GNPy: Lessons Learned and Future Plans [Invited]

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Abstract *We discuss the history, past challenges and future plans of GNPy, an open source project for simulating physical impairments in contemporary DWDM network. The paper describes the unique interaction among network operators, equipment vendors, and standard bodies, as well as challenges in implementing the digital twin of an optical network.*

Introduction

GNPy[1] is an open source project based on the state-of-the-art[2] Gaussian Noise (GN) model[3]. It aims to provide a vendor-neutral, cross-platform, and permissively-licensed software which is simulating physical impairments in contemporary Dense Wavelength Division Multiplexing (DWDM) networks. Operators able to describe their optical network in a sufficient level of detail[4],[5], can use GNPy to obtain a realistic estimate[6],[7] of the Quality of Transmission (QoT) metrics between any pairs of nodes in the network. GNPy can also optimize the network, ensuring that the signal launch power and amplifier operating points are set to optimal operating points[8].

GNPy's History

Performance estimation of optical transmission has long been an issue in multi-vendor context, because the only available tools were vendor specific and bound to proprietary designs. The lack of such tool created a knowledge bias between vendors and operators and imposed non-negotiable barriers in network design. In consequence operators demanded more openness and interoperability in optical transport network and called for a joint industry effort to tackle the problem.

The Photonic Simulation Environment (PSE) was initiated in 2016 as a targeted working group within the Telecom Infra Project (TIP) Open Optical Packet Transport (OOPT) framework activities. The scope to the PSE group was to foster an open optical planning and simulation environment as a basis for multilayer optimization:

> *This project group will define DWDM open packet transport architecture that triggers a new pace of technology innovation and flexibility, and avoids implementation lock-ins. Open DWDM system includes open line system & control, transponder & network management, packet-switch and router technologies.* (Statement of Work for OOPT[9])

PSE was one of the first operational groups in the OOPT framework and became a cornerstone of its optical ambitions. Since the first code commit in 2017[10], GNPy has been run as an open source project on GitHub. Twenty people have contributed code, ranging from researchers, network operators, and hardware vendors. Many more have provided valuable feedback, including hundreds of bug reports and suggestions for improvements.

By today GNPy has set an industry reference on a subject that used to be hidden, and it enabled system vendors and operators to negotiate the performance of optical networks in a level playing field. GNPy has been used with ONOS[11] and OpenDaylight Software-Defined Networking (SDN) controllers as path computation engine. It can be deployed with OpenROADM[12], and also run in production networks by operators for optimizing their procurement process[13]. GNPy was featured as a Path Computation Engine (PCE)[14] by a multi-operator collaboration within TIP Converged Architectures for Network Disaggregation and Integration (CANDI). Therefore GNPy is a key enabler towards sustainability of multivendor network deployments[15].

Modeling Optical Networks with GNPy

When GNPy simulates a signal which propagates through an optical network, it works with a *digital twin* of the physical network. This digital twin comprises Network Elements (NEs) which affect and manipulate the signal, such as the Erbium-Doped Fiber Amplifiers (EDFAs), Reconfigurable Optical

Add/Drop Multiplexers (ROADMs), and the optical fiber. During propagation, GNPy tracks signal power, Amplifier Spontaneous Emission (ASE) noise, non-linearities, Chromatic Dispersion (CD), Polarization Mode Dispersion (PMD), and Polarization Dependent Loss (PDL) for each carrier, computing their incremental change after crossing each element, yielding the resulting Generalized Signal to Noise Ratio (GSNR).

GSNR is a single metric which has been shown[16] to represent the effective quality of a coherent, polarization-multiplexed optical signal, and is therefore directly usable for qualifying the optical reach of deployed transponders[17]. No matter how dense the network graph is, a propagation follows a linear path, and since GNPy assumes full channel load on all links, the incremental impairment on the GSNR can be computed. Once the GSNR is known for all relevant pairs of start/end nodes in a network (and for a targeted channel load), GNPy compares the resulting GSNR with performance capabilities of transponders. As a result, the operator is presented with data which characterize the *quality* of their network.

Describing the Equipment

The most important sources of signal impairments are amplifiers, which introduce noise as a side effect of their operation and the optical fiber, which provides a medium for high-powered signals to interact between each other. The accuracy of a GNPy simulation largely depends on the accuracy of their machine-readable description.

Unlike a proprietary system which might, e.g., aggregate several contributors towards a single "OSNR" metric, GNPy focuses on raw data such as EDFA Noise Figure (NF) and fiber span loss for calculating impairments. The NF itself might be specified in multiple ways. At one end of the complexity spectrum, GNPy supports describing an EDFA's NF as a third-degree polynomial function based on the amplifier's actual gain, or its difference from the optimal gain, or via OpenROADM's gain mask. In practice, excellent results can be also obtained when using simplified NF models, e.g., a *min-max NF*. In this model, the minimal NF is achieved when the EDFA operates at its maximal gain, and the worst NF applies when the EDFA operates at its minimal gain.

A major challenge the team was facing since the beginning was that vendors consider optical performance details as proprietary information and did not openly disclose them. This created a situation where it wasn't easily possible to compare different options as vendors chose to expose or hide a variety of performance parameters. This situation changed with the advent of standard coherent 100 G Transponders pushed for by operators and members of the PSE Group[18]. The combination of both actions provided the basis for the development of GNPy. The modular nature of GNPy and the existence of standards enable to perform accurate baseline network planning tasks in a vendor agnostic manner. It also enables vendors to enrich the model with proprietary data in an external library without disclosing it to competition.

The choice of an external library, or a database of equipment performance, also raises operational challenges. These were identified in a multi-vendor collaboration within TIP CANDI and Mandatory Usecases for SDN Transport (MUST) in preparations for a demo at OFC'21[14], and resulted in a recommendation towards extending the OpenConfig device models (`device-manifest`) with a machine-readable description of optical impairments. The lesson learnt is that data interoperability is not only a technical issue, but a standardisation issue and a question of getting a reasonable agreement on workflows that preserves confidentiality. In this respect, GNPy is instrumental as an enabler: it is used as a baseline to express what operators want by utilizing open data. Since GNPy is vendor neutral, the baseline is usually well accepted by all parties in the negotiation process. GNPy acts as a great helper for standardization: the parameters it defines can be seen as a minimum set necessary to be able to utilize the data. Meanwhile GNPy can benefit from user feedback and also initiatives like OpenROADM or MUST to support their use cases and new requirements. This ends up with a virtuous circle where standards and GNPy tool can converge consistently towards user's needs. A key contributing factor towards the smoothness of this process was in-person collaboration; members of GNPy community are active within the IETF, OpenROADM and have engaged with OpenConfig and Open Networking Foundation (ONF) Transport API (TAPI).

Describing the Network

The digital twin of the optical network consists of just a few elementary building blocks. *Transceivers* act as start- and endpoints for requesting lightpaths, and for defining what modulation formats are supported. *Amplifiers* represents the EDFAs, which amplify the signal and introduce ASE noise. *Fibers* carry the optical signals, attenuating them, and providing space for nonlinear interference (NLI), Raman pumping, etc. *ROADM* nodes in GNPy represent just the internal switching plane which is capable of attenuating and equalizing channel power. There is also the *Fused* node which acts as an attenuator and also as a hint to GNPy's optimization algorithms.

These nodes represent a *function* instead of corresponding one-by-one to physical NEs, and the digital twin of the network is often decoupled from an Network Management Systems (NMSs) topology[19]. All GNPy-level elements are *unidirectional*, which means that even a relatively simple in-line optical amplifier comprises two GNPy-level EDFAs, one per each direction. A typical real-world ROADM consists of many GNPy elements – two EDFAs per each degree (one ingress, one egress), and an actual ROADM as the switching matrix. This functional representation is useful for simulating disaggregated ROADM whiteboxes[20]. An abstract representation also makes it easy to simulate greenfield deployments where it is often useful to have a tool assist with amplifier placement. Even brown-field deployments, where amplifier types and physical locations are largely fixed, benefit from gain optimization. To this extent, GNPy ships with a set of heuristics which fine-tune the optical network.

Going further, the team acknowledges that it is often not simple to get the data out of the operator infrastructure. Fiber length or distribution of lumped losses within a span are typically available out of operator's data bases (Information System). However, there are often difficulties in retrieving and matching infrastructure information with equipment information that needs to be extracted from the equipment NMS or the SDN controller. Confidentiality concerns have to be managed as well, especially with hardware disaggregation or multi-layer SDN software. In the end, the operator secures the privacy of both the operators and vendors data, sometimes using a multilateral NDA.

Ongoing Development

The current development of GNPy focuses on three core areas: (i) support of modern optical systems, (ii) interoperability, and (iii) ease of use.

To catch up on cutting edge transmission technologies that enlarge the capacity of already installed network infrastructure, as the flexible rate and multi-band transmission[21], GNPy is going to enable in the near future the framework required for the simulation of these transmission scenarios. Recently, the GNPy capability to accurately evaluate the optical impairments in case of flex-rate, flex-grid transmission scenario, up to symbol rates of 90 Gbaud and bit rates of 800 Gbit/s, has been experimentally validated[17],[22],[23]. GNPy has also shown efficient applications in launch power and amplifier working points optimization for multi-band optical line systems[24].

We plan to improve ROADMs impairment modeling. So far, GNPy has disregarded the filtering penalties of concatenated ROADMs, and the filtering capabilities of Add/Drop stages and the express interconnects were not considered, either. We are happy to have engaged with vendors and standard groups in order to align out effort.

In terms of interoperability, a self-documenting, machine-accessible YANG interface[19] will make it easier to integrate GNPy into third-party software. The team is using the opportunity of introducing a new I/O format to improve usability as well. Historically, GNPy came with a set of heuristics whose documentation was only sparse. With a move to YANG, network topologies and device operational points will become easier to reason about. The choice of functional representation which focuses on entities which impair the signal, however, will remain. While the competing standards mature and are extended, often in response to GNPy's features, we are committed to interoperability via converters and well-documented interfaces.

There is never enough of documentation and tutorials, and we are happy to have this opportunity to present GNPy's challenges in this paper.

Conclusions

We have described the ideas behind GNPy, an open source toolbox for simulating optical impairments in DWDM networks, its history and plans for the near future. Thanks to its focus on the functional description of the network, GNPy helps driving efforts for extending several standards with support for impairment-aware modeling.

Describing heterogeneous networks in a vendor-neutral manner is a complex task, though, and there are many operational challenges, especially in multi-vendor environment. However, we believe that network disaggregation is an inevitable process, and GNPy is in a unique position to help operators *build*, *optimize* and *operate* their networks in an efficient way.

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