

An Elastic Networks OMNeT++-Based Simulator

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ABSTRACT

An increasing number of studies about flexgrid-based elastic optical networks are currently being carried out by industry as well as academic research teams. As access to real test-beds is limited, there is a lack of effective tools that emulate realistic scenarios for testing algorithms and network architectures. In this paper, we present a simulation framework based on an active stateful Path Computation Element (PCE) with Global Concurrent Optimization (GCO) for flexgrid optical networks. The simulator is fully configurable and allows implementing and testing new algorithms and architectures easily and quickly.

Keywords: Flexgrid Optical Networks, Network simulator, Multilayer IP/MPLS-over-flexgrid, Elastic Spectrum Allocation.

1. INTRODUCTION

Flexgrid optical networks [1] are currently attracting high interest from telecommunication operators and the research community; therefore an increasing number of studies are being carried out [2]-[5]. In flexgrid optical networks, the optical spectrum is divided into a set of *frequency slots* of a fixed spectral width. In contrast to the Dense Wavelength Division Multiplexing (DWDM) [6] rigid frequency grid, flexgrid networks provide finer spectral slots and the capacity of the optical connections (*lightpaths*) varies by allocating a flexible number of contiguous slots to each of them. The number of slots to convey a requested bitrate depends not only on that bitrate but also on the modulation format used and the frequency slot width [1]. Taking advantage of this finer granularity, algorithms such as those proposed in [5], consider elastic spectrum allocation, so when the connections' required bitrate varies along the time, these algorithms try to fit the allocated resources to that requirement, providing thus better spectral efficiency.

Studies involving flexgrid optical networks, in particular those dealing with *on-line* network operation, may need to be evaluated in complex scenarios, requiring tools that simulate realistic networks and their dynamic behavior. These realistic scenarios can be found in test-beds, but they have limited access. Thus, we propose a simulator framework based on OMNeT++ [7] providing quick and easy access to the research community. Before testing algorithms in real elastic test-beds, they can be implemented and evaluated in our proposed simulation tool so they can be verified and improved in an accessible and controlled environment increasing thus success chances when those algorithms are afterwards integrated in real scenarios.

The proposed simulation tool has been developed in OMNeT++ Academic Edition, under Academic Public License, using C++ and Boost Graph Library (BGL) [8]. OMNeT++ is a discrete event simulation environment that provides functionalities for developing network simulators. This simulation environment is widely used by research teams in both universities and companies, and according to the data found in the OMNeT++ website, which are in turn based on Google Scholar search results, the number of publications involving this simulation environment is increasing dramatically. The rationale behind developing new network simulators over this framework is to take advantage of the already implemented functionalities that it provides.

The remaining of the paper is organized as follows. In Section 2 we present a network architecture for flexgrid optical networks and the protocols implemented in our simulation tool. In Section 3 we describe the main modules, functionalities and advantages of the framework. Finally, Section 4 concludes the paper.

2. NETWORK ARCHITECTURE AND PROTOCOLS

The simulation framework has been developed for research purposes and with the aim to cover a wide range of scenarios involving flexgrid optical core networks; the network architecture thus supports both single and multi-layer IP/MPLS-over-flexgrid architectures. For single-layer scenarios, we consider only an optical layer data plane, whereas for the multilayer scenario the data plane includes both the packet and the optical layer.

Flexgrid optical networks require specific components to be implemented such as Bandwidth-Variable Wavelength Selective Switches (BV-WSS) to build Bandwidth-Variable Optical Cross Connects (BV-OXC) nodes in the optical layer; whilst IP/MPLS routers are implemented in the packet layer. IP/MPLS routers can be connected to any BV-OXC using Multi-flow Transponders (MF-TP) [9] each with configurable capacity and number of flows.

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To operate a single or multi-layer network, a control plane based on a Path Computation Element (PCE) [10] is implemented in the simulator. Moreover a simplified version of the Path Computation Element Protocol (PCEP) [11] for communicating Path Computation Client (PCC) and the PCE is also implemented in our tool. PCE computes routes in response to path computation requests (PC Req) sent by a PCC. To that end, the PCE queries the Traffic Engineering Database (TED) and runs algorithms implemented within PCE to solve the Routing and Spectrum Allocation (RSA) problem. In addition to solve the RSA problem for a given Label Switched Path (LSP) request, some other algorithms are able to compute different type of requests, for example to perform elastic operations to increase or decrease the amount of spectrum allocated to the given LSP. The response (PC Rep) received by the PCC contains an Explicit Route Object (ERO) for the requested LSP. That ERO is then used by the Resource Reservation Protocol with Traffic Engineering extensions (RSVP-TE) [12] during the signaling process.

In addition, to be able to re-optimize the usage of network resources, a Label Switched Path Data Base (LSP-DB) and LSP delegation are also implemented [13]. Therefore, our PCE is in fact an *active stateful PCE* with a Global Concurrent Optimization (GCO) module [14]. The GCO module provides functionalities for obtaining better network-wide solutions by computing paths for a set of queries grouped together; in that way the optimal solution for the *bulk* of path requests can be obtained. As an example, our previous work in [4] uses the GCO module for restoration purposes. Figure 1 summarizes the architecture simulated in our tool for the multilayer scenario.

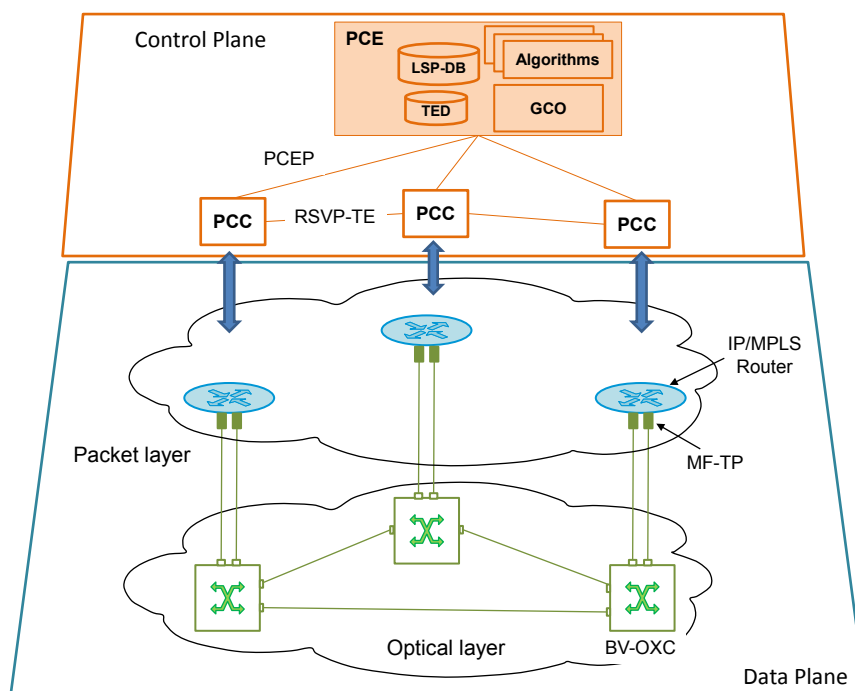


Figure 1. Simulated network architecture: multilayer data plane and PCE-based control plane.

3. NETWORK SIMULATOR MODULES AND FUNCTIONALITIES

As stated above, the network simulator has been developed in OMNeT++ 4.3 using C++11 with BGL 1.53.0 and Xerces-C++ 3.1.1 libraries. The simulator is organized in a number of modules representing either logical or physical elements in flexgrid optical networks: BV-OXC, IP/MPLS routers, PCE, MF-TPs, and TE links. Additionally, a Network Configuration module is included in the simulator in order to centralize generic configuration parameters, such as the frequency slot width or the modulation efficiency. In order to cover a wide range of scenarios, those modules can be configured for each specific scenario. Table 1 summarizes the principal configurable parameters for these components.

Each component includes its own set of methods simulating realistic functionalities. These modules and the interaction between them emulate the architecture and the protocols described in Section 2. By combining and configuring nodes and connections among them, specific flexgrid optical network topologies can be created in a *.ned* file; experiments can be afterwards run over that topology. A *Basic.ned* file is already defined with a default configuration for each module. For illustrative purposes, Fig. 2 shows the code in a *.ned* file extending *Basic.ned* and the network that it represents.

Table 1. A subset of configurable parameters in the network simulator.

| Modules and channels | Configurable parameters |
|-------------------------------|--|
| Nodes (BV-OXC and IP/MPLS) | <ul style="list-style-type: none"> Switching capabilities (packet or label switching) Traffic Generation capability Number of Converters/Regenerators available |
| MF-TPs | <ul style="list-style-type: none"> Number of OEO ports Maximum number of flows within the same port Maximum bitrate |
| TE links | <ul style="list-style-type: none"> Length and metric |
| Network configuration | <ul style="list-style-type: none"> Offered Load (Inter arrival time and holding time) Traffic profile Optical spectrum width Frequency slot width and modulation efficiency LSP maximum number of hops Delays and process times Elastic or fixed capability |

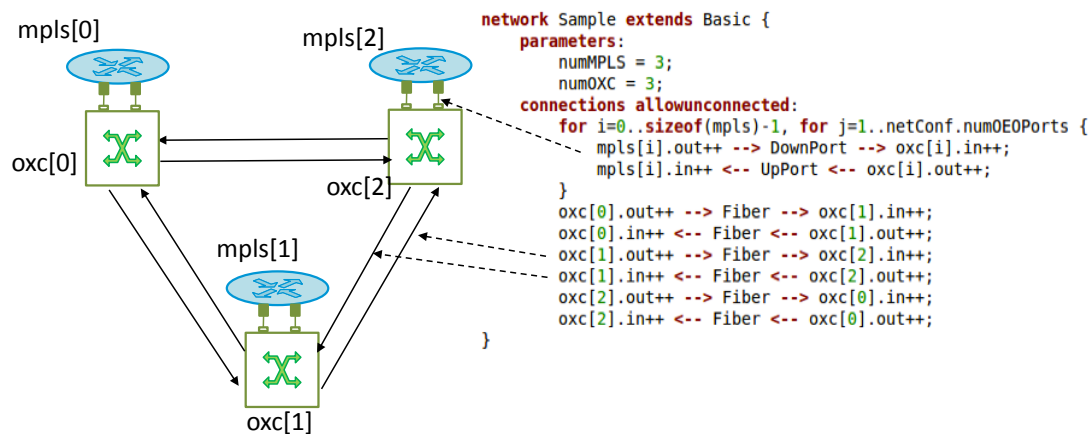


Figure 2. Sample of a .ned file and the network in the data plane that it represents.

Each node with traffic generation capability generates new requests messages according to a Poisson process independently, i.e. without prior knowledge of the traffic generated by other nodes. The holding time of the connection requests is exponentially distributed with a configurable mean value. Connection's destination is randomly chosen with equal probability (uniform distribution) among the rest of nodes with traffic generation capabilities. Different values of the offered network load are created by changing the inter arrival time while keeping the mean holding time constant. Furthermore, the bandwidth demand of each connection request is randomly selected according to a traffic profile.

PCEP and RSVP-TE implementations are based on OMNeT++ messages which are exchanged between PCCs and PCE. Physical characteristics of control links can be emulated by configuring a number of parameters, such as transmission delay.

To illustrate the interaction among the different modules Fig. 3 represents the messages exchanged to establish a new LSP on the network. The source PCC for the requested LSP sends a PCEP PC Req message (message 1 in Fig. 3) to the PCE requiring a new path computation. Upon the reception, PCE processes the message, finds the proper algorithm for that request and calls it (2); in the example, the selected algorithm is that for solving the RSA problem. After the algorithm finds a feasible solution, it builds the ERO with the route and spectrum allocation and returns it to PCE, which builds a PCEP PC Rep message, includes the ERO and sends it back to the originating PCC. Upon receiving the response message, the originating PCC starts the signaling process by sending a RSVP-TE PATH message to the next node in the route of the LSP. To that end, it uses the information in the received ERO. Once the destination PCC receives the PATH message, it allocates physical resources and sends a RSVP-TE RESV message back through the same path so that intermediate PCC allocate also physical resources. When the RESV message reaches the source PCC and the physical resources are allocated in the node, requested LSP is established.

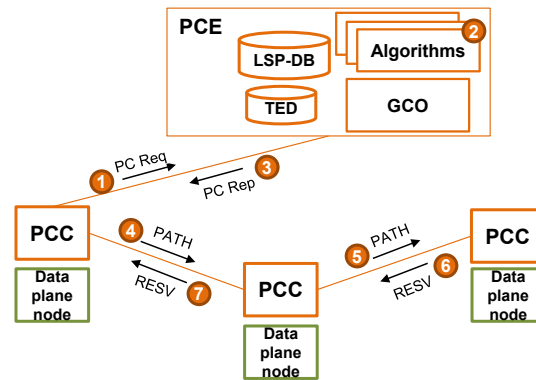


Figure 3. Messages exchanged to establish a new LSP.

Apart from the modules and functionalities described above, a set of auxiliary classes for different purposes is considered, such as those for statistics and data input and output. Although OMNeT++ provides statistics functionalities, additional output files with the desired format can be created by implementing ad-hoc classes.

Finally, it is worth noting that the proposed architecture can be extended with new modules and functionalities. Specifically, new algorithms can be implemented and tested easily by adding new C++ classes and making them accessible by the PCE.

4. CONCLUSIONS

Flexgrid optical networks are attracting the interest from telecommunication operators and research teams, but there is limited access to real test-beds implementing them. Thus, we propose a network simulator for flexgrid optical networks based on OMNeT++. To cover a wide range of scenarios, the simulator implements BV-OXC nodes and IP/MPLS routers, TE links and MF-TPs to simulate both single and multi-layer architectures. The control plane includes PCCs and an active stateful PCE with GCO. The PCEP protocol is used to communicate PCCs and PCE, whereas PCCs run the RSVP-TE protocol for signaling.

Many algorithms can be deployed in the PCE to solve different problems for a single LSP request, such as the RSA problem, elastic operations to increase or decrease the bitrate of already established connections, adaptive operations to shift already established connections in the spectrum, etc. In addition, thanks to the GCO module, more complex scenarios can be simulated, such as computing the optimal RSA for a set of connection requests. In that regard, we have used and are successfully using the network simulator described in this work in re-optimization and in recovery scenarios.

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