

# Design and OAM&P aspects of a DWDM system equipped with a 40Gb/s PM-QPSK alien wavelength and adjacent 10Gb/s channels

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## Keywords

NREN, DWDM, PM-QPSK, alien wavelength, OAM&P

## Abstract

We present theoretical and experimental investigations of the interaction, in terms of BER performance, between a 40Gb/s Polarization Multiplexed QPSK alien wavelength and adjacent (50GHz spacing) 10Gb/s NRZ-OOK channels. Experiments were conducted on the Hamburg-Copenhagen section of the Amsterdam-Copenhagen CBF (Cross Border Fiber) connection between SURFnet and NORDUnet. Furthermore, we investigated the OAM&P (Operation, Administration, Maintenance and Provisioning) of an alien wavelength in CBF transmission systems.

## 1 Introduction

The continuous roll-out of hybrid networks initiated the demand for international CBF (Cross Border Fiber) DWDM links between NRENS. For example, SURFnet established CBFs to Münster and Aachen in Germany (DFN), to Hamburg (NORDUnet), and, most recently at the end of 2009, SURFnet deployed a CBF connection between Amsterdam and the open exchange in Geneva <sup>[1]</sup>. Typically, at the transition between NRENS, the DWDM systems that are supplied by different equipment vendors are connected via transponders to provide a clear demarcation point and regenerate the received signal (i.e. remove distortion and noise and to re-time the signal) before it enters the next DWDM system. This may not be necessary from a transmission point of view and thus, alien wavelengths in CBF systems are an appealing concept. They eliminate the cost and (carbon) footprint of transponders at the transition between the DWDM systems from different NRENS. In an earlier report <sup>[2]</sup>, SURFnet and NORDUnet conducted a joint 40Gb/s PM-QPSK (Polarization Multiplexed-Quadruple Phase Shift Keying) alien wavelength experiment on the CBF connection between Amsterdam and Copenhagen. In that experiment, a single 40Gb/s bi-directional wavelength traversed a CIENA CPL DWDM system between Amsterdam and Hamburg and an Alcatel-Lucent DWDM system between Hamburg and Copenhagen without regeneration. However, in that experiment a large guard band of 350GHz between the 40Gb/s alien wavelength and the other live-traffic was used to ensure minimal interaction. More traffic will be deployed on this CBF system and in order to efficiently utilize the available system capacity, large guard bands are not sustainable.

In this paper we investigate the effects of the adjacent 10Gb/s channels on the performance of the 40Gb/s alien wavelength theoretically by numerical simulations (section 2) and experimentally (section 3) by measuring the pre-FEC BER rates of the 40Gb/s alien wavelength for different power levels of the adjacent 10Gb/s channels. Challenges arising from the lack of standardization for OAM&P related to alien wavelengths will be discussed in section 4.

## 2 System simulations

Figure 1 shows the system configuration of the CBF transmission system that we used for the 40Gb/s alien wavelength experiment. The transmission fiber was TWRS (True Wave Reduced Slope) fiber and the total transmission distance was

equal to 1056km. The DWDM system between Amsterdam and Hamburg is equipped with four 40Gb/s channels, at the wavelengths of 1546.52nm, 1546.92nm, 1547.32nm and 1548.11nm.

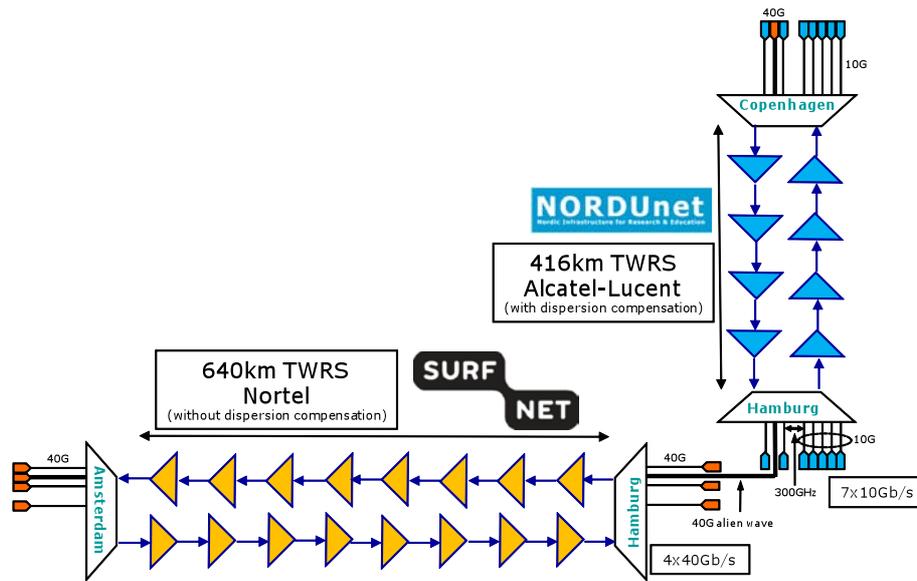


Figure 1. 40Gb/s alien wavelength transmission system setup

The four 40Gb/s channels used PM-QPSK transmitters and coherent receivers were capable of electronically compensating more than 40,000 ps/nm of chromatic dispersion. For this reason, this section was not equipped with optical in-line dispersion compensators. In Hamburg, the 40Gb/s wavelength of 1546.92nm is all-optically connected to the DWDM system between Hamburg and Copenhagen, spaced at 50GHz from two adjacent 10Gb/s OOK test channels, and transported as alien wavelength to Copenhagen. The traffic in the other three 40Gb/s wavelengths is routed through a geographically separate Alcatel-Lucent transmission system towards Copenhagen.

We modeled the BER performance of the 40Gb/s PM-QPSK alien wavelength by using the commercial software package VPI photonics. In this section, we describe the results of a theoretical study of the BER performance of the alien wavelength versus number of and the power level of the adjacent 10Gb/s OOK (On-Off Keying) channels in order to obtain more knowledge on the guidelines for the design of such transmission systems.

The system model used in VPI was designed as accurately as possible, including various effects such as nonlinearities, dispersion and noise.

PM-QPSK is known to reduce the requirements on electrical and opto-electrical components because it requires a symbol rate of only one fourth of the bit-rate. Furthermore, PM-QPSK is also known to have a relatively high tolerance not only towards chromatic dispersion but also polarization mode dispersion (PMD) can be effectively compensated in the digital signal processor (DSP) at the receiver. This was indeed also confirmed in our simulations which suggested that the signal did not suffer significantly from PMD in this link.

Although having a number of advantages, PM-QPSK is more sensitive to nonlinearities compared to for example DPSK. This in turn makes PM-QPSK signal sensitive to not only self phase modulation (SPM) but also cross phase modulation (XPM) induced by neighboring channels. Close neighboring channels modulated with the traditional on-off keying format can in particular be a source of XPM whereas other constant amplitude PSK signals will cause less harm.

Figure 2 shows the VPI simulation results where one 40Gb/s PM-QPSK signal was transmitted the 1056 km distance from Amsterdam to Hamburg and further to Copenhagen. The 40Gb/s PM-QPSK channel had two 10 Gb/s NRZ neighbors spaced 50 GHz on each side as illustrated in Figure 4. The power in these two 10 G/s channels is varied to record the change in signal quality of the 40 Gb/s PM-QPSK signal.

The other three channels that can be seen at lower wavelengths are representing regular traffic running on 10Gb/s NRZ channels. The power in these channels is not varied during the experiment. Note that the experimental setup, where the 10Gb/s signals co-propagate with the alien 40Gb/s PM-QPSK setup between Hamburg and Copenhagen, was different.

The set of data points are shown in Figure 2 represents an input power of 2 dBm for the 40 Gb/s signal, while the 10 Gb/s power is varied according to the x-axis. These powers should be seen relative to each other rather than absolute. It is quite obvious from the figure that the 40 Gb/s PM-QPSK signal quality drops as the neighboring 10 Gb/s channel powers increase. As the system proved very sensitive to power levels through the link, this could suggest that the neighboring channels are causing XPM, which in turn damages the PM-QPSK signal. In particular it seems that XPM effects set in around 10 Gb/s signal power of 2 dBm, at which point the 40 Gb/s signal power drops rapidly.

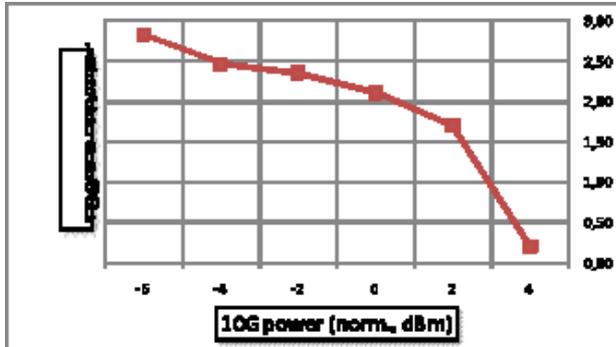


Figure 2. VPI simulation results showing how the 40Gb/s PM-QPSK signal quality changes with 10 Gb/s channel power.

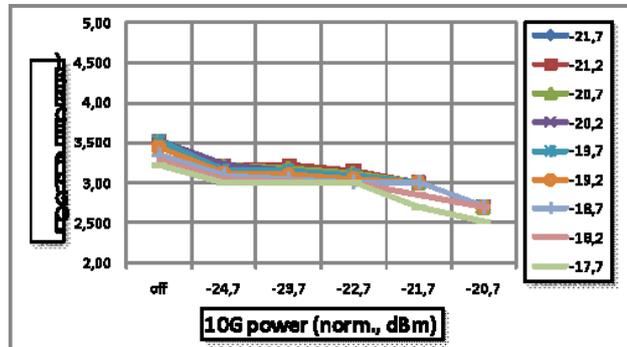


Figure 3. Experimental results showing how the 40Gb/s PM-QPSK signal quality changes when 10 Gb/s channel powers are varied.

Figure 3 shows the results for the experimental trial where the signal quality of a 40 Gb/s PM-QPSK channel was tested against the power of two neighboring 10 Gb/s NRZ channels spaced at  $-50$  GHz and  $+50$  GHz respectively. The  $\log_{10}$  (Pre-FEC BER) is for the 40 Gb/s PM-QPSK signal.

In the following section we will take a look at the experimental results for the Amsterdam – Copenhagen link and discuss them in relation this section.

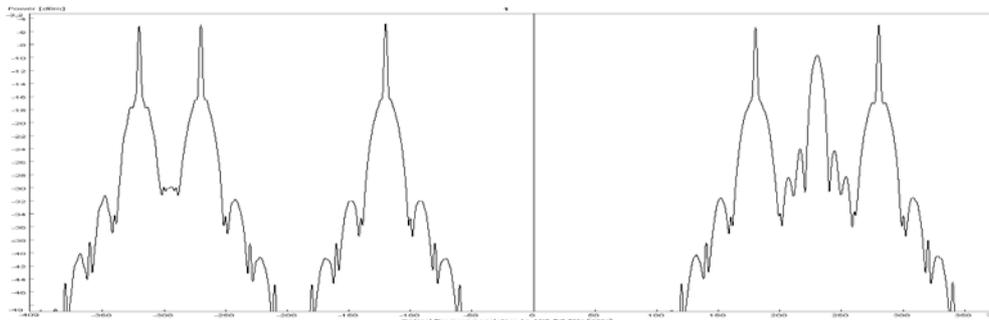


Figure 4. Spectrum from VPI showing the position of the 40 Gb/s PM-QPSK channel surrounded by two 10 Gb/s NRZ signals spaced 50 GHz from the PM-QPSK channel. In the left side of the spectrum three 10 Gb/s NRZ channels can be seen.

### 3 Transmission experiments

This section summarizes the comparison of the theoretical investigation of the previous section and experimental data of BER performance for the case of two adjacent 10Gb/s channels, spaced at 50GHz from the 40Gb/s alien wavelength, and for different power levels of the 40Gb/s alien wavelength and the adjacent 10Gb/s channels.

Comparing these experimental results with the simulations from above, it's clear to see that increasing the 10 Gb/s channel powers have the same effect in the two cases. In Figure 3 it can be seen how the BER keeps almost constant but then drops rapidly as the 10 Gb/s signal powers increase beyond  $-22$  dBm. Again this suggests that XPM could be causing it.

Summarizing these experimental and numerical trials we believe these initial results show how XPM is playing the major role in this type of transmission system, where a 40 Gb/s PM-QPSK alien wavelength is inserted into a 50 GHz slot in an already working 10 Gb/s NRZ system. To avoid severe signal degradation on the 40 Gb/s PM-QPSK signal it is necessary to optimize the power of the surrounding channels – in particular if these are amplitude modulated signals

such as NRZ or RZ. On the other hand PMD and SPM were both confirmed to play a smaller role in this system. Due to time constraints and the time consuming Monte-Carlo type VPI simulations, not all results made it for the deadline of writing this paper. Therefore numerical and experimental work will continue and final results will be presented at the Terena Conference held May 2011.

## **4 OAM&P (Operation, Administration, Maintenance and Provisioning)**

Lack of standardization prevents exchanging OAM&P information between DWDM systems from different vendors for monitoring alien wavelengths [3,4,5]. In this section we will provide an overview of standardization efforts for alien wavelengths at the ITU-T and a method that we used for monitoring the 40Gb/s alien wavelength between Amsterdam and Copenhagen. Finally, we compare the CAPEX (Capital Expenditures) and OPEX (Operating Expenditures) of the alien wavelength and native wavelength approaches.

### **4.1 Standardization efforts and state of the art**

The only work within standardization sector of the international telecommunication union, ITU-T, related to alien wavelength support can be found in recommendations G.698.1 and G.698.2, which specify operational ranges for interoperability of transponders for 2.5G/10G NRZ signals for different applications. Multi-vendor interoperability is guaranteed only if the same application codes (the same type of signals) are connected on a link. Mix of signals needs to be jointly “engineered”. The standards specify a generic definition of an alien wavelength: it is called a “single-channel interface” under a “black-link” approach. Under the specification, the native transponders at the entry of a standard DWDM system architecture are removed. The standard does not differentiate between UNI and E-NNI interfaces, i.e. the proposed architecture is generic.

Considering the state of the art though, there is a dual view of the alien wavelength concept. The authors of [3, 6, 7, 9] see it as a wavelength generated by an IP router (or an Ethernet switch) integrated with a DWDM transponder (i.e., at the UNI interface of a network between the digital and the optical layers), whereas the authors of [2, 4, 10] see it in a more generic way as a wavelength generated by a component which is from a different vendor than the considered DWDM system (i.e., could be applied at the E-NNI interface as in [2]). Under this view, an alien wavelength can potentially have an unsupported modulation format, framing and bitrate. Since a direct control (at the digital level) by the transport network provider is impeded, providing guaranteed performance for the wavelength is difficult to achieve. Accordingly, different field-trials have been documented, illustrating the technical feasibility of both alien wavelength concepts [2, 7, 9].

Furthermore, many vendors and providers have reported studies focused on CAPEX/OPEX savings due to electronic-bypass and alien wavelength support. Some support the CAPEX/OPEX saving hypothesis [5, 8] while others do conclude that such savings are marginal and are not worth the increased complexity, in terms of lack of manageability and problematic provisioning and troubleshooting [6].

### **4.2 Operational issues with introducing alien wavelengths**

Regardless of the differences in the concepts, several main challenges related to operating alien wavelengths (AW) have been outlined among interested vendors and operators [3, 4, 6]. These can be classified in several groups as follows:

- **Optical Transmission Performance:** it is possible that the performance of the system will be reduced since larger operating margins need to be considered in order to mitigate any possible performance degradations from introducing the AW together with existing legacy services. However, since the different equipment vendors often use transponders standardized in MSAs and supplied by a variety of transponder suppliers, the optical transmission performance of the alien wavelength can be the same as a native wavelength;
- **Reduced diagnostic and troubleshooting ability,** limited performance monitoring and fault isolation;
- **Lack of direct control over the AW,** which might lead to serious service disruptions for legacy services;
- **FEC interoperability:** in case an AW needs to be regenerated mid-way on a ULH system. If the 3<sup>rd</sup> party DWDM system does not support the client FEC, then it will be impossible to regenerate the signal;

- Service provisioning issues: lack of interoperability between the client and the server data/control plane systems makes automatic deployment impossible. Lack of knowledge on the exact performance of each system element under a scenario where arbitrary mix of signals with diverse modulation formats, framings and bitrates are deployed, makes engineering alien wavelengths a very complex task;
- Lack of robustness and increased complexity: may turn CAPEX/OPEX costs up, not down [6].

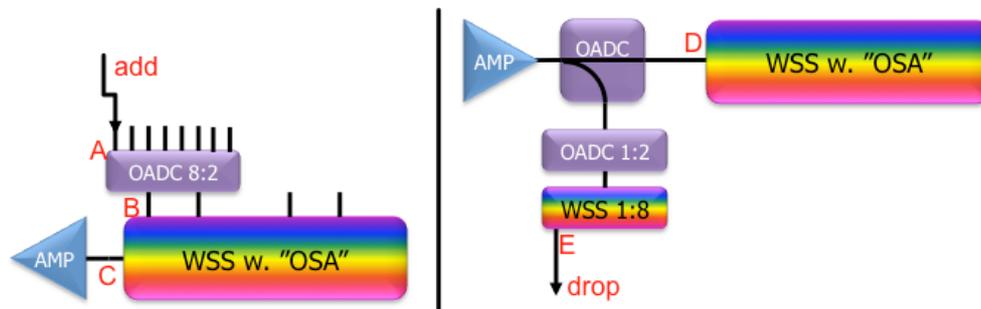
### 4.3 OAM&P solutions

Several solutions for some of the outlined AOM&P issues can be found. Cisco [3] suggest the so called virtual transponder solution, but it is a transponder which is between the client router and the network element, i.e., it cannot be applied at the E-NNI interface between two optical carriers. Their suggestion is to have an XML session between the client and the WDM NE [3] for OAM&P support. Such solution though is not universal since it does require the specific network elements presented in their trial. A universal solution should be built on either a standardized control plane (such as GMPLS) or a standard information exchange model.

Another solution is to utilize an intelligent demarcation card, which is able to add an optical tag to the alien wavelength. With the tag added it is then possible to trace, monitor and adjust the power levels of the alien wave throughout the network [11].

With respect to monitoring, Cisco [3] suggests using a test access point of the ROADM, where a copy of the alien wavelength is sent to an integrated monitoring device and in this way the integrity of the signal can be monitored without needing an access to the client transponder. This solution can perform very crude monitoring – power levels, presence of signal, OSNR. With more sophisticated monitoring devices also chromatic dispersion (CD) and polarization mode dispersion (PMD) can be monitored [12]. In order to provide a truly guaranteed transmission performance, the network operator needs digital access to the alien wavelength. Under the general definition of an alien wavelength this is not possible. An option is to have a direct communication between the management planes of the different vendors via a custom-made proxy or to design a standard for information exchange. Such works have not been addressed in the standardization bodies since the management plane implementation is a strictly proprietary matter.

The OAM&P environment for this experiment is best explained and discussed by describing the add and drop path of the alien wavelength. Figure 5 below shows the add and drop path respectively.



**Figure 5.** Add/drop path of alien system, identifying key components and monitoring/adjustment points for wavelength control.

The add/drop path consists of the following components:

- OADC 8:2            double 4:1 optical add/drop coupler with power monitoring (A)
- WSS w. OSA        Wave length selective switch with ability to shut input ports (B) and measure and adjust power (C)
- AMP                 two stage EDFA amplifier
- OADC                passive add/drop coupler
- WSS 1:8             tunable filter with ability to measure and adjust power (E).

The shown environment allows excellent control of the resulting optical spectrum at C as the WSS is able to adjust the alien and native wavelengths very precise according to predefined values. These values are most often calculated by vendor specific and proprietary simulation tools, why several problems can occur when used in combination with alien waves. In this specific case, 40G PM-QPSK isn't a modulation format utilized by Alcatel-Lucent, thus no predefined settings for the spectrum at C were present. The optimum spectrum at C was initially found by "trail and error" method.

While good control of the spectrum is possible, point A still remains a source of concern with regards to admission control to the spectrum. In native configuration several element control mechanisms prevents misconfiguration of native transponders why wavelength doubling at OADC8:2 isn't possible. These mechanisms are disabled when alien waves are installed, and only power monitoring is possible at point A, why injection of wrong wavelength at A can jeopardize existing traffic. Only option in case of wavelength doubling is to shut input port at point B, which could cause loss of service for additional 2 wavelengths.

The drop path does not have any severe drawbacks. The received spectrum can be measured at D, and the channel is dropped at E through the tunable filter were also power can be adjusted.

We found the above described environment secure enough for the test, where the setup was strictly controlled, but the lack of admission control at point A limits secure large volume implementations. Furthermore, it could be argued that not only wavelength admission control should be exercised at point A, but also modulation format control in order to fully control possible disturbing nonlinear effects.

Monitoring the alien wavelength was done with Element Manager (EM). As point A, C and E are monitored per wavelength, most fault scenarios on EM were similar to native waves. An important exception is LOS in point A which can cover line LOS (OTS/OMS) as well as transponder failures in the remote system.

#### **4.4 CAPEX and OPEX of alien wavelengths**

In order to investigate the CAPEX (Capital Expenditures) and OPEX (Operational Expenditures) in DWDM systems with alien wavelengths we calculated the cost of transponders, energy, installation and configuration for the implementation of a 200Gb/s link (with 20x10Gb/s at each client side) between Amsterdam and Copenhagen for the system of figure 1, for two cases: using alien wavelengths and using regeneration in Hamburg. We assumed 6 minutes per XFP installation, 12 minutes per muxponder card, and 30 minutes per DWDM card (all including fiberling). For the configuration we assumed 15 minutes per wavelength. We assumed 20 hours of travel for the alien wavelength case and 30 hours of travel for the case with regeneration.

Note that this analysis does not include the cost for the DWDM layer. Since all amplification sites need to be visited for the rollout of a DWDM system, the installation cost (including travel and lodging) make up a much larger part of the total cost of the system of about 10%~20% of the DWDM equipment cost. However, since the cost of the DWDM system is the same in both cases (i.e. alien and regeneration) and we did not include it in our analysis.

Figure 6 below shows the normalized cost (on a logarithmic scale) for the alien wavelength case. Cost is categorized by cost for the equipment (TRV-cost), the energy per year, the installation and the configuration and for three different bitrates per wavelength of 10Gb/s, 40Gb/s and 100Gb/s. It is important to note that the second and third largest costs, the cost for energy per year and the cost for labor for installation are two and nearly three orders of magnitude smaller than the cost of the transponders (respectively). Thus, equipment represents more than 98% of cost for an alien wavelength connection. In the case with regeneration, costs nearly double.

Cost per bit is lowest for the 100Gb/s solution. In conclusion, the use of alien wavelengths is clearly more cost efficient if compared to the case of two cascaded native wavelengths and furthermore CAPEX is the vast majority of the investment.

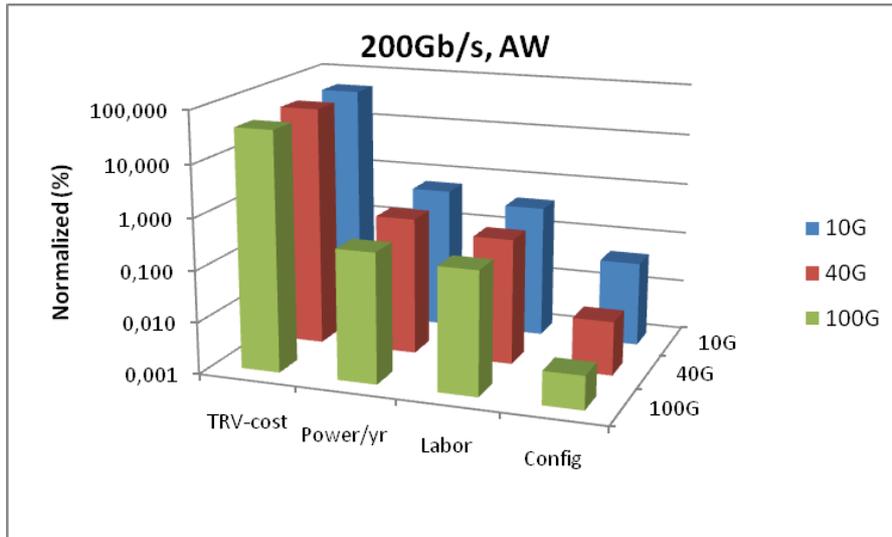


Figure 6. Normalized cost for a 200Gb/s alien wavelength connection between Amsterdam and Copenhagen

## 5 Conclusions

We investigated theoretically and experimentally the all-optical transmission of a 40Gb/s PM-QPSK alien wavelength between Amsterdam and Copenhagen via concatenated native and third party DWDM systems. The total transmission distance was equal to 1056km. All transmission fiber was TWRS (TrueWave Reduced Slope). We have presented the results of a meticulous theoretical and experimental investigation of the optimum BER performance of the 40Gb/s alien wavelength for different power levels of the adjacent 10Gb/s channels between Hamburg and Copenhagen. Furthermore, we have presented a VPI simulation platform for alien wavelength evaluation which conforms qualitatively to experimental results. Furthermore, a detailed review of the standardization efforts and the state of the art in the field of OAM&P has been presented. Together with our solution for monitoring the alien wavelength, we have analysed different options for coping with the main operational challenges related to introducing alien wavelengths.

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## Biographies

Lars Lange Bjørn is Optical Network Manager at NORDUnet and responsible for implementation, network planning and maintenance of NORDUnets DWDM network. During the last 10 years Lars has worked with SDH, DWDM and the associated management systems, holding different positions; operational engineer, system engineer, project manager and system administrator. He has worked at both green field operators as well as incumbents and holds a M.Sc in engineering from Department of Communications, Optics & Materials at the Technical University of Denmark.

Roeland Nuijts received the Ir. Degree in EE from the Eindhoven University of Technology (1993), and the PhD degree (with honours) in modeling of optical transmission systems from the ÉNST, Paris (1997). He conducted his Ph.D. research at AT&T Bell Labs in the USA. After graduation, he joined Lucent Technologies in the Netherlands and worked on integration of SDH and DWDM systems. From 1999, he supported the Asia-Pacific region technical marketing for Lucent based in Tokyo. In 2001, he joined OpNext in California, and subsequently AZNA in LA (acquired by Finisar). Roeland is currently a network services manager at SURFnet.

Martin Nordal Petersen is a post-doctoral researcher at the Fotonik Institute at the Technical University of Denmark. He is in charge of teaching within optical networks courses as well as managing and working on various research projects. Born in Denmark 1976, he received his Master of Engineering degree in 2001 and successfully defended his PhD thesis titled "Optical Performance monitoring in Optical Networks" in 2005. Both degrees were obtained at the Technical University of Denmark. Having worked on several fields within optical communication his main research areas remains to be optical performance monitoring as well as radio over fiber networks.

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