

Filtering Impact on High-Order Modulation Formats in Hybrid Filterless and Filtered Optical Metro Networks

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Abstract: Optical filtering impact in hybrid filterless and filtered optical metro networks is investigated considering 32 and 64 QAM and up to 96 GBd signals. Resulting OSNR filtering penalties foresee its application for future optical metro networks. © 2021 The Authors

1. Introduction

Flexible wavelength selective switches (WSSs) alongside with programable bandwidth variable transponders (BVTs) have enabled the deployment of elastic optical networks (EONs). EONs developments led to an overall increase of spectral efficiency (SE) by using the flexible grid concept and leading to a more efficient management of the available spectrum. Nowadays, BVTs can operate at symbol rates (SR) beyond 32 GBd and high-order modulation formats (MF) such as M -ary quadrature amplitude modulation (M -QAM) formats [1]. Additionally, based on currently commercially available WSSs, a frequency granularity of 6.25 GHz can be considered. All these technologies together lead to several configurations for different optical channels. The hybrid filterless and filtered optical networks were proposed not only to reduce the overall costs by avoiding the use of expensive WSSs at the filterless segments but also to extend the optical transmission technologies towards the networks edge [2].

Some studies about the impact of the optical filtering on high-order MFs and faster SRs can be found in the literature. For example, the authors in [3] studied that impact on signals that pass through several WSSs inside the reconfigurable optical add/drop multiplexers (ROADMs), assuming 75 GHz channel spacing and faster than 60GBd signals, on typical wavelength division multiplexing (WDM) core networks. Owing to the fact of physical layer impairments, such as optical filtering, lower order MFs must be considered in these scenarios.

In this work, we focus on the application of high-order MFs and faster SRs in hybrid filterless and filtered metro optical networks. Specifically, we investigate the optical filtering impact considering SRs of 32, 64 and 96 GBd; 32 and 64QAM signals and channels spacing from 37.5 to 150 GHz. The main goal is to avoid high optical signal-to-noise ratio (OSNR) penalties due to the optical filtering, while maximizing the SE of the resulting optical systems.

2. Scenario and Simulation Setup

Although, WSSs inside the ROADMs play an important role to transparently route an optical signal along its lightpath, they impair the network performance due to filter cascading effects and they are a point of failure that causes quality of transmission (QoT) degradation.

One important feature for 5G and beyond is that of low latency for connectivity services between the access and metro data centers (DCs). In that regard, filterless segments can be used to extend the filtered metro core network to reach the access one. Fig. 1 represents the targeted scenario with a filterless edge horseshoe topology with filterless nodes based on optical splitters/couplers and optical amplifiers (OAs) if needed. We are interested in investigating the QoT experienced by signals connecting a node in the horseshoe, and a metro DC collocated with one of the ROADMs.

Therefore, in the case that metro DC is collocated with one of the end ROADMs in the local horseshoe (ROADM-1A/B in Fig. 1), a lightpath connecting a filterless node (R1...4 in Fig. 1) to that DC1 would only traverse one single ROADM, i.e., two WSSs. However, since not all metro nodes could be equipped with computation capabilities, the lightpath might traverse additional ROADMs in its path, e.g., to DC2, or even to DC10.

To evaluate the system performance in those scenarios, we carried out extensive Monte-Carlo simulations. At the transmitter side, we generated 2^{13} pseudo-random binary sequences shaped by a root-raised cosine filter with 0.15 roll-off factor considering the SRs and MFs defined in the previous section. The optical filtering impact is investigated on two different scenarios that corresponds to the case where the DC is collocated with the ROADM in the local horseshoe

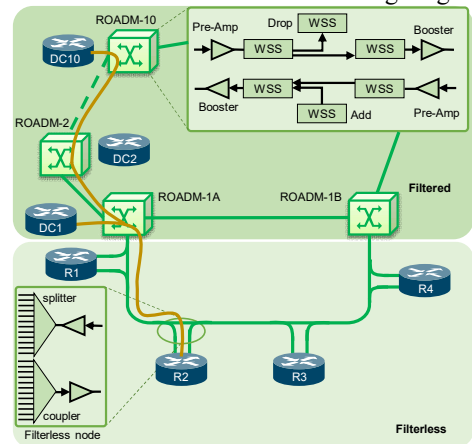


Fig. 1. Hybrid filterless and filtered metro network.

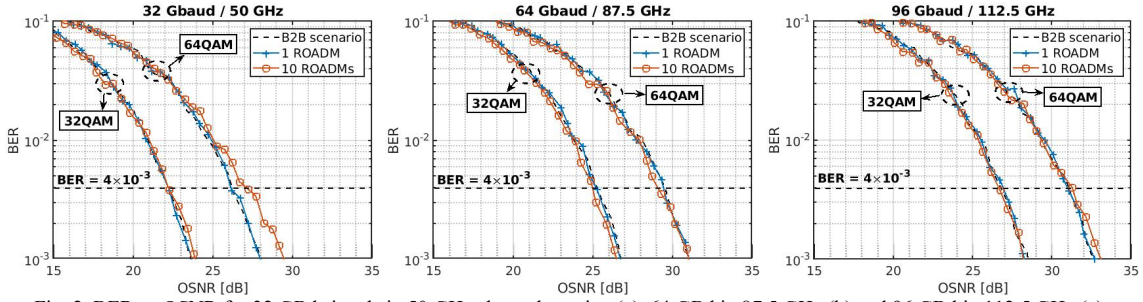


Fig. 2. BER vs OSNR for 32 Gbd signals in 50 GHz channel spacing (a), 64 Gbd in 87.5 GHz (b) and 96 Gbd in 112.5 GHz (c).

or with a different metro ROADM, denoted as Scenario 1 and 10 depending on the number of ROADMs that the signal traverses, e.g., Scenario 1: R2-DC1 and Scenario 10: R2-DC10, where the signal crosses 10 ROADMs.

To model the WSS spectral shape, we averaged out real spectral measurements from 4 different optical channels for each considered channel spacing [4]. For the 50, 87.5 and 112.5 GHz channels the -3dB bandwidth is about 46.3, 83.6 and 110.2 GHz, respectively. Note that, as the filter transfer functions were obtained by real spectral measures, they also include filter ripples, which accumulate with the cascaded filters. Regarding the optical amplification, all OAs are modeled as erbium doped fiber amplifiers with a noise figure of 6 dB. In this work, we consider a filterless segment with 40 km, a filtered one with 100 km and a fiber attenuation factor of 0.25 dB/km. Finally, we assume an ideal optical coherent receiver and direct error counting to estimate the bit error rate (BER), considering a total of 1000 errors and a target pre-forward error correction (FEC) BER of 4×10^{-3} .

3. Results and Discussion

To analyze the OSNR penalties due to the optical filtering in the two scenarios presented before, we considered 37.5 and 50 GHz channel spacing for 32 Gbd signals, 75 and 87.5 GHz for 64 Gbd ones and 100 and 112.5 GHz for 96 Gbd signals. Fig. 2 depicts the BER vs. OSNR for the two scenarios, and for the back-to-back (B2B) one, which does not suffer from optical filtering impairments. The required OSNR obtained for the threshold pre-FEC BER is about 22 and 26.5 dB for 32 Gbd signals, 25.5 and 29.5 dB for 64 Gbd, and 26.7 and 31 dB for 96 Gbd, all cases for 32 and 64QAM, respectively. Fig. 2(a) plots the results for 32 Gbd signals in a 50 GHz optical channel, Fig. 2(b) for 64 Gbd in an 87.5 GHz, and Fig. 2(c) for 96 Gbd in a 112 GHz, in all for both 32 and 64QAM.

We can observe that, the channels spacing considered reduce the optical filtering penalties to just less than 0.05 dB for almost all investigated scenarios, i.e., practically negligible penalties. The only scenarios where some filtering penalties are observed was that for 64QAM 32/96 Gbd signals in 50/112.5 GHz channel spacing after 10 ROADMs, with penalties about 1 and 0.3 dB, respectively. Notice that, for the other channels spacing considered, the two tighter ones for 32 and 96 Gbd signals (37.5 and 100 GHz) impose large filtering penalties (> 4 dB) for Scenario 1 and 32QAM signals. For 64 Gbd signals in the tighter channels (75 GHz), we obtained penalties lower than 1 dB (~ 0.7 dB) for Scenario 1 and both MFs.

Table 1 summarizes the SE as a function of the MF and SR considering a FEC overhead of 20% and 25% for 32 and 64QAM, respectively. We observe that the SE increases when increasing of MF and SR, achieving the better one for 96 Gbd signals, where the use of 112.5 GHz channel spacing results in SE about 6.83 and 7.68 b/s/Hz for 32 and 64QAM, respectively.

4. Conclusions

The impact of the optical filtering in hybrid filterless and filtered optical metro networks was investigated for faster SRs, high-order MFs, and several optical channels spacing. The results showed that optical filtering leads to negligible OSNR penalties, lower than 1 dB, for 32 Gbd signals in 50 GHz channels, 64 Gbd in 87.5 GHz and 96 Gbd in 112.5 GHz. Consequently, we foresee the use of such SRs and MFs to increase the transport capacity and improve the overall SE. The availability of such SRs and MFs will allow reducing the number of transponders, thus reducing not only the capital but also operational expenses for network operators.

References

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Table 1. SE as a function of the MF and SR.

MF	SR [Gbd]	Ch. [GHz]	Bit rate [Gb/s]	Net bit rate [Gb/s]	SE [b/s/Hz]
32QAM	32	50	320	256	5.12
	64	87.5	640	512	5.85
	96	112.5	960	768	6.83
64QAM	32	50	384	288	5.76
	64	87.5	768	576	6.58
	96	112.5	1152	864	7.68