THE NUMERICAL AND EXPERIMENTAL EVALUATION OF A COUPLED BLADE DYNAMIC LIMIT RESPONSE WITH FRICTION CONTACTS

Impact of Burst Traffic in Upstream Converged Coherent Metro-Access Networks

S. Alzoubi[(1)], G. Rizzelli[(2)], and R. Gaudino[(1)]

[(1)] Dipartimento di Elettronica e Telecomunicazioni (DET), Politecnico di Torino, Torino, Italy
[(2)] Photonext Center, Politecnico di Torino, Torino, Italy safana.alzoubi@polito.it

Abstract *For future all-optical metro-access networks using PON upstream burst mode transmission, we experimentally investigate on the resulting EDFAs gain transient and its impact on the "regular" DWDM coherent metro wavelengths, focusing specifically on typical 125 microsecond frame time-constants and evaluating the post-FEC OSNR penalty. ©2026 The Author(s)*

Introduction

Several recent research works [1–7] have investigated future architectures for all-optical convergence between metro and access, analyzing several transmission and network aspects, usually in the framework of coherent transmission also in the PON access. When and if this new vision is implemented, the resulting future DWDM metro will thus carry both "traditional" metro coherent λ_{metro} and some "access" λ_{PON} that can be bursty in the upstream (US) direction. In this paper, we experimentally investigate an US scenario where λ_{PON} are transmitted in TDMA burst mode using a 125 μs frame (as in any PON standards so far) and, after traversing the PON US path, are all-optically routed towards an EDFA-amplified metro segment and merged with regular DWDM metro λ_{metro}s. We focus specifically on estimating the bursty λ_{PON} impact on the coherent continuous λ_{metro} due to the gain time-transient arising in EDFAs. While EDFA gain transients in burst mode were already investigated in the past in several scenarios [8–10], our paper novelty is in focusing specifically on a situation in which most λs are continuous, while only a few are in burst mode and with typical PON sparsely and randomly loaded 125 μs time frames. We provide preliminary guidelines identifying conditions giving negligible penalty on λ_{metro}, demonstrating feasible mixed traffic coexistence in the metro segment, as well as conditions that significantly degrade performance on λ_{metro}. Since EDFA transients induced by λ_{PON} random burst traffic are non-stationary, we also show that pre-FEC BER is not a reliable metric for OSNR penalty estimation; thus, we rely on post-FEC metrics.

Experimental Setup and Results

The analyzed US metro+PON scenario is shown in Fig. 1(a), where US bursty PON and continuous metro λs are coupled into an EDFA in the metro segment. To investigate the impact of bursty US PON transmission, two configurations are considered: (a) a single metro channel, and (b) a 16-channel DWDM system including one λ_{PON}. In the single-channel setup, commercial coherent transceivers are employed to transmit at 69.4 GBaud (400 Gbps PM-16QAM with 27% FECoverhead). One transceiver generates the channel under test (CUT), corresponding to the continuous λ_{metro}, while the second is the bursty λ_{PON}. The latter is modulated through an acousto optic modulator (AOM) controlled by

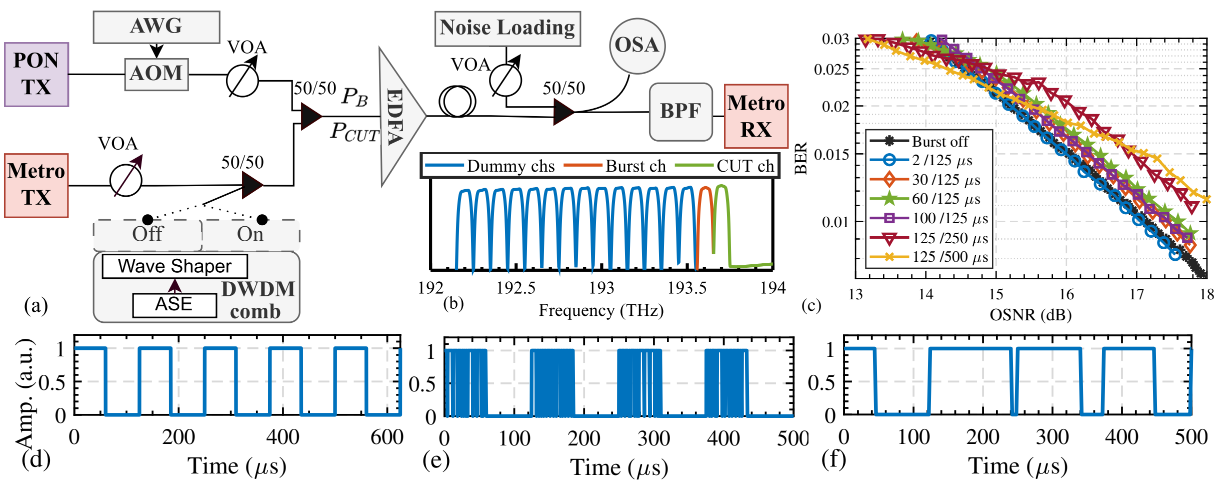

Fig. 1: Experimental configuration of upstream converged metro and PON considering single-channel and DWDM. (b) DWDM optical spectrum. (c) Pre-FEC BER as a function of OSNR under various burst patterns. Time-domain representations of (d) a periodic pulse (PP), (e) random burst (R-BR), and (f) random frame (R-FR) generated waveforms for upstream PON transmission.

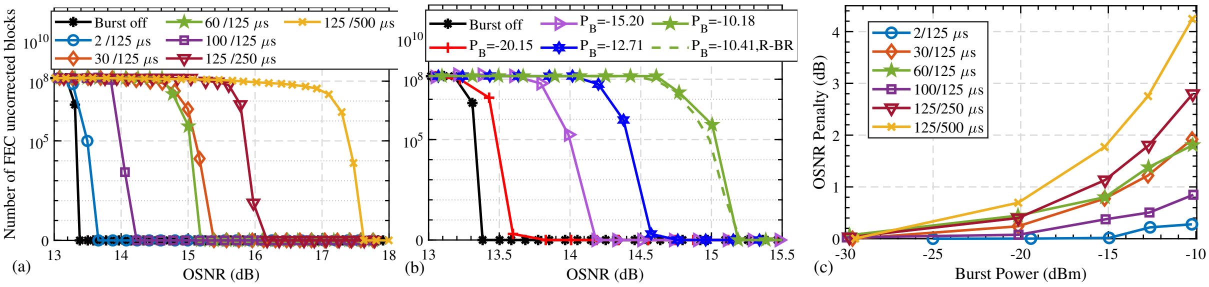

Fig. 2: Number of uncorrected FEC blocks versus OSNR for (a) a burst power of approximately -10 dBm across different periodic pulses (width/period), and (b) a periodic pulse of 60/125 μs at multiple burst power levels alongside a random burst (R-BR) waveform at -10.41 dBm. (c) OSNR penalty as a function of burst power for various burst patterns.

an arbitrary waveform generator (AWG). At the input of the EDFA, the average optical power P_{B} on λ_{PON} within the burst is computed based on the measured average power and the duty cycle $\mathrm{T_{ON}}/\mathrm{T_{total}}$ of the burst signal such that $P_{\mathrm{B}}^{dBm} = P_{av}^{dBm} - 10 \cdot \log_{10}(\mathrm{T_{ON}}/\mathrm{T_{total}})$. The CUT transceiver has an average transmitted optical power of 5 dBm, attenuated by a VOA to set the CUT power at the EDFA input to -20 dBm, which is kept constant throughout the experiments. The signal is then amplified by the EDFA operated at constant optical gain=20 dB to achieve 0 dBm per λ_{metro} at the fiber input (a typical value for metro). Amplified spontaneous emission (ASE) noise is generated around the CUT channel, filtered, amplified, adjusted through a VOA and then coupled with the signal to vary the CUT OSNR . Finally, the signal is optically filtered, received, and BER and post-FEC uncorrected blocks count are measured. In the DWDM setup, a DWDM comb source (ASE noise shaped by a Finisar 1000S Waveshaper) is used to generate 14 dummy channels emulating metro λs aligned with the ITU-T 100 GHz grid, as shown in Fig. 1(b). These are then coupled with the CUT and λ_{PON}.

By properly programming the AWG, we evaluated several traffic patterns on λ_{PON} to emulate real PON system behavior. First, we considered a periodic pulse (PP) condition, defined by a specified width and periodically repeated according to the width/period ratio. Timing was analyzed at both the burst level (e.g., $\mathrm{T_{ON}} = 60$ μs every $\mathrm{T_{TOT}} = 125$ μs as depicted in Fig. 1(d)), and the PON frame level, where the width corresponds to a full 125 μs frame repeated every 250 μs (two frames) or 500 μs (four frames). A random burst (R-BR) waveform was also defined, consisting of a repeated four-frame structure with each frame containing bursts with random duration between 2 and 8 μs, separated by a fixed inter-burst gap of 0.2 μs, for a total 60 μs active transmission per 125 μs frame, followed by no transmission for the remainder of the frame (see Fig. 1(e)). This pattern is used to assess the impact of PON-like short inter-burst gaps and to validate the use of the PP approximation. Finally, we considered a random frame (R-FR) pattern over 1048 frames, shown in Fig. 1(f), where each frame is assigned a random transmission width, ranging from 0 to a maximum of 124 μs per frame.

We first measure the average pre-FEC BER on the CUT channel vs. OSNR (over a bandwidth equal to the baud rate), as shown in Fig. 1c. We consider the single-channel setup with PPs defined by different width/period ratios and a burst power of $P_{\mathrm{B}} \simeq -10$ dBm. The reference case corresponds to the burst channel being off. The results for a 2/125 μs burst overlap with the no-burst reference, whereas burst of 30, 60, and 100/125 μs induce negligible penalty. However, increasing the pulse width and period to 125/250, representing frame-level timing, results in a pre-FEC BER penalty below 1 dB at a BER of 2×10^{-2}. This increased penalty can be attributed to EDFA transient response, as the burst duration is longer, so that the EDFA gain dynamically and nonlinearly responds to input power changes.

The impact of burst patterns on the number of post-FEC uncorrected blocks (measured over 1 minute) vs. OSNR is then shown in Fig. 2(a), for the same PP timings and a burst power of approximately -10 dBm. Post-FEC metrics clearly show deviation from the burst-off reference even for the shortest 2 μs burst, increasing with burst width for 30 and 60 μs, before reducing for 100/125 μs when the burst duration approaches the frame duration and thus the λ_{PON} transmission approximates a continuous mode without EDFA transients. The required OSNR to achieve zero uncorrected FEC blocks further increases for frame-level timings of 125/250 and 125/500 μs, consistent with the longer transmission/idle durations. Figure 2(b) illustrates the burst power P_{B} impact on the number of post-FEC errors versus OSNR for a PP burst of 60/125 μs. Increasing P_{B} leads to a higher number of uncorrected blocks, and the required OSNR to achieve zero FEC errors increases by about 0.4 dB even when the λ_{PON} P_{B} is comparable to that of the λ_{metro}. Additionally, the post-FEC uncorrected blocks are plotted for an R-BR pattern with an active transmission of 60/125 μs and a burst power of -10.41 dBm. The result closely follows

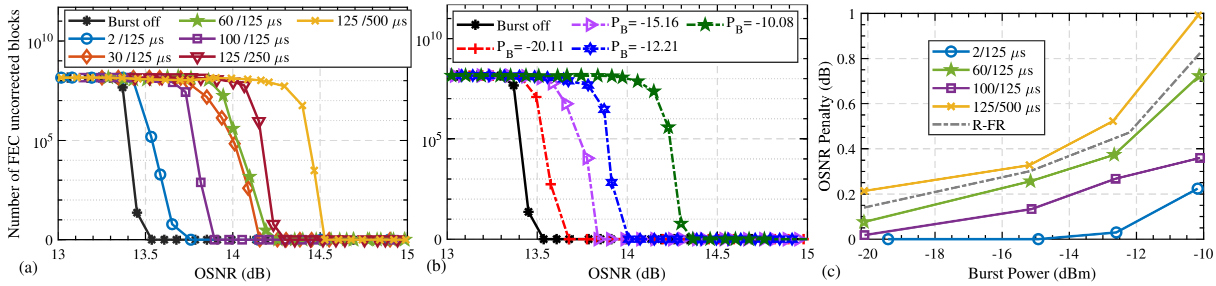

Fig. 3: Number of uncorrected FEC blocks as a function of OSNR in a DWDM configuration for (a) a burst power of approximately -10 dBm across various burst patterns of periodic pulse (width/period), and (b) random frames waveform for several burst power levels. (c) OSNR penalty as a function of burst power for different burst patterns in DWDM configuration.

that of the 60/125 μs PP case, demonstrating that the short inter-burst gap has a negligible impact and that random short bursts generate the same penalty as in the full PP case.

The measured OSNR penalty is shown in Fig. 2(c) as a function of the burst power for various PP timings. The OSNR penalty is defined as the OSNR difference to achieve zero uncorrected FEC blocks relative to the reference burst-off condition. The penalty increases for increasing P_{B} across all patterns. For PP width/period such as 2/125 and 100/125 μs, the penalty remains below 1 dB even at very high burst powers of -10 dBm, which is 10 dB higher than the -20 dBm CUT power. For PPs of 30/125 and 60/125 μs, the penalty reaches approximately 1 dB when the burst power exceeds the CUT power by 5 dB. In the extreme cases of 125/250 and 125/500 μs, the penalty increases further, reaching up to 3 and 4 dB, respectively, at a burst power of -10 dBm.

We also evaluate the impact of EDFA transients in the presence of several DWDM λs. Fig. 3(a) illustrates the post-FEC uncorrected blocks count vs. OSNR for various PP timings and P_{B}=-10 dBm. Similar to the single-channel case, the bursty λ_{PON} degrades the continuous λ_{metro} performance, with the impact determined by the PP width/period durations. However, in contrast to the single-λ case, the degradation remains below 1 dB even for the 125/500 μs timing. In Fig. 3(b), we study the impact of the previously described R-FR pattern for different P_{B} vs. OSNR, emulating realistic PON-like traffic. For burst powers comparable to the CUT power, the performance degradation is limited, but it increases at higher P_{B}. This is further illustrated by the OSNR penalty shown in Fig. 3(c) vs. P_{B} for various PP timings and the R-FR pattern. The 125/500 μs case exhibits the highest penalty, reaching about 1 dB for P_{B}=-10 dBm, whereas the R-FR penalty falls between that of the 60/125 μs and 125/500 μs cases, ranging from 0.2 to 1 dB depending on P_{B}. This R-FR penalty can be attributed to the random frames structure, which results in alternating periods of fully active, partially active, and idle frames. Transitions between transmission/idle induce EDFA gain transients, leading to post-FEC errors, while consecutive fully active or fully idle frames allow the EDFA gain to stabilize, resulting in lower errors. The overall impact results therefore in an intermediate penalty compared to deterministic PP patterns. Finally, the maximum OSNR penalty in the DWDM configuration is about 1 dB, compared to up to 4 dB in the single-λ case under similar conditions.

Conclusions

The impact of bursty upstream PON traffic on coherent metro channels was investigated across a range of PON-like traffic patterns and power levels. Our findings show that short bursts and short inter-burst gaps introduce limited penalty, while longer transmission/idle durations result in performance degradation. The effect is not evident in the pre-FEC BER but emerges in post-FEC metrics, consistently with the non-stationary nature of the EDFA gain transients. In the DWDM configuration, the OSNR penalty remains within approximately 1 dB depending on the burst power, whereas in a single metro channel scenario, it can reach 4 dB under high burst power and long transmission/idle durations. Although loud–soft PON dynamics were not experimentally verified, we anyway span a large range of P_{B} values. Loud-soft conditions are expected to exhibit similar behavior to the transmission/idle case, where the idle state represent the soft level and the loud level the considered P_{B} values.

In conclusion, Fig. 3(c) demonstrates that in the tested conditions, post-FEC OSNR penalty on DWDM metro λs can be kept low (below 0.2 dB) for most λ_{PON} burst patterns and up to $P_{\mathrm{B}} \leq -18$ dBm at EDFA input, while for higher P_{B} the penalty increases significantly. Our work is intentionally meant as a preliminary assessment, showing for instance that average BER is not a proper metric, but post-FEC metrics should be used.

Further work should focus on EDFAs cascades, on more general PON upstream traffic patterns and/or on partial modification to the PON US Dynamic Bandwidth Allocation (DBA) algorithm to ensure a stationary US frame load over the EDFA typical Erbium intrinsic time constant (i.e. ms [9]).

Acknowledgements

This work was carried out in the PhotoNext Center facilities at Politecnico di Torino (www.photonext.polito.it) and has received funding from the European Union's Horizon Europe research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 101073265 (EWOC). Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union. The European Union cannot be held responsible for them.

References

[1] S. Kaneko, Y. Kimura, K. Hara, J.-i. Kani, and T. Yoshida, "Metro/access converged all-photonics networks with remote control and management technologies accommodating various types of terminals [invited]", *IEEE/OPTICA Journal of Optical Communications and Networking*, vol. 17, no. 8, pp. C105–C116, 2025. DOI: 10.1364/JOCN.550891.

[2] G. Rizzelli, M. Casasco, V. Ferrero, A. Pagano, and R. Gaudino, "Analysis and experimental demonstration of possible architectures for future coherent metro+PON converged networks [invited]", *IEEE/OPTICA Journal of Optical Communications and Networking*, vol. 17, no. 2, A142–A154, 2025. DOI: 10.1364/JOCN.538835.

[3] G. Rizzelli, M. Casasco, E. Riccardi, A. Pagano, V. Ferrero, and R. Gaudino, "Experimental investigation on the fundamental physical-layer capabilities for converged metro–access architectures using coherent transceivers", *IEEE/OPTICA Journal of Optical Communications and Networking*, vol. 17, no. 7, pp. 648–658, 2025. DOI: 10.1364/JOCN.558563.

[4] G. Rizzelli, P. Torres-Ferrera, A. Napoli, and R. Gaudino, "Filtering effects characterization in metro-access networks and future high-speed coherent optical communication schemes", *IEEE/OPTICA Journal of Lightwave Technology*, vol. 43, no. 3, pp. 1114–1122, 2025. DOI: 10.1109/JLT.2024.3477552.

[5] Y. Hu et al., "All-optical metro-access integration network bidirectional transmission enabled by coherent digital subcarrier multiplexing", *IEEE/OPTICA Journal of Optical Communications and Networking*, vol. 17, no. 1, pp. 58–70, 2025. DOI: 10.1364/JOCN.541599.

[6] G. Rizzelli, M. Casasco, A. Pagano, E. Riccardi, V. Ferrero, and R. Gaudino, "Demonstration of converged metro+access bidirectional transmission using coherent transceivers and ROADMs", in *2025 Optical Fiber Communications Conference and Exhibition (OFC)*, 2025, pp. 1–3.

[7] G. Rizzelli, S. Alzoubi, A. Galardini, and R. Gaudino, "Analysis and demonstration of future coherent metro-PON converged networks", in *2026 Optical Fiber Communications Conference and Exhibition (OFC)*, 2026, pp. 1–3.

[8] D. Richards, J. Jackel, and M. Ali, "A theoretical investigation of dynamic all-optical automatic gain control in multichannel EDFA's and EDFA cascades", *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 3, no. 4, pp. 1027–1036, 1997. DOI: 10.1109/2944.649534.

[9] M. Karasek, A. Bononi, L. Rusch, and M. Menif, "Gain stabilization in gain clamped EDFA cascades fed by WDM burst-mode packet traffic", *IEEE/OPTICA Journal of Lightwave Technology*, vol. 18, no. 3, pp. 308–313, 2000. DOI: 10.1109/50.827501.

[10] A. Bianciotto, A. Carena, V. Ferrero, and R. Gaudino, "EDFA gain transients: Experimental demonstration of a low cost electronic control", *IEEE Photonics Technology Letters*, vol. 15, no. 10, pp. 1351–1353, 2003. DOI: 10.1109/LPT.2003.818267.