Added value of 90 GBaud transponders for WDM networks

Thierry Zami[(1)], Bruno Lavigne[(1)], Mathieu Lefrançois[(1)]
(1) Nokia, Route de Villejust, 91620 Nozay, France
thierry.zami@asn.com

Abstract: We quantify the benefit of 90 GBaud transponders versus the more mature 67 GBaud ones to possibly improve the maximum total throughput in WDM networks and the associated amount of deployed equipment per transmitted Gb/s.
OCIS codes: (060.1155) All-optical networks; (060.6718) Switching, circuit; (060.4256) Networks, network optimization.

1. Introduction

While Elastic Optical Transponders (EOT) modulated at nearly 70 GBaud [1] are now emerging in the actual WDM networks, the next EOT generation as fast as 90 GBaud is already on approach [2]. This may create a dilemma for some WDM network operators interested in the most profitable EOT technology in the medium-term for their telecommunication infrastructures. This study addresses this question similarly to [1], by modelling the design of two core WDM networks and by considering different distributions of traffic as well as various rules for placing regenerators. We complement this result with other faster analyses to assess the relevance of any EOT technology to a given network topology, without having to run very time-consuming statistical planning of WDM network.

2. Simulation assumption

For this study, we consider the 2 WDM backbone topologies sketched in Figure 1. G50 [1] (resp. IND71) is a German (resp. Indan) WDM core network made of 50 (resp. 71) wavelength routing Optical Cross-connects (OXC) and 88 (resp. 97) optical links reported as blue lines in Figure 1. Each link is a pair of counter-directional concatenated WDM spans of Standard Single Mode Fibers (SSMF) featuring 0.22 dB/km loss. The mean span length is 56.9 km for G50 and 75.5 km for IND71. The optical loss of each span is compensated for by an associated Erbium Doped Fiber Amplifier (EDFA) with 5.5 dB noise figure. The chromatic dispersion, not counterbalanced in-line, is offset by the electronical post-processing of the coherent detection, that also achieves soft decision Forward Error Correction (FEC). The WDM carriers are transmitted in the 4800 GHz-wide C-band window. The optical carriers can be handled via 2 distinct EOT technologies, both relying on Probabilistic Constellation Shaping (PCS) modulation and 0.1 root raise cosine pulse shaping: either 62/67 GBaud EOTs [3] with 75 GHz carrier spacing or 90 GBaud EOTs with 100 GHz carrier spacing. Over this C-band, the grid of the 75 GHz-spaced (resp. 100 GHz-spaced) optical frequencies exhibits 64 (resp. 48) carrier positions. An EOT qualified as "62/67 GBaud" indicates it can selectively run at 62 or 67 GBaud with 2 different FEC overheads for the same payload, depending on the most impacting physical impairment along its Light Path (LP) through the network: pure WDM transmission distance or optical filtering. The assumed set of carrier data rates at 62 and 67 GBaud is the same as in [3], from 100 Gb/s to 500 Gb/s with 50 Gb/s steps. At 90 GBaud, this set ranges from 200 Gb/s to 750 Gb/s also with 50 Gb/s granularity, as listed in Table 1. Our model of WDM transmission relies upon the model described in [4], with parameters updated for the higher 62, 67 and 90 GBaud carrier symbol rates and for the PCS modulation. Table 1 also reports examples of transmission reaches obtained with this model for 67 and 90 GBaud channels sent through a series of 90

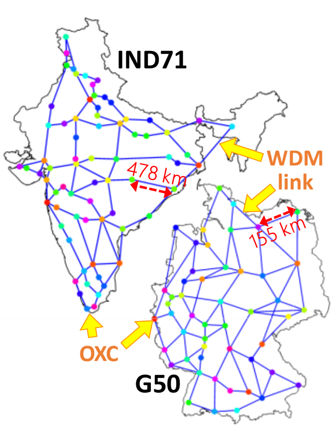

Figure 1: Illustration of the 2 studied network topologies

***Table 1:** List of reaches of **67 / 90 GBaud** PDM-PCS-QAM carrier*

carrier data rate	Transmission reach with 90 km-long spans of SSMF
100 Gb/s	6030 km / N.A.
150 Gb/s	4590 km / N.A.
200 Gb/s	3060 km / 5670 km
250 Gb/s	1980 km / 3420 km
300 Gb/s	1440 km / 2340 km
350 Gb/s	1080 km / 1800 km
400 Gb/s	540 km / 1350 km
450 Gb/s	360 km / 1170 km
500 Gb/s	180 km / 810 km
550 Gb/s	N.A. / 630 km
600 Gb/s	N.A. / 450 km
650 Gb/s	N.A. / 270 km
700 Gb/s	N.A. / 180 km
750 Gb/s	N.A. / 90 km

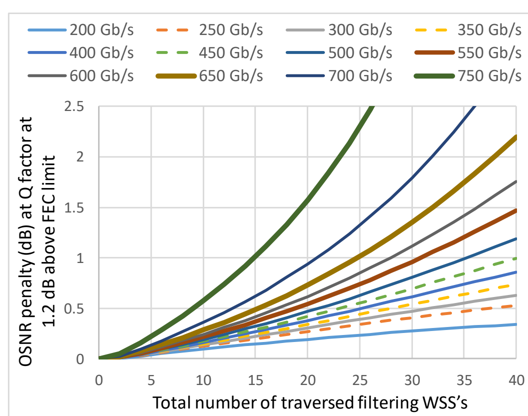

***Figure 2:** OSNR penalties on a 90 GBaud carrier through a cascade of 100 GHz-wide WSS filters*

km-long spans of SSMF with EDFA amplification, assuming fully loaded WDM C-band and 1 dB margin of Signal to Noise Ratio (SNR) margin. These indicative distances could be notably lengthened by using enhanced ultra-low loss fibers and/or enhanced in-line hybrid EDFA/Raman amplifiers. These improvements are beyond the scope of this paper. We assume "Route&Select" OXC architecture. The corresponding filtering-related penalty in terms of Optical SNR (OSNR) is established with the model proposed in [5], by accounting for the filtering transfer functions of actual Wavelength Selective Switch (WSS) measured in our laboratory for 75 and 100 GHz nominal bandwidths. Figure 2 illustrates such OSNR penalties undergone by 90 GBaud optical carriers through the cascade of 100 GHz-wide WSS filters, for data rates from 200 to 750 Gb/s. We also reported in [3] equivalent penalties for 62/67 GBaud PCS-modulated optical carrier going through a suite of 75 GHz-wide WSS filters.

For each simulated network planning, the matrix of traffic is randomly drawn We test 2 possible traffic breakdowns, both with even probability of connection between any pair of network OXCs. the exchanged throughput for traffic **T1** (resp. **T2**) uniformly ranges from 100 Gb/s to 1 Tb/s (resp. from 400 Gb/s to 2 Tb/s), by assuming end-to-end electrical traffic aggregation. Connections are successively accommodated along the Shortest Path (SP) bridging their source and destination OXCs, and exhibiting enough residual capacity on each of the WDM links they go through. Wavelength contention or insufficient Quality of Transmission (QoT) can be overcome by means of optoelectronic Elastic Regenerator (ER). We consider 2 rules regarding ER deployment: Under rule **R1** it is only enabled in case of wavelength blocking or insufficient QoT; whereas under rule **R2**, ER deployment is relaxed to yield a higher average Spectral Efficiency (SE) in the network and so a higher ultimate network capacity. Inverse multiplexing via parallel optical subcarriers is also performed when the demanded capacity exceeds the largest possible capacity of one single optical carrier along the tested transparent LP. If no appropriate SP can be found under the chosen conditions of ER deployment, then the whole throughput of the demanded connection is rejected. More details are explained in [1] about our combined optimization of inverse multiplexing, modulation selection and ER placement. To obtain the results reported in section 4, each of the tested network setups is simulated 200 times with 200 distinct random traffic drawing. Their figures of merit are reflected by the mean Maximum Network Capacity (MNC) that is the total accepted throughput up to the rejection of 1% of the total demanded throughput, and by the average number of needed EOTs (N_{EOT}) per 100 Gb/s services transmitted when reaching MNC. The higher MNC is, the better. Conversely, the smaller N_{EOT} is, the better.

3. Network-oriented metrics to benchmark different EOT technologies

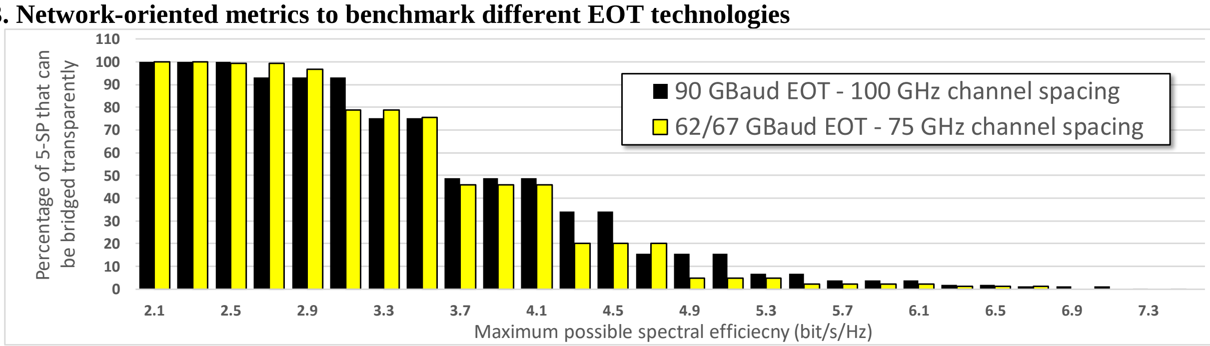

Figure 3: *Percentages of 5-SPs of the IND71 topology that could be bridged transparently with a maximum given SE*

Before running time-consuming statistical network dimensioning (the results of which are discussed in section 4), we investigate rapid methods to benchmark the network performance of the 90 GBaud EOTs versus the 62/67 GBaud EOTs. This is more insightful than only comparing their longest transmission distances listed in Table 1. Our approach considers the set of K-SPs of the network topology of interest. For this study, we consider K=5. Then, for each of these 5-SPs, we calculate its maximum channel throughput with respect to the examined EOT, according to the models of WDM transmission and optical routing described in previous section. Dividing this highest data rate by the channel spectral slot width provides the maximum SE the light path can support. From this information established for each 5-SP of IND71 topology, Figure 3 illustrates the related declining percentages of these 5-SPs that can be bridged with a given maximum SE. A similar network-oriented figure was reported in [6]. But, we differently propose to scale the x-axis in SE to be able to compare any EOT in the same manner, whatever the symbol rate of its optical carrier and the width of the spectral slot this carrier occupies. Figure 3 does not show a global higher SE with the 90 GBaud EOT technology against the 62/67 GBaud one. Besides, for a couple of SEs the percentage of 5-SPs that can be covered transparently in IND71 is slightly higher with 62/67 GBaud EOTs. Thus, MNC is expected to be similar for IND71 topology with the 62/67 EOT technology or the 90 GBaud one. Another network-based metric consists of the mean number of EOTs needed to transport a selected throughput along several classes of light path; these classes being defined as all the paths of the 5-SPs the length of which belongs to the same interval [n*200 km, (n+1)*200 km] (any step of interval other than 200 km could be considered). Figure 4 illustrates this figure of merit for transmitting 400 Gb/s or 1 Tb/s bidirectional service. It shows that along most of the IND71 5-SPs, 400 Gb/s can be served with the same number of 90 GBaud EOTs as with 62/67 GBaud EOTs. Whereas for most distances, 90 GBaud symbol rate can transport 1 Tb/s with notably fewer EOTs than 62/67 GBaud rate. Hence, 90 GBaud technology is expected to save EOTs, particularly when the mean connection throughput surges.

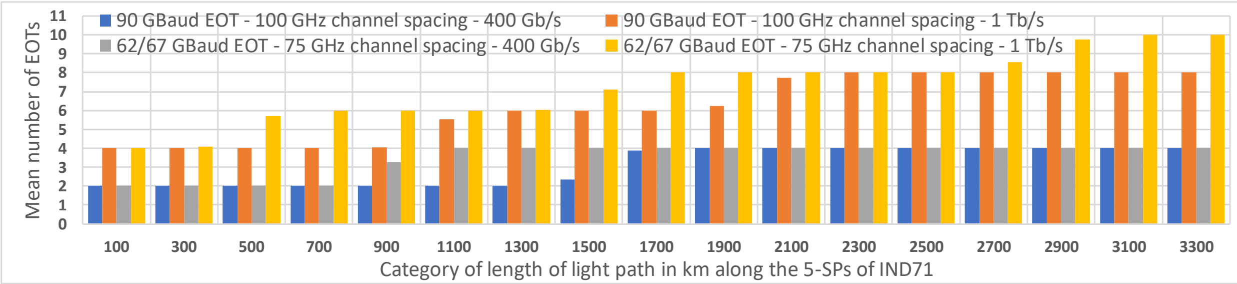

Figure 4: *Mean number of EOTs for transporting 400 Gb/s or 1 Tb/s with respect to the mean length of the light paths in IND71*

4. Results of network planning

Table 2: *simulation results*

62/67 GBaud carriers 75 GHz apart or 90 GBaud carriers 100 GHz apart + Rule of ER deployment	G50				IND71			
	Traffic T1		Traffic T2		Traffic T1		Traffic T2	
	MNC (Tb/s)	N_{EOT}	MNC (Tb/s)	N_{EOT}	MNC (Tb/s)	N_{EOT}	MNC (Tb/s)	N_{EOT}
62/67 GBaud carriers, Rule R1	266.2	0.68	298.9	0.61	138.4	1.02	145.1	0.96
62/67 GBaud carriers, Rule R2	270.6	0.69	301.9	0.63	163.1	1.1	171.2	1.05
90 GBaud carriers, Rule R1	252.4	0.55	309.5	0.45	138.6	0.79	151.3	0.7
90 GBaud carriers, Rule R2	254.7	0.57	311.3	0.46	163.4	0.85	181.5	0.76

For a more thorough analysis, actual network dimensioning is needed. Table 2 reports the outcomes of our related simulations for G50 and IND71 as well as for the 2 traffics T1 and T2. We observe that whatever the rule for placing ERs, the simulated topology or the traffic, deploying only 90 GBaud EOTs advantageously decreases N_{EOT} down to -27% for G50 (0.46 vs. 0.63) and for IND71 (0.76 vs. 1.05), both with traffic T2. The rule for regeneration does not meaningfully influence this reduction ratio. With traffic T2, 90 GBaud EOTs yield slightly higher MNC than only 62/67 GBaud EOTs (in between +2% and +5%) on both network topologies and whatever the rule for placing ER. On the other hand, with traffic T1 and particularly for G50, deploying only 90 GBaud EOTs decreases MNC nearly by -6% (270.6 Tb/s vs. 254.7 Tb/s), because the lowest throughputs of the range of traffic T1 less optimally fill the capacity of the 90 GBaud carriers that each takes 100 GHz, as compared to the filling of the capacity of the 62 or 67 GBaud carriers that each only occupies 75 GHz. Hence, the benefit of 90 GBaud EOT is clearly about N_{EOT}, whereas it would bring a relatively small added value in terms of network capacity and only if the average data flow exchanged between the network OXCs is large enough, typically larger than 500 Gb/s.

5. Conclusion

We propose 3 methods for assessing the upcoming 90 GBaud EOT technology versus the slower 67 GBaud one: i) the most usual comparison of the longest WDM transmission distances shown in Table 1; ii) an intermediate method reflecting SE improvements and transponder savings along the set of shortest paths of the tested network; iii) the conventional statistical actual network planning. The 2 latter approaches conclude the most significant advantage to be expected from the 90 GBaud interfaces on the studied networks is the substantial saving of EOTs down to -27%.

6. References

[1] T. Zami et al., "How 64 GBaud Optical Carriers Maximize the Capacity in Core Elastic WDM Networks With Fewer Transponders per Gb/s", IEEE/OSA JOCN, Vol. 11, no. 1, p. A20-A32, January 2019.
[2] J. Pedro et al., "Capacity Limits of Mesh Optical Transport Networks Exploiting Future High Baud-Rate Line Interfaces", Paper Sa.A2.3, ICTON'2019, July 2019
[3] T. Zami et al., "Simple Self Optimization of WDM Networks based on Probabilistic Constellation Shaping channel modulation", to be published in IEEE/OSA JOCN "OFC'2019" special issue in 2020.
[4] B. Lavigne et al., "System design tool for high bit rate terrestrial transmission systems with coherent detection", Bell Labs Technical Journal, Vol. 18, n°3, Page 251, December 2013
[5] I. Fernandez de Jauregui Ruiz et al., "An Accurate Model for System Performance Analysis of Optical Fibre Networks with In-line Filtering", Paper P78, ECOC'2019, September 2019
[6] M. Ghobadi et al, "Evaluation of Elastic Modulation Gains in Microsoft's Optical Backbone in North America", Paper M2J.2, OFC'2016