On the Role of Open-Source Optical Network Planning

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Abstract: We argue that open source network planning tools like Net2Plan, and related open repositories of planning resources, can help to bridge the gap between academia and industry speeding-up technology transfer of network planning investigations.
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1. Introduction

Network bandwidth is increasing significantly with a compound annual growth rate of ~20%. New optical technologies like CDCG (colorless, directionless, contentionless and gridless) multi-degree reconfigurable optical add/drop multiplexers (ROADMs), flex-grid WDM channels and super-channels are foreseen as the building blocks of next-generation networks. These continuous advances in optical technologies challenge network architects in their attempt to foresee which new technologies deserve investments for deployment, which existing infrastructures to keep, and how to interoperate legacy and new elements during continuous migration processes. In this task, network planners need to consider not just fiber capacity; cost reduction, reliability and sustainability concerns are major drivers. Topics like energy efficiency or disaster resilience have been intensively investigated through the past years. As a result, related R&D efforts have led to the proposal of a large variety of solutions making network planning a research hot-topic. Unfortunately, the adoption of these investigations into operator networks is not a reality but a challenging task. In our opinion, this is partially caused by the divergent philosophies of existing commercial planning tools used in the industry, with respect to academic network planning tools.

The market of commercial planning tools for IP/MPLS and optical networking is dominated by third-party suites. OPNET or Cariden MATE Design (acquired in 2012 by Riverbed and Cisco, respectively) are some examples. All of them provide a complete set of features to design and analyze networks, in a non-vendor-specific environment. These tools have the natural incentive to provide support just for mature technologies and protocols for which there is a definite and large market. However, carriers and providers willing to make prospective studies on novel technologies (i.e. flex-grid networks) see no support from commercial software tools. On the other hand, planning studies from academia often rely on own-developed software, and its source code is seldom provided (or even documented). Consequently, the associated research results are difficult to repeat, compare and reutilize by the industry, since it would be time-consuming for network operators and ISPs to reproduce them in their networks.

Under this situation, creating new algorithms, or reusing existing ones, is usually left by industry network planners as the last alternative to explore. Commercial planning tools have adapted to this reality, offering improved graphical interfaces to ease the production of "standard" planning studies in mature technologies with little effort, relying in non-disclosed heuristics to plan the network. Despite of being a decisive element in network planning, the ability of these heuristics to find minimum cost/maximum performance solutions is assumed as given. Actually, we believe that commercial tools do not compete in practice in this aspect. Moreover, some tools offering University licenses, forbid the licensed academic institutions to publish any study comparing the quality of the results of their (not disclosed) algorithms [1]. We see this as a barrier to technology transfer.

As a mean to bridge the gap between academia and industry, we developed Net2Plan [2]. Net2Plan is an open-source (multilayer) network planning tool, and a repository of planning resources. Net2Plan is not constrained to any specific network technology, and is thus suitable to any of them. It allows users to fast-prototype their own algorithms, or use the provided built-in ones. Users can evaluate their designs using either automatic report generation or post-analysis tools for network resilience, connection-admission-control and time-varying traffic resource allocation. Net2Plan enforces code reusability in two ways. The open-source nature enables code reutilization and public validation. The technology-agnostic nature permits reusing algorithms and studies for similar problems appearing in different network technologies. We believe that identifying these similarities permits incorporating well-known results in "old" technologies, to improve and speed-up the development of algorithms for "new" technologies.

2. Net2Plan – The open-source network planner

Net2Plan is an open-source Java-based network planning tool, licensed under the GNU Lesser General Public License (LGPL). It is publicly and freely available to download from its website [2].

Net2Plan is built on top of an abstract network representation, so-called network plan, based on six abstract components: *nodes*, *links*, *routes*, *traffic demands*, *protection segments* and *network layers*. Net2Plan network representation is technology-agnostic. Technology-specific information can be introduced via user-defined attributes attached to any of the abstract components mentioned above. In next section, we give some tips on how an IP-over-WDM network can be represented within Net2Plan.

Regarding to the features included in Net2Plan, the tool provides both graphical and command-line interfaces for six functionalities (as of version 0.2.2): *network design*, targeted to execute offline (multilayer) planning algorithms; *traffic matrix generation*, which assists users in the process of generating and normalizing traffic matrices; *resilience simulator*, which permits evaluating the availability performance of online protection and restoration algorithms in the network; *connection-admission-control simulation*, targeted to analyze the blocking performance of online provisioning schemes that allocate resources to incoming connections (i.e. on-demand lightpath requests); *time-varying traffic simulation*, which permits evaluating the performances of online algorithms that react to traffic variations (i.e. traffic rerouting schemes); and *reporting*, for the generation of reports, from any network design.

Algorithms in any of these features are Java classes implementing a specific interface defining the input and output parameters. For instance, in the *network design* functionality, algorithms receive as an input parameter a network representation, and return a modified one. As an example, a routing algorithm implementation would read the nodes, links and demands information from the input plan, compute the routes, and save them into the output plan. With Net2Plan users can progressively design their networks, chaining successive algorithms, each one completing a part of the network design. We recall that every algorithm, report, event generator, and provisioning/allocation algorithm in Net2Plan can be either built-in (from the Net2Plan repository) or user-made. Net2Plan makes no distinction between both. This is a major difference with respect to existing tools, that allow users to make use of (a small set of) built-in algorithms. Finally, once an algorithm is developed, it can be applied to any network instance.

We refer the reader to [2] for fully-detailed information about Net2Plan functionalities. In [2] you can also find a growing repository of built-in offline and online algorithms and reports. Finally, Net2Plan is being used since 2011 as a teaching resource in two networking courses in Universidad Politécnica de Cartagena (Spain), summing ~150 students per year. A collection of lab work wordings is included in [2].

3. Case study: Designing an IP-over-WDM network

As an example of the power and flexibility of Net2Plan, we present in [4] a complete case study based on the planning and evaluation of a multilayer IP-over-WDM network. Both novel and classical state-of-the-art (or slightly modified versions) planning algorithms are employed, and are publicly available for download on the website [2].

The study is focused on a core operator owning an IP-over-WDM multilayer network. The physical topology is composed of a set of nodes interconnected by pairs of unidirectional fibers, with 80 channels per fiber. Nodes are fully-equipped with IP and optical infrastructure. IP routers are connected via a virtual topology of 40G lightpaths, optically switched by ROADMs, while IP routing is governed by the OSPF protocol with static weights. Resilience against single-link failure is provided at the optical layer through dedicated 1+1 (fiber-disjoint) lightpath-protection.

The IP-over-WDM network is modeled in Net2Plan using a two-layer network representation. Upper (IP) layer has a set of demands defined by the IP traffic matrix. These are to be routed over a set of links, one per lightpath. Net2Plan multilayer concept makes each link in the upper layer (lightpath) become a demand at the lower (optical) layer. Then, optical lightpaths are routed at the lower layer over the given set of fibers (links), being its route the RWA. The IP-over-WDM technology-specific attributes in this network representation are as follows. For fiber links (links at the lower layer), we introduce the attribute “numWavelengths” to represent the number of WDM channels available (80); for working and protection lightpaths (represented by routes and protection segments, respectively), we introduce the attributes “seqWavelenghts”, a vector with the wavelengths used in each traversed fiber, and “nodesWithRegenerator” a vector storing those nodes in which a regenerator (or wavelength converter) is installed. Lightpaths have the Net2Plan attributes (i) “linkWeight” with its OSPF weight at the IP layer, (ii) “capacity” given by its nominal rate (40G). We remark that users are in charge to check the validity of the technology-specific attributes (i.e. two lightpaths cannot use the same wavelength in the same fiber). In this respect, Net2Plan provides the *WDMUtils* and *IPUtils* libraries to ease the prototyping of IP-over-WDM algorithms.

Using as a topology the well-known 14-node NSFNET network and a reference IP end-to-end traffic matrix [4], we describe a multilayer network design algorithm devoted to planning and resource allocation at IP and optical layers. The objective is to minimize the infrastructure cost (CAPEX), given by the lightpath and regenerator costs, while two constraints are met: (i) lightpath utilization must be below 50%, (ii) lightpaths need OEO regeneration after 2800 km, (iii) and end-to-end propagation delay for each IP traffic route is lower than 50 ms. Note that the latter is a complicating constraint coupling both layers.

The planning algorithm is divided into two parts. First, a 1+1 protected full-mesh virtual topology is dimensioned, where no grooming is allowed, using a RWA-ILP formulation that minimizes CAPEX. This optimization problem is modeled and solved using the Java Optimization Modeler (JOM) [3], an open-source Java library which allows fast-prototyping of problem formulations (i.e. using a vectorial MATLAB-like syntax) and interfaces to a number of external solvers such as GPLK, CPLEX or IPOPT. Once we have the full-mesh virtual topology, then traffic grooming is added to the design tuning OSPF weights using a variation of the well-known IGP-WO algorithm [5], which avoids violation of the maximum end-to-end delay. Finally, unused lightpath pairs (working and protection lightpaths) are removed.

For NSFNET network, we assume a traffic demand proportional to the reference traffic matrix [4]. In year 2014 the total traffic volume is equal to 1 Tbps, and forecasts estimate a 20% annual growth. In this scenario, our algorithm could not find solutions carrying 100% of the traffic after year 2025, so it determines that a major network upgrade (i.e. deployment of more fibers) would be required to support the expected traffic demand. In Fig. 1 we show the CAPEX forecasts for coming years. As can be seen, regenerator costs are negligible compared to the cost associated to lightpaths, which is given by the cost of transponders, slot cards and short-reach interfaces.

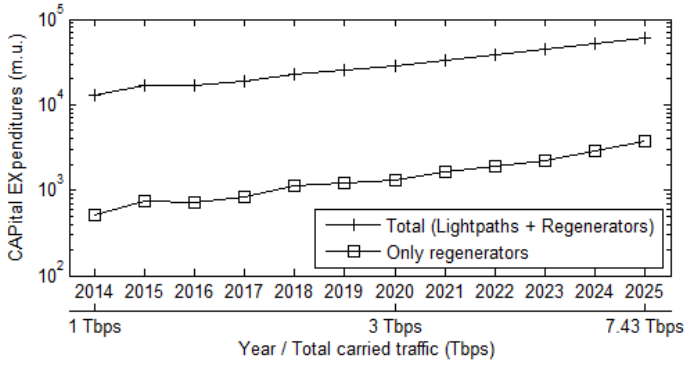

Fig. 1. CAPital EXpenditures (CAPEX) forecasts for NSFNET network

The case study, as presented in [4], also covers several post-design analysis. In the optical layer, we consider the usage of lightpath restoration schemes, as alternatives to the initial lightpath protection scheme. We perform comparisons regarding to CAPEX and resilience metrics under two different scenarios: (i) lightpath availability under single and double bidirectional-fiber failures, and (ii) service vulnerability under (catastrophic) disaster failures. On the other hand, energy efficiency under sleep-when-idle policies for the IP equipment is evaluated, in order to reduce operational costs (OPEX). Modified versions of state-of-the-art control plane algorithms are employed in every case. Due to the space limitation, we again refer to [2,4] for full details and source code.

4. Conclusions

In this work we presented Net2Plan, an open-source tool aimed to become a common resource for academia and industry. A real-world case study, based on the design of a multilayer IP-over-WDM network, is sketched as a proof of concept. Net2Plan includes a growing repository of planning algorithms and report templates, publicly available.

5. Acknowledgements

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