Reconfiguration of VNF Placement in an Optical Metro Network by a Modular Planning Tool

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Abstract: We demonstrate the recurrent reconfiguration of virtual network function placement and routing and wavelength assignment in optical metro networks supporting 5G services. Reconfiguration solutions are provided by a dedicated planning-tool module. © 2020 The Author(s)

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1. Introduction

In order to cost-effectively provision 5G services such as those required by Industry 4.0 [1] in optical metro networks, Network Function Virtualization (NFV) and Software Defined Networking have recently attracted a lot of attention. To provision these services, different Virtual Network Functions (VNFs) are chained together following a specific order to form a Service Chain (SC). Optical-network resources must be then allocated to connect the VNFs of each SC. Moreover, additional optical-network resources must be allocated to traffic demands that are not descending from SC requests, as the 5G mobile traffic. Although several algorithms for VNF Placement (VNFP) and Routing and Wavelength Assignment (RWA) have been already proposed, this paper aims at demonstrating the integration of the two functions on a common framework, called Planning Tool (PT), conceived for practical deployment [2] in a real optical metro network. The Metro-Haul (MH) project [1] addresses this issue by defining an optical metro network infrastructure with edge-computing capabilities to support 5G services and 5G mobile traffic. The reference architecture defined in MH consists of different components [3], among which a PT is responsible for periodically suggesting optimized VNFP+RWA solutions to the control plane of the network. For instance, the PT can suggest an optimal VNFP+RWA solution at each hour, to re-optimize the network according to traffic demand evolution. In this paper, we describe a realistic embodiment of the PT that implements two specific algorithms to dynamically and hourly provide VNFP+RWA optimized solutions. We assessed the effectiveness of our solution by considering two Key Performance Indicators (KPIs): (a) power saving that can be achieved by hourly re-optimizing the network; (b) execution time of the VNFP+RWA algorithms of the PT. The former is justified by the importance of environmental benefits and OpEx reduction. Regarding the latter, we did not aim at a low execution time in an absolute terms, but rather at having a time that allows the repetition of the algorithm at hourly intervals during the day, so to periodically re-optimize the system. In developing the PT, we also guaranteed its modularity and its easy integrability with other control-plane components.

2. Planning tool architecture

The PT architecture (shown in Fig. 1) was described in [3]. The Front-end block ensures the integrability with the other components of the MH control plane through the interface to the Control, Orchestration and Management (COM) system. The Back-end block is instead the decisional part, and it is conceived to be highly modular. It allows to "plug in" different algorithms to perform VNFP+RWA (including machine-learning algorithms).

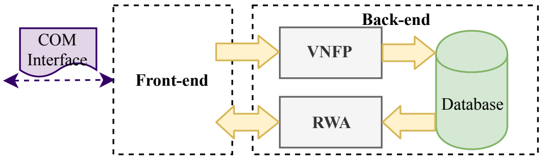


Fig. 1: Planning tool architecture

In this paper, we focused on the Back-end block with the intention to demonstrate the PT by providing two algorithms, a first one for VNFP and a second one for RWA, and testing them (by simulation) in a realistic MH network scenario. For each SC request, the placement of its VNFs is performed according to the algorithm in [4]. This algorithm tries to reuse VNFs already deployed as much as possible to minimize IT-equipment power consumption. Based on this VNFP, in a second phase, another module performs RWA: it takes in input the connection requests coming from the SCs to connect the VNFs, jointly with connection requests to carry mobile traffic. RWA is performed to minimize network-equipment power consumption. Then, the result of VNFP and RWA is sent to the COM interface to issue the appropriate inputs to the MH control plane [3].

The problem addressed in this paper can be stated as follows. We are given an optical metro network and a set of SC requests to be provisioned. Each SC request is characterized by bandwidth requirements at each hour of the day, a set of virtual nodes, i.e., SC source and destination, and a set of VNFs constituting the SC. These virtual nodes are connected using virtual links. To provision a SC, its virtual nodes need to be mapped to physical ones. All the physical nodes in the network have the computational (IT) equipment to host a VNF ("NFV-nodes"). Note that a VNF is deployed onto a physical node using a certain number of virtual machines, each requiring a certain computational and traffic processing capacity. In addition, the virtual links connecting these virtual nodes need to be mapped to a set of physical links. In our scenario, we assume that the nodes are directly connected by optical links. The proposed algorithms implemented in our planning tool target the minimization of total power consumption of the IT equipment.

2.1. VNF placement module

This module is responsible for mapping VNFs on NFV-nodes. At the first phase, based on the type of the SC to be provisioned, the algorithm tries to find a destination node for SC request from a set of candidate destinations. Specifically, the closest candidate destination to the source of the SC request, based on number of hops, is chosen. Then, for each VNF of the SC, an NFV-node with enough CPU resources (in terms of CPU core) and traffic processing capacity (in terms of input traffic in Gbps) is chosen. If there are several nodes that satisfy the CPU and input traffic requirement of the VNF, the NFV-node which is closest both to the source and destination nodes of the SC request is chosen. If more than one NFV-node satisfy this requirement, the one with less active VNF instances will be chosen to balance the load among all NFV-nodes. At the last step, when the suitable NFV-nodes are chosen for all the VNFs of SC, the IT resources are allocated to the VNFs. The full description of the algorithm can be found in [4]. For the power consumption model of NFV-nodes hosting VNFs (IT power consumption) we first assume that an active but idle processor consumes 15% of its maximum power. This value then increases linearly with respect to the CPU utilization until reaching its maximum capacity [5]. For the VNFP module, we implement our algorithm in Net2Plan open-source network planner [6].

2.2. RWA module

In this section we present the two RWA approaches used in our study to minimize power consumption:

1) ILP: an Integer Linear Programming (ILP) formulation can compute the optimal RWA solutions for a given set of traffic and SC demands. The formulation assumes Virtual Wavelength Path (VWP) model: at each NFV-node all wavelengths are converted to the electrical domain, allowing to perform wavelength conversion and traffic grooming to increase wavelength utilization. In VWP, an optical path can have a different wavelength on distinct links. The planning problem consists of finding the set of paths satisfying the traffic demands using 1+1 protection. The objective is to minimize the power consumption of the optical-layer network equipments of the metro network. The power consumption model of the metro nodes is based on [7]. The objective function minimizes the number of active fibers and wavelengths that are routing-dependent variables affecting the power consumption. While the ILP approach provides the best possible power-saving KPI value, it does not satisfy the expectations on the execution-time KPI. Typically, ILP complexity is extremely high and the required computation time may prevent the repetition of the algorithm on an hourly basis even for moderately large networks.

2) Heuristic: in order to overcome the computation-time KPI problem of ILP, we have adopted a heuristic algorithm to perform RWA in the planning tool. The algorithm is based on two phases: *i*) ***Offline ILP***: we assume that, prior to being set into production operations, the PT has observed the network for at least one day and stored a collection of traffic demands at each hour received by the RWA module (including both SC demands and mobile-traffic connections). Then, the ILP model is run offline for each hour of the day to get the optimal RWA solutions at each hour. During this "learning" period (that may last more that one day) RWA can be solved *e.g.* using shortest-path / first-fit approaches. At the end of the "learning" period, ILP will have computed 24 sets of weights to be used in the next phase. *ii*) ***Online routing***: we use a heuristic method running a minimum-cost routing on set of 24 edge-weighted graphs, one for each hour. The idea is to use the results of the offline ILP to assign weights for network links with the aim to guide real-time RWA for each traffic request.

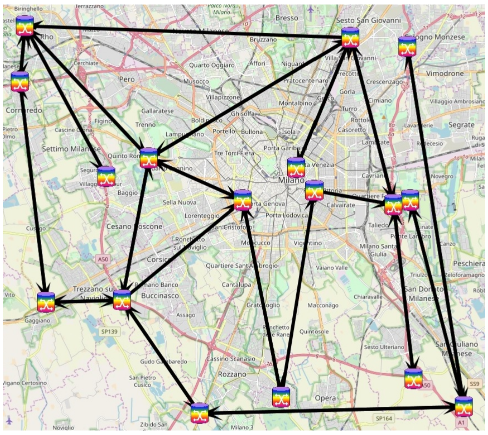
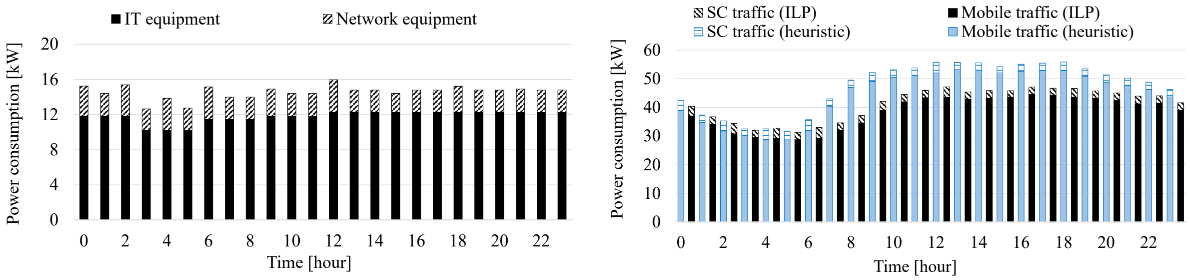


Fig. 2: Topology

The method is based on the assumption that, in a metro-area environment, the traffic daily profile (both from SC and mobile) does not change too much. Thus, requests that repeat the same every day (predictable) are forced by the weight system to follow the RWA results from the offline ILP model. Unpredictable requests are accommodated first by exploiting unused capacity of already active wavelengths, and if not possible by activating new



(a) IT vs network equipment power consumption (SCs only)

(b) Total power consumption (SCs+mobile traffic)

Fig. 3: (a) Power consumption due to SCs. (b) Total power consumption due to SCs and mobile traffic

wavelengths. For instance, considering day 1 used in the offline-ILP phase to compute the weights, we know that during hour j, a set of N demands from node 1 to node 2 have been routed through a set of links $E1 \in E$. During the same hour of day 2, if the heuristic algorithm receives M demands from node 1 to node 2 with $M \leq N$, then these demands are predictable, and thanks to the weights precomputed for that hour j, they will be routed through the same set $E1$. Otherwise, they will be routed on another set of links, first trying to use wavelengths that are already active (if any) and, if none is available, lighting up new wavelengths. In our Online routing algorithm, link-disjoint path pairs are found by a modified version of Bhandari algorithm [8]. The RWA module was implemented in Phyton.

3. Simulated testing of the PT and analysis of results

To test the performance of our PT, we consider the topology in Fig. 2, which is a realistic metro network scenario of a city in Italy [8]. It includes 17 NFV-nodes, each one equipped with 96 VCPUs. We considered 16 SCs requests randomly selected among services related to Industry 4.0, namely Robot, Massive Internet of Things, Video Surveillance and Vehicle to Vehicle communication. All the SCs are composed of Firewall and NAT VNFs. As for the mobile traffic that adds to SC traffic, we consider an average of 32 traffic requests per hour generated as in [8]. The demands are based on realistic weekday geo-localized traffic profile. Each NVF node is assumed to be also the access node of all the mobile base-stations located in its neighbourhood.

Figure 3 displays the results of our analysis, obtained considering the PT is run at each hour for a day, and mediating over a period of 4 days. As shown in Fig. 3a, the VNFP algorithm is effective in reducing the power consumption of both IT and network equipment. Adaptively reconfiguring the VNFs location hour-by-hour provides an advantage in terms of power-saving KPI of 21.02 kWh per day (-21.8%) compared to the static case. In Fig. 3b, the combined result of VNFP+RWA is assessed in terms of power consumption of the network equipment. The total power saving in this case is 295.8 kWh per day (-20.5%) compared to the case where network resources are allocated according to the peak hour. In Fig. 3b results of the ILP theoretically run at each hour are reported by comparison. As observed, the power-saving KPI obtained with the heuristic approach is very close to the theoretical maximum provided by ILP (optimality gap is about 15%). However, the ILP converges in about 50 minutes, making it impractical in real-time scenarios. The heuristic algorithm takes about 0.5372 seconds to find the RWA solution and, when summed to about 0.7 seconds taken by VNFP, it makes up a total of about 1.2 seconds, that is perfectly suitable for an hourly repetition.

4. Conclusion

We implemented the Back-end section of Metro-Haul planning tool using different modules to hourly compute optimal VNF placement and RWA. We tested this implementation by minimizing power consumption on a daily traffic pattern in a realistic optical metro topology and with feasible computation times.

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