Optimal Channel Spacing for Next-Gen WDM Networking with 800ZR+ Elastic Optical Transponders

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Abstract: By foreseeing an evolution from 800ZR to 800ZR+, like 400ZR+ just after 400ZR, we evaluate how WDM networks benefit from these 800ZR+ interfaces depending on their traffic and on their quality of wavelength routing equipment

1. Introduction

Operators of WDM networks are keen to harvest the ultimate Spectral Efficiency (SE) from their infrastructure before deploying extra parallel optical fibers. To that aim, they need solutions at a declining cost per transmitted Gb/s. The 400ZR+ initiative has been proposed in the wake of the 400ZR standard [1] to meet this requirement in metro and regional WDM networks [2]. Similarly, 800ZR+ interfaces are expected to come along with the 800ZR emergence in the upcoming years [3]. 800ZR+ will mainly consist of pluggable Elastic Optical Transponders (EOT) with double carrier throughput by doubling the 400ZR+ symbol rate. From 75 GHz-spaced 60 GBaud (GBd) 400ZR+ carriers, this could then imply 150 GHz-spaced 120 GBd 800ZR+ ones, leading to 150-120=30 GHz channel guard band that might be deemed as too wide after so much effort spent to maximize SE. In that context, we examine the relevance of 137.5 GHz channel spacing for future 800ZR+ channels depending on network topology, on traffic type (Ethernet or OTN), on flexibility of channel data rate and on performance of Wavelength Selective Switch (WSS) equipping the wavelength-routing Optical Cross-Connects (OXC) in the simulated networks.

2. Network and traffic modelling

We study the 2 network topologies depicted in Fig. 1. N30 is a Dutch national network comprising 30 nodes and 45 WDM links with 32.6/50 km mean/max fiber span lengths. N30 size also makes it representative for some regional topologies in sub-continental larger countries. G50 is a German core network made of 50 nodes and 88 WDM links with 59.6/80 km mean/max span lengths. Each couple of adjacent network nodes in the topology is interlinked via a pair of counter-directional suites of standard single mode fiber spans featuring 0.22 dB/km loss. Each span loss is compensated by an associated erbium doped fiber amplifier operating over a 4812.5 GHz-wide C-band with 5.5 dB noise figure. The network nodes consist of an electrical IP router or OTN cross-connect associated with an OXC based on the "*Route&Select*" WSS-based layout [4]. The electrical routers/cross-connects are simulated only with 400 Gb/s or 800 Gb/s ports. We presume these ports can lower their actual throughput to better fit the maximum capacity enabled by the quality of the light path covered by the WDM channel of the pluggable EOTs they are connected to. These EOTs can be 400ZR+, OpenROADM, future 800ZR+ or 800 Gb/s OpenROADM ones [5][6]. Table 1 lists their symbol rates, client rates and traffic types assumed for this study. Not to speculate too much about what the upcoming 800ZR+ and 800 Gb/s OpenROADM will be capable of, we envisage their channel modulations only by doubling the Baud rate and channel capacity from the current OpenROADM and 400ZR+ interfaces. A sole couple of symbol rate and channel spacing (Δf) is applied for each network simulation. One important aspect when changing the common channel spacing is its impact on the non-linear effects of WDM transmission and on the WSS filtering penalties. Our numerical model of WDM transmission and optical routing accounts for these 2 effects [7], also considering the impact of linear optical noise and polarization dependent loss of the components traversed by

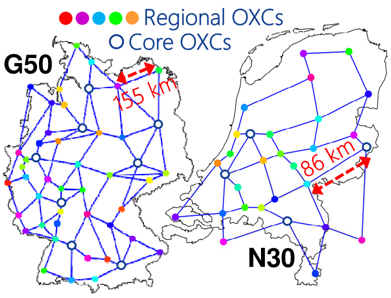

Fig.1: *2 studied networks topologies*

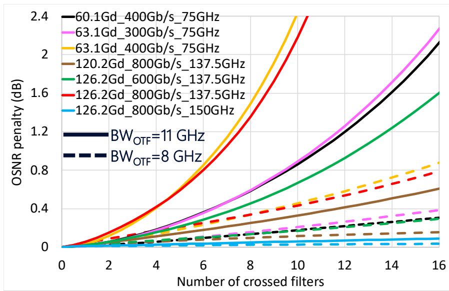

Fig.2: *OSNR penalties across a suite of filters, w.r.t modulation & filter sharpness*

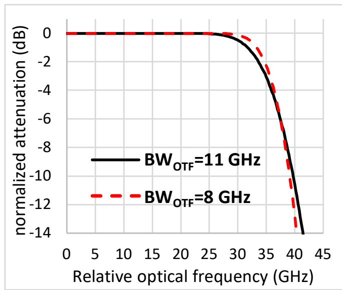

Fig.3: *Comparison of lateral 75 GHz-wide WSS filter shapes*

Table 1: *Considered channel modulations, traffic protocols and type of Forward Error Correction (FEC)*

	Symbol Rate	FEC type	Traffic protocol	Client data rates & corresponding channel modulation
400ZR+	60.1 GBd	OpenFEC	Ethernet	200 Gb/s QPSK, 300 Gb/s 8QAM, 400 Gb/s 16QAM
OpenROADM	63.1 GBd		Ethernet & OTN	
800ZR+	120.2 GBd		Ethernet	400 Gb/s QPSK, 600 Gb/s 8QAM, 800 Gb/s 16QAM
"800 Gb/s" OpenROADM	126.2 GBd		Ethernet & OTN	

the optical connection under test. Fig. 2 illustrates the significant difference of simulated penalties on Optical Signal to Noise Ratio (OSNR) experienced by the most emblematic channel modulations reported in Table 1 and induced by optical filtering through a cascade of WSS filters, with respect to their filtering sharpness characterized by the BW_{OTF} parameter [8]. BW_{OTF}=11 GHz represents the smoother initial WSS generation featuring 12.5 GHz spectral granularity [8], whereas BW_{OTF}=8 GHz corresponds to the more recent WSS generation capable of 6.125 GHz granularity [9]. BW_{OTF}=8 GHz means a sharper and better filtering function as shown by Fig. 3 illustrating only one side of the symmetrical filter. BW_{OTF}=11 GHz is also indicative of possible future WSS's working over a transmission window much larger than 4.8 THz [10] or more integrated [10] or exhibiting more than 3 common ports (like 8x8 WSS, [11]). Therefore, it is still relevant to examine the impact of filtering with BW_{OTF}=11 GHz in the idea of future WSS deployments. Fig. 2 compares the related OSNR penalties for the most iconic modulations of Table 1 with various channel slot widths indicated in the legend. They remain relatively low after up to 16 crossed filters with BW_{OTF}=8 GHz. If BW_{OTF}=11 GHz, they are much higher for 75 (resp. 137.5) GHz-spaced 63 (reps. 126) GBd channels, particularly for the most sensitive 16QAM constellation (see Table 1).
To further assess the possible usefulness of 137.5 GHz spacing for 800ZR+ channels, we compare them at network level by simulating G50 and N30 networks plannings. For that purpose, we emulate hierarchical traffic exchanged between the pairs of core OXCs and between the pairs of each regional OXC with their 2 closest core OXCs, by means of transparent optical connections without intermediate regeneration. For each simulated matrix of traffic, an initial constant subpart of traffic establishes full mesh interconnexions with 100 Gb/s services between all the pairs of OXCs previously mentioned. The second subpart of 100 Gb/s connections is then randomly drawn between these pairs. The demands are handled one by one, in priority via the electrical layer along one already established connection the capacity of which is not fully occupied. If such a resource is not available, the demand is transported via a newly allocated optical connection if a free spectral slot exists from the source node to the destination one with a good enough quality of transmission. Otherwise, the demand is discarded. Accommodating traffic stops once more than 1% of the total demanded throughput has been dismissed. Such a simulation is run for 100 different random traffics with respectively 100 distinct random seeds. Then, from these 100 runs we establish the mean Maximum Network Capacity (MNC) and Number of required EOTs per 100 Gb/s transmitted (N_{EOT}). These 2 metrics allow for the comparison of the network performance in the remainder. The higher MNC (resp. lower N_{EOT}), the better.

3. Simulation results

The 2 first lines of Table 2 show the performance with the initial OpenZR+/OpenROADM channel spacing and with the most modern WSS technology (BW_{OTF}=8 GHz). The 4 next lines 3 to 6 report the network effectiveness for a more ambitious 75 GHz channel spacing and different WSS sharpness's. With most modern WSS's, the ratio of extra MNC enabled by narrowing the channel spacing is very close to the related difference of number of 60 GBd channels/fiber (32% ratio and 33.33% from 48 up to 64 channels/fiber), but not when it comes to 63 GBd ones (only 12% ratio, instead of 18% from 55 to 64 channels/fiber). This difference already reflects the higher filtering impact when transmitting 63 GBd channels, especially through lower-quality WSS (see Fig. 2). Besides, N_{EOT} in line 2 remains notably better than in line 6. So, improving the filtering quality and maintaining 55 channels/fiber 87.5 GHz apart is more effective for the 2 simulated networks than adopting 64 channels/fiber 75 GHz apart if the WSS grade is suboptimal. Because better WSS filtering enables allocating channels with higher SEs in average and can offset fewer channels/fiber. These trends are the same for G50 and N30. Installing twice faster EOTs advantageously lower N_{EOT}, as shown from line 7 for both tested networks. Since the symbol rate is doubled, one may initially think about also doubling the channel spacing from 75 to 150 GHz as reported from lines 7 to 10. The very close MNC and N_{EOT} values in lines 9 and 10 confirm the 150-126=24 GHz channel guard band is then so large that the network performance is not influenced by the considered filtering qualities, even for the widest 126 GBd channels. But this setup also substantially reduces MNC, for instance by down to -17% when comparing G50 equipped with 60 and 120 GBd channels (360 Tb/s vs. 299 Tb/s). This MNC decline mainly exists because an 800 Gb/s 120 GBd carrier cannot always replace 2 parallel 400 Gb/s 60 GBd carriers owing to more severe limitation on the chromatic dispersion compensation at higher symbol rate, particularly to ensure relatively low power consumption for the pluggable interfaces [12]. The intrinsic lower performance of the less mature transponders at 120/126 GBd also

Table 2: *MNC and N_{EOT} simulated for N30 and G50 networks equipped with different EOT technologies*

		Carrier Symbol Rate (GBd)	BW_{OTF} (GHz)	Δf (GHz)	N30 MNC (Tb/s)	N30 N_{EOT}	G50 MNC (Tb/s)	G50 N_{EOT}
1	OpenZR+ EOTs	60.1	8	100	142.6	0.56	272.2	0.59
2	OpenROADM EOTs	63.1	8	87.5	168.2	0.55	318.2	0.58
3	OpenZR+ EOTs	60.1	8	75	188.5	0.56	360.2	0.59
4	OpenZR+ EOTs	60.1	11	75	179.4	0.58	350.9	0.61
5	OpenROADM EOTs	63.1	8	75	187.4	0.56	357	0.59
6	OpenROADM EOTs	63.1	11	75	169.7	0.61	319.9	0.63
7	OpenZR+ EOTs	120.2	8	150	168.3	0.31	299.1	0.34
8	OpenZR+ EOTs, only 400&800 Gb/s carriers	120.2	8	150	134.5	0.37	241.1	0.42
9	OpenROADM EOTs	126.2	8	150	171.3	0.31	306.5	0.34
10	OpenROADM EOTs	126.2	11	150	170.5	0.31	305.1	0.34
11	OpenZR+ EOTs	120.2	8	137.5	181.1	0.32	324.9	0.34
12	OpenZR+ EOTs, only 400&800 Gb/s carriers	120.2	8	137.5	138.8	0.4	257.7	0.42
13	OpenZR+ EOTs	120.2	11	137.5	176.9	0.33	324.6	0.34
14	OpenROADM EOTs	126.2	8	137.5	181.1	0.32	328.1	0.34
15	OpenROADM EOTs	126.2	11	137.5	170.7	0.34	323.6	0.35

explains this MNC reduction. 137.5 GHz channel spacing instead of 150 GHz mitigates this MNC drop by allowing 35 channels/fiber instead of 32 over the 4812.5 GHz-wide C band. But this does not always improve MNC by the ratio 35/32, i.e 9.3%. In Table 2, this improvement ranges in between 8.6% and 0%. 8.6% is close to the nominal 9.3% gain and this means despite the narrower 137.5 GHz spacing, filtering is not significantly more impairing than with 150 GHz spacing, typically for 120 GBd channels and BW_{OTF}=8 GHz. On the other hand, there is no MNC improvement when the extra related OSNR penalty induced by narrower WSS filtering cancels the benefit of the 3 extra channels per fiber, like with 126 GBd channels and BW_{OTF}=11 GHz (see line 10 vs. line 15 for N30).
Lines 8 and 12 notably report the network performance if limiting the set of channel data rates to 400 and 800 Gb/s for simplified mapping of the electrical port capacity with the optical channel throughput in case of IP router equipped with 400 or 800 Gb/s ports. This could streamline the IP layer operations. But this is also at the expense of a large degradation of the MNC and N_{EOT} performance in the WDM layer, as quantified by comparing lines 7 vs. 8 or 11 vs. 12. Hence, it reduces MNC by more than 20% and increases N_{EOT} by at least 19%.

4. Conclusion and further comments

We have quantified the benefit of installing the future 800ZR+ generic pluggable interfaces in the N30 and G50 WDM networks. While deploying these generic 800ZR+ EOTs instead of the 400ZR+ ones reduces in average by 40% the number of required EOTs per Gb/s, it also decreases by 11%/17% the maximum achievable N30/G50 capacity with 150 GHz channel spacing for the 800ZR+ channels as compared to 400ZR+ 75 GHz-spaced channels. We have shown that narrower 137.5 GHz channels spacing for 800ZR+ carriers can result in up to 8% extra MNC, especially for the 120 GBaud carriers and provided that the WSS filtering quality is sufficient. Additional more favorable conditions (not reported here) could be envisaged to further relax this MNC reduction. For example, intermediate optoelectronic regeneration would shorten the average length of the transparent light paths and thereby would foster the cases when one single 800 Gb/s channel can advantageously supplant 2 parallel 400 Gb/s 60 Gb/s carriers with the same spectral efficiency. Moreover, demands of connections with throughput notably higher than 100 Gb/s (for instance 400 Gb/s) would also partially close this MNC gap, by decreasing the mean ratio of unfilled capacity for the 800 Gb/s channels when reaching 1% rejection of the total demanded throughput.

5. References

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