Field Trial Demonstration over Live Traffic Network of 400 Gb/s Ultra-Long Haul and 600 Gb/s Regional Transmission

A. Arnould(1), H. Mardoyan(1), F. Pulka(2), A. Ghazisaeidi(1), V. Aref(3), B. Bordez(2), P. Tondo(2), L. Dalle Cort(4), E. Pincemin(5), N. Brochier(5), F. Chatter(5), V. Guillot-Common(6), O. Bertran-Pardo(4), M. Frascolla(4), L. Luchesini(4), J. Renaudier (1)

(1) Nokia Bell Labs, Paris-Saclay, Nozay, France, (aymeric.arnould@nokia.com)
(2) Nokia IP Optical Networks, Paris-Saclay, Nozay, France
(3) Nokia Bell Labs, Stuttgart, Germany
(4) Nokia IP Optical Networks, Vimercate, Italy
(5) Orange Labs Networks, Lannion, France
(6) Orange International Networks Infrastructures and Services, France

Abstract *We demonstrate the successful trial of 400 to 600 Gb/s per carrier over Orange live network. Based on Nokia PSE-Vs technology, 400 and 600 Gb/s channels were transported up to 3446 and 1100 km respectively, thanks to probabilistic constellation shaping and flexible symbol rate optimization.*

Introduction

Driven by the deployment of 5G infrastructures, cloud-based applications or high-speed optical access networks, upgrading optical networks towards higher speed services is required to meet the ever-increasing demand for bandwidth, not only over short distances but also over longer ones in backbone networks. While 400 ZR[1] will answer the need for short distances at lower cost as required for example for data center interconnections, the use of higher symbol rates (~90 GBd) is appealing to achieve 400 Gb/s services over long distances in backbone transport networks. On top of reducing the number of transponders used in the network, increasing the symbol rate enables a more efficient use of deployed infrastructures by simplifying the network management as well as improving the use of available bandwidth and increasing spectral efficiency. Moving from 50 to 100 GHz grids in WDM systems to operate individual channels at higher symbol rates provides a better utilization of the available spectrum owing to the response of deployed wavelength selective switches (WSS)[2],[3]. Carrying high speed services at such high symbol rates over a single wavelength however requires the use of powerful forward error correction (FEC) schemes and modulation formats, together with the utilization of advanced digital signal processing (DSP) to compensate for implementation impairments[3],[4]. Furthermore, as the number of nodes crossed by the channel will vary from one route to another, efficient optimization requires flexible modulation formats and flexible symbol rates to maximize capacity versus reach depending on the network channel.

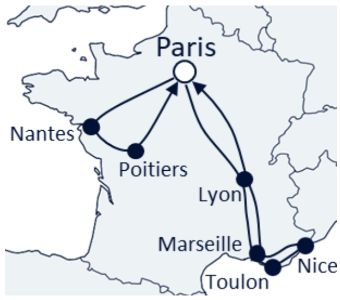

Fig. 1: Field trial performed from Paris network node to 15 PoPs on Orange International Networks Infrastructures and Services (OINIS) network based on Nokia PSE-Vs technology

In this paper, we report the successful trial of 400G to 600G transmission based on the Nokia PSE-Vs technology over the Orange optical transport network. The trial was performed from Paris network node to 15 points of presence (PoP), as shown in Fig. 1. The tests were run alongside live commercial traffic on the Orange International Networks Infrastructures and Services (OINIS) network and show the potential of the joint optimization of symbol rate and probabilistic constellation shaping (PCS) to enhance transmission performance. We demonstrate 400 Gb/s channel transmission in a 100 GHz slot up to 3446 km while crossing more than 20 reconfigurable optical add drop multiplexers (ROADM) and 30 wavelength selective switches (WSS). We also show 600 Gb/s channel transmission with 6 b/s/Hz spectral efficiency over more than 1000 km.

Field trial setup

Whereas hero laboratory experiments are usually based on ideal fiber infrastructure, with newly developed fibers, regular and/or short spans, advanced amplification techniques and

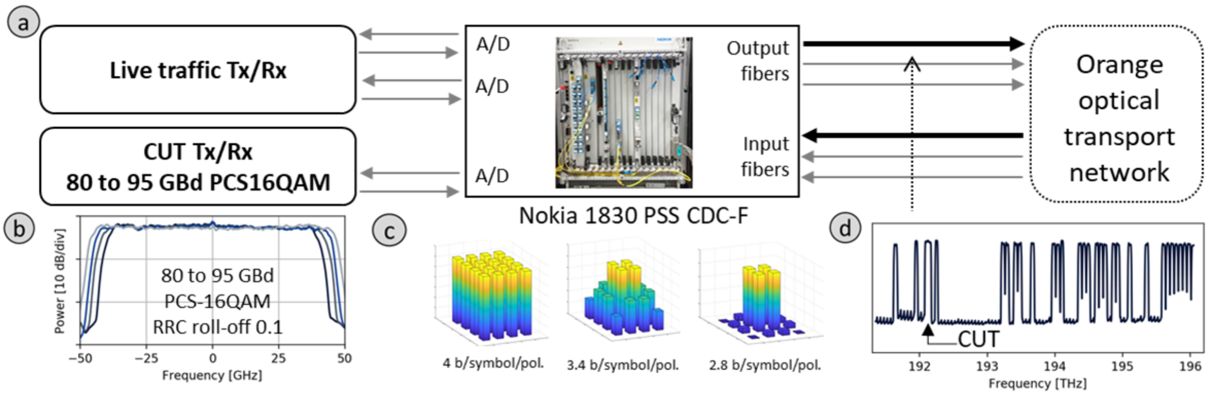

Fig. 2: Experimental setup of the field trial over Orange network with live commercial traffic

manually optimized transmission settings, field trials enable to assess performance of new transponder technologies over existing fiber infrastructure with real-world implementation constraints (i.e. losses, optical amplifiers and nodes). Contrary to some recent trials conducted over dark fibers[2],[5],[6], this field trial was conducted over a live backbone network, from Paris network node to 15 PoPs.

Fig. 2 illustrates the experimental setup of the field trial. For the channel under test (CUT), a 4-channel high speed CMOS DAC operating at 118 GSa/s was used to generate PCS-16QAM sequences, with root-raised cosine (RRC) pulse-shaping (roll-off 0.1), variable symbol rate (80 to 95 GBd) and constellation entropy (2.8 to 4 bits/symbol/polarization), as illustrated by the spectra and the constellations in Fig. 2(b) and Fig. 2(c). More details about the implementation and DSP of the CUT can be found in[3]. Using a Nokia 1830 Photonics Service Switch (1830 PSS) colorless directionless contentionless and flexgrid (CDC-F) node[7], this channel was sent to a multi-cast switch followed by an optical amplifier before being inserted into an optical cross-connect element through an add/drop (A/D) port, enabling routing to and from different directions in the OINIS backbone.

The channel occupied a 100 GHz slot, with central frequency varying between 191.525 and 192.125 THz for the different tests and was run alongside live commercial services with a fixed optical power set by the network control plane. Fig. 2(d) shows an example of the optical spectrum observed in the input fiber of the optical node, with our CUT centered at 192.125 THz and with live-traffic channels over the C-band, that were either added/dropped in the Paris PoP or transparently routed to other directions through the optical cross-connect.

At the receiver side, the channel was dropped, pre-amplified and sent into a coherent receiver composed of a tunable local oscillator, a coherent mixer and 70 GHz-bandwidth balanced photodiodes. The electrical waveforms were sampled with a 113 GHz bandwidth, 256 GSa/s high speed oscilloscope and stored for offline DSP. The DSP consists in chromatic dispersion compensation, polarization demultiplexing using pilot-aided multi-modulus algorithm, frequency and phase estimation and a last blind least mean square fast equalizer[3].

Table 1: Summary of performed tests

Route	Distance	#ROADM (#WSS)
Paris-Lyon-Paris	1100 km	6 (12)
Paris-Marseille-Paris	1851 km	9 (18)
Paris-Toulon-Paris	2037 km	13 (21)
Paris-Nice-Paris	2323 km	15 (23)
Paris-Nantes-Paris-Toulon-Paris	3161 km	20 (35)
Paris-Nantes-Paris-Nice-Paris	3446 km	22 (37)

Table 1 sums up the different tested routes over the Orange network in France. Network configurations from Paris to major cities in the south of France (Lyon, Marseille, Toulon, Nice) enabled to emulate transmission up to 2323 km. An additional route between Paris and Nantes allowed to reach distances beyond 3000 km over legacy standard single mode fibers (SSMF), the CUT was only routed from one path to the other when coming back to Paris. In all the remote PoPs, routing was performed only with ROADM, and the number of WSS varied between 12 for 1100 km transmission to 37 when reaching 3446 km.

Field trial results

First, we varied the entropy of shaped constellations for different symbol rates for three different distances (namely 1100 km, 2037 km and 3446 km) to assess the achievable net bit rate for each distance. For each symbol rate considered here, a FEC code from a family of spatially-coupled low density parity check (SC-

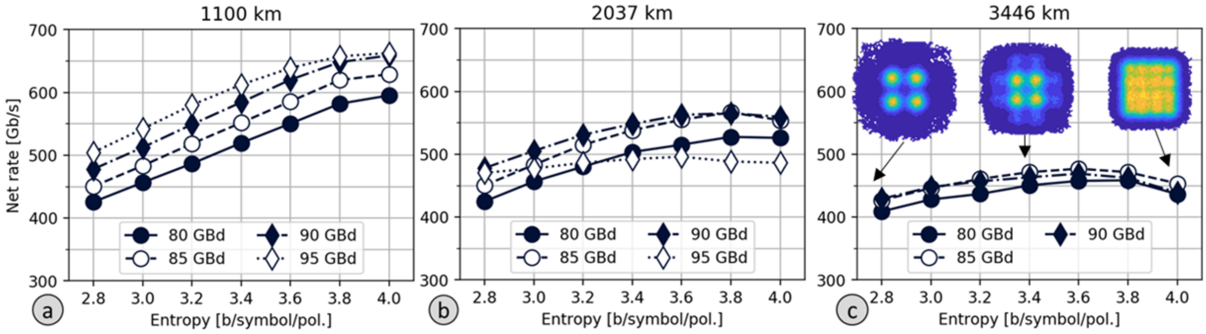

Fig. 3: Net channel rate vs. constellation entropy for a) 1100km, b) 2037 km and c) 3446 km. Constellation plots are shown for 90 GBd signals.

LDPC) codes[4] was chosen to accommodate with the change of entropy of the constellations: we varied the code rate from 0.51 to 0.97 with a fine granularity, and we selected the highest code rate allowing error-free transmission. Fig. 3 shows the evolution of the net throughput of the channel under test for 80, 85, 90 and 95 GBd, after FEC decoding and 1% DSP pilot removal. Fig. 3(a) shows that 600 Gb/s can be achieved over 1100 km with symbol rates of 85, 90 and 95 GBd. Not surprisingly here, the highest symbol rate transmission at 95 GBd provides the highest achievable bit rate. It is worth noting that 90 GBd leads to almost the same bitrate than 95 GBd at highest entropy. Fig. 3(b) then displays the results obtained at 2037 km, as the CUT was crossing 13 ROADM (21 WSS) along the route. The 95 GBd appears strongly penalized, which is attributed to the impairments induced by filtering from ROADM cascade. According to this figure, the 90 GBd signal reaches the highest net rate for an entropy close to 3.8. This result indicates that the 90 GBd signal did not suffer much from filtering penalties, contrary to the 95 GBd signal. It is also worth noting that 80 and 85 GBd signals enable the transport of 500 Gb/s services with entropies around 3.8, although they are slightly suboptimal compared to the 90 GBd signal. Finally, Fig. 3(c) shows the performance measured after ultra-long distance of 3446 km. Note that this figure only shows results for 80, 85 and 90 GBd since the 95 GBd signal was severely impaired by filtering effects of the 22 ROADMs crossed along the route. This filtering impact also starts being visible on the 90 GBd signal: for entropies above 3.0, the achievable rate for 90 GBd is lower than for 85 GBd signals. The maximum achievable rate is then obtained at 85 GBd for an entropy of 3.6, but all three symbol rates can transport 400 Gb/s services on this > 3400 km long route.

Finally, we summarize the performance of the different symbol rates using routes from 1100 km to 3446 km. Fig. 4 shows the optimal net rate evolution as a function of the distance. 80 and 85 GBd transmissions show steady reductions of the net rate as the distance increases. The benefit of increasing the symbol rate is reduced as the distance and the number of ROADM increase. 90 GBd outperforms 95 GBd for the different tested distances, except for 1100 km where the two symbol rates lead to barely the same bitrate. For distances greater than or equal to 1851 km, the performance is severely degraded by the filtering effects for the 95 GBd case. Considering 5% overhead for network protocols, 600G service is achievable at 1100 km with 90 and 95 GBd, 500G transport is possible up to ~2300 km with 85 and 90 GBd, whereas 400G transmission is demonstrated up to 3400 km with 80 to 90 GBd signals. Therefore, flexibility and in-field optimization of the symbol rate and the constellation shaping is a major asset to consider the actual network constraints.

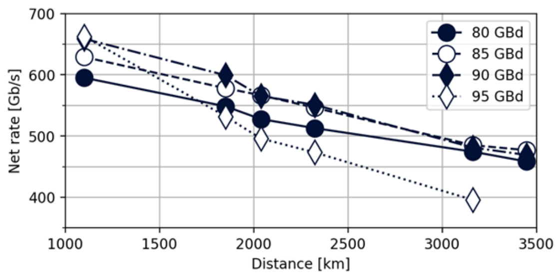

Fig. 4: Optimum net channel rate vs. distance

Conclusions

We demonstrated the in-field transmission of high symbol rate signals over the Orange optical network amidst commercial live-traffic, able to transport 400 Gb/s over 3400 km, 500 Gb/s over 2300 km and 600 Gb/s over 1100 km using 90 GBd signals. Thanks to the flexibility in constellation shaping and symbol rate tuning to take into account the real-world network context, these tests highlight the need of optimizing the tradeoff between spectral efficiency and transmission reach, to make 400G Ultra Long Haul and 600G Regional a reality.

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