Multifactorial performance comparison of WDM fully transparent core networks fitted with 96 GBd or 130 GBd transponders

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Abstract We simulate the performance of various backbone WDM networks equipped with 96 or 130 GBd carriers, quantifying how their ultimate overall network capacity notably depends on their traffic distributions and their most likely channel capacity. ©2023 Nokia

Introduction

While each of the main WDM system vendors has been proposing a new generation of high-ranked Elastic Optical Transponders (EOT) every 3 years, the network operators need to assess the associated added value to efficiently meet their need for further throughput. To that aim, network planning is relevant to benchmark these generations of EOT [1-4]. But accurately modelling the physical impairments is not sufficient to avoid the biases of this method as the score of network planning strongly depend on the modelled topology and on its traffic mix. In that context, this paper illustrates and explains some conditions under which the novel 130 GBd EOTs maximize their benefit versus the previous generation 96 GBd EOTs, not only in terms of number of deployed EOTs per Gb/s, but also in terms of mean total network capacity.

Context of simulations

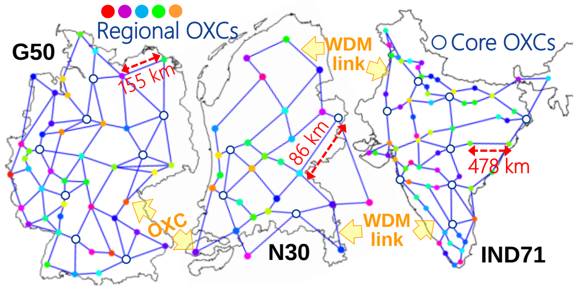

Fig. 1: *Studied WDM networks G50, N30 & IND71*

In this study, we emulate 3 of the core networks presented in [3][4] and still under the same physical modelling the details of which can be found in these 2 prior arts. These 3 topologies sketched in fig. 1 are the Dutch N30 network, the German G50 one and the Indian IND71 one. We model them with links as suites of spans of bidirectional pairs of standard single mode fibers interleaved with Erbium doped fiber amplifiers, all operating over the 4800 GHz-wide C-band transmission window. The wavelength-routing Optical Cross-Connects (OXC) are considered as "Route&Select" ones [5].

These networks are modelled with 2 EOT types: either EOT_{96} emitting and receiving 112.5 GHz-spaced 96 GBd optical channels carrying from 200 to 800 Gb/s [1] or EOT_{130} handling 150 GHz-spaced 130 GBd carriers transporting from 300 to 1200 Gb/s [3]. Both EOT categories can adjust their channel data rate with 100 Gb/s steps and Probabilistic Constellation Shaping (PCS) modulation up to 6 bits/symbol. End-to-end traffic grooming (TG) is applied with 100 Gb/s granularity, without intermediate TG nor optoelectronic regeneration. Thus, the WDM layer is fully transparent to ensure the lowest global capital expenditure.

Unlike [3] that only handles 800 Gb/s services, this study examines the influence of various granularities of service data rate. In that respect, we test several traffic setups, each one denoted T_x, which consists of a set of uniform X Gb/s bidirectional connections with X=400, 800, 1000 or 1600. The geographical distribution of traffic is made of a 1st fixed part followed by a random part. During the fixed part, a X Gb/s connection bridges each pair of core OXCs as well as each regional OXC and its 2 closest core OXCs (see fig. 1). During the 2nd part, 33.3% of the X Gb/s connections are required between randomly drawn pairs of core OXCs and 66.6% of them between regional OXCs and core OXCs also randomly chosen. For each demand of optical connection, a transparent shortest Light Path (LP) is calculated across the network in between its source and destination OXCs. If such a LP does not exist due to lack of spectral resources in the network, then the demand is rejected. If this LP can be found, then our routing algorithm allocates the carriers enabling the highest Spectral Efficiency (SE) along this LP depending on the EOT type. Inverse multiplexing is used via several parallel optical carriers if the requested throughput exceeds the ultimate carrier data rate of this chosen EOT type. The connections of the 2nd traffic part are established one by one until more than 1% of the total requested capacity is rejected. Then, the total capacity already served so far in the simulated instance of network is its Maximum Network Capacity (MNC) and the total number of planned

EOTs divided by MNC is its mean Number of EOTs per 100 Gb/s, called N_{EOT}. The higher MNC, the better. The lower N_{EOT}, the better. To be meaningful, MNC and N_{EOT} values reported in the remainder are averaged over 100 randomly drawn traffics with 100 respective distinct random seeds in accordance with the forementioned distributions.

MNC under highly hierarchical traffic

This section reports results assuming each link of the topologies in fig. 1 is a bidirectional single pair of fibers. Moreover, the connections of the 2nd part of traffic matrix involving regional OXCs are only with their 2 (resp. 3) closest core OXCs for G50 and IND71 (resp. N30).

The outcomes shown in Table 1 confirm the expected substantial N_{EOT} improvement when the carrier symbol rate raises from 96 to 130 GBd. In average, N_{EOT} drops by -24% as already observed in [3]. So, the remainder will more focus on MNC. It does not vary by more than 3.6% from EOT_{96} to EOT_{130} with a given traffic in G50 and IND71 networks. Whereas for N30, it significantly changes by up to 9% for T_{1000}. It still varies by 7.5% for T_{1600} from 282.2 down to 261 Tb/s, surprisingly with peak value obtained by EOT_{96}, as for T_{800}. It is noteworthy because one would rather expect that EOTs featuring the largest symbol rate better fit the connections carrying the highest average throughput. Besides, the MNC evolution as a function of T_x traffics for a given EOT type is also interesting. In this case, we see meaningful MNC drops from T_{400} or T_{800} traffics to T_{1600} one, particularly for N30 and G50 topologies.

EOT_{130} brings more intermediate SE steps and a highest SE than EOT_{96} (800/112.5=7.1 bit/s/Hz vs. 1200/150=8 bit/s/Hz). But this is reflected by better MNC only if the average filling ratio of the provisioned optical carriers is similar for both EOT types. This ratio depends on how the data rates of the demanded connections match with the carrier data rates distribution related to the network topology, for maximizing end-to-end TG efficiency. For instance, for N30 equipped with EOT_{96} (resp. EOT_{130}) and serving T_{400} traffic, this ratio is 94.9% (resp. 89.5%), not shown here. When N30 serves T_{1000} traffic, this ratio

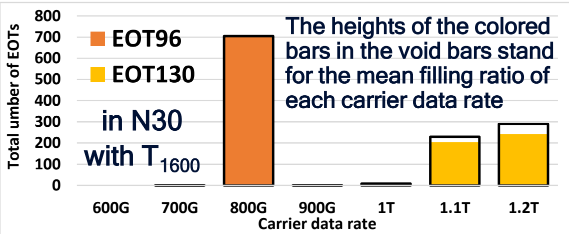

Fig. 2: *Channel data rate breakdowns and their mean filling ratios reflected by the orange and yellow bars*

Table 1: *MNC in Tb/s & N_{EOT} per 100 Gb/s simulated with EOT_{96} & EOT_{130} when regional OXCs exchange random traffic with their 2 or 3 closest core OXCs*

		T_{400}	T_{800}	T_{1000}	T_{1600}
N30 &	*MNC*	280.5	290.3	258.6	282.2
EOT_{96}	*N_{EOT}*	0.263	0.25	0.278	0.25
N30 &	*MNC*	282.8	277.4	284.3	261
EOT_{130}	*N_{EOT}*	0.195	0.197	0.195	0.202
G50 &	*MNC*	559.9	548.2	530.4	528.1
EOT_{96}	*N_{EOT}*	0.265	0.259	0.271	0.258
G50 &	*MNC*	571.2	549.1	544.3	529
EOT_{130}	*N_{EOT}*	0.195	0.197	0.199	0.198
IND71 &	*MNC*	342.3	340.5	339	346.1
EOT_{96}	*N_{EOT}*	0.349	0.344	0.35	0.338
IND71 &	*MNC*	345	353.1	345	351.6
EOT_{130}	*N_{EOT}*	0.271	0.265	0.264	0.261

reaches 90.1%/80.3% for EOT_{96}/EOT_{130}. While under T_{1600} traffic in N30, it reaches 99.9% for EOT_{96} and only 85.8% with EOT_{130} as depicted in Fig. 2 quantifying the related suites of applied carrier modulations. This is because 95% of the short LPs across N30 can be bridged either by 800 Gb/s EOT_{96} channels or 1.1 Tb/s EOT_{130} ones or 1.2 Tb/s EOT_{130} ones. 800 Gb/s and 1.2 Tb/s carriers can be optimally filled by 400 Gb/s demands, leading then to similar MNC for both EOTs with T_{400} traffic. 1.1 and 1.2 Tb/s carriers can transport one or two 1 Tb/s demands with a substantially higher SE than 800 Gb/s carriers needing more inverse multiplexing. It explains how EOT_{130} allows this 9% higher MNC than EOT_{96} when serving T_{1000}. Transporting 1.6 Tb/s requires two fully filled 800 Gb/s EOT_{96} carriers only occupying 225 GHz of optical spectrum. Whereas it requires two 1.1 or 1.2 Tb/s EOT_{130} carriers taking 300 GHz and only 72.7% filled at most. This entails lower SEs not fully compensated by TG and then also generates the lower counterintuitive MNC observed in Table 1 for N30 with EOT_{130} and T_{1600} traffic. The same suboptimal alignment of traffic granularity and distribution of channel data rate contributes to the notable lower MNC of EOT_{130} in G50 when serving T_{1600} vs. T_{400} traffics (529 vs. 571 Tb/s).

MNC with less hierarchical traffic

This section presents further simulation results from less hierarchical traffic in G50 and IND71 networks. To that aim, the traffic is nearly the same as in the previous section, but the random connections are enabled between any pair of regional and core nodes. This implies longer mean LP length for 66% of the connections from the 2nd random part of traffic. Moreover, this context is less favourable to end-to-end TG than the previous more hierarchical traffic, because of the significantly larger number of possible

Table 2: *MNC in Tb/s & N_{EOT} per 100 Gb/s if regional OXCs exchange random traffic with any core OXC*

		T_{400}	T_{800}	T_{1000}	T_{1600}
G50 & EOT_{96}	*MNC*	301.7	327.7	324.1	366
	N_{EOT}	0.336	0.3	0.333	0.275
G50 & EOT_{130}	*MNC*	274.1	345.7	341.2	360.2
	N_{EOT}	0.289	0.238	0.225	0.231
IND71 & EOT_{96}	*MNC*	168.3	206.2	226.8	285
	N_{EOT}	0.474	0.419	0.413	0.358
IND71 & EOT_{130}	*MNC*	161.4	205.9	227	287.1
	N_{EOT}	0.405	0.316	0.311	0.278

pairs of regional and core OXCs that can interconnect. Our new simulation scores appear in Table 2 showing a more marked trend than Table 1. Thus, MNC and N_{EOT} dramatically improve along with the connection throughput growing from 400 to 1600 Gb/s, whatever the EOT type. Because the degraded TG conditions hamper the MNC performance with the lower traffic granularity that fills the carrier data rates less efficiently than the cases of Table 1. In addition, due to their longer lengths, the ratio of LPs supporting 800 Gb/s EOT_{96} carriers and 1200 Gb/s EOT_{130} ones is reduced. Therefore, there are fewer optimal carriers to transport 400 Gb/s submultiple services or 800 Gb/s ones than with more hierarchical traffic. So, the better MNC values indicated in Table 1 with the lowest traffic granularities or slower EOTs are not systematic and rely on the traffic breakdowns.

MNC in case of fiber bundling

The inappropriateness of the largest channel data rates to effectively aggregate some specific traffic types across the smallest topologies (as explained under highly hierarchical traffic) is more salient if only a few services are groomed together along a connection. This condition will be less frequent in the future WDM networks resorting to fiber bundling for multiplying MNC by more than 3 [6]. Because more numerous channels per WDM link, even along distinct parallel fibers, will enable more end-to-end TG before exhausting the total network capacity. To illustrate the MNC performance of EOT_{96} and EOT_{130} in such circumstances, we run new simulations on N30 and G50 networks with T_{400} and T_{1600} traffics as described in previous "*MNC under highly hierarchical traffic*" section, but assuming each link in these topologies is made of 4 bidirectional pairs of WDM fibers. Since the maximum node connectivity is 5 in G50, 4 fibers per link induces 20-degree OXCs at most which remains feasible with the "Route&Select" OXC layout based on the current 1x32 wavelength selective switch [7]. Table 3 shows these last simulation results. Its N_{EOT} values are practically

Table 3: *MNC in Tb/s & N_{EOT} per 100 Gb/s in G50 & N30 implemented with 4 fiber pairs per WDM link*

		T_{400}	T_{1600}
N30 & EOT_{96}	*MNC*	1180.3	1100.7
	N_{EOT}	0.253	0.25
N30 & EOT_{130}	*MNC*	1215.3	1114.6
	N_{EOT}	0.185	0.187
G50 & EOT_{96}	*MNC*	2266.1	2034.5
	N_{EOT}	0.26	0.259
G50 & EOT_{130}	*MNC*	2316.4	2118.8
	N_{EOT}	0.192	0.193

identical to those in Table 1, while MNCs are globally multiplied by 4 as expected. The factor of multiplication is not exactly 4 because our algorithm for searching the shortest path is slightly less optimal when bundling fibers, in the interest of running time saving. Nevertheless, under this common routing rule and unlike the results in Table 1 for a given traffic T_x, Table 3 reports that EOT_{130} always simultaneously leads to better MNC and N_{EOT} than EOT_{96}. Because bundling 4 fibers per link leaves more time along the traffic growth for more effective TG before saturating the network with 1% rejection of the demanded total throughput. Hence, EOT_{130} carriers can now benefit this TG at least as much as the EOT_{96} ones. It also appears that T_{400} still brings about 9% extra MNC in G50 than T_{1600}, similarly to G50 in Table 1 and differently from N30 and IND71. This suggests this discrepancy is specific to G50 topology and its hierarchical arrangement of core/regional nodes that get overloaded earlier along the growth of traffic when 1.6 Tb/s connections require wider spectral fragments than 400 Gb/s ones.

Conclusion

Benchmarking successive generations of WDM transponders via networks simulations is a powerful tool giving access to various metrics, like comparing the network power consumption [8]. One of its most regarded indicators is the ultimate total network capacity. However, it is multifactorial, depending on other parameters uncorrelated to the intrinsic WDM transmission performance of the tested transponders. In that respect, we have stated very specific conditions (relatively small fully transparent core WDM network with service data rates multiple of 800 Gb/s) under which the 130 GBd transponders technology can lead to not as high total network capacity as 96 GBd ones. Having said that, we have also established that under more forward-looking bundling of fibers, the faster 130 GBd technology brings the 2 meaningful benefits of higher network capacity and fewer transponders per Gb/s at the same time.

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