Net2Plan: An Integrated Open-Source Framework for Multilayer Network Planning and In-Operation Simulation

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ABSTRACT
Multilayer networking is an enabling technology to support the exponential growth of traffic and its dynamicity, with sustainable costs. However, automation and collaboration between layers are still on an early stage. One of the reasons is the absence of pure multilayer planning and management solutions considering the network as a whole entity, where layers cooperate with each other, instead of the sum of individual layers providing isolated services. In this paper, we revisit our open-source Net2Plan tool to present its new multilayer features. The novel technology-agnostic multilayer network model integrates into the Net2Plan offline network design and online network simulation tools, to provide practitioners a framework to understand the benefits of multilayer capabilities.

Keywords: Net2Plan, multilayer network planning and simulation, open-source software, technology-agnostic environment, IP-over-optical networks.

1. INTRODUCTION

For a long time, IP/MPLS-over-WDM networks have been the enabling solution for addressing the so-called electronic bottleneck: the breach between the enormous transmission bandwidth of a fiber (tens of Tbps) and the electronic packet processing limits of router line cards (tens/hundreds of Gbps). However, the rising number of Internet users and advanced applications that demand instant and massive network bandwidth and high QoS requirements, have created new challenges to the current operational network architecture.

Today, given the diversity in the Operation, Administration and Management (OAM) of the IP layer and the optical layer, network operators are typically structured into two different departments to manage their corresponding infrastructures [1]. Moreover, to minimize the interaction between these departments, IP/MPLS networks are often over-provisioned. However, the increasing demand not only in terms of bandwidth but also in dynamicity is forcing carriers to explore multilayer provisioning techniques, to optimize the resource usage and support novel services.

In this sense, multilayer network planning has been a recurrent research topic for years. The most common use case is the adoption of enhanced multilayer resilience mechanisms where the optical and the IP layer cooperate in different forms to adapt to failure conditions. Other multilayer drivers are the new flexible and agile optical technologies like reconfigurable optical add/drop multiplexers (ROADMs), flex-grid WDM channels and super-channels, which open the door to CAPEX and OPEX improvements if IP and optical layers are jointly optimized.

Unfortunately, the adoption of research multilayer proposals into operator production networks is still not a reality but a challenging task. Commercial planning tools have little or none multilayer capabilities. As a result, operators willing to make prospective studies on novel multilayer schemes see no support from them. On the other hand, planning tools from academia often rely on ad-hoc 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 operators to reproduce them in their networks.

In this paper, we revisit our open-source Net2Plan tool [2][3] to present its new multilayer features. From the first version, Net2Plan provides a technology-agnostic and vendor-neutral solution to evaluate network planning algorithms as well as post-analyzing network designs using either automatic reports or event-driven simulation. The new Net2Plan development extends this philosophy with a flexible multilayer network representation which opens the door to develop novel cross-layer approaches to network planning, combining optimization of the optical and electronic layers. In addition, we present a new online multilayer network simulator within Net2Plan, to support the (joint) evaluation of network recovery schemes, connection-admission-control (CAC) systems, or dynamic provisioning algorithms for time-varying traffic.

The rest of the paper is organized as follows. Section 2 is devoted to describe the new network model. Section 3 describes the main features of the offline and online networking tools. Section 4 is used to briefly discuss further extensions of Net2Plan. Finally, Section V concludes the paper.

2. NET2PLAN MULTILAYER NETWORK MODEL

Net2Plan defines a network representation, so-called network plan, based on abstract concepts such as nodes, links, routes, traffic demands, protection segments, shared-risk groups and network layers, without relying on any network technology. We believe that these are the key features enabling Net2Plan to be applicable to almost

any (existing or not) technology, in contrast to the restricted scope of commercial tools, limited to mature technologies and built-in algorithms.

In order to generalize the previous single-layer model to a multilayer environment in a simple manner, we choose the integrated capacity model presented in [4]. The seminal concept behind this model is the following: an upper-layer link is considered to be realized by (or *coupled* to) a lower-layer demand, then the summation of carried traffic for such demand determines the capacity of the link at the upper layer. Hence, we are able to cover a wide range of multilayer network scenarios and services, with an arbitrary number of layers coupled in arbitrary forms. Fig. 1 illustrates this with an example. Model flexibility permits putting together in a single study e.g. not only layer 3 service provisioning (IP/MPLS routers multiplexing/grooming client signals into lightpaths), but also we may include layer 1 service provisioning (lightpath on-demand).

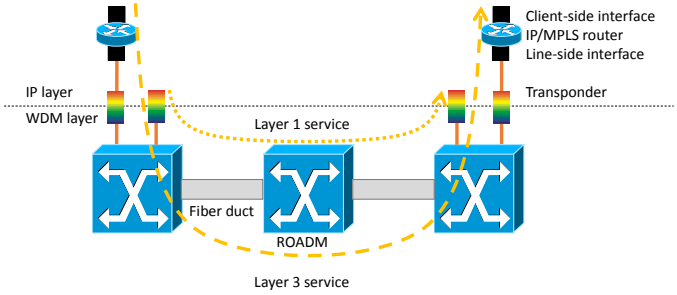


Figure 1. Example of IP-over-WDM multilayer scenarios.

Nonetheless, the technology-agnostic nature of the network representation opens the door to incorporate (almost) any technological constraint posed by real networks:

- The model permits representing novel optical layer technologies like fixed-grid/flex-grid, mixed-line rate or split-spectrum techniques. Lower-layer links (fibers) provide a certain capacity (i.e., wavelengths, slots or bandwidth in GHz) to carry lower-layer demands over the physical topology along a certain route (even bifurcated routing if split-spectrum is allowed). Each physical route is the realization of a lightpath, which provides a certain capacity to the upper layer (i.e., Gbps), occupying some link resources (i.e., wavelengths, slots or bandwidth in GHz). To ease the development of algorithms in different optical technologies, Net2Plan provides some specific libraries such as `WDMUtils` (for wavelength-routed networks) or `FlexGridUtils` (for distance-adaptive flex-grid networks).
- It is possible to apply different routing schemes at the IP layer such as explicit (or source) routing or hop-by-hop routing. The former is the classical operation of MPLS networks, where traffic flows are routed over so-called label-switched paths (LSPs), which univocally determines the ordered sequence of traversed nodes and links. However, the latter is typical of OSPF/IS-IS networks, where the IP layer decides in a hop-by-hop basis the next-hop forwarding of the traffic.
- Net2Plan is able to emulate failure propagation across network layers. From our model, it is clear that a failure in the lower layer will imply that the affected routes in that layer will become down. Then, non-recovered routes in a layer, reflect into a capacity reduction at the upper layer. For instance, if an IP link is composed of the aggregated capacity of 10 lightpaths (lightpath bundling), lightpath failures automatically reflect in the IP layer as capacity reductions. Net2Plan permits including used-defined online algorithms that define further specific details on how the network should react to failures and reparations. For instance, the network model is able to support pre-computation of backup paths, any type of restoration schemes, dedicated or shared protection with arbitrary cooperation among layers etc.

In sum, the new multilayer scheme is designed to be utmost flexible, allowing the users to perform a variety of studies. The code repository in [2] includes numerous examples implementing the aforementioned features so that can be reused and/or extended.

3. TOOL DESCRIPTION

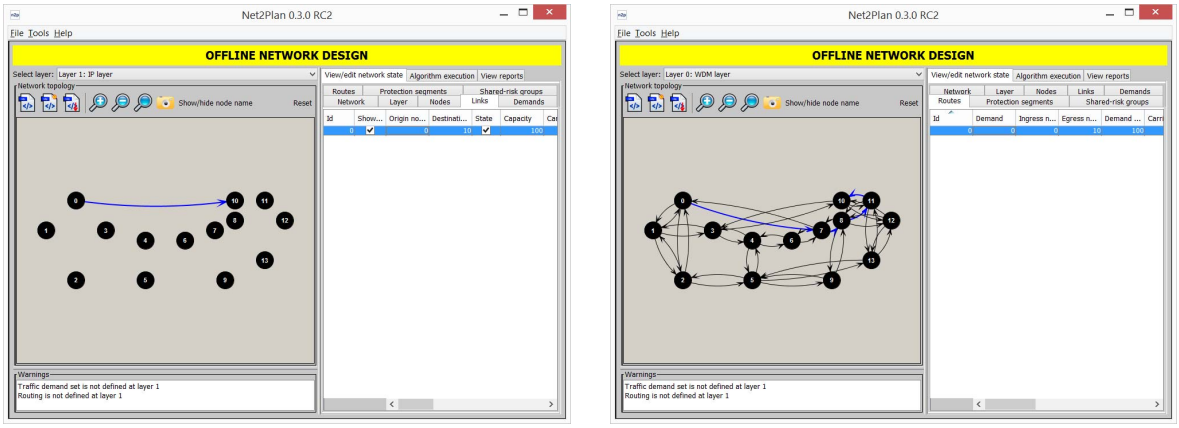
In this section, we briefly describe the main features of the tools for multilayer network design and simulation. We focus on the graphical user interface (GUI) instead of the command-line interface (CLI). Interested readers are encouraged to visit the website [2] for a complete user's guide and video tutorials.

3.1 Offline network design

This tool is targeted to evaluate the network designs generated by built-in or user-defined offline network design algorithms, deciding on aspects such as the network topology, the traffic routing, link capacities, protection segments and so on. Independently of the type of problem solved by the algorithm (topology design, capacity assignment, flow assignment, or even combinations of them), each one must implement the interface

`IAlgorithm`. Execution of algorithms, including parameter selection, is controlled from the "Algorithm execution" tab.

Essentially, previous versions of Net2Plan already provided an incipient multilayer offline network graphical interface, so the tool aspect remains pretty similar. Due to space reasons, we use Fig. 2 just to illustrate the new multilayer model. In Fig. 2a, we show the IP view of an end-to-end 100 Gbps lightpath in the NSFNet network, whereas in Fig. 2b we can see the realization of such lightpath at the WDM layer. In the upper left side of the tool there is a layer selector which allows changing the current active layer to show, so that we can visualize the topology and detailed information in the left and right panels, respectively.



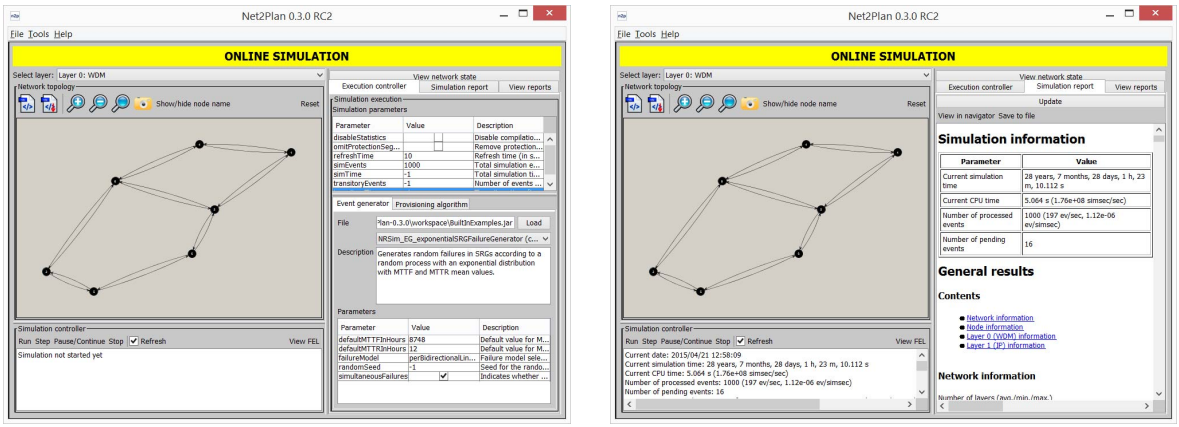
(a) View of an IP layer link (lightpath) *(b) Lightpath realization at the WDM layer*

Figure 2. Multilayer representation in the offline network design tool.

Net2Plan permits enabling/disabling nodes and links at any layer using the "State" column in the "View/edit network state" (see highlighted row in Fig. 2a). Whenever a resource is down, it is emphasized in red in the topology view.

3.2 Online network simulation

With the purpose of taking advantage of the novel multilayer model, the previous Net2Plan simulators (for resilience, CAC, and time-varying traffic) have been merged into a common one. As a result, now it is possible to include in the same tests more complex algorithms that react e.g. to failures and traffic fluctuations simultaneously. The interface is an extension of the offline network design tool, with three basic differences: (i) users cannot modify manually the design in the "View network state" tab, (ii) users should incorporate an event generator (extending the base class `IEventGenerator`) and an event processor (extending the base class `IEventProcessor`) instead of a design algorithm in the "Execution controller" tab (see Fig. 3a), and (iii) after finishing the simulation a report with some metrics (including either predefined or own-developed metrics) is shown in "Simulation report" tab (see Fig. 3b).



(a) Execution controller *(b) Simulator controller*

Figure 3. Online simulation tool

Another improvement developed for the online simulator is that the event generator and the event processor can now send events between them, and also to themselves. The typical interaction is sending events from the generator to the processor, e.g. conveying failure/reparation notifications. However, self-events permit simulate e.g. the effect of a "hold-off" timer in a IP over WDM resilience algorithm, which first tries to reroute affected lightpaths at the WDM layer, and then, after a hold-of timer expires, reroutes not restored IP traffic over the

surviving virtual topology. This can be modeled in the following manner: (i) the event processor receives the failure event from the event generator and tries to restore lightpaths, (ii) if succeeded, we are done, (iii) otherwise, re-schedules the event for itself at the current simulation time plus the "hold-off" timer so that the IP layer reacts after receiving this latter event.

4. FURTHER WORK

There are two main open paths to be explored in upcoming versions. First, Net2Plan provides support just for unicast routing, which means that each demand is expected to have a single source-destination pair. Instead, there are two additional types of routing: (i) multicast routing, where demands have a single source, but multiple destinations and a copy of the traffic is to be delivered to all of them; and (ii) anycast routing, where demands have multiple sources and destinations, to choose among them. On the other hand, an ongoing research line is the utilization of Net2Plan as a Path Computation Element (PCE). A PCE is a network component, application or node that can apply computational constraints and compute a network path or route based on a network graph. Some preliminary work is already published in [5], a proof-of-concept where a Net2Plan instance orchestrates a network interacting with the OpenDaylight controller, or in preparation as in [6], where we present an extension of Net2Plan to work as a PCE using PCEP and BGP/LS communication protocols.

5. CONCLUSIONS

In this paper we present the main features of Net2Plan as a solution for multilayer network planning and operation simulation. The novel technology-agnostic multilayer representation allows users to represent realistic network scenarios, with an arbitrary number of layers connected in arbitrary forms. Previous Net2Plan functionalities such as offline network design and online simulators have been upgraded considering the new multilayer approach. Hence, Net2Plan is a valuable resource for easing the development and evaluation of novel multilayer schemes for offline network design, network recovery, connection-admission-control, dynamic network provisioning, or even a mix of them.

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