

Extending Contemporary Network Modeling Towards the Photonic Layer

Jan Kunderát and Stanislav Šíma

CESNET, z.s.p.o.,

Praha, Czech Republic

E-Mail: jan.kundrat@cesnet.cz

Abstract—A significant interest recently sprouted towards describing a production computer network in a machine-readable way. Most of the effort has, however, so far focused on providing an accurate description starting at the L2/L3 of the ISO/OSI model. Such an approach cannot accommodate advanced applications, such as accurate transfer of ultra-stable frequency signal. In this work, we aim at outlining possible ways of extending the existing network models towards describing the photonic properties of the contemporary networks. When a network model allows for an accurate description of the photonic substrate, it becomes suitable for automated verification of critical properties which are required by emerging network users.

Keywords—*photonics; optical networking; network modeling; CAD.*

I. INTRODUCTION

When dealing with contemporary networks, a list of interesting properties includes much more than just the available bandwidth and an administrative cost of a given interconnect. Optical networking, or photonic networking, is a novel way of designing networks where the light which travels through a fibre link is not converted to electricity at various points [1]. A photonic network is capable of carrying concurrent optical signals between the connected nodes. Properties which are sufficient for a reasonably accurate description of a generic packet-switched network no longer make sense for a photonic service. It is irrelevant whether the provisioned transceivers at exchange points support 100 Gbps Ethernet. What matters is how the light is affected by the fibre paths, or by the active devices which amplify, switch and otherwise modify the carried signal.

Having a well-established model of how a photonic network (or, indeed, any computer network in general) is constructed allows for many advanced applications. If the model includes physical properties like location of the actual hardware devices, it can be used for optimizing dispatching the technicians in case of an outage. A well-designed abstraction scheme along with a well-maintained inventory can be used for checking the bill-of-materials needed when building networks. Model checking and verification can be used to verify upfront that a network which is about to be built, with fibre buried a few meters deep, is capable of achieving the properties its owners expect, and are willing to pay for.

This paper starts by explaining the state of art in the area of network modeling in Section II. In Section III, we explain what properties of the photonic substrate have to be tracked in the model, and outline how to cover them as an extension of an existing modeling language. The article wraps up with a plan for future work and conclusion in Section IV.

II. RELATED WORK ON NETWORK MODELING

Different use cases require varying level of detail to be present in a model of the network. As an example, a typical network router usually needs to know where to forward packets destined for a particular IP address. On the other hand, a

Network Operating Center (an *NOC*) usually has more stringent requirements. In our use case we are going to focus on modeling the complete topology of a network, i.e., a situation where at least one node is aware of every property of the network being modelled. This is in contrast to a distributed system where each node typically maintains just a subset of the required information.

In this work, we are investigating universal models, which are capable of conveying a wide range of information. We are looking for a single model which is usable for (or at least extensible to) describing the actual computer network on many levels.

A. Network Description Language

The Network Description Language (NDL) is a format which was introduced by Jeroen van der Ham [2]. Based on the RDF (Resource Description Framework) standard [3], the NDL builds a distributed set of documents, each referenced by a special URL (Uniform Resource Locator), along with relations among the described entities. The basic NDL contains three classes of modeled entities:

Location which describes a physical location where *Devices* are to be found in real-world.

Device which represents a physical piece of equipment which is a part of the network.

Interface which is used to model an interface or port of the physical *Device* which is used for connecting to other devices.

These objects or classes are connected by various predefined relations. The NDL format predefines these six properties:

locatedAt for tying together *Locations* and *Devices*.

hasInterface for assigning *Interfaces* to *Devices*.

connectedTo which represents an external connection of two *Interfaces*.

switchedTo which, compared to the `connectedTo`, represents an internal connection, presumably within a single *Device*.

name for conveying the name of a resource in a RDF way.

description which includes a free-format, human-readable description to any class.

The original, baseline NDL did not offer much functionality. While its features were sufficient for describing the *topology* of the network, no provisions were included for adding machine-readable properties such as the type of actual link, or available capacity. Due to the nature of the RDF format, though, the NDL itself was very extensible. As a logical next step, its main authors built on top of the existing standard and attempted to introduce the NDL concept to contemporary optical networks in their follow-up work [4]. It should be noted that while the article in which this extension was first presented was titled *Using the Network Description*

Language in Optical Networks the word “optical” does not refer to the optical properties of photonic networks.

This refinement of the NDL language added (among other changes) a single new class, a **Link**, which represents a previously implied connection between two entities, and the following new properties:

capacity which provides the provisioned throughput over a *Link*.

encodingType which defines the encoding used on a given *Link*.

encodingLabel which extends the information provided by `encodingType`.

These properties addressed one of the major shortcomings of the original NDL specification, as useful properties were now assignable to individual links. A perfect example is the `encodingType`, which enabled specifying the type of a link, such as whether it represents an L2 Ethernet segment, or a lower level lambda path. There was still little to no support for machine-readable analysis of the attached information, though, and the model did not consider multiple layers which constitute modern computer networks.

As shown by Dijkstra [5], it is rarely sufficient to describe just a single layer of the network at a time. Similarly, it is often not feasible to always operate on the full node graph of a moderately-sized network. The NDL format was therefore extended by provisions for multi-layer network modeling, as demonstrated by van der Ham [6].

The authors show how the NDL can be extended with a concept of *adaptation* and *multiplexing*. Together, these features allow modeling common concepts such as aggregating multiple VLANs into one Ethernet port. The concept is further extended with support for the so-called *Switch Matrix*, a construct suitable for describing features which the network provides on each of the represented layers.

It should be noted that, as Dijkstra shows, opening up the model for multilayer description brings along unintuitive situations. As an example, he presents a use case [7] where the only feasible path within a laboratory in *Universiteit von Amsterdam* and the *Université du Quebec* actually crosses the same fibre *twice*.

An attempt at extending the NDL for photonic services was conducted at CESNET. In a deliverable of the Phosphorus project, CESNET contributed an add-on schema [8] suitable for conveying a wide range of properties concerning the optical path. The proposed extension was capable of accurately describing specialized equipment, such as the DCM (Dispersion Compensation Module, a device which corrects for phenomena resulting from different propagation speeds of different wavelengths in the fibre medium, including its effect on a single-color modulated light) as well as actual, real-world fibre spans and optical light paths deployed in the CESNET2 network at that time. However, the proposal did not make use of the usual NDL features such as the concept of adaptations, and it was not formally merged into the upcoming revisions of the NDL standard.

B. Network Markup Language and the Network Service Interface

The NDL language described in the previous section was not the only contender for delivering a format capable of accurately describing multilayer computer networks. The GÉANT

collaboration worked on the cNIS [9], while the US-based ESnet was independently working on a similar solution needed by perfSONAR. The Network Markup Language (NML) working group [10] was eventually formed within the Open Grid Forum [11] to create a unified, multi-layer network model.

Roughly in parallel, an effort was ongoing on delivering a unified specification for communicating between networks of different administrative contexts. There was a huge range of envisioned applications, from bandwidth-hungry users of the Bandwidth-on-Demand (BoD) service, to testbed users and network students to experiment on a real network, yet in a controlled and harmless manner. These applications, however, required understanding of the underlying network topology.

The Network Service Interface (NSI) framework [12] and its associate suite of protocols is designed to facilitate establishing of multi-domain network connections using a RESTful (Representational State Transfer) web service API (Application Programming Interface). As of 2014, the NSI and the associated specifications are subject of active research and development work. There are plans to use the resulting software throughout the newly developed Testbed as a Service (TaaS) offering by GÉANT. The network topologies represented by NML are being studied for further uses, such as multi-constrained path selection [13], a process where the choices of a link path are affected by several parameters. It seems that the academy has finally settled on a single modeling framework after a phase where concurrent projects were each pushing for their own solution.

C. Nodes, Links and Adaptations

A common feature found in each sufficiently mature multi-layer or multi-domain schema is the appearance of the following building blocks:

Nodes for entities which represent active network devices, or abstraction points which serve a certain purpose which is visible to the other layers.

Links or *Connections* whose purpose is to represent interconnections between the *Nodes*. Each link typically carries a set of *Properties*.

Adaptations which are capable of interconnecting *Nodes* belonging to conceptually different layers of the abstraction.

Within the NDL, these concepts were accurately represented by the *Device/Interface* and *Link* entities. Under the NML abstraction, these are realized through the *Node/Port*, *Link* and *Adaptation/SwitchingMatrix* classes. On a basic level, these building blocks are enough for representing the contemporary network hardware as long as a mechanism for tagging the entries with appropriate machine-readable properties is supported.

At CESNET, the author is developing a graphical CAD (Computer-Aided Design) application which should be capable of handling the future development of the NML scheme as long as the additions and changes remain within the bounds of these three broad categories of functions. Internally, the application uses these classes for manipulating a hierarchy of objects which correspond to actual real-world entities, such as optical amplifiers, Ethernet switches or a leased line between two points of presence (PoP) on a network. The clean architecture of the NML specification enables its users to be written in a generic way. A compliant application will require no code changes to support an updated or new NML schema. The

ultimate goal is to have all the required information present in the newly developed schema; that is, the computer program, which is the user of the extended NML, shall be able to infer any required details from the schema itself.

III. ACCOMMODATING THE PHOTONIC LAYER

While the NSI suite and the associated NML protocol are generic, support for describing the physical layer is explicitly said to be out of scope for the core specification [14]. However, based on personal contact with the GLIF (Global Lambda Integrated Facility, an international consortium that promotes lambda networking) members who are working on the NML adoption, the project is open to external contributions adding support for additional schemes.

A. Importance of the Photonic/Optical Properties

The contemporary Internet, and computer networks in general, are very good at delivering high bandwidth with reasonable latency and mid-to-high jitter. (Jitter describes how much a latency between the end points, which are communicating together fluctuates over time. A low jitter means that the latencies are stable, while high jitter indicates that the latencies might be very low at one point in time, but can grow significantly at any instant.) These properties are usually sufficient for a wide range of applications, from modest HTTP (Hypertext Transfer Protocol) requests and interactive SSH (Secure Shell) or RDP (Remote Desktop Protocol) traffic on one hand to VoIP (Voice over Internet Protocol) or media streaming applications at the other end of spectrum. It is usually acceptable that a latency of each packet varies between, e.g., 15 ms and 45 ms, and the applications which are more sensitive to increased jitter can usually cope with this phenomenon through additional buffering to smooth-over the variance.

However, there are other sorts of applications which are much more demanding, to an extent where a classic network equipment cannot keep up the pace [15]. A photonic service guarantees that the optical signal is transmitted throughout the network without any conversion between the light and electricity, or even statistical processing by a DSP (Digital Signal Processing) circuit common in contemporary systems. The signal is amplified along the fibre paths by dedicated, all-optical amplifiers, and circuit switching is implemented by all-optical equipment. The existing applications which require a photonic service include for example extremely accurate frequency transfers, which are used for comparison of national-level atomic clocks, precise instruments which are involved with the maintenance of the UTC (Coordinated Universal Time) time standard, or other metrological applications [16].

Being able to understand the underlying network opens up opportunities for more intelligent system procurement and significant cost savings [17, p. 20-22], both due to improved network design and innovative concepts such as bidirectional single fibre transmission [1].

B. Extending NML towards the Photonic Layer

Within a computer network which is capable of providing a photonic service, the emphasis on the tracked properties shifts down to the lower layers of the transmission stack. The total available bandwidth of a link is no longer the focus of the model; instead, the data describe how each link can transfer the light, and what modifications are inflicted on the signal as it travels through the fibre.

The total attenuation is one of these properties. However, as the total loss of signal is dependent on the frequency, the attenuation is not a single number, but instead a function, which computes the total loss based on the wavelength, or color of the light beam which passes through the fibre. Because the fibre usually conforms to one of predefined quality/performance classes, it makes sense to track the properties of each of the fibre type separately, and calculate the expected loss as a function of the fibre class and the total fibre length. However, in real world, the attenuation is not affected just by the fibre length. Mechanical stress or vibrations along the fibre path affect the transmission, too, and it is unfortunately common for construction works to interfere with a buried cable in a catastrophic mode, which typically involves an excavator's bucket. When the fibre is spliced back into a working state, the newly introduced joint deteriorates the overall transmission properties, and as such, the measured attenuation increases. Each splice also contributes to an increased in-fibre scattering of the source signal. The model therefore must distinguish between the theoretical, computed values and actual behavior of the fibre established by measurements.

There are other phenomena besides the total attenuation, though. Different frequencies (or wavelengths) travel through the fibre at different speeds, therefore the light impulses received at the end of an uncompensated fibre are distorted, and care has to be taken to reconstruct the original shape of the signal before further processing [1]. There are different means of compensation for this chromatic dispersion, including Dispersion Compensating Fibre or Fiber Bragg Gratings. Properties of both must be carefully described by the model because they impact the transmission properties of the installed fibre path.

Another problem is an accurate representation of devices which are capable of changing the wavelength of the transmitted signal. Conceptually, this transformation does *not* constitute an adaptation, in the NDL/NML sense, as the signal transformation occurs on a single level of the model. However, a naive scheme which simply compared wavelength of adjacent ports of a wavelength converter would assume that a given wavelength would not be able to pass through the device.

There are other interesting phenomena, such as PMD, the polarization mode dispersion, or non-linear effects, which contribute to signal deterioration over a fibre span. An accurate description of these phenomena is needed if the model is to be used as a basis for planning and procurement of optical networks which offer a photonic service to their users.

IV. CONCLUSION AND FUTURE WORK

This work has illustrated that while the NML model is promising, it cannot presently accommodate the requirements of a photonic service without further work. Hence, the NML scheme should be extended to allow describing the photonic layout of the network. The extended NML scheme should be self-describing, that is, it must contain enough information to allow its interpretation by a machine with no prior knowledge of photonics, but with a thorough understanding of the NML features. That way, a compliant application designed for supporting all aspects of NML will be able to work even in face of future additions to the conceptual model without a costly retrofit.

In order to verify feasibility of the chosen approach, a

sizable chunk of a real-world, production network should be described at the chosen level of detail. Adaptations between the low-level photonic layer and the upper layers shall be developed and tested to ensure that the NML's concepts allow an accurate representation of functionality of the modern hardware. To further prove the viability of the general concept and to study applications of semantic network modeling, a demo application shall be built. The technical demo should cover adaptations across multiple layers as well as verification of example properties of the modeled network.

The extended NML suite can be used not only for modeling of existing networks, but also for a design of new transmission paths. A user should be assisted with an extensive, semi-automatic validation of the proposed network topology. For example, while it is perfectly acceptable from the perspective of the semantic model to connect two fibres with a sequence of two add-drop multiplexers which effectively filter out all channels, the resulting topology would present little utility to its operator. A powerful validation framework should therefore be built to check whether the end product of the design is *usable*, i.e., to verify signal propagation paths across the network.

In order to prevent obsolescence and a dangerous situation where the modeled situation no longer matches reality, work should be undertaken to periodically reconcile the model with actual network in an automated manner; a topic which involves queries and call-outs to physical devices deployed in the field.

It is our plan to explore these possibilities in our work at the Optical networks department at CESNET, and in the upcoming GN4 project at GÉANT. As a first step, we will define the required NML extensions on a formal level, and verify their utility on a selected transmission path in the CESNET2 network. We also plan to use the NML extensions in formal description of the Photonic Testbed, a testbed-as-a-service (TaaS) laboratory developed at CESNET, and to benchmark its utility for describing the lowest layer of the GÉANT Testbed Service (GTS), a Europe-wide distributed testbed network.

ACKNOWLEDGEMENTS

This work was supported by the Czech institutional funding of research by project Large Infrastructure CESNET LM2010005 and by the GN3 project under the EU FP7 programme. The authors would like to thank Jan Radil and Josef Vojtěch for their valuable feedback.

REFERENCES

- [1] J. Kandrát, "Why we should care about the photonic layer," in 2nd TERENA Network Architects Workshop, November 2013. [Online]. Available: <http://www.terena.org/activities/netarch/ws2/slides/131113-cesnet-photonics.pdf>
- [2] J. van der Ham, F. Dijkstra, F. Travostino, H. Andree, and C. de Laat, "Using RDF to describe networks," *Future Gener. Comput. Syst.*, vol. 22, no. 8, Oct. 2006, pp. 862–867. [Online]. Available: <http://staff.science.uva.nl/~vdham/research/publications/0510-NetworkDescriptionLanguage.pdf>
- [3] "Resource description framework (RDF)." [Online]. Available: <http://www.w3.org/RDF/> [Accessed: 2015-03-05]
- [4] J. van der Ham, P. Grosso, R. van der Pol, A. Toonk,

- and C. de Laat, "Using the network description language in optical networks," in *Integrated Network Management*, 2007. IM '07. 10th IFIP/IEEE International Symposium on, May 2007, pp. 199–205. [Online]. Available: <http://staff.science.uva.nl/~vdham/research/publications/0606-UsingNDLInOpticalNetworks.pdf>
- [5] F. Dijkstra, "Framework for path finding in multi-layer transport networks," Ph.D. dissertation, 2009. [Online]. Available: <http://www.macfreek.nl/work/Dijkstra-multilayer-pathfinding.pdf>
- [6] J. van der Ham, "A semantic model for complex computer networks: The network description language," Ph.D. dissertation, 2010. [Online]. Available: <http://staff.science.uva.nl/~vdham/research/publications/vdham-phdthesis.pdf>
- [7] F. Dijkstra, "Lessons learned in multilayer network modelling," in *Phosphorus/Federica tutorial at TNC 2008 and NML-WG meeting at OGF 23*, June 2008. [Online]. Available: <http://staff.science.uva.nl/~fdijkstr/presentations/20080518%20Network%20Modelling.pdf>
- [8] L. Altmannová et al., "Recognizing, description, deployment and testing of new types L0/L1 resources," June 2009, pp. 17–39, deliverable Phosphorus-WP6-D.6.9. [Online]. Available: <http://www.ist-phosphorus.eu/files/deliverables/Phosphorus-deliverable-D6.9.pdf>
- [9] "cNIS, Common Network Information Service." [Online]. Available: <http://geant3.archive.geant.net/service/cnis/pages/home.aspx> [Accessed: 2015-03-05]
- [10] "The NML working group (NML-WG)." [Online]. Available: <https://forge.gridforum.org/sf/projects/nml-wg> [Accessed: 2015-03-05]
- [11] "Open grid forum (OGF), an open global forum for advanced distributed computing." [Online]. Available: <https://www.ogf.org/> [Accessed: 2015-03-05]
- [12] G. Roberts, I. Monga, and T. Kudoh, "Network service interface," in *GLIF Meeting*, Atlanta, March 2014. [Online]. Available: <http://www.glif.is/meetings/2014/winter/roberts-nsi-tf.pdf>
- [13] M. Živković, "Multi-constrained path selection," in *GLIF Meeting*, Atlanta, March 2014. [Online]. Available: http://redmine.ogf.org/dmsf_files/13221?download=
- [14] C. de Laat and F. Dijkstra, "NML outreach session," in *OGF 31*, Taipei, March 2011, p. 5. [Online]. Available: <http://www.delaat.net/talks/cdl-2011-03-22a.pdf>
- [15] J. Vojtěch, V. Smotlacha, S. Šíma, and P. Škoda, "Photonic services and their applications," in *Infinity Tridentcom Thessaloniki*, Greece, June 2012. [Online]. Available: http://czechlight.cesnet.cz/documents/publications/transmission-systems/2012/PS_Tridentcom12_2.pdf
- [16] J. Vojtěch, V. Smotlacha, and P. Škoda, "Optical infrastructure for precise time and stable frequency transfer," *Proc. SPIE*, vol. 8866, 2013, pp. 886 620–886 620–5. [Online]. Available: <http://czechlight.cesnet.cz/documents/publications/network-architecture/2013/ITMSfin.pdf>
- [17] J. Vojtěch, M. Hůla, J. Nejman, J. Radil, and P. Škoda, "Equipment for open photonic networking," in *CEF Networks Workshop*, 2010. [Online]. Available: <http://czechlight.cesnet.cz/documents/publications/fiber-optics/2010/Vojtech-EquipmentForOpenPhotonicNetworking.ppt>