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Recognizing, Description, Deployment and Testing of new types L0/L1 resources

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Abstract

Phosphorus developed method and open software enabling on-demand e2e network services across multiple domains and use of heterogeneous network infrastructures with transmission and computational resources. Concurrently, network infrastructures started transition from electronic to photonic transmission and processing, enabling higher transmission speed and lower energy consumption. This had and will further have influence on Phosphorus results.

This document deals with recognizing, description, deployment and testing of new types of L0/L1 photonic resources. A questionnaire was prepared to identify potential importance of such new resources considered by the PHOSPHORUS partners. Then the situation with tools for design and maintenance of photonic networks is presented and primitives for description of such networks are introduced. Development of Transport Network Resource Control (TNRC) for new L0/L1 resources and plans for testing are summarized. Real deployment of new L0/L1 resources in the CESNET2 network and CESNET Experimental Facility is discussed. Practical results of an international demo with CzechLight (CL) optical switches CLS controlled by G2MPLS are demonstrated. The demo uses the global Phosphorus testbed across four countries – UK, NL, CZ and PL. In conclusion, recommendations for development of future TNRC are formulated, based both on theoretical and experimental work (using CzechLight family of commercially available open photonic devices).

There are four appendixes included in the deliverable showing answers to the Questionnaire, basic NDL descriptions of photonic elements, vendor independent terminology and description of photonic switches used for testing.

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0 Executive Summary

The Deliverable identifies and specifies new types of network resources, which are and will be available for Network Resource Provisioning Systems (NRPS). Fibre availability to network users had a big influence on network services development and NRPS development, which have not been understood soon enough. The identified resources were deployed on the Phosphorus test-bed and the CESNET2 network as much as it was affordable.
Layer 0 and layer 1 network resources can be considered as a rather important part for new, bandwidth-demanding network services. Dark fibres have already been identified as very important and strategic layer 0 resources for building new generations of advanced networks. Other layer 0 resources, like optical amplifiers, tuneable compensators or new transponders with advanced modulation formats, are equally important to enable true end-to-end service development. New photonic components are constantly developing and improving, so it is essential to recognize new types and categories, which may be important for usage of Phosphorus results and for specification of targets for new projects.

The Deliverable presents achievements in Recognizing, Description, Deployment and Testing of new types of L0/L1 resources, especially results of their integration to testbed and developing of TNRC interface, attempts to identify and specify new types of low-level network resources, which are and may be available for Phosphorus software deployments. Fibre availability to network users had a big influence on network services development and new low-level resources may have the similar impact. For example, influence of programmable optical devices on network design and management has successfully been demonstrated both in the CESNET Experimental Facility and the CESNET2 network.
Development of a SW called TNRC is essential for deployment and testing of new resources. The TNRC model and configuration examples are the integral part of the Deliverable. Basic Open WDM design concepts, practical results and experience with deployment of CzechLight (CL) devices together with traffic statistics are included too.

Asking of all Phosphorus partners about their suggestions concerning possible deployment or development of new types of devices was a very important step and evaluation of results is available now.

Description (accurate and precise) of network resources is an important task because terminology is confusing or even misused in some cases, standardization needs long time, and it means it is difficult to understand each other. As very first step, careful description using vendor independent terminology in natural language (English) is supposed and then description in NDL to improve consistency and to achieve formal syntax and semantics important for machine aided design and maintenance and enabling exact deduction of description on higher level of abstraction.

Conceptualization is the next important step when describing optical equipment, which is considered as network resources, especially on the lower layers.

Deployment documentation and support for optical devices is described as an important part of optical route projecting.

A vendor independent terminology concerning photonic devices used in the deliverable is explained in Appendix C, and Appendix D with description of photonic switches CLS and Calient follows. CESNET has been developing such equipment (together with software enabling practical deployment) for some time under the name CzechLight family of programmable optical devices. Attempt of development of interfaces between CzechLight family SW and NRPSs being developed by other work-packages in Phosphorus was in principle successful, and manpower needed for TNRC deployment in new environment can be better estimated now. This new type of layer 0 and layer 1 resource can be fully controlled and utilized by end power users.

1 Introduction

When talking and thinking about Resources, CPU and Storage capacities is the first (and perhaps the only) choice for many people. Networking equipment like optical amplifiers or compensators is seldom considered as the true resource with similar importance and magnitude. It is one of the aims of this Deliverable to provide other view on this topic and to emphasise new roles of networking equipment considered up to now as “low-level”.
Layer 0 and Layer 1 network resources can be considered as a rather important part for new, bandwidth-demanding network services. Dark fibres have already been identified as very important and strategic layer 0 resources for building new generations of advanced networks. Other layer 0 resources, such as optical amplifiers, tuneable compensators or new transponders with advanced modulation formats are equally important to enable true end-to-end service development. Optical switches are considered to be very important layer 1 network resources, enabling not only well-known bit rate or protocol independent features, but also introducing new capabilities, like photonic multicasting or broadcasting (photonic means without OEO conversions).

New optical (or photonic) equipment is constantly being developed and improved so it is essential to recognize new types and categories, which may be important for results of Phosphorus - or at least for specification of targets for new projects.

CESNET has successful results in research of open photonic devices, followed by licensing of developed technologies to vendors. Family of open photonic devices is based on the most advanced components developed and delivered by photonic industry and on Linux operating system. It is extension of a successful and well-known idea of vendor-independent open Linux software development to hardware and firmware development, where advanced optical components (optical amplifiers, ROADMs, switches, etc.) are controlled by Linux drivers as peripheral devices of a small rack-mounted PC. This method enables network research driven by experimentation and influencing of vendors development road maps. This feature proves to be important also for Phosphorus project.
In Milestone M6.4 – ‘New types of network resources available for test-bed’ we decided, that new types of network resources available for NRPS will be mainly all-optical resources as all-optical lambdas transiting network nodes without OEO conversion (all-optical lambda

segments), optical amplifiers and dispersion compensators allowing lengths of that lambda segments up to hundreds km, bands of multiple all-optical lambda segments, all-optical switches and all-optical multicast switches including multiband multilambda switching.

Embedding of photonic components to devices for deployment in test-beds and networks is solved by CESNET independently on Phosphorus project (CzechLight family of devices) and licensed to vendors. Connection or adaptation of that or similar devices to Phosphorus testbed and their control are examined in Phosphorus.

New features of CzechLight Switch (CLC) are available, especially the first version of Scheduler, allowing to configure the optical switch remotely via web-based GUI and thus allocating resources for different purposes. CLS can be delivered with the following configuration: PLC based 8x8, 16x16 cross-connect, MEMS based 16x16 cross-connect or in case of interest 4x4 or 8x8 MEMS based cross-connect. Number of ports will be increased concurrently with more advanced embedded photonic components availability, keeping cost of device low.

Working on the Transport Network Resources Controller (TNRC) API documentation (specifically CzechLight Switch description), CESNET elaborated CLS command line interface, which listen to TCP/IP connection from TNRC API). We worked on CzechLight Switch Command Line Interface (CLI). Command line interface was the first step before implementation of Phosphorus's TNRC. CLI listen on TCP/IP socket for incoming connections from clients (i.e. Phosphorus, etc.). CLI supports making of cross-connects, getting the system version and later getting the power level. We evaluated issues concerned with optical power monitoring at inputs or/and outputs. CzechLight Switch (CLS) and CzechLight Multicast switch (CLM) have the first version of Command Language Interface ready. Subset of Telnet protocol is used, with VTY interface. New show commands were added (especially port-mapping, status of cross-connections). We elaborated work on TNRC adapter.

The advantage of CESNET approach, in comparison with building of NREN by “procure and buy” method, lies in its own research and development of networking equipment. This option is used, if needed, for research of networking or for serving to research and education community, and procurement is not satisfying requests in equipment functionality, delivery time, costs, energy and space savings, etc., i.e. requested equipment is missing on the market. This approach is possible, if suitable components (products of photonic industry, electronic components, FPGAs, open software modules, etc.) as building blocks for equipment construction are available and interoperability on physical layer between new designed equipment and other (procured) equipment in the network is solved. We should understand, that request of interoperability here is not special, because it is inherent in multi-domain research networking in general. Final and crucial step is transfer of new developed technology (new equipment) into production and service.

We have decided to use other part of CESNET2 network and CESNET Experimental Facility, equipped by open photonic devices and extend this part by open optical switching equipment (similar more to the optical switch from Calient then ADVA ROADMs). These optical switches (CLS) are available as 8x8 ports, with 16x16 being developed. Optical multicast (CLM) switch (4x4) is also available and can be tested.

With SW already written and available for ADVA and Calient equipment, it was feasible to write our part so the 8x8 switch was tested together with other equipment in CESNET Experimental Facility or CESNET2 network. CLS is prepared for remote IP control and remote scheduling of switching times. Multicasting photonic switch CLM with similar management is also available.

Chapter 5.4 deals with a deployment documentation and service support of optical devices deployed in an optical route.

2 Recognizing and Description of New Layer 0 and Layer 1 Resources

This chapter deals with the questionnaire sent out to participants to investigate interest in new L0 and L1 resources. Questionnaire is briefly described and results are discussed. Partially on these results and other feedbacks gained from participants during run of Phosphorus project, the recommendations for future development of control plane are stated.

In consequence of this the emphasis is given to importance of impairments in present and future optical networks. These can be partially eliminated, however due to permanent increase of bandwidth and QoS demand, the future control planes should take impairments into account. The possibilities of impairments monitoring are also briefly discussed here.

2.1 Questionnaire Description

Questionnaire is intended to examine interest of participants in photonic network resources. It is divided into two basic groups according to wavelength sensitivity of these resources.

2.1.1 Wavelength insensitive devices

The first group consists of wavelength insensitive devices. The devices don't treat particular wavelength channels and they are broadband (in defined bandwidths). Questionnaire deals with fibre switches without and with an optical multicast option. These devices can route whole defined bandwidth from each input to one or more (with a multicast option) outputs.
They can be deployed in the both LAN and WAN applications as e.g. clever patch panels, in protection applications, etc. The multicast option could be used for multimedia streaming or monitoring purposes.

2.1.2 Wavelength Sensitive Devices

The second group consists of wavelength sensitive devices. The devices treat particular wavelength channels. Questionnaire deals with Variable Multiplexers (VMUX), Reconfigurable Optical Add Drop Multiplexers (ROADM), Wavelength Selective Switches (WSS) and all optical wavelength converters.

The first four devices are typically deployed in wavelength division multiplex (WDM) systems. VMUXes have typically more arbitrary inputs and one composite output and they are intended for application at terminals for signal equalization and binding or alternatively un-binding.

ROADMs typically offer the same number of composite input and output interfaces-network interfaces. The number of network interfaces determines the degree of ROADM. Tributary wavelength channels can be added or dropped through group of ADD inputs or respectively DROP outputs. Typical configuration contains one group of ADD inputs and one group of DROP outputs.

WSSs are similar to ROADMs, but offer only network interfaces without ADD/DROP tributaries.

All optical wavelength converters convert input signal (can be on-grid or "grey") to one or more output copies, they are typically on-grid. These converters can also perform all optical regeneration – 2R or 3R.

2.2 Results of Recognizing

2.2.1 Questionnaire

Asking Phosphorus partners about their suggestions concerning possible deployment or development of new type devices was seen as crucial step. Asking Phosphorus partners we have acquired interest in testing and interest in operation of advanced photonic devices.

Interest in testing was understood mainly as interest to acquire more information about device including practical experience. Interest in operation was understood mainly as interest to improve networks by deployment of devices in general. We have received valuable answer from eight partners. Answers are available in Appendix A, including questions used in Questionnaire.

2.2.2 Evaluation of Results

- **Highest or high recommended devices for testing by preference:**
  - All-optical wavelength conversion (from grey signal to ITU-T grid)
  - Reconfigurable Optical Add/Drop Multiplexer (ROADM)
  - Wavelength selective switch (WSS)
  - Path (fibre switch) with multicast option
  - Path (fibre switch)
  - Variable multiplexer (VMUX)

- **Highest or high recommended devices for using in operation by preference:**
  - All-optical wavelength conversion (from grey signal to ITU-T grid)
  - Path (fibre switch) with multicast option
  - Reconfigurable Optical Add/Drop Multiplexer (ROADM)
  - Wavelength selective switch (WSS)
  - Path (fibre switch)
  - Variable multiplexer (VMUX)

Participants prefer group of wavelength sensitive devices for testing and using in operation. In context with this, participants were rather network users than transmission systems designers.

2.3 Recommendations for Future Control Plane Development

Today various real-time applications, such as audio and video conferencing are being deployed over the Internet. This requires the network to provide guarantees of the service provided to the receiver. The needs of applications are specified in terms of Quality of Service (QoS) metrics such as the desired bandwidth, response time, loss rate, expected reliability, etc.

Support for QoS must be provided at each of the layers of the protocol stack for overall efficiency in network utilization. Routing algorithms supporting QoS differentiation differ from traditional routing algorithms in that, in QoS routing, the path from the source to the destination must satisfy multiple constraints simultaneously, while in conventional routing, routing decisions are made only on a single metric, such as cost or delay.

The latest TNRC version is using a simple metric based on the line/port bandwidth. This simple metric is not enough for future requirements. Recommendation is to use more complex metric based on user requirements, e.g. jitter, delay, fibre length, number of hops, line quality or reliability.

With the rapid progress of optical networking technology, it is now a unique technique to support point-to-multipoint connections directly on the physical layer, giving rise to optical multicast. Multicasting technology using L0/L1 transport provides a number of significant benefits, including higher performance, cost effectiveness, and excellent quality of service. Optical multicast allows for much larger streams than packet routed networks, e.g. multicast at multiple Gbps. In this context, high-performance refers to reliable, consistent, high-quality delivered service, with minimal jitter and latency over very long distances. Our suggestion is a real multicasting implementation in the future of Phosphorus project. The current TNRC release assumes only simplex or duplex unicasting topology, but the multicasting trends will play more important role in the future.

The main purpose of TNRC is abstract interface implementation between the Transport Plane data model and the real equipment. The latest TNRC version supports base functions as make/drop cross-connection, but additional information about equipment is missing. The idea is to implement a better TNRC interface for getting more detail information, such as port name, description, in/out statistic, error rate, etc. In/out statistics and error rate allow for computation of the best path algorithm.

2.4 Towards Impairments Sensitive Future Control Planes

It is obvious that influence of impairments is unfortunately growing with increasing of transmission speeds [14]. Influence of some impairment can be partially compensated or mitigated, for example by utilisation of advanced, to some impairment less sensitive formats. Unfortunately, compensation of one of the impairment introduces other impairments, and in the same manner, the modulation format less sensitive to one of the impairments is higher sensitive to others.

2.4.1 Impairments in Optical Networks

Fibres together with components of optical networks introduce a lot of different impairments. We can start with the simplest one – the attenuation. It can be overcome by amplification. But real amplifiers add to output signal some amount of noise and cause thus

Optical Signal to Noise Ratio (OSNR) degradation. Other impairments are dispersions. Modal dispersion occurs in Multi Mode Fibres (MMF) because particular modes propagate with different speeds and cause broadening of input pulse at the fibre end. The different wavelengths (colours) propagate with different speeds fibre because the refractive index is a function of wavelength [15]. Additionally, real pulses are no monochromatic, but consist of more wavelengths. As each wavelength propagates at different speed, the input pulse is also broadened; this phenomenon is called Chromatic Dispersion (CD). Other group is polarization related impairments: Polarization Dependent Loss or Gain (PDL/PDG) and Polarization Mode Dispersion (PMD). Almost all optical materials exhibit some polarization sensitivity and because source can change its polarization state randomly, attenuation or gain can also change its value [15]. This makes e.g. power budget and other calculations more complicated. Because a fibre core is not absolutely circular, different states of polarization can travel at different speeds. This again leads in pulse broadening at the fibre end. This phenomenon is denoted as PMD. Unfortunately, optical media also presents not an absolutely linear environment and last group of impairments is based on non linear properties of fibre: Self Phase Modulation (SPM), Cross Phase Modulation (XPM) and Four Wave Mixing (FWM) [14].

2.4.2 Impairments elimination (incl. advanced modulation formats)

Different optical impairments can be eliminated by different means. For example using low-noise amplification techniques like Raman amplification will help to increase optical signal-to -noise ratio. Another well-known impairment like chromatic dispersion can be mitigated relatively easy with many types of compensators. On the other hand, nonlinear effects like self-phase modulation or statistic phenomenon like PMD are more difficult to eliminate.

One possible solution to improve tolerances to such ‘unpredictable’ phenomena is to use so called advanced modulation formats. Well-known and simple (and therefore not expensive) modulation format called On-Off Keying is used for bit rates up to 10 Gb/s. Modulation formats like ODB, DPSK or DQPSK are used for 40 Gb/s bit rates. These modulation formats have better spectral efficiency and tolerances to non-linear effects and dispersions. Unfortunately transceivers for such formats are inherently more complicated and expensive.

2.4.3 Impairments monitoring

Basically optical link impairments are measured offline when no live traffic is carried. These results can give basic ideas regarding e.g. attenuation, CD and PMD. However PMD is stochastic and may vary in time (especially in aerial cables). Furthermore, when dynamical path or wavelength assignment at higher transmission speeds is considered, the impairments must be monitored online.

We can distinguish between active and passive approaches. In active approaches, the special measurement signal is generated.

In an approach according to [16], the signal is launched into unused fibre or wavelength paths and received by a special receiver. This obviously enables monitoring of temporary unused paths only.

According to [17], the special signal is inserted after data transmitter (or transmitter have ability to generate such a signal) and at receiver side the measurement signal is removed before reaching data receiver. In an alternative approach, the data receiver is insensible to measurement signal, thus the composite signal is split only before reaching the data receiver.

Fully passive approach can be utilized too, e.g. asynchronous sampling and histogram processing according to [18]. The data signal before reaching receiver is split and one part is used for measurement.

3 Tools for design and maintenance of photonic networks

3.1 Need for machine aided tools

Work on transmission system designs by using advanced optical amplifiers started in CESNET in 2001. We operated 189 km NIL transmission line Praha-Pardubice since 2002 [20]. We have entered scenario of building NREN transmission system as multivendor domain by this step. Further steps were lighting of some other dark fibre lines, development of more advanced photonic devices and licensing it for industry manufacturing, delivering and service. We understand importance of tools supporting transmission line design, testing of abstract transmission line models, specification, documentation, implementation with possibility of remote setup and maintenance including machine aided recovery. Based on development of CLS, CLM and other advanced photonic devices, we should speak about design, models, testing, specification, documentation and maintenance of photonic networks instead of transmission lines only. Having experience with electric circuit design tools and computer design tools, we keep in mind that formal syntax and formal semantics of a specification language will be needed for advanced tools allowing composition of specifications, testing of consistency between description and real network setup and deriving properties of network specification.

3.2 Importance and tools for photonic network design

Importance of photonic (all-optical) transmission and processing in networking is strongly growing. Main drivers are higher freedom of design, higher transmission speed (100Gb/s and more) and saving energy and network maintenance costs (secure economical and “green“ advantages). All-optical design is not necessarily reduced to enumerable set of possible configurations defined usually by an equipment manufacturer or standard, we can work with continuum.

Freedom of design and other advantages could be fully exploited, if **network aided network design tools** are available. Similar needs and tools are well understood in electrical circuit design, computer design, database and software design, but is rather new in network design. It is usually spoken about tools for Computer-aided design (CAD), but advantages of using remote tools in network instead of one computer only are supposed implicitly.

Development of CAD tools as well as Network Aided Network Design (NAND) tools needs conceptualization and ontology as background for programming of tools. It is more than standardisation and technical documentation, we need:

- network descriptions suitable for machine analysis and elaboration (formal syntax needed)
- small set of network primitives suitable for describing all-optical networks by combination (semantic definition of formal language needed, at least in natural language)
- deducing (inferring) or proving of properties from network description (formal semantics needed)

Standardization work is needed for vendor-independent human understanding of network descriptions, but machine processing needs more. Formalization needed for machine processing brings difficulty for wide human understanding, so technical contribution of the work on description is not obvious. Of course, it is possible to write explanations but they are rarely exact. If you should elaborate some design tool, you need to do programming work and acquire building blocks for this work.

3.3 Conceptualization for photonic device and network design

For this purpose, we used the Network Description Language [6]. It was designed for universal description of networks. Our general intent is to use what is available and to develop further schemas needed for our purposes.

At Network Description Language (NDL) [6] homepage, there are already available created schemas for network description. Abstract layer schema for description of relations between network layers, domain schema for description of administrative domains, technology schemas for protocol and technologies description (e.g. ip, ethernet, tdm, wdm, wireless, etc.) and some other. There is not available schema which would describe physical layer of optical transmission, layer that uses property of laser beam, like optical power amplitude, attenuation, gain, dispersion, etc.

We discuss conceptualization and ontology for all-optical data transmission and data processing networks. Optical schema is suggested, then expressed in Network Description Language (NDL) and its application is demonstrated in description of Optical Fibre, Optical Transmitter, Optical Receiver and Optical Switch. Approach to Optical device design is described and refined, enabling more exact communication with research partners in design and application of advanced photonic devices and network.
Description of photonic (all-optical) elements, devices and networks in formal language (NDL) can be used for improvement of mutual understanding between photonic networks designers (for example when interconnection of photonic networks belonging to different domains is needed) and also for improvement of mutual understanding between photonic networks designers and optical experts. Description and understanding are not limited to standardized transmission methods or to certain level of abstraction, so it could help for multilevel description (starting for example on laser beam level), on special (atypical) solutions, description of experiments or new types of devices. Despite of this, we should note that work on conceptualization and design tools is not to bring new results in photonic or optical experimentation.

NDL was designed in order to describe arbitrary part of telecommunication networks; it could be divided into thematic layers. Each layer is stand-alone described and can be connected to higher and lower layers. And each layer is stand-alone administrated. Individual NDL documents are textual RDF documents [7] with XML syntax [13].

In principle, formal description enables machine processing of some important designer tasks, such as testing or verification of properties of network created by interconnected elements (using formal description of network before implementation) or expansion of description (for example to have more ports in an Optical Switch device). It is also supposed to have user-friendly interface for generation of NDL descriptions. Very important task is abstraction, i.e. derivation of higher level (simpler) description from lower level (more detailed) description, leaving some (inner) parts or properties of device or network "invisible". In network operation, physical devices should be able to deliver their own NDL description on demand, enabling to update automatically description of network (for example in the case of device upgrade, band allocation or network restructuring). Design support of this kind needs software tools using description in formal language as input or output. Those tools are not available now and should be elaborated in a suitable next project.

We didn't use NDL during OpenDWDM planning but there are some visions for future. When an optical route is designed and is similar to already designed one, by NDL would be easy to duplicate it and change only required parameters. It is considered to be useful to generate automatically NDL description documents from backups of configurations of CL devices, which are saved at the CzechLight server, as it is mentioned in the chapter 5.4. But for all this, sophisticated user SW tools are required.

In writing and using device descriptions, we should distinguish between the Device type and Physical device.

Device type is specification of a class of Physical devices, belonging to this type. This means type of device is an abstract entity. Specification of device type should allow deciding, if any physical device belongs to that type.

For decision, Device type specification written in natural language (usually in English) or in a formal language is needed. Furthermore, description of Physical device sufficient for optical and electrical circuit designers is needed (written usually in natural language with symbols common for designers). We should understand that Physical device description delivered by vendor is also an abstract entity describing a class of objects (any two physical devices conforming to this description are not exactly the same), but this deeper refinement is not needed for all-optical network designer and network usage designer.

By description in formal language we mean description in language with formal definition of syntax and semantics, allowing specifying mutual interconnections of different device types. We need to be able to compare devices or networks and to keep uniqueness, consistency and integrity of description. Formal language should also allow deriving higher level specification (for example by abstraction from interconnections inside higher device type).

We should also distinguish, if description of Device type is available in natural language or in formal language and if description of Physical device is available in natural language written by independent institution or written by vendor PR-style. Each item could be publicly available, available for Phosphorus participants, available for owners only or not available.

We use adjective “photonic” or “optical” for all-optical elements here, realizing optical data transmission or optical data processing without optic-electro-optic (OEO) conversion. Photonic devices and photonic networks are concatenation of photonic elements. Data transmission or processing by photonic elements, devices and networks could be controlled by electrical signals. (This terminology differs from frequent texts where optical network means any network using optical fibres.)
In this paragraph, one of the first attempts to write formal description of photonic elements, devices and networks is presented.

Conceptualization and ontology for all-optical data transmission and data processing networks are discussed in introduction. Optical schema is suggested, then expressed in Network Description Language (NDL) and its application is demonstrated in description of Optical Fibre, Optical Transmitter, Optical Receiver and Optical Switch. Approach of authors to Optical device design is described and refined, enabling more exact communication with research partners in design and application of advanced photonic devices and networks. Possible next steps in machine processing of formal description of all-optical networks for designers are indicated.

In this introduction, we shortly explain method of abstract description of photonic elements and devices, for specifying building blocks of photonic networks independently on some physical properties of elements and devices and independently on terminology and descriptions used by their vendors. Purpose of such description is to enable unified description of multivendor and multi-domain photonic networks. This level of description is considered as fundamental level for photonic networks design and for mutual understanding of designers (or users) of photonic networks. We speak usually about conceptualization and ontology, i.e. creation of formalized knowledge of some environment for given purpose. Overview and references to ontology works in computer science are available for example in [1].

Conceptualization and ontology presented here could be seen as an “interface” for mutual understanding and collaboration between photonic research community and networkers discussing the future Internet development. That interface has not been fully explored anywhere and will potentially require major contributions from the photonics research community. Research on ontology is expected to have an important role in the future engineering design thinking [2] and seems to be viable in the future networks design and the interoperation. In some computer and network design workplaces, the approach based on knowledge of formal semantics has long tradition [3], whereas has not been supported by processing tools yet. It is recognized, that the importance of knowledge management is constantly increasing.

In general, conceptualization should also help people without deeper knowledge of optics to understand photonic networks design and potential applications (knowledge of informatics or mathematics could be sufficient). It looks relevant also for people studying new application possibilities in the Future Internet.

In the writing and using device descriptions, we should distinguish between an abstract element or device and a physical element or device. The abstract device (called also Device type) is specification of a class of Physical devices, belonging to this type. This means Device type is an abstract entity. Specification of the abstract device type should allow deciding, if any physical device belongs to that type. Similar relations are between the abstract element and the physical element.

For decision, Device type specification written in a natural language (for example in English) or in a formal language is needed. Furthermore, description of the Physical device sufficient for optical and electrical circuit designers is needed. It is usually written in natural language with symbols common for designers; see for example Standards (free short sample is available on-line in [4]). We should understand, that the Physical device description delivered by vendor is also an abstract entity describing a class of objects (any two physical devices conforming to this description are not exactly the same), but this deeper refinement is supposed to be not necessary for photonic network designer and network application designer.

By description in formal language, we mean description in language with the formal definition of syntax and semantics, allowing specifying mutual interconnections of different abstract elements or abstract devices. The purpose of description in formal language is to enable computer aided design, processing, verification etc., whereas terminology and semantics should be based on available Standards.

The ability to compare elements, devices or networks and keep uniqueness, consistency and integrity of the description should be maintained. Formal language should also allow deriving higher level specification (for example by abstraction from interconnections inside higher device type or inside network). This is an important request, because formal description on elementary photonic level is frequently very long text. Nevertheless, we should say exactly, what is the rule for abstraction (for example, what internal elements or properties will be

disregarded on given higher level view). That rule will allow us to decide, whether a higher level description is an abstraction of basic level description (or is “wrong”).
We made efforts to use Network Description Language (NDL) [5 - 7], because it deals with interconnections in general sense. We show how NDL enables to create schemes describing optical devices (a technology scheme in the NDL terminology). We decided to describe optical devices with help of spectral width of a basic element called a ‚passband‘. In the NDL language we created a new technology scheme called an optical scheme. This approach is based on experience in open photonic devices family design and deployment in dark fibre networks [8 – 11].
This new optical scheme can be described as follows: a new optical device is defined together with input and output ports. Transmission functions between ports are defined by means of a passband – certain limited amount of bandwidth can be transmitted between particular ports. Every passband is defined with two basic properties: frequency beginning and end (in Hertz). Other various passband properties like attenuation, gain, length or chromatic dispersion are defined in the context of a particular optical device. For example, optical fibre is characterized by attenuation, length and chromatic dispersion but not gain. On the other hand, an optical amplifier is characterized by gain and other properties specific for an amplifier, but length or attenuation are meaningless. When the optical device is described, it has to be decided, which properties are relevant for a given purpose and subsequently a specific passband, respective to this optical device, which can be defined.

3.4 Primitives for description of optical devices

As a basic parameter for the description of optical devices we choose the transmission bandwidth. Bandwidth clearly identifies the use of the transmission path for each transmission channel, and the most of transmission parameters (attenuation, amplification, dispersion, ...) are related to the bandwidth.

Each optical device has optical input and (or) output ports. By the transmission bandwidth can be described, between which ports can be transfer made and which direction. This bandwidth is described by the beginning and the end. As next, the impairments in the bandwidth are described together with their impact on the transmitted signal.

Optical schema with primitives for descriptions

Primitives for designer are set of all items (or basic description entities) available in given language for description. The first step to conceptualization could be the definition of above set for descriptions still written in natural language. For photonic networks, following primitives are suggested:

OpticalElement (properties) (range)

	hasOpticalPort	OpticalPort
OpticalPort	(properties)	(range)
	passBandTransmit	PassBand
	minimalPower	float
	maximalPower	float
	connectorType	string
	connectorPolish	string
PassBand	(properties)	(range)
	hasSpreadPassBandParameters	PassBand
	passBandTransmit	OpticalPort
	passBandBegin	float
	passBandEnd	fload
	isNotAvailable	boolean
	isOccupied	boolean
	attenuation	float
	attenuationCoefficient	float
	length	float
	gain	float
	setPowerLevel	float
	chromaticDispersion	float
	chromaticDispersionCoefficient	float
	polarizationModeDispersion	float
	polarizationModeDispersionCoefficient	float
	minimalPower	float
	maximalPower	float

3.4.1 OpticalElement

OpticalElement class is a foundation stone for creating description. We are starting by creating an object which is instance of this class. OpticalElement could be optical fibre, attenuator, transmitter, receiver, MUX, DEMUX, amplifier, DCF, and other.

3.4.2 OpticalPort

When we have defined some OpticalElement, we can define its ports. Port means here a pluggable connector, or just a cut bare end of a fibre. It doesn't matter if the port is input or output. Optical fibre should have defined two OpticalPorts, a transmitter only one, all-optical switch with 4 input ports and 4 output ports should have defined 8 OpticalPorts.

3.4.3 PassBand

When we have defined OpticalElement with OpticalPort(s), we can define a possibility to transfer signals between OpticalPorts. For this purpose we have defined a PassBand class. It is a class with many properties and its application is more obvious from description of its properties. When the instance of the PassBand class is defined, it means that there is a capability to transfer signals between two objects that are connected by passBandTransfer property.

3.4.4 Properties

hasOpticalPort

This property belongs to OpticalElement class and its value is OpticalPort. That means Optical element owns some optical ports (eg. fibre has two ports).

passBandTransmit

Property belongs to OpticalPort or PassBand and its value is PassBand or OpticalPort. It is usually applied from OpticalPort object to PassBand object and from PassBand object to OpticalPort object. That means there is a capability to transfer signals in pass-band with adjusted parameters (attenuation, gain ...) between two optical ports.

hasSpreadPassBandParameters

Property belongs to PassBand and its value is PassBand. It is useful for separation pass-band to smaller sub-bands, e.g. separation to channels according to ITU-T specifications.

passBandBegin

Property belongs to PassBand and its value is float. Begin of the pass-band is in units of Hz.

passBandEnd

Property belongs to PassBand and its value is float. End of the pass-band is in units of Hz.

isNotAvailable

Property belongs to BassBand and its value is boolean. When is set and value is true, pass-band is not currently available, but device is capable to provide it.

isOccupied

Property belongs to PassBand and its value is boolean. When is set and value is true, device is capable to provide a pass-band, but the pass-band is currently occupied by another signal.

attenuation

Property belongs to PassBand and its value is float. It is an attenuation of optical power in a defined pass-band. Units are decibels [dB].

attenuationCoefficient

Property belongs to PassBand and its value is float. It is a coefficient of attenuation which depends on length. Coefficient multiplied by length is attenuation. It is useful for fibres. Units are decibels per meter [dB/m].

length

Property belongs to PassBand and its value is float. It is useful for fibres, or DCF, etc. Units are meters [m].

gain

Property belongs to PassBand and its value is float. It is a gain of input signal (added power). It is useful for optical amplifiers. Units are decibels [dB].

setPowerLevel

Property belongs to PassBand and its value is float. When it is set, output power has that value regardless to an input signal. It is useful for optical amplifiers or transmitters. Units are watts [W].

chromaticDispersion

Property belongs to PassBand and its value is float. Value of chromatic dispersion added in a pass-band. It can be positive or negative. It is useful for DCF, CD compensation modules, etc. Units are picoseconds per nanometre [ps/nm].

chromaticDispersionCoefficient

Property belongs to PassBand and its value is float. It is value of chromatic dispersion depends on length. Coefficient multiplied by length is value of chromatic dispersion. It is useful for DCF. Units are picoseconds per nanometre and kilometre [ps/(nm*km)].

polarizationModeDispersion

Property belongs to PassBand and its value is float. Value of polarization mode dispersion added in a pass-band. Units are picoseconds [ps].

polarizationModeDispersionCoefficient

Property belongs to PassBand and its value is float. Coefficient of polarization mode dispersion added in a pass-band. Units are picoseconds per square root of kilometre [ps/sqrt(km)].

minimalPower

Property belongs to PassBand or OpticalPort and its value is float. It is a minimal power which can be transmitted (detected). When property is defined for OpticalPort, a total amount of power in all pass-bands coming to the port can’t be set under that value. It is useful for optical amplifiers or receivers. Units are watts [W].

maximalPower

Property belongs to PassBand or OpticalPort and its value is float. It is a maximal power which can be transmitted (received). When property is defined for OpticalPort, a total amount of power in all pass-bands coming to the port can’t overflow that value. It is useful for any inputs ports, or output ports of optical amplifiers. Units are watts [W].

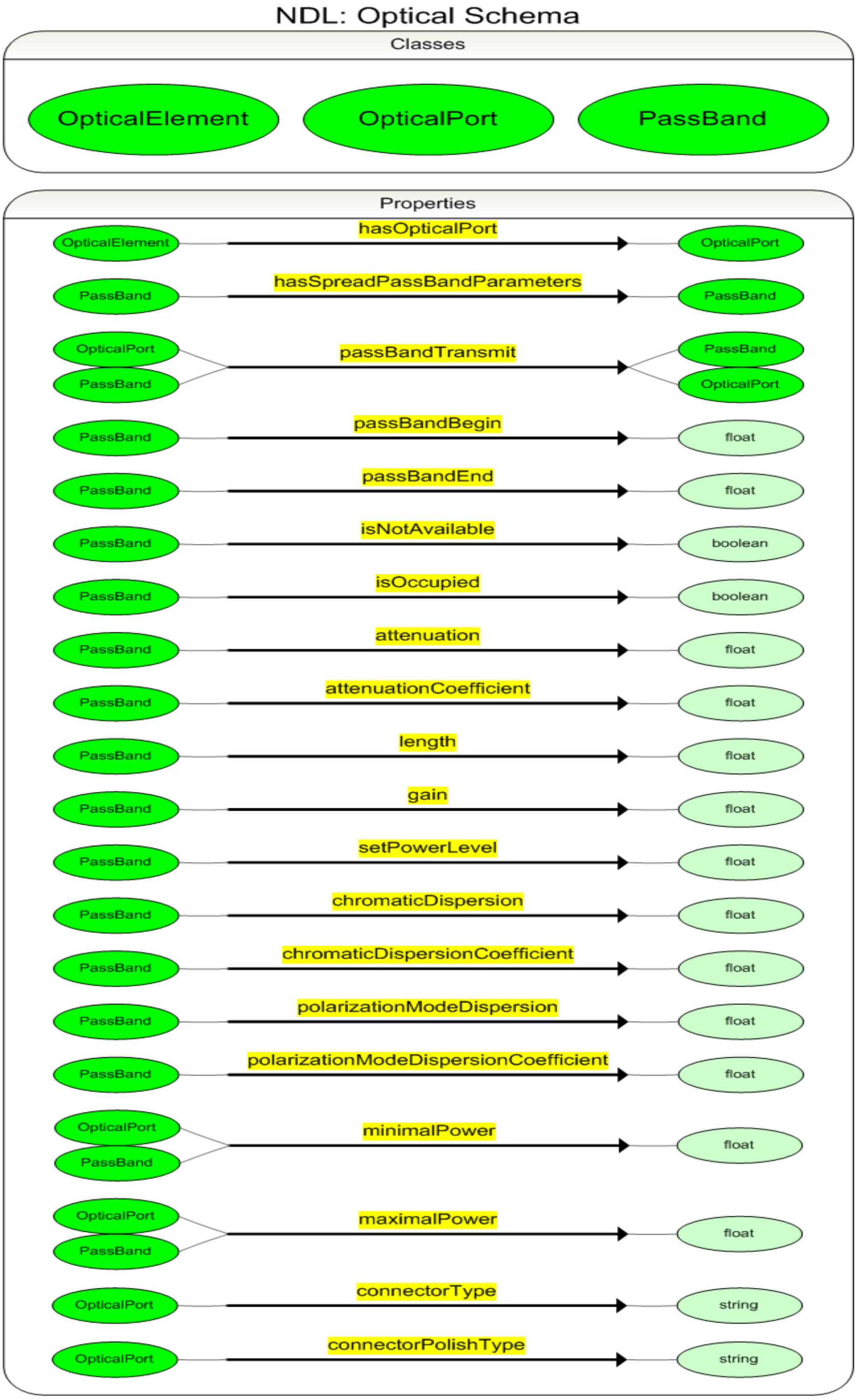
connectorType

Property belongs to OpticalPort and its value is string. It is a type of connector, e.g. FC, LC, SC, ST, etc.

connectorPolishType

Property belongs to OpticalPort and its value is string. It is a polish type of connector, e.g. APC, PC, UPC, etc.

Graphical representation of above mentioned Optical schema is in Figure3.1. Full description in NDL is available in Appendix B or on-line [12].



.

Figure 3.1: Optical schema

3.5 Description of abstract optical devices

Using optical schema, we can write descriptions of abstract photonic devices, including devices for edge of all-optical network: transmitters for electro - optic conversion and receivers for optic - electro conversion.

Transmitter

Transmitter is a device that converts electrical signal to laser beam. Laser beam is modulated and has a specific carrier wavelength with side bands. After modulation (and some additional few steps) is laser beam transmitted into fibre. A bandwidth of laser beam is important in this description. NDL diagram of Transmitter is on Figure 3.2.

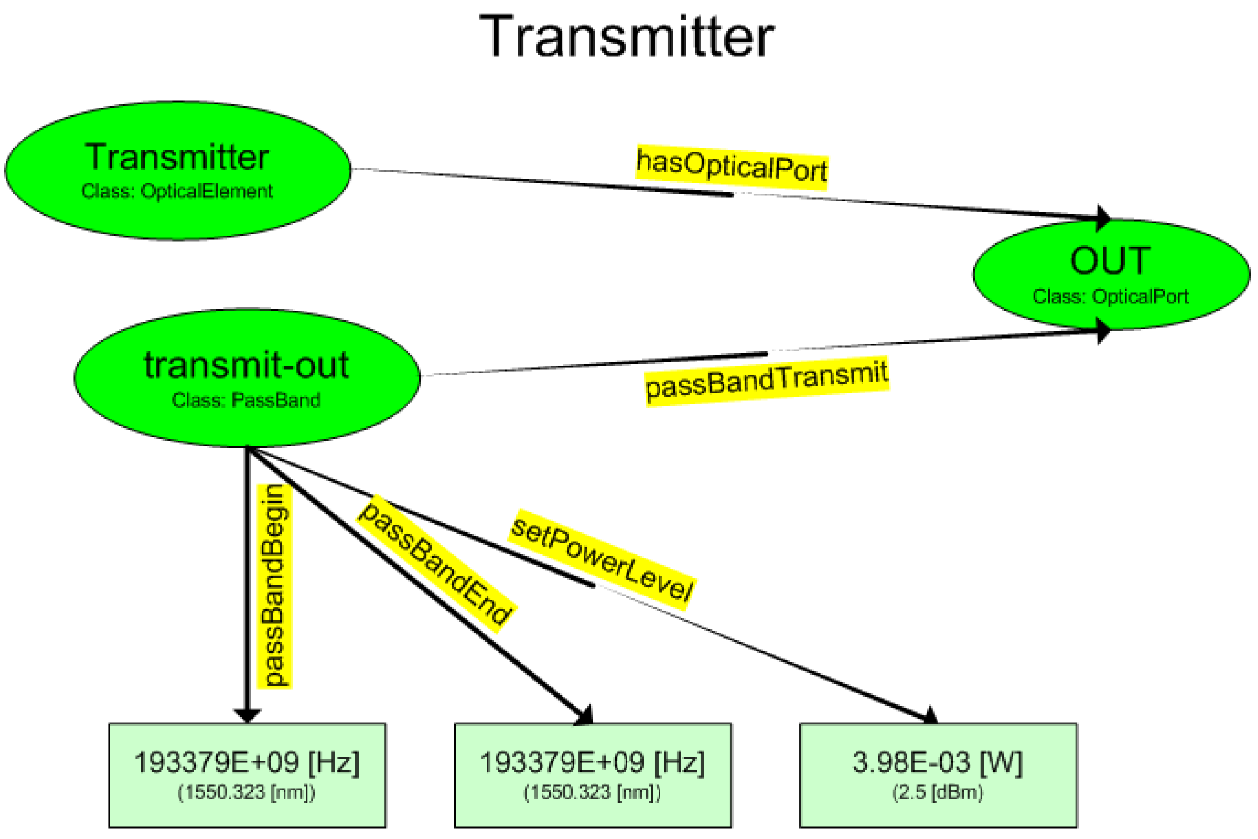


Figure 3.2: NDL Diagram of Transmitter

Transmitter – Description in NDL

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE rdf:RDF>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
         xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
         xmlns:ndl="http://clserver.cesnet.cz/rdf/ndl/optical_schema.rdf#"
>

<!--
  This document describes an optical transmitter.

  There is 1 output port.
-->
<ndl:OpticalElement rdf:about="#Transmitter">
  <rdfs:label xml:lang="en">Source of laser beam</rdfs:label>
  <ndl:hasOpticalPort rdf:resource="#OUT" />
</ndl:OpticalElement>

<!--
  Optical ports.
-->
<ndl:OpticalPort rdf:about="#OUT">
  <rdfs:label xml:lang="en">Output optical port</rdfs:label>
</ndl:OpticalPort>

<!--
  Pass-band transmit into OUT port.

  Trasmitted is wavelength 1550 nm (193419E+09 Hz) with 80 GHz spacing (40 GHz on both sides),
so,
  pass-band from 193379E+09 Hz to 193459E+09 Hz is transmitted.

  Optical power of transmitted beam is set to 3.98E-03 W (2.5 dBm).
-->
<ndl:PassBand rdf:about="#transmit-out">
  <rdfs:label xml:lang="en">Transmit from transmitter inside to OUT port.</rdfs:label>
  <ndl:passBandTransmit rdf:resource="#OUT" />
  <ndl:passBandBegin>193379E+09</ndl:passBandBegin>  <!-- 1550.323 nm -->
  <ndl:passBandEnd>193459E+09</ndl:passBandEnd>      <!-- 1549.682 nm -->
  <ndl:setPowerLevel>3.98E-03</ndl:setPowerLevel>
</ndl:PassBand>

</rdf:RDF>
```

Receiver

A receiver converts laser beam back to electrical signal. There are many types of receivers with various demodulations. Common properties are bandwidth and sensitivity of input power. These are used in this example. NDL diagram of Receiver is on Figure3.3.

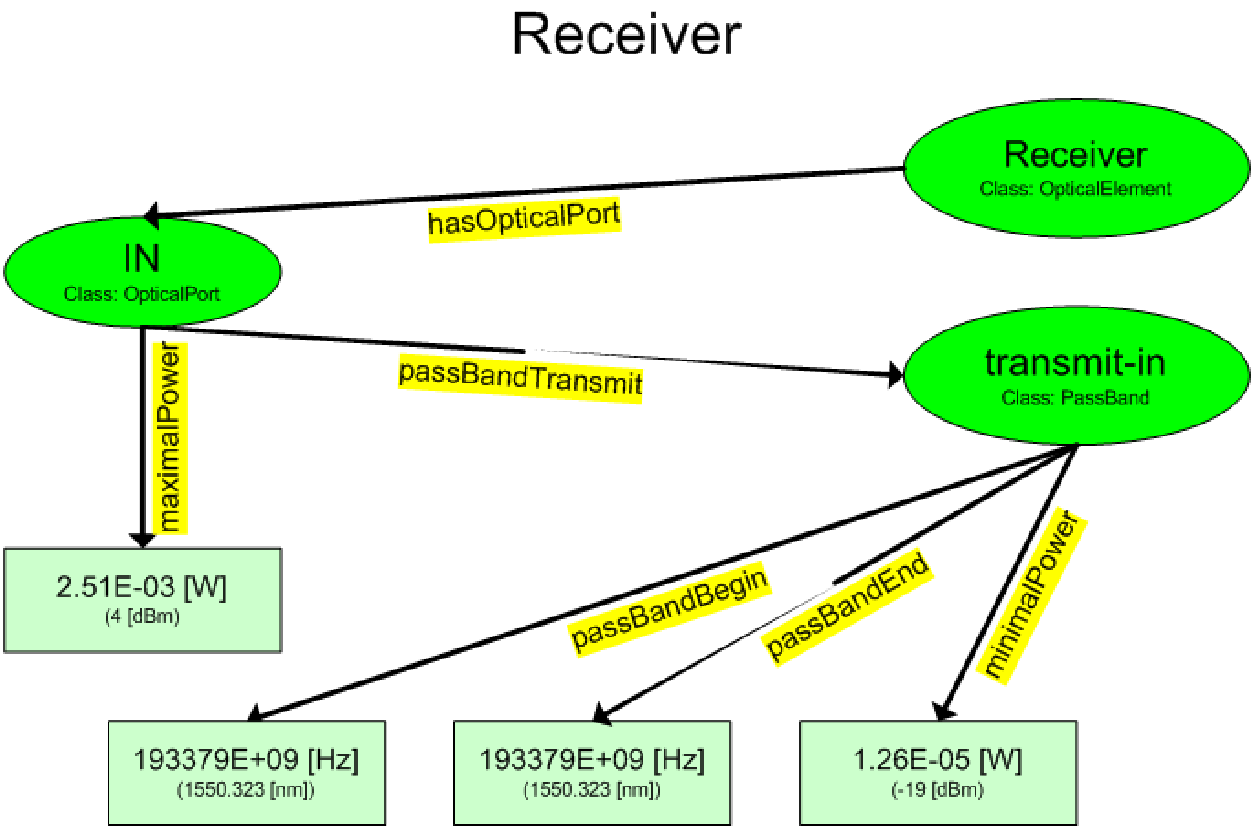


Figure 3.3: NDL Diagram of Receiver

Receiver – Description in NDL

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE rdf:RDF>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
         xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
         xmlns:ndl="http://clserver.cesnet.cz/rdf/ndl/optical_schema.rdf#"
>

<!--
  This document describes an optical receiver.

  There is a 1 output port.
-->
<ndl:OpticalElement rdf:about="#Receiver">
  <rdfs:label xml:lang="en">Receiver of laser beam</rdfs:label>
  <ndl:hasOpticalPort rdf:resource="#IN" />
</ndl:OpticalElement>

<!--
```

```
  Optical ports.

  Maximal power of received optical signal (overall band) is 2.51E-03 W (4.0 dBm).
-->
<ndl:OpticalPort rdf:about="#IN">
  <rdfs:label xml:lang="en">Input optical port</rdfs:label>
  <ndl:passBandTransmit rdf:resource="#transmit-in" />
  <ndl:maximalPower>2.51E-03</ndl:maximalPower>
</ndl:OpticalPort>

<!--
  PassBand transmit from IN port.

  Trasmitted is wavelength 1550 nm (193419E+09 Hz) with 80 GHz spacing (40 GHz on both sides),
so,
  pass-band from 193379E+09 Hz to 193459E+09 Hz is transmitted.

  Minimal power of received optical signal is 1.26E-05 W (-19.0 dBm).
-->
<ndl:PassBand rdf:about="#transmit-in">
  <rdfs:label xml:lang="en">Transmit from IN into receiver</rdfs:label>
  <ndl:passBandTransmit rdf:resource="#OUT" />
  <ndl:passBandBegin>193379E+09</ndl:passBandBegin>  <!-- 1550.323 nm -->
  <ndl:passBandEnd>193459E+09</ndl:passBandEnd>      <!-- 1549.682 nm -->
  <ndl:minimalPower>1.26E-05</ndl:minimalPower>
</ndl:PassBand>

</rdf:RDF>
```

Optical fibre

Optical fibre is a glass or plastic fibre that carries light along its length. In telecommunications is glass fibre used mostly and as light is used laser beam. There are many types of fibres. Length of the optical fibre can be hundreds of kilometres without any inline devices. Important property of optical fibre is attenuation coefficient, describing how much is optical power attenuated along fibre length. NDL diagram of Optical Fibre is on Figure3.4.

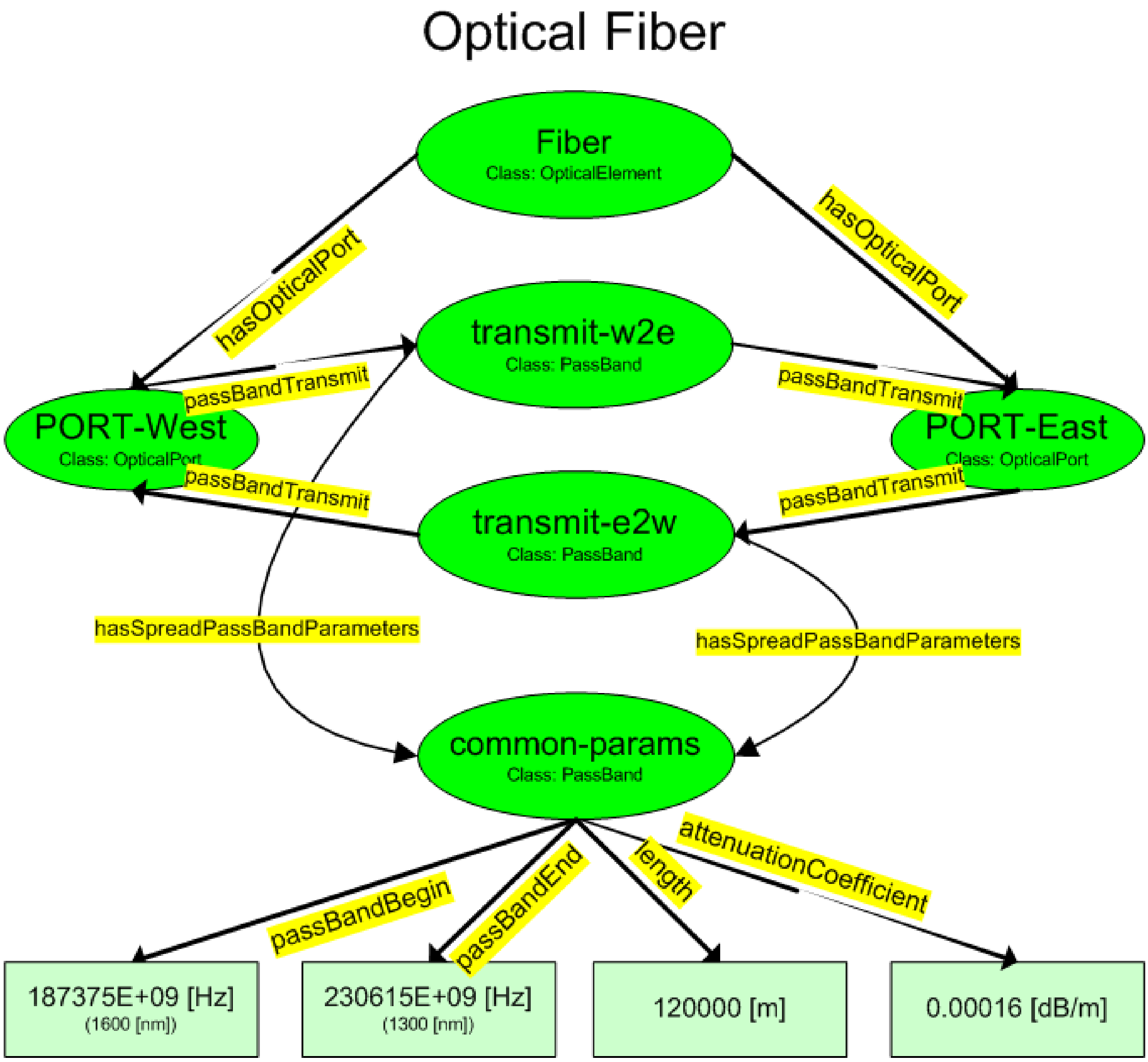


Figure 3.4: NDL Diagram of Optical Fiber

Optical Fiber – Description in NDL

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE rdf:RDF>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
         xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
         xmlns:ndl="http://clserver.cesnet.cz/rdf/ndl/optical_schema.rdf#"
>

<!--
```

```
  This document describes an optical fiber (in most simple way).

  There are 2 ports. Pass-band is available between them bidirectionaly with the same
parameters in both directions.
-->
<ndl:OpticalElement rdf:about="#Fiber">
  <rdfs:label xml:lang="en">Optical fiber</rdfs:label>
  <ndl:hasOpticalPort rdf:resource="#PORT-West" />
  <ndl:hasOpticalPort rdf:resource="#PORT-East" />
</ndl:OpticalElement>

<!--
  Optical ports.

  Maximal power of input optical signal (overall band) is 2E-01 W (23.0 dBm).
-->
<ndl:OpticalPort rdf:about="#PORT-West">
  <rdfs:label xml:lang="en">The first termination of fiber</rdfs:label>
  <ndl:passBandTransmit rdf:resource="#transmit-w2e" />
  <ndl:maximalPower>2E-01</ndl:maximalPower>
</ndl:OpticalPort>

<ndl:OpticalPort rdf:about="#PORT-East">
  <rdfs:label xml:lang="en">The second termination of fiber</rdfs:label>
  <ndl:passBandTransmit rdf:resource="#transmit-e2w" />
  <ndl:maximalPower>2E-01</ndl:maximalPower>
</ndl:OpticalPort>

<!--
  Pass-band transmit. There are a two trasmissions between PORT-West and PORT-East ports.

  Trasmitted are wavelengths between 1300 [nm] and 1600 [nm].

  Attenuation coeeficient is 0.16 [dB/km].

  Length of transmission (in this case of fiber) is 120 [km].

  Parameters of this pass-bands are unified into one object and connected by
  hasSpreadPassBandParameters.
-->
<ndl:PassBand rdf:about="#transmit-w2e">
  <rdfs:label xml:lang="en">Transmit from PORT-West to PORT-East</rdfs:label>
  <ndl:hasSpreadPassBandParameters rdf:resource="#common-params" />
</ndl:PassBand>

<ndl:PassBand rdf:about="#transmit-e2w">
  <rdfs:label xml:lang="en">Transmit from PORT-East to PORT-West</rdfs:label>
  <ndl:hasSpreadPassBandParameters rdf:resource="#common-params" />
</ndl:PassBand>

<ndl:PassBand rdf:about="#common-params">
  <rdfs:label xml:lang="en">Common parameters of pass-bands</rdfs:label>
  <ndl:passBandBegin>187375E+09</ndl:passBandBegin>  <!-- 1600 nm -->
  <ndl:passBandEnd>230615E+09</ndl:passBandEnd>      <!-- 1300 nm -->
  <ndl:attenuationCoefficient>0.16</ndl:attenuationCoefficient>
  <ndl:length>120000</ndl:length>
</ndl:PassBand>

</rdf:RDF>
```

Optical switch

Optical switch is a device which switches light paths between input ports and output ports. Laser beams are switched without intervention into them. Switch process is running on optical (photonic) level. There are no optical-electrical-optical conversions. Switch combination is controlled by electrical signals at most. Inputs and outputs ports are composite and important parameter is a bandwidth (waveband) which is optical switch capable to switch. Other important parameters are count of ports, typically 4x4, 8x8, 16x16 and attenuation from input to output port. NDL diagram of Optical Switch 2x2 is on Figure 3.5.

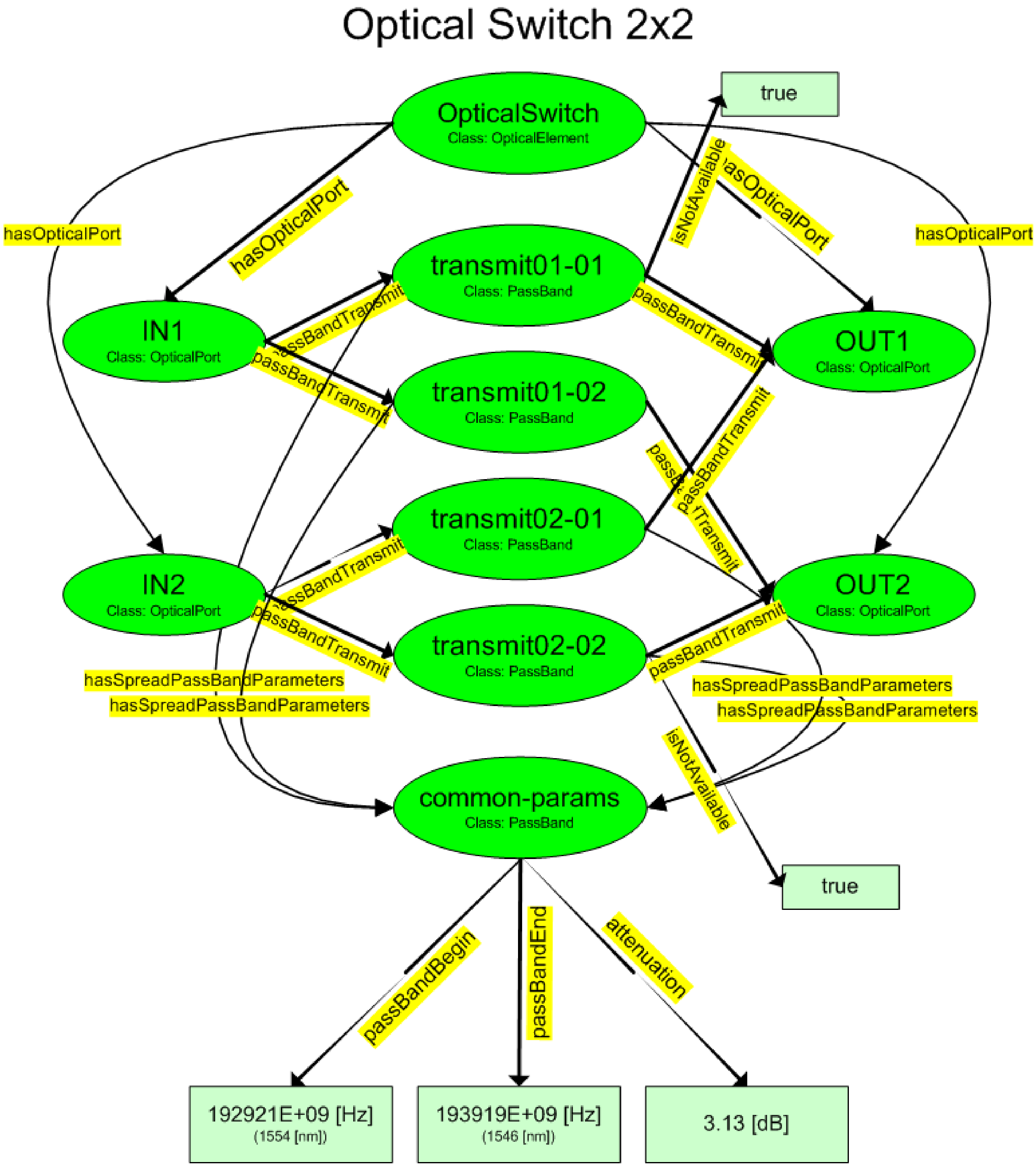


Figure 3.5: NDL Diagram of Optical Switch 2x2

Optical switch – Description in NDL

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE rdf:RDF>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
         xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
         xmlns:ndl="http://clserver.cesnet.cz/rdf/ndl/optical_schema.rdf#"
>

<!--
  This document describes an simple optical switch 2x2.

  CLS is abbreviation of CzechLightSwitch (developed by Cesnet). In real, switch
  is bidirectional, so transmits from OUT ports to IN ports are possible like
  transmits from IN ports to OUT ports. But in this example is defined only
  variant from IN ports to OUT ports for simplified and shortest code.
-->
<ndl:OpticalElement rdf:about="#CLS-2x2">
  <rdfs:label xml:lang="en">Optical switch 2x2</rdfs:label>
  <ndl:hasOpticalPort rdf:resource="#IN1" />
  <ndl:hasOpticalPort rdf:resource="#IN2" />
  <ndl:hasOpticalPort rdf:resource="#OUT1" />
  <ndl:hasOpticalPort rdf:resource="#OUT2" />
</ndl:OpticalElement>

<!--
  Optical ports.

  Maximal power of input optical signal (overall band) is 2E-01 W (23.0 dBm).
  There are all combinations of transmits from inputs to outputs.
-->
<ndl:OpticalPort rdf:about="#IN1">
  <rdfs:label xml:lang="en">1st input port</rdfs:label>
  <ndl:passBandTransmit rdf:resource="#transmit01-01" />
  <ndl:passBandTransmit rdf:resource="#transmit01-02" />
  <ndl:maximalPower>2E-01</ndl:maximalPower>
</ndl:OpticalPort>

<ndl:OpticalPort rdf:about="#IN2">
  <rdfs:label xml:lang="en">2nd input port</rdfs:label>
  <ndl:passBandTransmit rdf:resource="#transmit02-01" />
  <ndl:passBandTransmit rdf:resource="#transmit02-02" />
  <ndl:maximalPower>2E-01</ndl:maximalPower>
</ndl:OpticalPort>

<ndl:OpticalPort rdf:about="#OUT1">
  <rdfs:label xml:lang="en">1st output port</rdfs:label>
</ndl:OpticalPort>

<ndl:OpticalPort rdf:about="#OUT2">
  <rdfs:label xml:lang="en">2nd output port</rdfs:label>
</ndl:OpticalPort>


<!--
  Pass-band transmit. There are a four coumbinations of trasmissions.
  IN1 -> OUT1
  IN1 -> OUT2
  IN2 -> OUT1
  IN2 -> OUT2
  But two of them aren't availaible, setup of switch is IN1->OUT2 and IN2->OUT1.

  Trasmitted are wavelengths between 1546 [nm] and 1554 [nm].

  Attenuation is 3.13 [dB].

  Parameters of all defined pass-bands are unified into one object and connected by
  hasSpreadPassBandParameters.
```

```
-->
<ndl:PassBand rdf:about="#transmit01-01">
  <rdfs:label xml:lang="en">Transmit from IN1 to OUT1</rdfs:label>
  <ndl:bandwidthTransmit rdf:resource="#OUT1" />
  <ndl:hasSpreadPassBandParameters rdf:resource="#common-params" />
  <ndl:isNotAvailable>true</ndl:isNotAvailable>
</ndl:PassBand>

<ndl:PassBand rdf:about="#transmit01-02">
  <ndl:bandwidthTransmit rdf:resource="#OUT2" />
  <rdfs:label xml:lang="en">Transmit from IN1 to OUT2</rdfs:label>
  <ndl:hasSpreadPassBandParameters rdf:resource="#common-params" />
</ndl:PassBand>

<ndl:PassBand rdf:about="#transmit02-01">
  <ndl:bandwidthTransmit rdf:resource="#OUT1" />
  <rdfs:label xml:lang="en">Transmit from IN2 to OUT1</rdfs:label>
  <ndl:hasSpreadPassBandParameters rdf:resource="#common-params" />
</ndl:PassBand>

<ndl:PassBand rdf:about="#transmit02-02">
  <ndl:bandwidthTransmit rdf:resource="#OUT2" />
  <rdfs:label xml:lang="en">Transmit from IN2 to OUT2</rdfs:label>
  <ndl:hasSpreadPassBandParameters rdf:resource="#common-params" />
  <ndl:isNotAvailable>true</ndl:isNotAvailable>
</ndl:PassBand>

<ndl:PassBand rdf:about="#common-params">
  <rdfs:label xml:lang="en">Common parameters of all transmits</rdfs:label>
  <ndl:passBandBegin>192921E+09</ndl:passBandBegin>  <!-- 1554 nm -->
  <ndl:passBandEnd>193919E+09</ndl:passBandEnd>      <!-- 1546 nm -->
  <ndl:attenuation>3.13</ndl:attenuation>
</ndl:PassBand>

</rdf:RDF>
```

3.6 Goals for next work

One of the first attempts to elaborate description of photonic (all-optical) elements, devices and networks in formal language (NDL) was presented. It can be used for improvement of mutual understanding between photonic networks designers (for example when interconnection of photonic networks belonging to different domains is needed) and also for improvement of mutual understanding between photonic networks designers and optical experts.

In principle, formal description enables machine processing of some important designer tasks, such is testing or verification of properties of network created by interconnected elements (using formal description of network before implementation) or expansion of description (for example to have more ports in Optical Switch device). It is also supposed to have user-friendly interface for generation of NDL descriptions. Very important task is abstraction, i.e. derivation of higher level (simpler) description from lower level (more detailed) description, leaving some (inner) parts or properties of device or network “invisible”. In network operation, physical devices should be able to deliver own NDL description on demand, enabling to update automatically description of network (for example in the case of device upgrade, band allocation or network restructuring). Design support of this kind needs software tools using description in formal language as input or output. Those tools are not available now and should be elaborated in the future.

As data transmission speed grows gradually, the number of necessary transmission path parameters, which must be taken into account is also growing. The same applies for difficulty of photonics networks topologies. It is obvious that to be able to offer more bandwidth and low latencies for present high demand and future applications, machine controlled all optical interconnection and all optical routing should be available. This effort tries to use NDL to offer necessary basis for these interconnection and routing.

Photonic networks are expected to be fundamental contributor in defining the future Internet. Formal descriptions and machine tools should enable to utilize its huge potential effectively.

4 Developing of TNRC interface for new layer 0 and layer 1 devices and testing them in the CESNET lab

The Transport Plane data model is stored in Transport Network Resource Controller (TNRC). The TNRC module is a separate process (*tnrcd*), not part of Quagga routing suite and is developed from scratch. It is integrated into Quagga framework according to Quagga daemon main structure. This process is the mediation between Control Plane and the Transport Plane equipment. The tnrcd automatically retrieves port information from the equipment, but not all options can be retrieved directly from the CzechLight equipment. Irretrievable options must be declared by the user on the command line. Further details of TNRC are available in deliverable D2.3.

The interface allows the translation of Control Plane actions into specific actions to be carried out by underlying Transport Network Equipment. CzechLight family is using TELNET protocol for communication with real device. Developed TNRC cls_plugin implements the following actions:

- CzechLight device discovery
- Retrieve all available physical ports
- Configure ports (e.g. make/drop cross-connections)
- Inform the upper-lying Control Plane of change status (planed feature)

4.1 TNRC data model

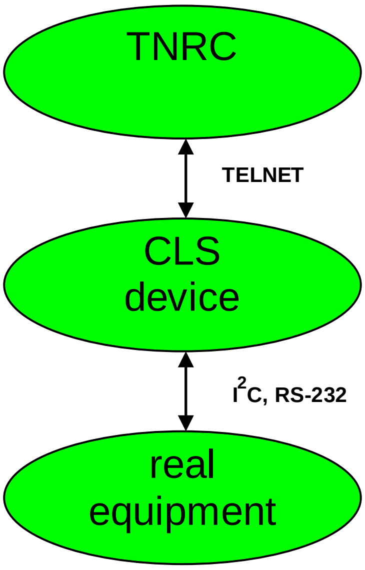


Figure 4.1: Communication with real equipment

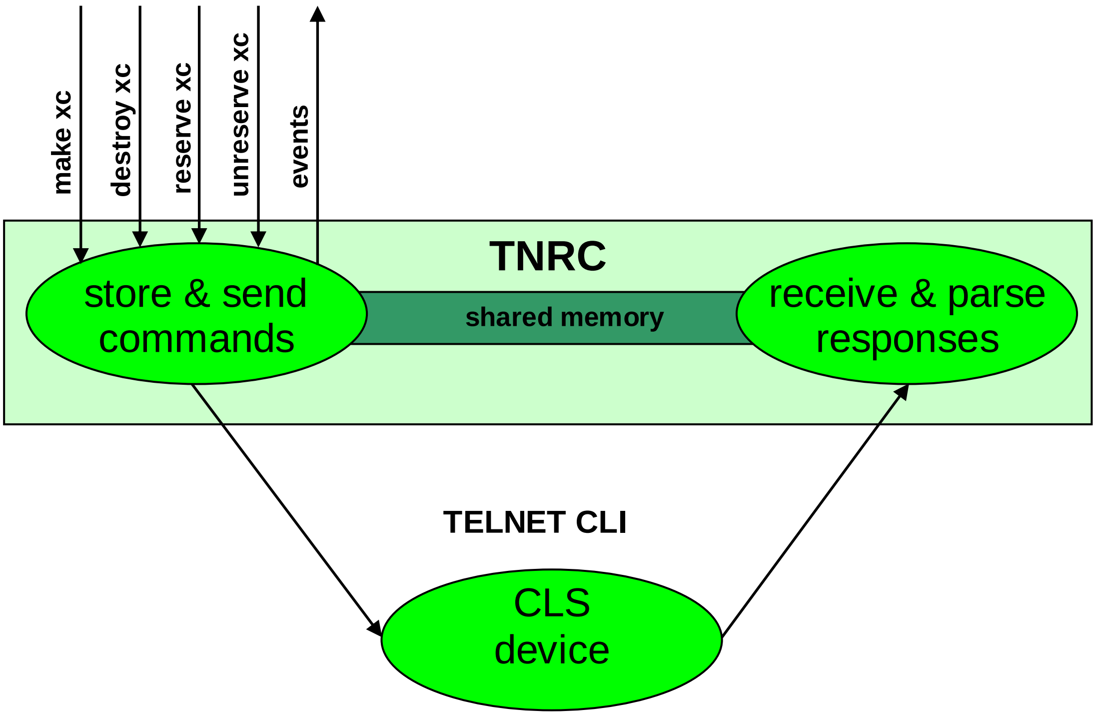


Figure 4.2: Communication schema

4.2 TNRC Plugin Telnet

The TNRC_plugin_telnet file defines several classes for manipulation with real equipment via TELNET protocol. TELNET protocol must recognize control sequence and data stream sequences. The most relevant fields are:

- the device IP address and port number
- a command prompt string
- a telnet new line string

TELNET class definition is provided in the following:

```
  class TELNET {
    public:
      TELNET() {};
      ~TELNET() {};

      virtual int          connect() = 0;
      virtual int          send(std::string* msg) = 0;
      virtual int          recv(std::string* msg, int buff_size) = 0;
      virtual int          close() = 0;
      virtual int          fd() = 0;
  };


/*
Abstract class PluginTelnet_listen
Listen and process received TELNET responses
*/
  class PluginTelnet_listen {
    public:
      PluginTelnet         *plugin;

      PluginTelnet_listen();
      ~PluginTelnet_listen();

      void                 add_handler(int key, tnrc_sp_handle_item value);
      void                 del_handler(int key);
      void                 add_message(std::string *msg);
      void                 process_message(std::string *msg);
      void                 command_prompt_set(std::string *msg);
      virtual void         check_func_waittime()=0;

    protected:
      std::string          command_prompt;
      std::string          responce_block;
      std::map<const int, tnrc_sp_handle_item>  handlers;

      virtual void         do_responce(tnrc_sp_handle_item *item,std::string
*responce)=0;
      static  void         *entry_point(PluginTelnet_listen* self);
  };

  class PluginTelnet: public Plugin {
    public:
      friend class PluginTelnet_listen;
```

```
      friend class PluginClsFSC_listen;

      PluginTelnet();
      PluginTelnet(std::string name);
      ~PluginTelnet();

      int                 getFd();                  // Get socket handle
      void                readT(thread *read);      // Read from socket thread
      void                retriveT(thread *retrive);// "cron" for equipment state
      int                 doRetrive();
      int                 doRead();

    protected:
      std::string         telnet_newline;     // New line string, i.e. "\r\n"
      std::string         received_buffer;    // TELNET received buffer
      TELNET              *sock;              // Real device (TELNET_socket)
                                              // or simulator (TELNET_simulator)

      PluginTelnet_listen *listen_proc;
      tnrc_sp_state       TELNET_status;
      thread              *t_read;
      thread              *t_retrive;

      int                 telnet_connect();
      int                 telnet_close();
      void                newline_set(std::string *newline);
      tnrcsp_result_t     asynch_send (std::string* command,int state=0,void
                          *parameters=NULL);

      virtual void        get_device_info()=0;
  };
```

Code 1-1: TELNET, TELNET_listen and PluginTelnet classes

4.3 TNRC Plugin Telnet CLS

The TNRC_plugin_telnet_cls defines several classes for communication between TNRC SP and real equipment. These classes are using a TELNET protocol that is available for all CzechLight devices.

TNRC CLS class definition is provided in the following:

```
  class PluginClsFSC_listen: public PluginTelnet_listen {
    public:
      PluginClsFSC_listen();
      PluginClsFSC_listen(PluginClsFSC *owner);
      ~PluginClsFSC_listen();

      void   check_func_waittime();

    protected:
```

```
    void   do_responce(tnrc_sp_handle_item *item,std::string *responce);
    void   save_equipments(tnrc_sp_handle_item *item,std::string *response);

  private:
    PluginClsFSC        *pluginClsFsc;       // Pointer to TNRC SP
};



class PluginClsFSC : public PluginTelnet {
  friend class PluginClsFSC_listen;

  public:
    tnrcsp_telnet_map_fixed_port_t    fixed_port_map;
    tnrcsp_telnet_map_fixed_board_t   fixed_board_map;

    PluginClsFSC(std::string name);
    ~PluginClsFSC();

    void                 get_device_info(void);
    void                 tnrcsp_set_fixed_port(
                             uint32_t key,
                             int flags,
                             g2mpls_addr_t rem_eq_addr,
                             port_id_t rem_port_id,
                             uint32_t bandwidth,
                             gmpls_prottype_t protection,
                             bool managed);
    wq_item_status             wq_function  (void *d);
    void                 del_item_data(void *d);
    tnrcapiErrorCode_t   probe(std::string location);

  /* -----   CLS SP API ----- */
    tnrcsp_result_t            tnrcsp_make_xc(
                                     tnrcsp_handle_t *handlep,
                                     tnrc_port_id_t portid_in,
                                     label_t labelid_in,
                                     tnrc_port_id_t portid_out,
                                     label_t labelid_out,
                                     xcdirection_t direction,
                                     tnrc_boolean_t isvirtual,
                                     tnrc_boolean_t activate,
                                     tnrcsp_response_cb_t response_cb,
                                     void *response_ctxt,
                                     tnrcsp_notification_cb_t async_cb,
                                     void *async_ctxt);

    tnrcsp_result_t            tnrcsp_destroy_xc(
                                     tnrcsp_handle_t *handlep,
                                     tnrc_port_id_t portid_in,
                                     label_t labelid_in,
                                     tnrc_port_id_t portid_out,
                                     label_t labelid_out,
                                     xcdirection_t direction,
                                     tnrc_boolean_t isvirtual,
                                     tnrc_boolean_t deactivate,
                                     tnrcsp_response_cb_t response_cb,
                                     void *response_ctxt);

    tnrcsp_result_t            tnrcsp_reserve_xc(
                                     tnrcsp_handle_t *handlep,
                                     tnrc_port_id_t portid_in,
```

```
                                        label_t labelid_in,
                                        tnrc_port_id_t portid_out,
                                        label_t labelid_out,
                                        xcdirection_t direction,
                                        tnrcsp_response_cb_t response_cb,
                                        void *response_ctxt);

      tnrcsp_result_t           tnrcsp_unreserve_xc(
                                        tnrcsp_handle_t *handlep,
                                        tnrc_port_id_t portid_in,
                                        label_t labelid_in,
                                        tnrc_port_id_t portid_out,
                                        label_t labelid_out,
                                        xcdirection_t direction,
                                        tnrcsp_response_cb_t response_cb,
                                        void *response_ctxt);

      tnrcsp_result_t           tnrcsp_register_async_cb(tnrcsp_event_t *events);

    protected:
      //AP data model parameters
      eqpt_id_t     data_model_id;      // Equipment ID FIXIT now is equal to 1
      g2mpls_addr_t data_model_address; // Equipment address displayed in data model
      eqpt_type_t   data_model_type;    // Equipment type - FSC or LSC
      opstate_t     data_model_opstate; // Equipment state - UP or DOWN
      admstate_t    data_model_admstate;// Equipment administrative state displayed
in data model
      std::string   data_model_location;// Equipment location displayed in data
model
  };
```

Code 1-2: PluginClsFSC_listen and PluginClsFSC classes

4.4 TNRC Configuration

After running a *tnrcd* process it will open default configuration file (usually located in the */usr/local/etc* directory). Device configuration can be specified in the configuration file (see below). Users can connect to the tnrc via VTY interface and specify any configuration command on the line. Because CLS device doesn't support all information needed by tnrc, it is necessary to specify it on the line or in the configuration file. As soon as is the port registered in the data model it can be used for cross-connecting. The following command bi-directionally connects port 1 (0x04011101) with port 3 (0x04011103) on board/device ID 4:

make-xc lab-in 1001 port-in 0x4040001 board-in 4 eqpt-in 1 lab-out 1003 port-out 0x4040003 board-out 4 eqpt-out 1 dir bidir activate no rsrv-cookie 1

Example of tnrcd configuration file for the CzechLight Switches is provided in the following:

```
!*********EQUIPMENT CONFIGURATION FILE*********!
!
!Enter in TNRC_NODE
tnrc
!
equipment name cls_fsc location 10.0.0.1
!
!!!! UNI ports
cls set port 0x04011101 board 1 flags 0 rem-eq-addr 0.0.0.0 rem-portid 0x0 protection
none
cls set port 0x04011102 board 1 flags 0 rem-eq-addr 0.0.0.0 rem-portid 0x0 protection
none
cls set port 0x04011103 board 1 flags 0 rem-eq-addr 0.0.0.0 rem-portid 0x0 protection
none
cls set port 0x04011104 board 1 flags 0 rem-eq-addr 0.0.0.0 rem-portid 0x0 protection
none
cls set port 0x04011105 board 1 flags 0 rem-eq-addr 0.0.0.0 rem-portid 0x0 protection
none
cls set port 0x04011106 board 1 flags 0 rem-eq-addr 0.0.0.0 rem-portid 0x0 protection
none
cls set port 0x04011107 board 1 flags 0 rem-eq-addr 0.0.0.0 rem-portid 0x0 protection
none
cls set port 0x04011108 board 1 flags 0 rem-eq-addr 0.0.0.0 rem-portid 0x0 protection
none
```

Code 4-3: A sample tnrcd configuration file for 8x8 CzechLight Photonic Switch

5 Recognition and Deployment of new layer 0 and layer 1 resources

There are few confusions and causalities when people are talking and referring to different layers. The original 7 layer OSI/ISO model is misunderstood by many and not everybody read

this document. As the result, terms like 1.5 or even 2.25 have been used with protocols like ATM or SDH/SONET. SONET is considered as a layer 1 technology but as stated in OSI [OSI1] or ITU documents, physical layer (layer 1) provides transmission of unstructured bits across the physical medium and describes physical properties of these media (cables, connectors, electrical or optical levels for ones and zeros...). Physical media itself is not the part of the physical layer and sometimes is considered to be layer 0 but this is not part of the OSI model. If there are things like framing, error detection or flow control there, it's a link layer (layer 2). So SONET is both layer 1 and layer 2 protocol and technology and the same goes for Ethernet, which is defined both on layer 1 and 2. Things are even more complicated with ATM (it is out-of-date technology now but the example may be useful). For some, ATM was layer 1.5 technology and for others it was layer 2.25 technology but with physical specifications, addressing schemes and even a link-state routing protocol (PNNI), ATM is L1/L2/L3 protocol and technology.
We consider this short introduction about layers to be very important because we are describing Layer 0 and Layer 1 resources. Layer 0 is not defined by OSI but the concept of L0 as physical transmission media itself is reasonable and useful. So in our definition Layer 0 resources are transmission devices like optical amplifiers or transceivers i.e. part of a transmission path. Layer 0 resources are necessary to build any network but they do not manipulate or change paths of optical signals. Layer 1 resources, like optical switches or ROADMs, have more capabilities and can switch (or crossconnect) optical signals but they are protocol and bit speed agnostic and clearly they are not working on the layer 2 (i.e. no header recognition).

It is obvious that many Layer 0 resources, like optical fibres and amplifiers, are already deployed within any network or testbed. The important issue here are new resources. For example, different types of tuneable compensators of chromatic dispersion are commercially available and with their help it is possible to offer new services (e.g. adding more lambdas to increase bandwidth for new data-intensive research applications).
The situation is different when we're talking about Layer 1 resources like all-optical switches. Despite the fact that optical switches have been commercially available for few years, they have not been deployed very widely and if yes, they were used as clever patch panels. Projects like Phosphorus have been improving this situation, developing software tools and frameworks for provisioning high-bandwidth and end-to-end services.

Optical fibres (not limited to transmission fibres like G.652 or G.655 but new fibres like nonlinear or hollow), transceivers and transponders, optical amplifiers (EDFA, Raman, semiconductor or any other type) and compensators of chromatic and polarization mode dispersions are considered to be Layer 0 resources.

Fibre switches (with or without multicasting capabilities), ROADM, WSS, VMUX and all-optical wavelengths convertors are considered to be Layer 1 resources.

New types of Layer 0 and especially Layer 1 resources can be deployed within the global Phosphorus testbed or elsewhere if such resources will be considered useful by Phosphorus partners or by users of Phosphorus software. For this reason, the questionnaire has been

prepared and answers of partners will be used as a guidance which Layer 1 resources are considered to be important for an eventual successor of the Phosphorus project.
We have indications that for example fibre switches with multicasting capabilities could be very useful for certain applications, like high definition video transmissions to different and geographically distant places, as already demonstrated during GLIF workshops in 2007 and 2008. Plans for dark fibre testbed development were presented in Tridentcom 2009 [21].

Deployment of Layer 0 resourcers in the CESNET2 network (CzechLight optical amplifiers) is described in the following section 5.1. The only tested and deployed Layer 1 CL resource in Phosphorus project is the CzechLight switch, details are given in the section 5.4. CzechLight switch was deployed in the global Phosphorus testbed. Experience with deployment of other CzechLight devices in CESNET was used in Phosphorus for suggestion of the future development of TNRC, according to Task 6.6.

5.1 Realized CL deployments and traffic statistics in the CESNET2

The CESNET2 is the network that serves the Research and Education community in the Czech Republic, using 5,112 km of fibre lines (including 995 km of single fibre lines). High coverage is given by the size of the country and the population numbers. In addition to the Cisco 15454 MSTP n x 10 Gb/s DWDM transmission systems, fifteen lines in CESNET2 are lit by open photonic n x 10 Gb/s DWDM transmission systems, including 6 single fibre lines. Further lines will be lit in the year of 2009. The CESNET Experimental Facility (EF) uses 512km of dark fibre, connected to the CESNET2, ACONET, PIONIER and SANET networks and to the Global Lambda Integrated Facility (GLIF) and GÉANT2 lambda service. Open photonic n x 10 Gb/s DWDM transmission systems are used in the CESNET2 and EF networks.
CESNET, as one of NRENs in the Phosphorus project, is expected to test optical equipment with G^2MPLS capabilities and to demonstrate its potential and advantages for end users and network applications. CESNET has special possibilities in early adoption of new technologies, because is not fully dependent on availability of hardware developed by network equipment vendors, their implementation of protocols etc.

5.1.1 Used CL in the CESNET2 and CzechLight EF

CESNET is developing new optical transmission DWDM systems, based on own open photonic devices called the CzechLight (CL) family.

Main types without gain flattening for up to 8 channels:

- **CLA PB01** Low noise preamplifier and booster amplifier with output power up to 20dBm and optional ALS (Automatic Laser Shutdown)
- **CLA PB02** Low noise preamplifier and high-power booster amplifier with output power up to 27dBm and built-in ALS
- **CLA DI01** Dual in-line amplifier with output powers up to 15dBm

Main types with gain flattening for up to 32 channels:

- **CLA PB01F** Gain flattened low noise preamplifier and booster amplifier with output power up to 20dBm and optional ALS
- **CLA PB02F** Gain flattened low noise preamplifier and high-power booster amplifier with output power up to 27dBm and built-in ALS
- **CLA DI01F** Gain flattened dual in-line amplifier with output powers up to 15 dBm

CzechLight Amplifier devices (CLA) are placed in CzechLight experimental facility (EF) and CESNET2 network.
First CL deployment in the year 2004, specifically CLA PB01 (CzechLight Amplifier 2in1, Booster and Preamplifier) was on Praha – Plzeň line with length of 159km and attenuation of 36.7dB in CzechLight EF and on Praha – Hradec Králové, length of 150km and attenuation of 35.7dB in CESNET2 network.
Since March 2005 CLA DI01 has been successfully working on CzechLight EF line Praha-Brno, 284km, attenuation of 66.35 dB, as one and only inline amplifier.
At the beginning of 2006 CLA PB01 was equipped on the first Cross Border Fibre (CBF) line Brno – Bratislava 182km, attenuation of 45 dB. In the middle of 2006 CBF Brno – Vienna was deployed by a new prototype CLA PB02.
Other CL deployments were realised on CESNET2 network. The overview of CL utilizing in CzechLight EF and CESNET2 network we can see on the Table 5.1.

CESNET2	**Type of CLA**	**Number of CLA**	**Length (km)**	**Attenuation (dB/1550nm)**	**Since year**
Brno - Bratislava	PB01	2	182	45	2006
Brno - Vídeň	PB02	2	224	50	2006
Praha - Ústí n. L.	PB01	2	131	30	2007
Ústí n. L. - Liberec	PB01	2	123	26	2007
Brno - Ostrava	PB02F	2	235	51	2008
ČB - Jihlava	PB01F	2	164	41	2008
Cheb - Most	PB01F	2	171	45	2008
Jihlava - Brno	PB01F	2	156	36	2008
Letohrad - Opava	PB01F	2	186	44	2008
Most - Děčín - Ústí n.L.	PB01F	2	135	32	2008
Most - Ústí n.L	PB01F	3	68	16	2008
Plzeň - Cheb	PB01F	2	137	37	2008
Praha - Pardubice	PB02F	2	189	46	2008
Brno - Zlín	PB02F	2	129	32	2009

Hradec Králové - Pardubice	DI02F	1	30	8	2009

CzechLight EF	Type of CLA	Number of CLA	Length (km)	Attenuation (dB/1550nm)	Since year
Praha - Potěhy - Brno	DI01F, 2x PB02Fx	3	284	66	2005
Brno - Štetovice - Bielsko Biala	DI01F, 2x PB02Fx	3	263	NA	2007

Total deployed (March 2009)		**36**

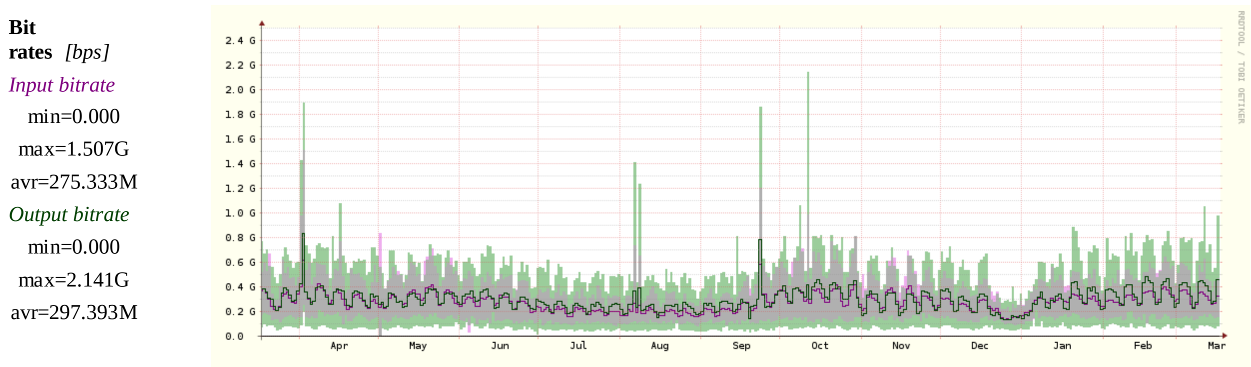
CLA DI01 (originally CzechLight Amplifier DualInline)
CLA PB01 (originally CzechLight Amplifier 2in1, Booster and Preamplifier)

Table 5.1: Utilization of CL devices in CzechLight EF and CESNET2

5.1.2 Traffic statistics of the lines with CL

CL amplifiers have been equipped in CzechLight EF and CESNET2 network since the year 2005 without significant problems. For example, detailed statistics of the line Brno – Bratislava are shown on http://www.cesnet.cz/provoz/zatizeni/ten155_mapa_static_output/Line_usage_Brno-_SANET.10min.current.html and statistics of Brno – Vienna on http://www.cesnet.cz/provoz/zatizeni/ten155_mapa_static_output/Line_usage_Brno-_ACONET.10min.current.html.

Time frames of high intensity of Ethernet errors corresponds with time frames of increased attenuation caused by ground works and consequent repairs of lines Brno – Bratislava and Brno – Vienna are shown on the Figures 5.1 – 5.4.



author: Tom Kosnar, copyright: © 2004-2009 , CESNET a.l.e.

Figure 5.1: One year load of Brno – Bratislava line

Ethernet errors I. *[fps]*

Alignment errors

min=0.000

max=0.000

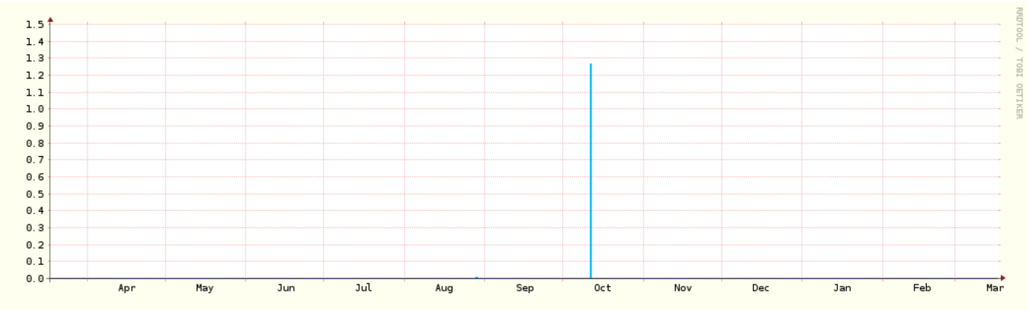
avr=0.000

Checksum errors

min=0.000

max=1.267

avr=5.180u



author: Tom Kosnar, copyright: © 2004-2009 , CESNET a.l.e.

Figure 5.2: One year representation of low level errors of Brno - Bratislava

Bit rates *[bps]*

Input bitrate

min=0.000

max=3.168G

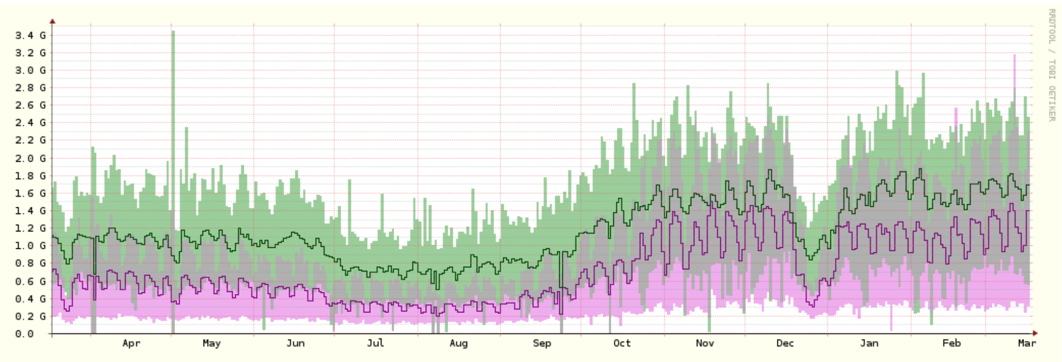
avr=709.886M

Output bitrate

min=0.000

max=3.437G

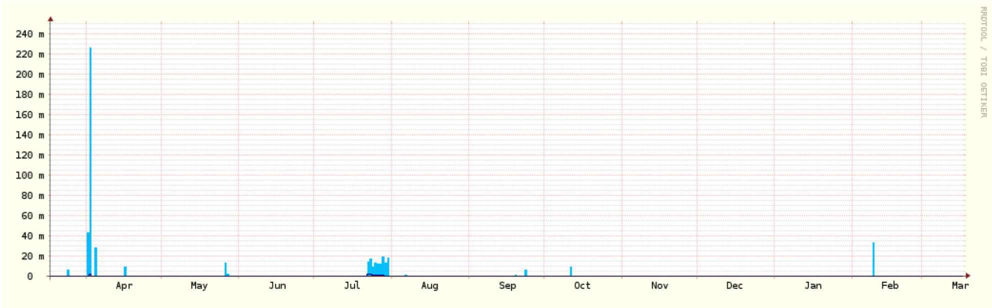
avr=1.178G



author: Tom Kosnar, copyright: © 2004-2009 , CESNET a.l.e.

Figure 5.3: One year load of Brno - Vienna

Ethernet errors
I. *[fps]*
Alignment errors
min=0.000
max=0.000
avr=0.000
Checksum errors
min=0.000
max=226.131m
avr=32.504u



author: Tom Kosnar, copyright: © 2004-2009 , CESNET a.l.e.

Figure 5.4: One year representation of low level errors of Brno - Vienna

5.1.3 Results

CzechLight **(**CL) family is affordable set of photonic devices enabling to use full advantage of up-to-date products of photonic industry by programmable devices and it is very cost effective comparable to the traditional approach, including energy savings. Devices allow availability of transmission parameters for monitoring and management (impairment monitoring and lightpath switching and restoration, testing of reconfigurable optical transport systems, etc.). Open approach from software development to hardware and optical devices development and management allows improvements during network life cycle [22-24].

5.2 Design of all-optical network segments (e.g. OWDM)

Design of all optical networks is given by specific parameters which must be taken into account. Their number is growing with transmission speed and distance.
The basic parameter is attenuation; it is an attribute of transmission fibres and passive components. The power budget of designed line must be met, i.e. transmitter output power minus attenuations of line and passive must fit into receiver sensitivity zone with some margins. This applies for passive solutions. When attenuation is too big, it must be compensated by optical amplification. The most common are the Erbium Doped Fibre Amplifiers (EDFAs). In special cases, like extreme distances or undersea applications, are also Raman amplifiers deployed. In principle, receiver sensitivity is decreasing with growing transmission speed.
However, no real optical amplifier is ideal, thus each adds noise to signal, so degrades the OSNR. The second important parameter which must be considered is an OSNR, the OSNR requested by receiver is increasing with transmission speed.

High powers can be achieved at the amplifiers output, but these can invoke non-linear effect. So the total composite power and per channel powers must be kept under thresholds of non-linear effects, e.g. SPM, XPM, FWM.
The fibres and component also exhibits dispersions as mentioned in chapter 2.4.1. The influence of CD is grooving with the square of transmission speed, the influence of PMD is growing linearly with the transmission speed, but the PMD is stochastic phenomenon. Major part of CD and PMD is caused by transmission fibres, small amounts of CD and PMD are added by passive components too.
The CD can be compensated routinely by different ways, e.g. compensating fibres, Fibre Bragg Gratings (FBG), Giress-Turnois Etalons (GTE), Virtual Imaged Phase Arrays (VIPA) and others [19]. Some of these also exit in tuneable versions. As PMD is stochastic element it is difficult to compensate it. Some optical methods of PM compensation exist, but are not widespread. Now an electronic signal conditioning shows interesting possibilities of elimination of both dispersions.
At 1Gbps, transmission speeds dispersions are negligible and only the attenuation, OSNR play roles.
At 2.5Gbps speeds, CD influences transmission only over extreme distances and PMD only in exceptional cases (very old or bad fibres).
At 10Gbps, the compensation of CD is necessary and it can be recommended to measure PMD, also the influence of nonlinearities limits the powers.
The present 40Gbps transmissions are very sensitive to residual CD, PMD and nonlinearities.

5.3 Deployment documentation and service support

CESNET leases optical fibres between required nodes in the network. As next step, we are deploying passive and active devices onto these leased optical fibres. Among passive devices belong multiplexors, demultiplexers, chromatic dispersion compensators and others. Among active devices belong amplifiers of optical signal, switches of optical signal, variable chromatic dispersion compensators and others. Active devices for deploying optical lines were developed at CESNET under overall name CzechLight family devices, CLx at short.
Components of network are not deployed only in Czech Republic, but are deployed over the borders too, hundreds of kilometres faraway. For a comfort administration and network enlarging we reached following state of documentation in optical lines enlightening.

5.3.1 Documentation for administrators

Documentation for administrators includes all potential information necessary for administrating optical layer of network, to wit, that elementary part across are transmitted signals of higher layers.
Major part of documentation arising from designing and assembling optical line and from taking charge is archived in paper form and ready for next network enlarging like information

source. Next component is online electronic documentation stored at CzechLight server which will come up.
What all is documented? Fundamental is the documentation of physical deploying. GPS coordinates determine precise location, followed by precise building address, part and floor in the building, room with a rack, the rack and a position in the rack where the device is.
Next parts of documentation are information concerning optical signals transmits. It is a list of channels, their type, wavelength and power levels in input and output nodes of transmission. Follow types and attenuations of multiplexers and demultiplexers, types and values of chromatic dispersion compensators. Parameters of other passive devices are entered similar.
Complicated situation comes in case of active components of network. Type of device and setting of parameters impacting at errorless line function are documented. Particularly, power levels and safety algorithms settings in amplifiers of optical power are very sensitive and at replacing by another piece it must be strictly kept back. Similar, wrong restored configuration of optical switch can fail transmission in some lines as a consequence. All parameters of these devices are documented carefully.
Next part of documentation is also concerning active components, but at view of entries for remote access. Control of CzechLight devices is Linux based and devices are accessible over remote terminal. They are mostly connected into IP network and parameters of IP protocol are documented. But some inline devices have no IP network disposal and are accessible over the GPRS of GSM network. In the documentation is just noted GSM phone number of GPRS modem. Authentication information isn’t covered in documentation for security reason and it is told only to interested administrators.

5.3.2 Support for administrators

As mentioned before, control of CzechLight devices is Linux based. This is closely related to proprietary software stored in devices. In order to update the software and its distribution, we have created the repository with software packages. This repository is located on CzechLight server, so centralized distribution is ensured.
CzechLight server is a Linux rack-mount server accessible from public internet network. Besides the repository with packages server offers a part of online documentation for administrators and some other services.
One of them is access into secured terminal from public internet network. In this way, administrator can control and configure settings of active network components, which have normally forbidden access from public network.
A next important service of CzechLight server is a firmware and configuration backup service for CzechLight family devices. During an exchange of broken device firmware can be restored from backup, or setting can be returned to previously saved configuration. It is rather important for network administrators and management to feel comfortable, but we have experienced device failure very rarely.

5.4 Testing of CLS with G²MPLS deployments in CESNET2

An international demo was realized to demonstrate possibilities of remote configuration of CzechLightSwitches (CLS) by G^{2}MPLS software.
Following functions were successfully demonstrated among others:
- deployment of TRNC on Optical switches CLS produced by Czech SME Optokon (www.optokon.cz) under CESNET licence
- international remote control of two CLSs by G^{2}MPLS software
- usage of CBF line CESNET2 – Pionier
- usage of CESNET Experimental Facility all-optical line Praha-Brno with in-line CLA produced by Optokon under CESNET licence
- usage of CESNET2 production network all-optical line Praha - Brno - Ostrava with Cisco equipment and interconnection with Experimental Facility
- usage of Experimental Facility for evaluation of equipment and SW with traffic redirected from production network

More details follow.
We should note, that deployment of new devices and software in dark fibre experimental facility with possibility of production traffic is crucial, because it make feasible its fast subsequent deployment in production networks.

Two CLS were deployed in two main CESNET PoPs Praha and Brno to demonstrate automated switching between two geographically different paths, as shown in the Fig. 5.5. The Phosphorus global testbed was used to create data plane between University of Essex (Colchester) and PSNC (Poznan). Control plane was configured between CESNET (Praha) and PSNC (Poznan) only. Both data plane and control plane were created by means of Ethernet VLANs and other technologies like Ethernet over MPLS, details are depicted in Fig. 5.5.
Two CESNET paths used either DWDM technology (solid purple line, CESNET2 network) or Ethernet over SONET technology (dashed purple line, CESNET Experimental Facility).
CLS equipment was configured by the G^{2}MPLS controller located in Poznan, control plane connections are represented by black dashed lines. CLS were configured in three different ways:
- manually, using Telnet
- using only G^{2}MPLS tnrcd
- using full G^{2}MPLS domain signalling (setup via G^{2}MPLS UNI interface)

Logical schema and connectivity are showed in Fig. 5.6. We acknowledge Eduard Escalona (UEssex), Jakub Gutkowski (PSNC), Damian Parniewicz (PCNS) and Peter Tavenier (SARA) help with demo setup and measurements.

Measured average RTT is 42 ms for 1500 B packets for e2e path UEssex and PSNC. RTT was very similar for both CESNET paths.
Switching times for CLS are 35 ms. We have measured also time needed for restoration of IP connectivity (with help of well-known utility PING). This time was approx. 20 seconds, much

longer then switching time of CLS. The reason for such behaviour is Spanning Tree protocol (STP). When STP was switched off (the demo does not include any layer 2 loops and therefore STP is not needed), restoration time was below 1 second. Routers and switches do not allow for more precise time measurements.

In case of interest, other fibre lines of CESNET Experimental Facility can be put into service allowing also lambda services for Phosphorus testing.

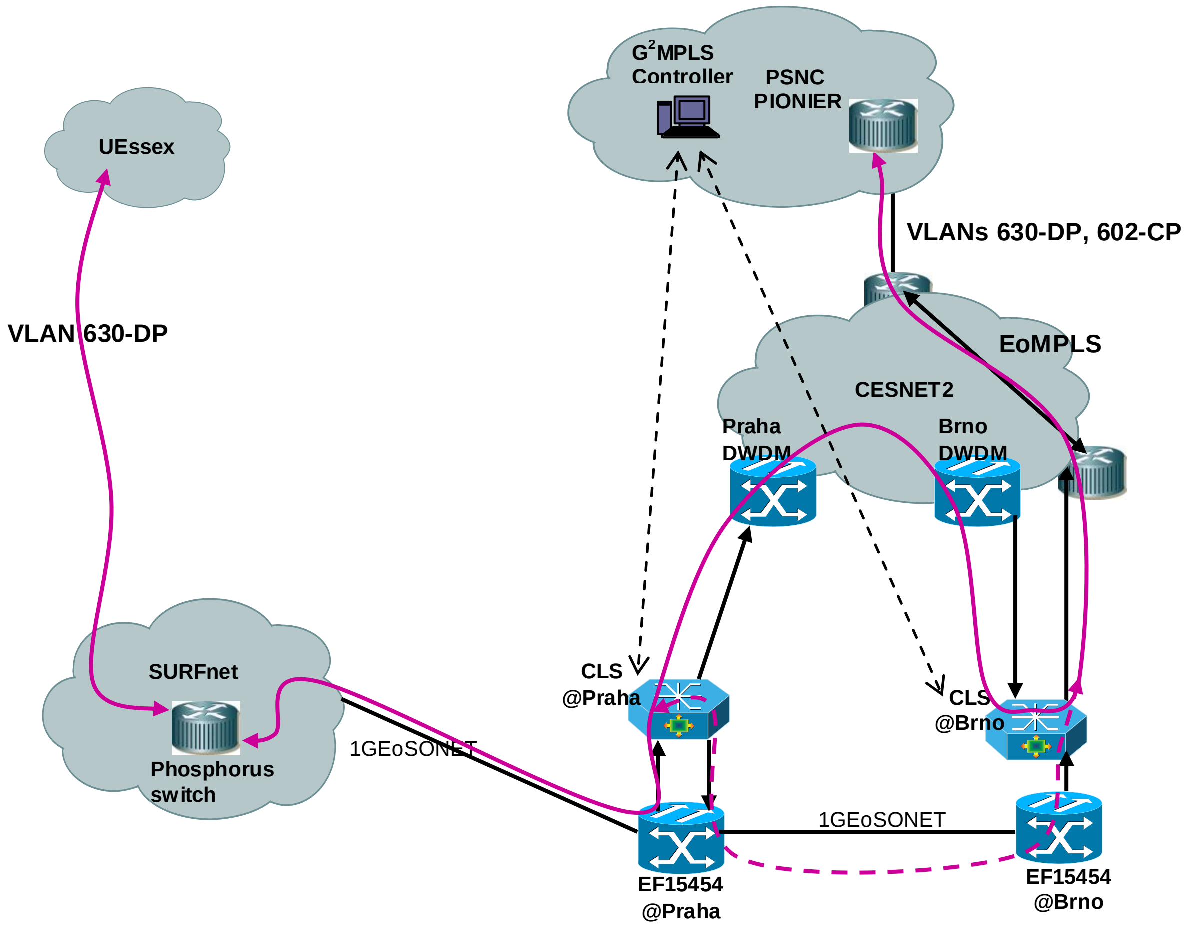


Figure 5.5: Part of the global Phosphorus testbed UEssex/SURFnet/CESNET/PSNC

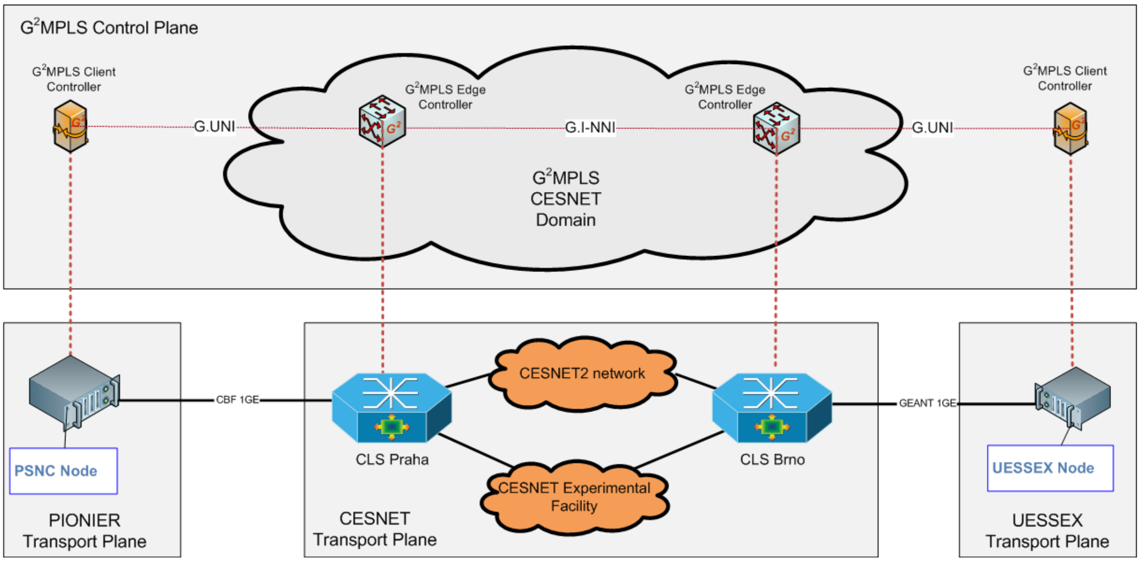


Figure 5.6: Logical schema and connectivity between G^{2}MPLS controllers and CLS

5.5 Recommended and planned TNRC deployments

TNRC and G^{2}MPLS should be deployed everywhere where we deal with shared resources and resources which could be withdrawn (pre-emptive resources). From L0 and L1 perspective it can be whole fibre connections or lambda connections. TNRC can be used for remote automatic cross connect or lambda provisioning in advance. It can minimize necessity of costly human work (e.g. patching, fibre cleaning) and minimize probability of human errors.

To allow automatic path/fibre provision, TNRC should be available for fibre switches and also switches with multicast option for distribution of high demand data streams (e.g. 4k or even 8k video signals).

To allow automatic lambda provision, TNRC should be available for simple or multi degree ROADMs and Wavelength selective switches.

In CESNET, we plan TNRC TL1 plugin for Cisco 15454, if not implemented by Cisco company itself. Estimation of needed programming MP is about 3 man months, based on work for CLS. It could be deployed in CESNET2 network in step-wise manner, after testing of reliability in Experimental Facility. This will help to build a modern GRID environment in which demanding applications use a transmission network to exchange data between the nodes and dispersed end points and devices.

Recommendations for further development of TNRC are below in Conclusion chapter.

6 Conclusions

The deliverable shows results achieved in area of finding new types of low level resources, like photonic switches. The Questionnaire was sent to project participants and some interesting results were collected. Tools for design and maintenance of photonics networks are not widely available and mature enough and it is evident that future work and improvements are needed. Development of TNRC for CLS equipment was successfully demonstrated, taking advantage of the global PHOSPHORUS testbed. During testing, CLS were remotely managed by G^2MPLS controllers located in Poznan. These results may be interesting and encouraging for a possible successor of the PHOSPHORUS project.

Main recommendations for the next project are following:

- The range of network element types acceptable in TNRC should be as wide as possible while users of the software should be free to decide on which elements that would like to control and on which not.
- The range of network element types acceptable in the future TNRC should be as wide as possible while users of the software should be free to decide on which elements that would like to control and on which not.
- Acceptation of new network element types and their attributes in TNRC should be simple (prepared modules should be used for easy portability)
- The most important device types for the future TNRC are
    - Path (fibre) switches
    - Path (fibre) switches with multicast option
    - Reconfigurable Optical Add/Drop Multiplexers (ROADM)
    - Wavelength selective switches (WSS)
    - All-optical wavelength conversions (from grey signal to ITU-T grid)
    - Variable multiplexers (VMUX)
- To use more complex metric or metrics based on user requirements, e.g. jitter, delay, fibre length, number of hops, line quality.
- Impairments should be monitored online, if needed. This applies especially for higher data rates and complex topologies.
- Control of transport network resources in the future TNRC should be developed as superstructure/extension of tools for design and maintenance of photonic networks.

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8 Acronyms

AAA	Access, Authentication, and Authorization
ALS	Automatic Laser Shutdown
ATM	Asynchronous Transfer Mode
CBF	Cross Border Fibre
CD	Chromatic Dispersion
CL	CzechLight
CLA	CzechLight Amplifier
DCF	Dispersion-Compensation Fiber
DEMUX	Demultiplexer
DPSK	Differential Phase-Shift Keying
DQPSK	Differential Quadrature Phase-Shift Keying
DWDM	Dense Wavelength Division Multiplexing
EDFA	Erbium Doped Fibre Amplifier
EF	Experimental Facility
FBG	Fibre Bragg Gratings
FWM	Four Wave Mixing
GPRS	General Packet Radio Service
GSM	Groupe Spécial Mobile
GTE	Giress-Turnois Ethalon

ITU-T	International Telecommunication Union- Telecommunication Standardisation Sector
LDAP	Lightweight Directory Access Protocol
MMF	MultiMode Fibre
MUX	Multiplexer
NDL	Network Description Language
NRPS	Network Resource Provisioning Systems
ODB	Optical Duo Binary
OEO	Optical-Electronic-Optical conversion
OSI	Open Systems Interconnection
OSNR	Optical Signal to Noise Ratio
OWDM	Open Wavelength Division Multiplex
PDL/PDG	Polarization Dependent Loss or Gain
PMD	Polarization Mode Dispersion
PNNI	Private Network-to-Network Interface
RDF	Resource Description Framework
ROADM	Reconfigurable Optical Add-Drop Multiplexer
SDH	Synchronous Digital Hierarchy
SNMP	Simple Network Management Protocol
SONET	Synchronous optical networking
SPM	Self Phase Modulation
STP	Spanning Tree protocol
TCP/IP	Transmission Control Protocol / Internet Protocol
TELNET	Telecommunication Network
TNRC	Transport Network Resource Configuration
VIPA	Virtual Imaged Phase Array
VMUX	Variable Multiplexers
WDM	Wavelength Division Multiplexing
WSS	Wavelength Selective Switches
XML	Extensible Markup Language
XPM	Cross Phase Modulation

Appendix A: Questionnaire answers

Device	Description	Participants															
1 **Path (fibre switch)**		**1**		**2**		**3**		**4**		**5**		**6**		**7**		**8**	
Operational principle		**a)**	**b)**	**a)**	**b)**	**b)**	**a)**	**a)**	**b)**	**b)**	**a)**	**a)**	**b)**	**a)**	**b)**	**b)**	**a)**
Mechanical (MEMS)	Broadband operation (typ. O and C band). Lifetime is limited by number of cycles (e.g. 1E7)	5	5	3		3	3	2		2	2			4	4		
Non-mechanical	Single band operation (typ. C band). Lifetime is limited by operational hours (e.g. 1E5)	5	5			3	3	2		3	3			3	3	3	3

Comment													
Number of Inpust and outputs													
32x32		5	5	3	3	3	2	3	3	4	5	3	3
16x16		3	3	3	3	3	2	3	2	3	3	3	3
8x8		1	1	3	3	3	2	1	1	3	3	3	3
Comment													
Operational band													
O+C+L	Such broadband operation inhbits non mechanicaly based principle of operation	1	1	3	3	3	2	2	2	3	3		
C+L		5	5		3	3	2	3	3	4	4		
C		4	4		3	3	2	2	2	4	4	3	3
Comment													
Power monitoring	Increases device attenuation and price												
Inputs+Outputs		5	5	2	3	3	2	3	3	5	5	2	2
Outputs only		3	3	2	3	3	2	1	1				
Inputs only		3	3	2	3	3	2	1	1				
None					3	3							
Comment													

2 **Path (fibre switch) with multicast option**

Operational principle													
Mechanical	Broadband operation (typ. O and C band). Lifetime is limited by number of cycles (e.g. 1E7). Fixed split ratios.	5	3	3	3	3	2	2	2	5	5	4	4
Non-mechanical	Single band operation (typ. C band). Lifetime is limited by operational hours (e.g. 1E5). Split ratios could be settable.	5	3	3	3	3	2	3	3			4	4
Comment													
Number of Inpust and outputs													
4x4		1	1	3	3	3	2	2	2				
8x8		3	3	3	3	3	2	2	2	5	5		
2x16		4	4	3	3	3	2	3	3				
8x8		3	3	3	3	3	2	3	3				
16x16		4	4	3	3	3	2	3	3			4	4
Other, please specify					3	3							
Comment													
Operational band													
O+C+L	Such broadband operation inhbits non mechanicaly based principle of operation	1	1	3	3	3	2	1	1	5	5		
C+L		5	5		3	3	2	3	3			4	4
C		4	4		3	3	2	3	3			4	4
Comment													

Power monitoring	Increases device attenuation and price											
Inputs+Outputs		5	5	2	3	3		3	3	5	5	
Outputs only		3	3		3	3		2	2			
Inputs only		3	3		3	3		2	2			
None					3	3						
Comment												
3 Variable multiplexer (VMUX)												
Operational principle												
Mechanical	Lifetime is limited by number of VOA cycles (e.g. 1E7)	2	2		3	3	2	2	2	4	4	
Non-mechanical	Lifetime is limited by VOA operational hours (e.g. 1E5)	2	2		3	3	2	3	3	4	4	
Comment												
Number of DWDM channels												
32		2	2		3	3	2	3	3	4	4	
40		2	2		3	3	2	2	2	4	4	
Other, please specify					3	3				4	4	
Comment												
Spacing of DWDM channels												
100 GHz		1	1		3	3		3	4	4	4	
50 GHz		2	2		3	3		3	3	4	3	1

Other, please specify					3	3						
Comment												
Operational band												
C		1	1		3	3	2	3	3	4	4	
C+L		2	2		3	3	2	3	3	4	4	
L		1	1		3	3	2	1	1	2	2	
Comment												
Power monitoring	Increases device attenuation and price											
Input+Outputs		2	2		3	3		3	3	5	5	
Outputs only		1	1		3	3		2	2			
Input only		1	1		3	3		2	2			
None					3	3						
Comment												

4 **Reconfigurable Optical Add/Drop Multiplexer (ROADM)**

Operational principle												
Mechanical	Lifetime is limited by number of switch+VOA cycles (e.g. 1E7)	5	5	4	3	3	2	4	3	4	4	3
Non-mechanical	Lifetime is limited by switch+VOA operational hours (e.g. 1E5)	5	5	4	3	3	2	4	3	4	4	3
Comment												
Number of directions												

2		3	4	4	3	3	2	3	3	5	5	3	
Other, please specify		5	5	4	3	3							
Comment													
Number of DWDM channels													
32		3	3	4	3	3	2	4	4	4	4	3	3
40		5	5	4	3	3	2	3	3	4	4		
Other, please specify					3	3				4	4		
Comment													
Spacing of DWDM channels													
100 GHz		3	3	4	3	3		3	4	4	4	3	3
50 GHz		5	5	4	3	3		3	3	4	3	3	3
Other, please specify					3	3							
Comment													
Operational band													
C		3	3	4	3	3	2	3	3	4	4	3	
C+L		5	5	4	3	3	2	4	4	4	4		
L		3	3	4	3	3	2	2	2	2	2		
Comment													
Power monitoring	Increases device attenuation and price												
Composite inputs/outputs+Add/Drop channels		5	5	4	3	3		4	4	5	5	2	2

Add/Drop channels		3	3	4	3	3		3	3			2	2
Composite inputs/outputs		3	3	4	3	3		3	3				
None					3	3							
Comment													

5 **Wavelenght selective switch (WSS)**

Operational principle													
Mechanical	Lifetime is limited by number of switch+VOA cycles (e.g. 1E7)	5	5	4	3	3	2	2	2	5	5		
Non-mechanical	Lifetime is limited by switch+VOA operational hours (e.g. 1E5)	5	5	4	3	3	2	3	3	5	5		
Comment													
Configuration													
3 directions		4	4	4	3	3	2	2	2	5	5		
Other, please specify		5	5		3	3							
Comment													
Number of DWDM channels													
32		3	3	4	3	3	2	3	4	4	4		
40		5	5	4	3	3	2	1	1	4	4		
Other, please specify					3	3				4	4		
Comment													
Spacing of DWDM channels													

100 GHz		3	3	4	3	3	2	3	4			4	4
50 GHz		5	5	4	3	3	2	3	3			4	4
Other, please specify					3	3							
Comment													
Operational band													
C		3	3	4	3	3	2	3	3			4	4
C+L		5	5	4	3	3	2	4	4			4	4
L		3	3	4	3	3	2	2	2			2	2
Comment													
Power monitoring	Increases device attenuation and price												
Composite inputs/outputs		3	3	4	3	3		3	3			5	5
Dicrete channels		3	3	4	3	3		3	3			4	4
Composite inputs/outputs + Dicrete channels		5	5	4	3	3		4	4			4	4
None													
Comment													

6 **All-optical wavelength conversion (from gray signal to ITU-T grid)**

Output signals													
Single		5	5	4	3	3	2	2	2	5	5	5	4
More, indicate number (allow all optical multicast)		5	5		3	3		2	2			5	4

Comment													
Maximal speed													
1 or 2.5 G				4			2	2	2	5	5	3	3
10 G		4	4	4	3	3	3	4	4	4	4	4	4
40 G, indicate modulation formats		5	5	3	3	3		3	3			5	5
Other, please specify		5	3										
Comment													
Operational band - Input													
C		5	5	4	3	3	2	3	3	5	5	5	5
L		5	5	4	3	3	2	3	3	3	3	4	4
O				4	3	3	2	2	2			2	2
Comment													
Operational band - Output													
C		3	3	4	3	3	2	3	3	5	5	5	4
C+L		5	5	4	3	3	2	4	4	3	3	4	4
Comment													

Note:

Interest	**a)** interest in testing
……	**b)** interest in operation
5 highest	

4	high
3	normal
2	low
1	lowest

Appendix B: NDL Description of Optical schema

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE rdf:RDF>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
         xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
         xmlns:dc="http://purl.org/dc/elements/1.1/"
         xmlns:dcterms="http://purl.org/dc/terms/"
         xmlns:vs="http://www.w3.org/2003/06/sw-vocab-status/ns#"
         xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
         xmlns:owl="http://www.w3.org/2002/07/owl#"
>


<!--
  Description of this schema
-->
<rdf:Description rdf:about="http://cesnet/about/uri#">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Ontology"/>
    <rdfs:label>ndl</rdfs:label>
    <dc:title xml:lang="en">Network Description Language: Optical module</dc:title>
    <dc:description xml:lang="en">A vocabulary for defining a optical layer (none optical to
electrical conversions, only pure optic) in telecomunication network. Defining only attributes
like pass-band, attenuation, amplification, chromatic dispersion, etc. Not defining layers
like ethernet, Sonet, SDH, etc.</dc:description>
    <dc:publisher xml:lang="en">Miloslav Hůla, CESNET z.s.p.o., Czech Republic</dc:publisher>
    <dcterms:issued>2008-01-01</dcterms:issued>
    <dcterms:modified>2008-10-24</dcterms:modified>
    <owl:versionInfo>2.2</owl:versionInfo>
    <vs:term_status>unstable</vs:term_status>
    <vs:userdocs rdf:resource="http://cesnet/detailed/user/description#"/>
    <vs:moreinfo xml:lang="en">WARNING: this schema is unstable and simple, describing only
piece of optical layer and a list of technical options is incomplete. Schema should be divided
and structured to more layers.</vs:moreinfo>
</rdf:Description>


<!--
  Classes
-->
<rdfs:Class rdf:about="#OpticalElement">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>OpticalElement</rdfs:label>
    <rdfs:comment xml:lang="en">Any optical element like a amplifier, attenuator, optical
switch, fiber, etc...</rdfs:comment>
```

```
</rdfs:Class>

<rdfs:Class rdf:about="#OpticalPort">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>OpticalPort</rdfs:label>
    <rdfs:comment xml:lang="en">Can be understanded as mechanical pluggable port (connector)
on a device chasis, end of fiber, end of pigtail, etc...</rdfs:comment>
</rdfs:Class>

<rdfs:Class rdf:about="#PassBand">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>PassBand</rdfs:label>
    <rdfs:comment xml:lang="en">Piece of frequency spectrum, limited by lower and upper
frequency, where an signals can be transmitted. E.g. pass-band from 184 THz (1625 nm) to 196
THz (1530 nm) is known as C+L band (C+L window).</rdfs:comment>
</rdfs:Class>


<!--
  Propertities
-->
<rdf:Property rdf:about="#hasOpticalPort">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>hasOpticalPort</rdfs:label>
    <rdfs:comment xml:lang="en">The hasOpticalPort property assigns optical port for the
optical element. E.g. optical switch (OpticalElement) could have a 32 ports (32 x
OpticalPort). Or optical fiber (OpticalElement) have only 2 ports (2 x
OpticalPort).</rdfs:comment>
    <rdfs:domain rdf:resource="#OpticalElement"/>
    <rdfs:range rdf:resource="#OpticalPort"/>
</rdf:Property>

<rdf:Property rdf:about="#hasSpreadPassBandParameters">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>hasSpreadPassBandParameters</rdfs:label>
    <rdfs:comment xml:lang="en">Inform that an parameters of pass-band are divided into
smallest sub-bands.</rdfs:comment>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:range rdf:resource="#PassBand"/>
</rdf:Property>

<rdf:Property rdf:about="#passBandTransmit">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>passBandTransmit</rdfs:label>
    <rdfs:comment xml:lang="en">Defining a possibility of frequency transmission in pass-band
between two optical ports.</rdfs:comment>
    <rdfs:domain rdf:resource="#OpticalPort"/>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:range rdf:resource="#OpticalPort"/>
    <rdfs:range rdf:resource="#PassBand"/>
</rdf:Property>

<rdf:Property rdf:about="#passBandBegin">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>passBandBegin</rdfs:label>
    <rdfs:comment xml:lang="en">Begin of pass-band [Hz].</rdfs:comment>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#float"/>
    <xsd:minInclusive
rdf:datatype="http://www.w3.org/2001/XMLSchema#float">176350E+09</xsd:minInclusive>  <!--
About 1700 nm -->
    <xsd:maxInclusive
rdf:datatype="http://www.w3.org/2001/XMLSchema#float">400000E+09</xsd:maxInclusive>  <!--
About  750 nm -->
</rdf:Property>

<rdf:Property rdf:about="#passBandEnd">
    <rdfs:isDefinedBy rdf:resource="#"/>
```

```
    <rdfs:label>passBandEnd</rdfs:label>
    <rdfs:comment xml:lang="en">End of pass-band [Hz].</rdfs:comment>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:domain rdf:resource="#OpticalPort"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#float"/>
    <xsd:minInclusive
rdf:datatype="http://www.w3.org/2001/XMLSchema#float">176350E+09</xsd:minInclusive>  <!--
About 1700 nm -->
    <xsd:maxInclusive
rdf:datatype="http://www.w3.org/2001/XMLSchema#float">400000E+09</xsd:maxInclusive>  <!--
About  750 nm -->
</rdf:Property>

<rdf:Property rdf:about="#isNotAvailable">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>isNotAvailable</rdfs:label>
    <rdfs:comment xml:lang="en">Inform that a pass-band is not available at now. E.g. optical
switch matrix is configured in different combination.</rdfs:comment>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#boolean"/>
</rdf:Property>

<rdf:Property rdf:about="#isOccupied">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>isOccupied</rdfs:label>
    <rdfs:comment xml:lang="en">Inform that a pass-band is occupated by some
signals.</rdfs:comment>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#boolean"/>
</rdf:Property>

<rdf:Property rdf:about="#attenuation">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>attenuation</rdfs:label>
    <rdfs:comment xml:lang="en">Attenuation of optical power inside of band
[dB].</rdfs:comment>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#float"/>
</rdf:Property>

<rdf:Property rdf:about="#attenuationCoefficient">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>attenuationCoefficient</rdfs:label>
    <rdfs:comment xml:lang="en">Attenuation coefficient of optical power, dependent on length
[dB/m].</rdfs:comment>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#float"/>
</rdf:Property>

<rdf:Property rdf:about="#length">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>length</rdfs:label>
    <rdfs:comment xml:lang="en">Distace between two ports which trasmitting pass-band [m].
(Useful for optical fibre.)</rdfs:comment>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#float"/>
</rdf:Property>

<rdf:Property rdf:about="#gain">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>gain</rdfs:label>
    <rdfs:comment xml:lang="en">Gain of optical power inside of pass-band [dB]. E.g. Pout =
Pin + 10.5 dB</rdfs:comment>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#float"/>
    <rdfs:seeAlso rdf:resource="#setPowerLevel"/>
</rdf:Property>
```

```
<rdf:Property rdf:about="#setPowerLevel">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>setPowerLevel</rdfs:label>
    <rdfs:comment xml:lang="en">Similar to gain property, but level of output power is set to
specific value [W]. E.g. Pout = 0.1 W</rdfs:comment>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#float"/>
</rdf:Property>

<rdf:Property rdf:about="#chromaticDispersion">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>chromaticDispersion</rdfs:label>
    <rdfs:comment xml:lang="en">Value of chromatic dispersion added inside of pass-band
[ps/nm].</rdfs:comment>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#float"/>
    <rdfs:seeAlso rdf:resource="#chromaticDispersionCoefficient"/>
</rdf:Property>

<rdf:Property rdf:about="#chromaticDispersionCoefficient">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>chromaticDispersionCoefficient</rdfs:label>
    <rdfs:comment xml:lang="en">Chromatic dispersion coefficient is a value of CD dependent on
length [ps/(nm*km)].</rdfs:comment>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#float"/>
    <rdfs:seeAlso rdf:resource="#chromaticDispersion"/>
</rdf:Property>

<rdf:Property rdf:about="#polarizationModeDispersion">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>polarizationModeDispersion</rdfs:label>
    <rdfs:comment xml:lang="en">Value of polarization dispersion added inside of pass-band
[ps].</rdfs:comment>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#float"/>
    <rdfs:seeAlso rdf:resource="#polarizationModeDispersionCoefficient"/>
</rdf:Property>

<rdf:Property rdf:about="#polarizationModeDispersionCoefficient">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>polarizationModeDispersionCoefficient</rdfs:label>
    <rdfs:comment xml:lang="en">Polarization mode dispersion coefficient is a value of PMD
dependent on square root of length [ps/sqrt(km)].</rdfs:comment>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#float"/>
    <rdfs:seeAlso rdf:resource="#polarizationModeDispersion"/>
</rdf:Property>

<rdf:Property rdf:about="#minimalPower">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>minimalPower</rdfs:label>
    <rdfs:comment xml:lang="en">Minimum of optical power which can be transmitted (detected)
at pass-band [W]. (Useful for receivers.)</rdfs:comment>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:domain rdf:resource="#OpticalPort"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#float"/>
</rdf:Property>

<rdf:Property rdf:about="#maximalPower">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>maximalPower</rdfs:label>
    <rdfs:comment xml:lang="en">Maximum of optical power which can be trasmitted (received) at
pass-band [W]. (Useful for input ports, receivers, ...)</rdfs:comment>
    <rdfs:domain rdf:resource="#PassBand"/>
    <rdfs:domain rdf:resource="#OpticalPort"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#float"/>
</rdf:Property>
```

```
<rdf:Property rdf:about="#connectorType">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>connectorType</rdfs:label>
    <rdfs:comment xml:lang="en">Type of connector (FC, LC, SC, ST, ...)</rdfs:comment>
    <rdfs:domain rdf:resource="#OpticalPort"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#string"/>
</rdf:Property>

<rdf:Property rdf:about="#connectorPolishType">
    <rdfs:isDefinedBy rdf:resource="#"/>
    <rdfs:label>connectorType</rdfs:label>
    <rdfs:comment xml:lang="en">Polish type of connector (APC, PC, UPC, ...)</rdfs:comment>
    <rdfs:domain rdf:resource="#OpticalPort"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#string"/>
</rdf:Property>

</rdf:RDF>
```

Appendix C: Terminology for vendor independent description of photonic devices

This appendix explains vendor independent terminology used for photonic devices and functions naming in this deliverable.

Path switch

Path switch is optical switch, where whole operational band from one of the inputs (fibres) can be switched to one of the outputs (fibres). Assignment is done in 1:1 manner. Control of the path switch is done in electric domain.
In TNRC (Transport Network Resources Controller) terminology this type of device is called FSC.

Typical configurations:
8I x 8O,
16I x16O,
32 I x 32O,
64 I x 64O,
128 I x 128O
etc.

Path switch with multicast option

Path switch is optical switch, where whole operational band from one of the inputs (fibres) can be switched to one or more of outputs (fibres). Assignment is done in 1:N manner.
Control of the path switch is done in electric domain.
In case of switching to more output ports (fibres) input power is divided to output powers.

Typical configurations:
4I x 4O,
8I x 8O,
16I x 16O
2I x 16O
4I x 8O

Reconfigurable Optical Add/Drop Multiplexer - ROADM

The device has two kinds of inputs/outputs: composite and arbitrary.
Each signal (wavelength - on grid) from composite input port (fibre) can be either switched to arbitrary output according wavelength of signal (this is so called “DROP” of wavelengths) or passed to one of composite outputs (fibres) with attenuation/ equalization (this is so called “PASS” of wavelengths).
Signals (wavelengths - on grid) from arbitrary inputs corresponding “DROP” wavelengths are switched to one of composite outputs port (fibre) with attenuation/equalization (this is so called “ADD” of wavelengths).

Typical configurations:
1 composite I, 1 composite O, 32 arbitrary I, 32 arbitrary O
1 composite I, 1 composite O, 40 arbitrary I, 40 arbitrary O

Wavelength selective switch – WSS

The device has only composite input and output port/ports. Each signal (wavelength - on grid) from input port (fibre) can be switched (and optionally attenuated / equalized) independently to one from the output ports (fibres).

Typical configurations:
1 I, 4 O
4 I, 1 O
1 I, 8 O
8 I, 1 O

Appendix D: Description of used photonic devices

CzechLight Switch CLS

CzechLight Switch CLS is a 1 or 2U photonic path switch with 4x4, 8x8 or 16x16 ports developed by CESNET, which is commercially available from Optokon Co. Ltd. Number of ports can be increased by changing photonic switching component. Communication between CLS and Phosphorus's control plane is done via standard TCP/IP TELNET protocol. The following steps are used for management by TELNET protocol:

1. Open TELNET session to the CLS
2. Send command to the switch (create/delete cross-connections, get parameters)
3. Get state of operation status
4. Go to step 2 or close session

The following features are available for the CLS:

1. HTTP management
2. TELNET protocol
3. Authentication based on username/password using standard AAA
4. Internal port scheduler
5. Centralized management

The following commands are implemented:

1. Create/delete cross-connection
2. Get port/device information
3. Get system information
4. System configuration (accounts, time etc.)
5. Close session

Software features include support for standard HTTP and TELNET interface with possible future enhancements and time-scheduler capabilities. Time scheduling is rather important for sharing very expensive resources (i.e. long distance connectivity from CESNET to StarLight).

DiamondWave FiberConnect

Calient DiamondWave FiberConnect is a 17U path switch with 320x320 (in the maximum configuration) ports which is commercially available from Calient Networks, Inc. The switch used in the PSNC local testbed was equipped with cards supporting 144x144 ports. Communication between DiamondWave FiberConnect and Phosphorus's control plane is achieved via standard TCP/IP.
Calient DiamodWave FiberConnect offers the following features:

1. Telnet protocol
2. TL1 protocol
3. SNMP protocol
4. HTTP Management
5. Authentication based on username/password
6. Commands handling (cross-connections requests, information retrieving requests)
7. Sending responses for commands
8. Sending asynchronous messages about events, alarms

Following commands are available:

1. Reservation/unreservation of cross-connection
2. Create/delete cross-connection
3. Get port list with details, states, power levels
4. Get installed cross-connections with details, states and power levels
5. System configuration (accounts, time, network, services, software)
6. Alarm customization