Open Optical Networks: The Good, the Bad and the Ugly

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Abstract *We discuss the progress made in designing Open Optical Networks from the humble beginnings to the present state. After analysing the current state of the art, we finish by discussing open issues, challenges and future directions. ©2023 The Author(s)*

Introduction

It has been over two decades since DWDM technology got deployed in large numbers. Standards were considered to slow down innovation, hence DWDM-networks became closed vendor silos. This created a know-how gap where much of the inner workings were considered proprietary information and operators had little chance to scrutinize a design. Today, Open Optical Networks (OON) are arguably one of the most interesting and exciting innovations since decades. The vision of OON draws inspiration from open standards available throughout a plethora of networking technologies. Openness has far-reaching implications, and the industry is still grappling to fully leverage the opportunities it brings. Openness of optical networks and network elements play a pivotal role in the continuing progress of optical communication and freely share know-how. A breakthrough in OON was the possibility to design and plan open networks in an open-source tool called GNPy.

GNPy [1] is an open-source project based on the state-of-the-art Gaussian Noise (GN) model [2]. 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. GNPy is under development in the framework of the www.telecominfraproject.com.

The difficult birth of Open Optical Networks

In the proprietary world before 2013, a transmitter needed to be matched by a receiver of the same provenience to be able to work. So, the transmitter + optical network + receiver was considered a "black link". A neutral observer had little insight into the specifics of the signal, the transmitter and the receiver characteristic.

OON started in 2013 when Deutsche Telekom was the first operator investing into open optical networks in a project named Terastream [3]. DT managed to convince ASIC vendors to implement the same Forward Error Correction (FEC) algorithm that made these ASICs interoperable. To some observers this appeared to be a miracle as previously the optics industry considered the FEC implementation as "secret sauce" that got defended with patents and lawyers. Wisely, DT picked a FEC which was public and not protected by property rights also known as Staircase-FEC or SC-FEC.

At the time, Terastream leaders were content in having achieved interoperability but did not invest in standards. This changed in 2017, when some system vendors like Juniper, Cisco and Deutsche Telekom jointly pushed for a FEC standard in ITU-T which led to a published standard in 2020 based on the well-known SC-FEC [4].

Parallel activities to achieve interoperability between DWDM Transceivers have been launched by OIF and other groups which gave the impetus to think about opening the optical line system (OLS) as well. In Addition, in 2014 standardization activities started with the aim to expose a standard management model for transponders to an open controller in IETF.

Then in 2016, OpenROADM started to disaggregate the OLS itself by specifying performance requirements for each element of the line system separately. This activity was launched by AT&T who understood the chances of an open system and wanting to push standardization further.

In the same year, the www.telecominfraproject.com (TIP) launched a working group named Physical Simulation Environment (PSE) which plugged an important gap in OON: How to design and plan open optical networks delivering on performance? Before TIP addressed this question, it has not been addressed in any meaningful way and had no place in standards either.

Investors need confidence that a given network architecture supports the amount of traffic it is designed for and performs according to a well-defined criterion. Creating this confidence has always been a challenge since each supplier has developed their own design metrics and tools based on different approaches and margins.

That's why from the beginning PSE attracted lots of support from pioneering companies such as Orange, Telia and Microsoft who wanted a vendor independent means to design OON.

Early Lessons learned

Lesson 1: Transceiver Characterization

A major hurdle for standardization was the need to characterize the transmitter independently from the receiver. It is of great utility to have a standard transceiver in a measurement device that can be utilized for all vendors and allows to analyse issues narrowing them down to transmitter, optical line and receivers. With a standard available, measurement device vendors started to invest into capabilities to encode and decode coherent signals for signal and quality testing of transponders. This new capability of compliance testing also helped the industry to advance standards compliant modules faster than proprietary implementations.

Lesson 2: Performance Characterization

Of particular importance is the ability to characterize the performance of optical network equipment. Traditionally, some performance characteristics were documented, some were not, and others needed conversion to make them comparable. What was lacking was a way to summarize different effects to obtain an overall Quality of Transmission QOT indicator that could be correlated with Bit Errors. Here, the Gaussian Noise Model GN proved to be a game changer. It allowed to express linear and non-linear impairments in form of Gaussian noise equivalents which could be serialized end-to-end as the signal travelled through the optical network.

Lesson 3: Network planning and design

In a world where optical characteristics were considered proprietary, the only practical way to model networks was to use vendor proprietary planning tools. In turn, these proprietary tools created a vendor lock-in because to figure out if a new technology of a different vendor could perform in any given network was to use the planning tool of the vendor in competition. This situation changed with GNPy becoming available. GNPy is the first vendor agnostic planning tool providing accurate predictions of optical performance. Still, it was slowly adopted in the Operator community which were comfortable to continue in a proprietary model despite the fact that Microsoft tested GNPy and confirmed its excellent accuracy in predicting performance [5]

Lesson 4: The critical Use Cases

When Operators were planning to build new networks, they received divergent offers they had to juggle with different proprietary tools and performance parameters unable to compare different models in a simple manner. So, benchmarking different supplier's systems against each other was hard.

GNPy provided Operators with a solution of this problem [6]. In a first step, Operators could describe their planned network in a way allowing them to perform a Quality of Transmission (QoT) estimation based on openly available data. In a second step they would provide this model to their equipment suppliers asking them to model the same network with their own proprietary data and funnel it back in a format that could be interpreted by GNPy. This allowed them in a third step to compare divergent offers, work with vendors on bottleneck conditions and improve the ON design in a collaborative manner together with their system vendors.

Lesson 5: Simple or Expert Tool?

The initial use case for GNPy was to quickly design a reasonable model of an OON without the need to enter too many details. This for example required an automated selection and placement of amplifiers in the network as the precise locations of amplifiers were often unknown or too complex to fill in for a quick model. While this was great for academia and greenfield simulations in an early stage, it proved to be questionable choice for other use cases. When modelling already existing networks where specific nodes are placed on fixed locations the automatism to insert new amplifiers at locations where there were none, became an annoyance. Hence, a more specific functionality was required to facilitate planning for existing networks without automated topology adjustments.

Current work on GNPy

As of today, GNPy has set an industry reference which enables system vendors and operators to negotiate the performance of optical networks in a level playing field [7]. GNPy has been used to feed a path computation engine (PCE) for perform impairment aware routing of wavelengths.

An early integration is already available in two open-source implementations (OpenDaylight [8], ONF[9]) which both leverage GNPy and have been demonstrated at various occasions. The team's intention is to further ease this integration by working on an updated version of the YANG interface to GNPy.

To further improve the accuracy of the model, work has also been started to consider the statistical effect of Polarization Dependent Loss (PDL) accumulation effects on transparent lightpaths [10]. This performance impairment depends on the Transmitter which needs to be characterized accordingly. All this work is accompanied by a YANG model to describe an impairment aware topology in IETF [11] which can serve as an input to GNPy.

In summary, GNPy became a key enabler of vendor independent network design and planning network deployments.

The Good …

… news is that the PSE-team is looking into the use case of a "Digital Twin" whereby actual network parameters are regularly monitored and injected into GNPy to gain insight into performance bottlenecks in real-time [12]. This exciting new capability empowers operators to constantly monitor the overall quality of the deployed network by benchmarking measured performance to a Digital Twin reference. A useful Application is a Optical Network Observer (ONO) which could be seen as the GUI of the Digital Twin. Such ONO not only provides insights into actual network performance but also delivers the basis for localizing impairments and excess optical performance.

…, the Bad, …

… news is that this building Digital Twins are not as easy as it sounds. For dimensioning and planning, it was sufficient to characterize transponders at their performance limit. However, transponders are rarely operated at their performance limit. Hence, to assess the actual performance in operation, it is necessary to characterize components at various points of operation. This creates the need for a more extensive model of individual parameters across the usage spectrum.

Furthermore, monitored data needs to be accurate. Not every implementation has the same capability and accuracy. Hence it is necessary to consider statistical deviations of parameter values in the parameter model as well. It is therefore important to tightly control the quality of monitored data and account for inaccuracies that still exist.

… and the Ugly

… truth is that inaccurate data feeds upon itself. Feeding inaccurate data into an otherwise accurate model will inevitably result in questionable predictions.

A particular source of inaccuracy is time. In most cases, Operators have accurate data measured at the time of deployment, but the accuracy of that data deteriorates quickly.

Another source of inaccuracy is the actual point of operation of amplifiers along the optical line system [13]. The noise generated by those components has an outsized effect on the overall system performance and an inaccurate measurement is bound to distort the prediction substantially.

Furthermore, some effects are hard to quantify and of statistical nature like PDL. However, experiments have shown that there is the possibility to estimate the effect in a controlled setup [14].

In other words, the Digital Twin reference has to deal with potentially accurate but deteriorated data and with data that is actual but only available with a wide margin of error. Eventually, this requires a Digital Twin to become a self-learning system that is able adapt itself to the observed network while acting as performance reference to pinpoint impairment effects and their location [15].

Conclusions

GNPy became the tool of choice for many operators to design and plan open optical networks. Leveraging GNPy as impairment calculation tool to dynamically provision wavelength using a path computation engine raised the desire to use GNPy in a more dynamic manner, tailored to the network conditions that are monitored during operation, the Digital Twin.

An Optical Network Observer application can leverage Digital Twins. Network Observers and Digital Twins are bound to further advance the concept of Open Optical Networks and facilitate operational simplicity.

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References

[1] A Ferrari, M Filer, K Balasubramanian, Y Yin, E Le Rouzic, J Kundrát, ..., , GNPy: an open source application for physical layer aware open optical networks Journal of Optical Communications and Networking 12 (6), C31-C40, 2020

[2] Vittorio Curri, "GNPy model of the physical layer for open and disaggregated optical networking," J. Opt. Commun. Netw. 14, C92-C104 (2022).

[3] Peter Lodberg, „Terastream“, RIPE 67, 2013. https://ripe67.ripe.net/presentations/131-ripe2-2.pdf

[4] ITU-T G.709/Y1331, Interfaces for the optical transport network, 06/2020

[5] M Filer, M Cantono, A Ferrari, G Grammel, G Galimberti, V Curri, Multi-vendor experimental validation of an open source QoT estimator for optical networks, Journal of Lightwave Technology 36 (15), 3073-3082, 2018

[6] E. L. Rouzic, O. Renais, J. Meuric, *et al.*, “Operator view on optical transport network automation in a multi-vendor context [Invited]”, *J. Opt. Commun. Netw.*, vol. 14, no. 6, pp. C11–C22, Jun. 2022. DOI: 10.1364/JOCN.450008.

[7] J Kundrát, E Le Rouzic, J Mårtensson, S Melin, A D’Amico, G Grammel, ..., GNPy: Lessons Learned and Future Plans, European Conference and Exhibition on Optical Communication, We3B. 6, 2022,

[8] OpenDaylight Project, 2016-2023, retrieved May 12, 2023: https://docs.opendaylight.org/projects/transportpce/en/latest/developer-guide.html

[9] J. Kundrát, A. Campanella, E. Le Rouzic, A. Ferrari, O. Havliš, M. Hažlinský, G. Grammel, G. Galimberti, and V. Curri, "Physical-Layer Awareness: GNPy and ONOS for End-to-End Circuits in Disaggregated Networks," in *Optical Fiber Communication Conference (OFC) 2020*, OSA Technical Digest (Optica Publishing Group, 2020), paper M3Z.17.

[10] A D’Amico, G Borraccini, S Straullu, F Aquilino, S Piciaccia, A Tanzi, ..., Statistical Analysis of PDL Penalty on Coherent Transmission Technologies Based on WSS Experimental Characterization, 2022 Asia Communications and Photonics Conference (ACP), 874-877, 2022.

[11] A YANG Data Model for Optical Impairment-aware Topology, https://datatracker.ietf.org/doc/draft-ietf-ccamp-optical-impairment-topology-yang/

[12] A D’Amico, G Borraccini, S Straullu, F Aquilino, E Virgillito, ..., Disaggregated Optical Network Orchestration based on the Physical Layer Digital Twin, Optical Fiber Communication Conference, Tu3D. 4, 2023.

[13] M Devigili, PN Goki, N Sambo, P Castoldi, L Potì, A D’Amico, V Curri, Multi-band Optical Network Assisted by GNPy: an Experimental Demonstration, 2022 IEEE Latin-American Conference on Communications (LATINCOM), 1-5, 2022.

[14] A D’Amico, G Borraccini, S Straullu, F Aquilino, S Piciaccia, A Tanzi, ..., Experimental Probing and Modeling of the PDL Impact on the Optical Signal-to-Noise Ratio, Optical Fiber Communication Conference, W1E. 6, 2023.

[15] G Borraccini, A D’Amico, S Straullu, F Usmani, A Ahmad, V Curri, Iterative supervised learning approach using transceiver bit-error-rate measurements for optical line system optimization, Journal of Optical Communications and Networking 15 (2), 111-118, 2023.