Software-Defined Optics in Last Mile for Research and Education in the Czech Republic

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Original scientific paper

***Abstract* — The Software Defined Networking (SDN) gained recognition due to its improvements at the packet switching and routing layers. The benefits of programmable, remotely controllable networking devices can be applied to the optical layer of contemporary networks as well. This work introduces CESNET's Czech Light~® family of devices and their role in enabling the SDN approach within the CESNET's production network. As a case study, an upgrade of the Cheb node in CESNET's network from a hard-spliced add-drop multiplexers to SDN-capable Reconfigurable Optical Add-Drop Multiplexers (ROADM) is presented. The upgrade improved operational capabilities of the network, including remote channel equalization, and the possibility to deploy new channels or lambdas without physical intervention. The deployment of ROADM also improved the optical properties of the network.**

***Index terms* — Optical fibre network, metropolitan area network, software-defined network, OpenFlow, photonics.**

I. INTRODUCTION

National research and education networks (NREN) provide connectivity for universities, research centres and other advanced users. Their backbone networks use dense wavelength division multiplexing (DWDM) coherent transmission systems rather routinely, and the data rates of 100 Gb/s are quite common. Successful 1 Tb/s trials have been performed in networks where dark fibres are abundant and available for experiments [1] [2].

In contrast to the core, the transmission capacity situation is rather different in access parts of the networks. The DWDM systems are not deployed commonly and transmission speeds are usually limited to 10 Gb/s. [3] Sometimes the legacy time division multiplexing (TDM) technology is still used. [4] This stark contrast with the backbone networks is often caused by economic reasons as upgrades are not conducted that often.

This situation presents an obstacle for certain new scientific applications with rather special requirements. Examples of these are an accurate time transfer, or a very stable frequency transfer. For these applications, increasing the transmission speeds to 100 Gb/s or even 1 Tb/s is not important and will not help when such applications are deployed [5]. The reason for this constraint is that the time and/or frequency transfer is not about 'big data' transfers, but rather about stable and very low jitter. An accurate time transfer uses speeds well below 1 Gb/s.

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A transmission of stable frequency consists of a so called continuous wave (CW) signal, i.e., a signal without any modulation because the frequency of photons is the useful property of the transmitted information, and any additional modulation would be superfluous.

These signals find application in various fields, for example sensing, metrology, navigation, geodesy, radio-astronomy, Earth surveying, seismology, fundamental physics, etc, as manifested by the EU joint research project NEAT-FT [6].

Given the spatial properties of the access networks and the recent trends towards the flexibility of the deployed hardware and the "self-service" approach towards customer requests, it is important to minimize the need for manual reconfiguration of the in-field hardware. [7] The Software-Defined Networking (SDN) approach in particular brought a new way of evaluating the network design. Instead of relying on autonomous devices with some built-in decision-making logic, there is a modern trend of lifting the control algorithms out of the actual active devices. In an SDN network, these devices are remotely controlled, and network topologies can change in response to dynamic events without a manual reconfiguration. [8]

This contribution describes our approach towards applying the SDN concepts towards the optical layer within the CESNET network. A notable difference from the work performed at SWITCH [3], our work focused on SDN use on top of bidirectional fibre links.

The challenges of the optical last miles along with CESNET's solutions in terms of the Czech Light ® devices are described in chapters II and III, respectively. A practical case study about deploying SDN at CESNET's node in Cheb is presented in chapter IV. Finally, the article wraps up with an overview of the future work (section V) and a summary (VI).

II. OPTICAL LAST MILES

The issues related to last miles are well-known and all operators have learned to deal with them. Sometimes Last Miles have been dubbed as First Miles to emphasize their importance for high speed optical networking. In an NREN ecosystem, the last miles' problems cannot be solved by means of wireless networking because capacity (or bit rate) is not large enough for big demanding applications. With the higher bit rates, one has to utilize higher carrier frequencies, but their reach decreases significantly.

One example of such demanding application can be the ultra-high definition video transmission required for medical applications [9]. Moreover, new applications such as hard realtime controls require very low and constant jitter which can be satisfied successfully with an optical fibre [10]. Real-time network services are needed for an interaction with external processes, in other words for any processes running outside the network. Examples of these use cases include collecting dana from remote sensors or telescopes, or remote machine control. Importance of these topics can be found for example in the Strategy document for the pan-European network G´EANT for the 2020 time frame [7].

These challenges are similar to what the adoption of clouds has meant for traditional networks. It is believed that moving to SDN even for the optical transport is a reasonable next step [11].

To provide new opportunities for the research, education and scientific community, CESNET has developed new equipment – the Czech Light ® family of advanced photonic devices. All of the Czech Light ® devices are open. The word "open" means that third parties are allowed to modify the Czech Light ® devices, so it is easy to deploy them in new networking scenarios. The Czech Light ® devices can be also customized by power end users, e.g., by augmenting them with a custom, specific control software. This is usually not possible with equipment from traditional big vendors.

At the time the Czech Light ® devices were first introduced to the market, the OpenFlow protocol, a staple of the southbound Application Programming Interfaces (APIs) in the SDN world, was not yet available. As of September 2015, the OpenFlow protocols do not yet provide a comprehensive suite of concepts related to L0/L1 control of the optical signal. The most promising candidate, the Optical Transport Protocol Extensions [12], is limited to the concept of switching. This leaves many important properties, such as manipulating the gains of the amplifiers at various frequency bands, undefined by the OpenFlow.

For these reason, the Czech Light ® devices are usually controlled through the Simple Network Management Protocol (SNMP). However, thanks to their inherent extensibility and their open firmware, users will be able to upgrade to a firmware which supports an OpenFlow-compatible control and monitoring when these standard become available and mature.

III. CESNET'S SOLUTIONS FOR SDN IN THE LAST MILES

Dark fibres have been used in the CESNET network for many years. The first dark fibre was lit back in 1999, with Packet over SONET (PoS) technology with 2.5 Gb/s speed. At that time electro-optical regenerators for SONET/SDH were the primary option for extending the reach. Later on, optical amplifiers started to emerge, especially when optical gigabit Ethernet was deployed in metropolitan (MAN) and even wide area networks (WAN).

One of the first device developed by CESNET in their network were the Czech Light ® optical amplifiers (CLA). The most significant drawback of contemporary commercial offerings was the lack of standardized monitoring capabilities. Support for the de-facto standard Simple Network Monitoring Protocol (SNMP) was one of the key requirements for practical deployment for any NREN or Internet Service Provider (ISP). This is similar to the situation being addressed by the unification of the southbound SDN APIs, such as OpenFlow, where a set of common APIs facilitate interoperability and helps drive the costs of operation down.

The family of the Czech Light ® devices also include reconfigurable add-drop multiplexers (ROADM), wavelength selective switches (WSS) or tuneable dispersion compensators (TDC). All of these devices consist of the optical module, an embedded Linux system, and essential control electronics. The Czech Light ® devices are housed in a standard rack chassis of size 1U or 2U, and can be customized on demand.

Various Czech Light ® products are protected by several patents in the EU [13] and within the US [14] [15] [16]. As of 2015, the Czech Light ® equipment is used on 4890 km of the CESNET networks, including 2012 km of bidirectional single-fibre transmission.

IV. CASE STUDY: DEPLOYING ROADM IN CHEB

As a practical example of the utility of the SDN approach applied to the lowest photonic layer (L0 in the ISO/OSI model), we present the upgrade of one PoP in the CESNET network which was performed in 2011 at Cheb. Cheb is a site within a single-fibre bidirectional transmission path Plzeň-Cheb-Most-Ústí nad Labem whose overall length is 320 km, see Figure 1. The original topology of the Cheb node is shown in Figure 2.

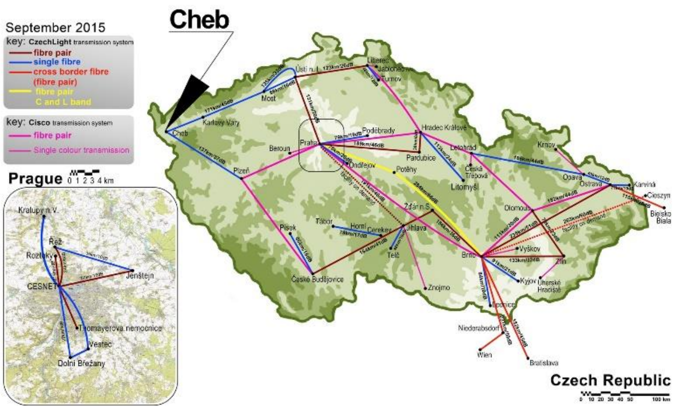

Figure 1. Location of Cheb in CESNET's network

Prior to this upgrade, various wavelenghts were distributed by means of a fixed, spliced-in Optical Add-Drop Multiplexes (OADMs) at Cheb. These relatively low-cost high-reliability devices came with a significant downside – any reconfiguration involved manual work and service interruption related to an onsite fibre re-splicing. Any change in optical spectrum allocation (channel allocation), even to an end-user site unrelated to Cheb, required a service interruption at Cheb because of the fixedspectrum properties of the OADMs. Furthermore, any change in attenuation along the transit path led to a need to perform a manual channel equalization in order to guarantee safe and efficient operation of the Erbium-Doped Fibre Amplifiers (EDFAs) along the way. Under typical scenarios and due to the technical aging of various components, including the amplifiers and fibre cables, channel equalization

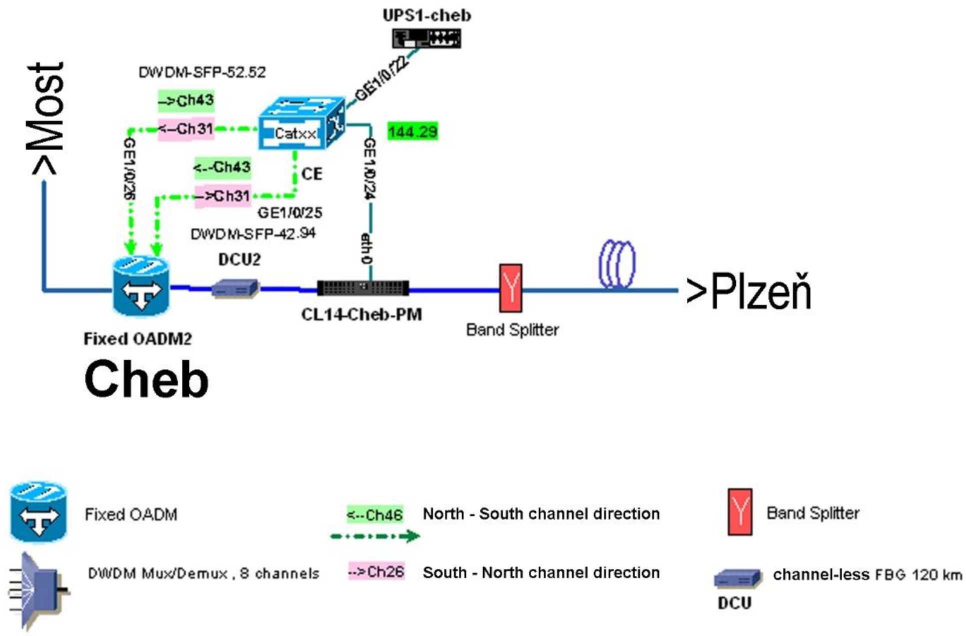

Figure 2. The Cheb node prior to its upgrade

had to be performed roughly every three months. This necessity translated to about four physical interventions on-site, with the inherent risk of affecting the other part of the infrastructure, and an associated downtime or service degradation.

During the upgrade, the fixed OADMs were replaced by a set of CL-ROADM devices, the Reconfigurable Optical Add- Drop Multiplexers. The new topology of the Cheb node is shown in Figure 3. For a whole-picture overview of the northwest area of CESNET's network, please consult Figure 4. The north-western part combines long-range channels (370 km, 107 dB attenuation, 7 EDFAs) with much shorter channels (126 km). The upgrade brought along several improvements, including improvements to the optical properties, and improvements to operational capabilities.

A. Improvements in Optical Performance

Each band splitter, or even an optical connector, are prone to a certain cross-talk. Given a typical booster amplifier configuration with an output power level of 10 dB, the crosstalk induced by the band splitter leads to about -30 dB of signal propagation back to a pre-amp, which is usually operating on incoming signal levels of around -25 dB. The channels are well-spaced, so the noise affects mostly the effective gain of the preamp. These phenomenons are — to a certain extent — unique to bidirectional single-fibre transmissions.

As an additional bonus, the ROADMs were configured to stop propagation of noise on unused channels, which contributes to an overall decrease in noise levels along the path. Finally, the ROADM can be also used as a channel monitor.

B. Improvements due to the SDN Properties

The improvements brought through the SDN control are mostly operational. First of all, it is now possible to perform channel equalization remotely. An operator can selectively adjust the signal strengths on different channels in order to better suite the operation of EDFAs deployed along the line. What used to require a manual, hands-on intervention at a remote side, including a physical splicing process, can now be performed remotely, using a software-controlled procedure. [8] In our experience, this new approach typically saves around four maintenance operations per year.

The key benefit of this upgrade, however, is the newly gained ability to deploy new lambda services or Alien Waves at Cheb. Eventual channel reallocation will not require physical access anymore. Because the network ring which connects Cheb is implemented through bidirectional, single-fibre light path, it is especially suitable for demanding applications, such as the time and frequency transfer.

V. FUTURE WORK

Deployment of an SDN-capable hardware is just a first step towards leveraging all benefits of SDN in one's network. In particular, even without an SDN controller taking care of the optical domain, the ability to remotely set all operational parameters of an optical device eliminates the need of on-site physical interventions. As of 2015, this is the state which we achieved in our CESNET network.

An important open challenge is integrating the knowledge of the optical layer with the SDN controller software — especially considering the implications of how the different layers of the network play together [11], and a lack of standard-based interoperable solutions. We are working on making the SDN capabilities of the optical layer available to researchers and students via an optical testbed [17]. In order to fully benefit from the SDN approach, further work is needed towards

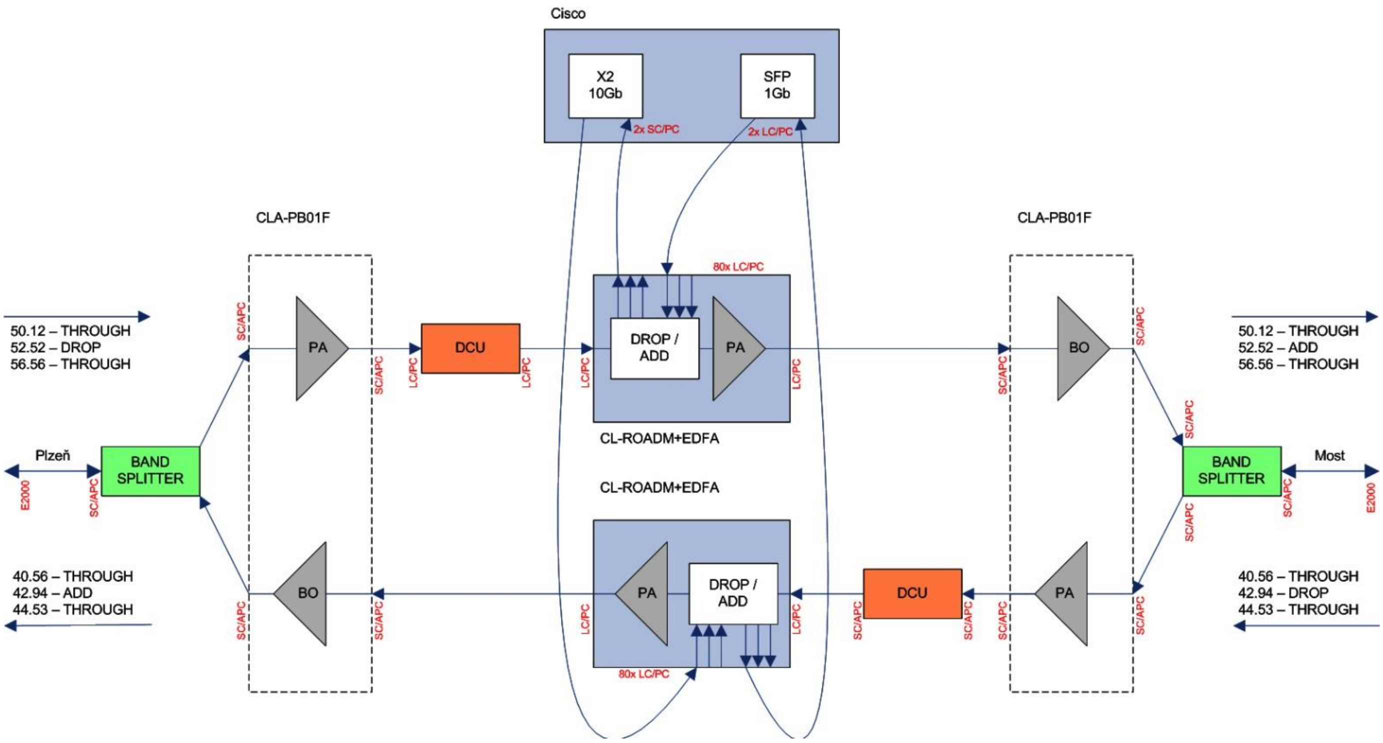

Figure 3. The topology of the Cheb node after an upgrade to ROADM

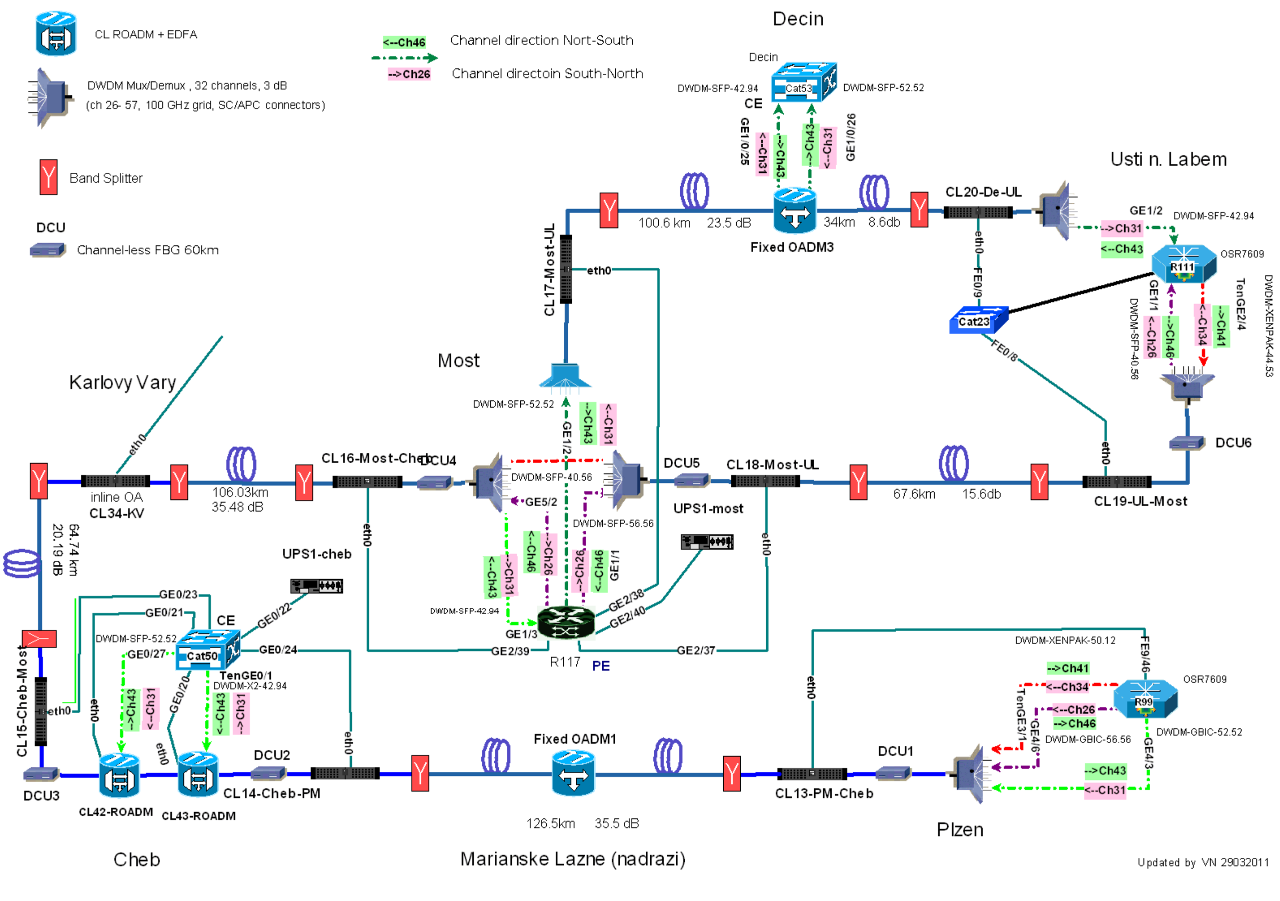

Figure 4. Figure 4. A big-picture overview of the north-western part of the CESNET’s network

standardization, understanding and modeling of the optical/photonic properties of the network and the deployed devices [18]. The SDN controllers also have to be taught about the existence of the underlying optical layer and its reconfigurability – all in a possibly multi-vendor, multi-domain environment.

VI. CONCLUSION

In this paper, we presented the SDN capabilities of the Czech Light ® family devices and their deployment in the CESNET network. Our focus was on the CL-ROADM model and its application in the Cheb node of a single-fibre bidirectional transmission path. The upgrade brought improvements on two fronts: in the optical transmission itself, and in the operational capabilities of the network.

The optical transmission got improved through an overall lower noise levels, and through more optimized mode of operation of the amplifiers.

The improvements in the operation capabilities of the network are brought by the software-defined aspect of the ROADMs. We have gained a new capability to deploy advanced lambda services, and reduced the need to perform onsite tweaks which mandated physical presence. We expect that these light paths will be needed by our users in the coming years, for example in response to their need for a precise time or frequency signal transfer.

A key advantage of the SDN approach is our ability to provision the light paths or Alien Waves remotely, with no hands-on presence on site.

ACKNOWLEDGEMENTS

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Jan Kundrát graduated at the Faculty of Mathematics and Physics, Charles University in Prague in 2012. He works as a researcher at CESNET, specializing in network modeling and software engineering. Jan is involved in a number of open source projects including KDE, and has contributed to the IETF standardization process of the IMAP protocol extensions. He is currently pursuing a PhD study at the Department of Distributed and Dependable Systems, Faculty of Mathematics and Physics at the Charles University in Prague. Jan participated in the GN3+, FI-PPP XIFI, COMPLETE, EGI-InSpire, EGEE-III and EGEEII projects.

Jan Radil received the MSc. and PhD. degrees in electrical engineering from the Czech Technical University, Praha, in 1996 and 2004, respectively. Jan joined the Research and Development Department, CESNET, a.l.e. in 1999, where he is responsible for optical networking and the development of the next generation of the Czech research and educational network. Jan participated in the EU projects SEEFIRE, Porta Optica Study, Phosphorus, GN2, GN3, GN3Plus, GN4, FI-PPP XIFI and COMPLETE and also is active in the worldwide GLIF activities. Jan holds 8 patents, including 3 US and 1 EU, and utility models. Jan's Hirsch index is 6 with more than 40 impacted papers. In 2007 Jan was given, together with his colleagues M. Karásek and J. Vojtěch, the research award of the Minister of Education, Youth and Sports.

Lada Altmannová holds Dipl. Ing degree from the Czech Agriculture University in Prague, Faculty of economy in 1983. She worked for the Computing centre of this University. She joined CESNET in 1996. She was Head of Financial department and since 1999 she has been a deputy of Head of Research and development department. She is interested in dark fibres lines for CESNET2 and CzechLight networks and has extensive experience of wavelength and fibre procurements on national level. Since year 2000 she has been responsible for transformation of CESNET2 from wavelength service to dark fibre lease. Lada participated in the EU projects SEEFIRE, Porta Optica Study, Phosphorus, GN2, GN3, GN3Plus and COMPLETE.

Ondřej Havliš received the Master's degree in the field communications and Informatics science from the Brno University of Technology, in 2012. He joined Optical networks department of CESNET, a.l.e., in 2012. He is active in research, design and verification of Photonic Services in the optical networks and development Photonic Testbed. He was actively involved in the project GN3 and GN3plus. In 2015 Ondřej has started to study in Brno university of technology at faculty of electrical engineering and communication doctor study with topic of this name Effective Optical Function in Fibre Photonic Networks. Currently Ondřej participates in the project DOBI.

Miloslav Hůla was born in Rakovník, Czech Republic, in 1982. He received the M.Sc. degree in electrical engineering from the Czech Technical University, Praha, in 2008. Miloslav joined the Reseaerch and Development Department, CESNET, Praha, in 2007 where he is responsible for optical networking and software programming for the Czech research and educational network. He has participated in the EU projects Geant2 and Phosphorus.

Radek Velc received his dipl. Ing. arch. Degree from the Faculty of Architecture, Czech Technical University, Prague, in 2004. He joined Cesnet, a.l.e. in 2005, where he has been working in the area of network infrastructure design and documentation within the Department Optical Networks. He has been also engaged in international project COMPLETE, FI-PPP XIFI, GN4, GN3+, GN3.

Stanislav Šíma passed away on Friday, 16 October 2015. He was born in 1944, graduated from the Czech Technical University in Prague in 1968, and in 1983 he received the CSc. degree in informatics. Prior to joining CESNET in 1996, he worked in the FEL CˇVUT in Prague, at the U´ AVT Prague, in Tesla Pardubice, and at Czech Ministry of Education, Youth and Sports. Stanislav was the father of many pioneering ideas and approaches that influenced the development of networks for research and education, including the cross-border fibre connection ofoptical research networks or an optical network concept running on an open communication system. Stanislav also was one of the founders of the international workshop focused on networks created by customers (CEF Networks workshop).

Josef Vojtěch received with honors M.Sc. degree in Computer Science, B.Sc. degree in Pedagogy and Ph.D. in field of optical networking from the Czech Technical University, Prague, in 2001, 2003 and 2009 respectively. Since 2003, he has been with research Department of Optical Networks, CESNET, a.l.e., which leads now. He participated in international projects: COMPLETE, FI-PPP XIFI, GN4, GN3+, GN3, GN2, Porta Optica Study, SEEFIRE. He has been also responsible for development of open family of photonic devices. He holds 15 patents (including 3 US and 1 EU) and utility models. His record shows Hirsch index 5 with more than 64 citations. He is a member of IEEE, OSA and SPIE. In 2007 he received the Research prize of the Czech minister of education.