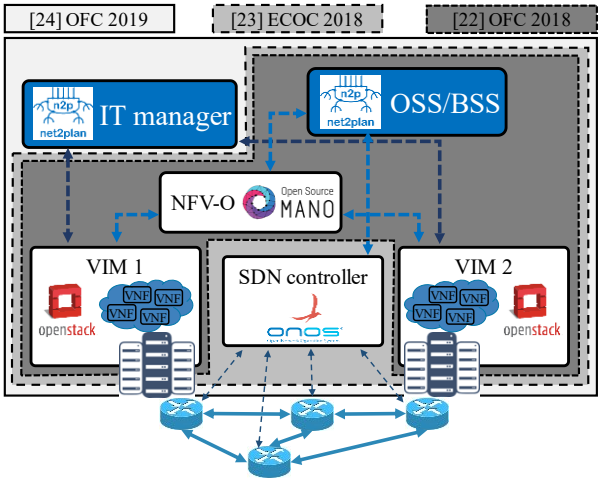

Fig 2. Net2Plan-related demonstrators.

B. *Net2Plan in SDN/NFV Architectures*

In the last two years, we performed three demonstrations that leverage on Net2Plan extensions for optimizing online resource allocation decisions in SDN/NFV architectures. Fig. 2 contextualizes these works, which are the following:

- In [22], Net2Plan played the role of operations support system (OSS) / business support system (BSS) for assisting OSM to optimally place the VNFs of a service chain in distributed COs interconnected with a simulated metropolitan network. Those multi-COs, managed by an OSM instance, leveraged on as OpenStack virtual infrastructure manager (VIM).
- In [23], we included the work in [22] plus an ONOS instance governing an emulated network with Mininet. Notably, packet flows, belonging to the service chain instantiated by OSM, traversed the Mininet network for reaching VNFs instantiated in different OpenStack clusters. Additionally, the Net2Plan development for [23] considered, as part of its OSS/BSS role, latency requirements in the calculation of the network path and the placement of the VNFs.
- The main contribution of [24] was a separated Net2Plan instance devoted to IT resource manager in a SDN/NFV ecosystem based on the environment developed in [23]. Specifically, the developed Net2Plan extension interfaced multiple OpenStack instances for enabling multi-tenant slicing of COs, IT resource visualization and VM migration.

IV. Proposed Offline-Online Synergistic Approach

This section discusses our approach for exploiting the similarity between addressing the IT, IP and WDM resource allocation in offline capacity planning problems (section II) and online in experimental demonstrations (section III) through the same algorithmic solutions.

A. *Synergy through Network Optimization-as-a-Service*

Among the latest developments in Net2Plan, we recently introduced the concept and architecture of network optimization-as-a-service (OaaS) that relies on a classical REST-based client-server approach [25]. The main motivation behind the network OaaS architecture is for third-party players to host (server side) an accessible repository of optimization algorithms while focus on providing high-performance computing (HPC) infrastructural resources for their execution. Then, holders of network infrastructures (i.e. client role) may request the resolution of a network resource allocation problem through the execution of an algorithmic technique. In other words, algorithms are externalized from the control and management of the infrastructure into a network OaaS module.

Fig. 3 illustrates the network OaaS architecture with a combination of its original conception and our current research direction. Specifically, the network OaaS server module is accessible by both capacity planning applications and online resource allocations in experimental demonstrations. Three major tasks are performed by the network OaaS server module. First, it gathers monitoring and topology/inventory information from control and managements systems of the network infrastructure. Second, it offers an API for addressing online resource allocation problems (e.g. IT over IP over WDM) acting as an extended PCE. Third, it offers an API with optimization functionalities for network dimensioning that is consumed by applications of offline capacity planning.

The network OaaS concept was applied in an experimental work [26], encompassing VNF placement and allocation of multi-layer network resources. Finally, it is worthwhile mentioning that our recent contribution in [15] is precisely the combination of online resource allocation and an offline capacity planning study, in which we report our preliminary results on this offline/online synergistic approach.

V. Summary and Future Work

In this paper, we covered several ongoing trends that combine NFV in terms of IT resources and SDN in the form of IP over WDM networks. We provided an overview of works in the literature that addressed *offline* capacity planning problems and *online* resource allocation in experimental works. In both cases, we contextualized our recent contributions within the framework of Net2Plan. Among our works, we made special emphasis on our recently proposed network OaaS architecture, in which we will keep working for increasing its functionalities, available resources and potential applicability.

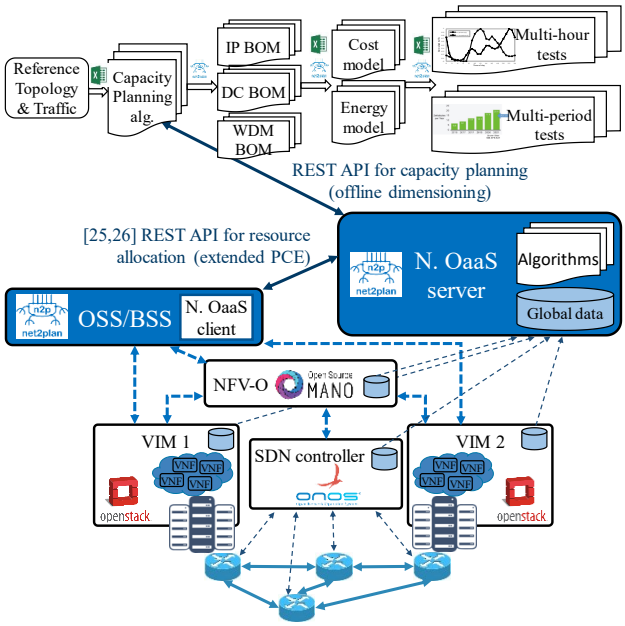

Fig 3. Schematic of the proposed offline-online synergistic approach that leverages on the network OaaS architecture [25].

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