Spectrum and Cost Savings from Beyond-100Gbaud Optical Transponders

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Abstract: We quantify spectrum usage and transponder cost when deploying next-generation transponders that support up to 1.6 Tbit/s, in both C- and C+L bands. We compare two transponder architectures: a) single-carrier, operating beyond 100 Gbaud and b) multi-carrier with each carrier operating below 100 Gbaud.

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1. Introduction

To cope with the growing client traffic, coherent optical transponders have been developed to support higher-order modulation formats (up to PM-64QAM with Probabilistic Constellation Shaping) and increase symbol rates (up to 90 Gbaud) - resulting in 800G-capable transponders. Reaching higher data rates helps to avoid upgrades in the number of ports at optical nodes, despite the increasing traffic, and can lead to savings in transponder costs. As utilization of even higher-order modulation formats is restricted to very short paths (i.e., a few fiber spans [1]), research is currently moving towards new single-carrier (SC) optical transponders with symbol rate beyond 100 Gbaud, that can effectively accommodate client requests larger than 800 Gbit/s [2,3]. Another way to achieve the same transmission rates is to adopt dual-carrier (DC) transponders that operate at lower symbol rates, hence being more suitable for smaller traffic requests, as individual carriers can be turned off, reducing spectrum occupation. On the other hand, DC transponder tends to be more expensive than a SC beyond-100Gbaud one, as DC transponder contains two copies of some hardware components (e.g., modulators).

In this work we evaluate spectrum occupation and transponder cost for SC and DC architectures of next-generation coherent optical transponders with different data rate capabilities. For this comparison, we suggest two transponder-cost approximations: increasing cost with the growth of maximum data rate or with the growth of symbol rate. As not all the considered traffic scenarios can be supported in C-band, in this study we also extend our evaluations to C+L-band.

In the next sections, we first describe the underlying physical modelling and the Routing and Spectrum Assignment algorithm used to perform the comparative analysis, then we provide a numerical evaluation of spectrum and cost savings enabled by next-generation optical transponders.

2. Physical Layer and Transponder Modelling for Beyond-100Gbaud Coherent Transmission

To investigate their effect on spectrum occupation and network cost, we consider five different types of next-generation transponders (see Table 1). *Baseline* transponder can transmit at most 800 Gbit/s at 90 Gbaud. Single carrier beyond-100Gbaud transponders, named *SC140* and *SC190*, operate at 140 and 190 Gbaud, and can reach a capacity of 1200 and 1600 Gbit/s, respectively. Dual-carrier transponders *DC70* and *DC90*, on the other hand, use 2 carriers, and operate at 70 (resp., 90 Gbaud), while reaching the same data rates as *SC140* (resp., *SC190*). In all cases, we assume that transponders utilize PM-64QAM with Probabilistic Constellation Shaping [4].

We suggest two different approximations of transponder cost (see Table 1): *bitrate-scaled* (cost increases by 60% as maximum bitrate doubles), as in [5], and, likewise, *baudrate-scaled* (cost increases by 60% as baudrate

Table 1. Transponder options and their characteristics

Option	Symbol rate, Gbaud	Channel spacing, GHz	Bitrate-scaled cost, Cost Units	Baudrate-scaled cost, Cost Units
Baseline	90	100	1.0	1.0
SC140	140	150	1.3	1.3
SC190	190	200	1.6	1.6
DC70	70+70	75+75	1.3	1.5
DC90	90+90	100+100	1.6	1.85

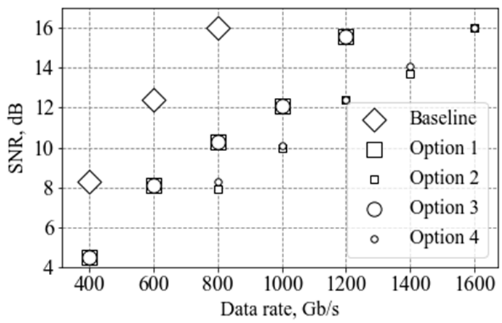

Fig. 1. SNR requirements

doubles, plus 10% for dual-carrier transponders over single-carrier ones with the same bitrate capabilities, as motivated in the Introduction).

In Fig. 1, we report our estimation of the required Signal to Noise Ratio (SNR) for each data rate and transponder option, obtained using the approach in [6], based on the concept of mutual information in the Gaussian channel, and assuming 8% of raw data rate used to transmit protocol overhead. It is worth noting that *SC140* and *DC70* require almost the same SNR, while *SC190* requires slightly lower SNR over *DC90*, as less information is transmitted per symbol, and higher noise can be tolerated. Note also that we consider wide spectrum bands, in which Stimulated Raman Scattering (SRS) is non-negligible, and apply SRS-aware closed-form Generalized Gaussian Noise model [7] to estimate non-linear interference between the channels. We always consider fully occupied spectrum and, thus, worst-case amount of interference.

As for other physical layer parameters, wavelength-dependent loss is set as in [8], connector losses are 0.5 dB, and multi-band optical amplifier filters and combiners induce additional 0.5 dB losses. Erbium-Doped Fiber Amplifiers (EDFAs) are placed every 80 km. We set their gain and tilt to compensate for propagation loss and SRS-induced gain/loss. Noise Figure is equal to 5 dB in C-band, and 6 dB in L-band. Power optimization is done according to Locally-Optimized Globally-Optimized (LOGO) strategy [9] separately in C- and L-bands. Transponder back-to-back SNR is set to 18 dB, so that transmission at the highest data rate is possible across a couple of fiber spans, considering 1 dB system margin.

3. Routing and Spectrum Assignment (RSA) Algorithm in C and C+L Bands

To perform RSA, we employ the multi-objective Genetic Algorithm, based on the concept of Pareto dominance, as in [10], that selects lightpath routing among 7 shortest paths, with the objective of minimizing the number of occupied frequency slots and the number of transponders in the network. We assume that an aggregate request between two optical nodes can be split into separate lightpaths, possibly going across different routes.

We allocate spectrum in a First Fit manner, starting with the requests with the largest product of data rate and number of hops along the shortest path. In multiband scenario we start from L-band, as it guarantees better signal quality. Note that, for *DC70* and *DC90* spectrum for the second carrier is not reserved if only one carrier is used.

4. Case Studies and Results

We perform our numerical evaluations on two realistic topologies, a 19-node European network (EU19) and a 17-node German network (GE17) [11]. Results are averaged considering 20 traffic matrices with different data rate requests randomly distributed within 400 Gb/s and 2000 Gb/s with 400 Gb/s step. We consider mesh traffic matrices, where 80% of node pairs transmit traffic. We consider 3 different distributions of traffic request bitrate (in short, traffic scenarios), called TS1-TS2-TS3, as shown in Fig. 2. TS1 mimics realistic short-term traffic distribution in transport optical networks, where most of node pairs require 800 Gbit/s. TS2 and TS3 represent an increase of approximately 30% and 65% in overall network traffic, obtained by increasing the probability of selecting higher data rate requests. In TS1 and TS2 spectrum is allocated only in 6 THz C-band, and about 70% and 90% of spectrum, respectively, is used on average on the most occupied link. In TS3 a 10 THz C+L-band is used to match the 65% increase in traffic with 66% increase in available spectrum, and 70% of spectrum is used on average on the most occupied link.

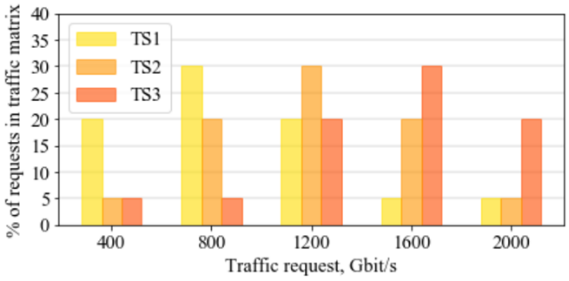

Fig. 2. Traffic scenarios TS1, TS2, TS3

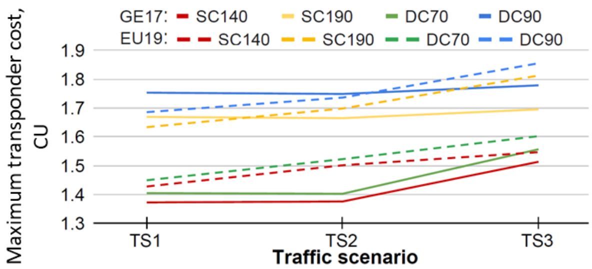

Fig. 3. Maximum cost of transponder options in TS1, TS2, TS3

We start with an analysis of transponder cost in Fig. 3. We assume the *Baseline* transponder cost to be 1.0 Cost Units (CU), and calculate the maximum transponder cost for the other options, so that the original network cost is preserved. In other words, cost savings can be achieved, if transponder cost is lower than the reported value. We observe that our cost approximations from Table 1 allow to achieve savings (i.e., they are always below the curves plotted in the Fig. 3). As *SC190* and *DC90* have higher bitrate ranges and save more transponders in absolute numbers, they can be more expensive compared to *SC140* and *DC70* in both GE17 and EU19, reaching 1.7-1.8 CU for *SC190* and 1.8-1.85 CU for *DC90*. We observe that maximum cost monotonically increases along with traffic in TS1, TS2 and TS3, as the advantage in maximum bitrate over *Baseline* transponder becomes more steady.

Let us now move to the numerical results obtained using the cost approximations for next-generation transponders that were anticipated in Table 1. In Table 2 we report savings in spectrum occupation (SO) and cost of transponders with *bitrate-scaled* and *baudrate-scaled* cost (Bit. cost and Baud. cost) for GE17 and EU19.

Table 2. SO and transponder cost savings (positive) and losses (negative) compared to *Baseline* (in %) for different transponder options on GE17 and EU19 topologies

Topology	Option	SO			Bit. cost			Baud. cost		
		TS1	TS2	TS3	TS1	TS2	TS3	TS1	TS2	TS3
GE17	SC140	-6.0	-9.3	3.9	7.7	5.2	14.0	7.7	5.2	14.0
	SC190	-22.6	-23.9	-15.4	1.3	4.1	5.6	1.3	4.1	5.6
	DC70	12.5	5.2	15.0	8.4	7.4	16.4	-5.7	-6.8	3.6
	DC90	1.2	1.3	4.0	4.8	8.7	10.0	-10.4	-5.6	-4.1
EU19	SC140	-6.3	0.8	-0.1	8.9	13.4	15.9	8.9	13.4	15.9
	SC190	-24.1	-17.7	-11.5	2.4	5.7	11.7	2.4	5.7	11.7
	DC70	12.4	13.3	10.1	10.3	14.6	18.8	-3.5	1.5	6.4
	DC90	1.1	1.9	4.5	5.0	7.8	13.7	-9.8	-6.6	0.2

In both GE17 and EU19, all the next-generation transponder options provide transponder cost savings (up to 19%) if we assume a bitrate-scaled cost approximation. Instead, assuming baudrate-scaled cost, dual-carrier options are penalized for their higher cost of hardware. Savings increase with both cost approximation for higher amount of traffic (i.e., moving from TS1 to TS3), when higher maximum bitrate provides a bigger advantage over the *Baseline*. On the other hand, if we observe results on SO, only the dual-carrier options provide spectrum savings, due to their ability to allocate spectrum only for a single carrier, when traffic requests are small.

If we compare in more details the performance of the various transponder options, we can see that in GE17 *DC70* provides the highest savings in SO (12.5% in TS1, 5.2% in TS2 and 15% in TS3). Dual-carrier options save most also in bitrate-scaled cost, namely *DC70* in TS1 (8.4%), *DC90* in TS2 (8.7%) and *DC70* again in TS3 (16.4%), as better bitrate granularity of individual carriers allows to save also in the number of transponders. *SC140* saves most in baudrate-scaled cost (7.7% in TS1, 5.2% in TS2 and 14% in TS3). Savings in SO and both cost approximations reduce in TS2 with *SC140* and *DC70*, as longer paths, often used in the occupied network, cannot support high data rates, reducing the advantage over the *Baseline*. Savings with *SC140* and *DC70* grow back in TS3, as additional spectrum in L-band allows the use of shorter paths and higher data rates. In EU19, *DC70* again saves most in SO (12.4% in TS1, 13.3% in TS2 and 10.1% in TS3), and in bitrate-scaled cost (10.3% in TS1, 14.6% in TS2 and 18.8% in TS3). *SC140* provides highest savings in baudrate-scaled cost (8.9% in TS1, 13.4% in TS2 and 15.9% in TS3). In EU19 there is no decrease in savings in TS2 with *SC140* and *DC70*, as average path is already fairly long, and there is no relevant SNR degradation.

5. Conclusion

We quantified spectrum and cost savings, obtained by next-generation coherent optical transponders with single- and dual-carrier transmission, and with different data rate capabilities. For the considered traffic scenarios, compared to the baseline, options with lower bitrate ranges (*SC140* and *DC70*) provide highest savings in spectrum occupation (*DC70* - up to 15%), in bitrate-scaled cost (*DC70* - up to 18.8%) and baudrate-scaled cost (*SC140* - up to 16%).

Comparing single- and dual-carrier options (*SC140* vs. *DC70* and *SC190* vs. *DC90*), we found that, for the given traffic and network scenarios, dual-carrier transponders save more in spectrum occupation and bitrate-scaled cost, while single-carrier transponders save more in baudrate-scaled cost.

References

1. S.J. Savory *et al.*, “Design considerations for low-margin...,” in IEEE/OSA JOCN, vol.11, no.10, pp.76-85, Oct.2019.
2. https://acacia-inc.com/blog/acacia-unveils-industrys-first-single-carrier-1-2t-multi-haul-pluggable-module/
3. J.Pedro *et al.*, “Optical transport network design...,” in IEEE/OSA JOCN, vol.12, no.2, pp.A123-A134, Feb.2020.
4. T. Zami *et al.*, “Simple self-optimization of WDM networks...,” in IEEE/OSA JOCN, vol.12, no.1, pp.82-94, Jan.2020.
5. J.A. Hernandez *et al.*, “Comprehensive model for techno...,” in IEEE/OSA JOCN, vol.12, no.12, pp.414-427, Dec.2020.
6. D.A.A. Mello *et al.*, “Optical Networking With Variable...,” in IEEE/OSA JLT, vol.32, no.2, pp.257-266, Jan.2014.
7. D.Semrau *et al.*, “A Closed-Form Approximation of...,” in IEEE/OSA JLT, vol.37, no.9, pp.1924-1936, May.2019.
8. A. Ferrari *et al.*, “Assessment on the Achievable Throughput...,” in JLT, vol.38, no.16, pp.4279-4291, Aug.2020.
9. P.Poggiolini *et al.*, “The GN-Model of Fiber Non-Linear...,” in IEEE/OSA JLT, vol. 32, no.4, pp.694-721, Feb.2014.
10. O.Karandin *et al.*, “Quantifying resource savings from low-margin design in optical...,” in ECOC 2021, Sep.2021.
11. A.Betker *et al.*, “Reference transport network scenarios”, in Tech. Rep. BMBF MultiTeraNetProject, Jul.2003.