Equalizer Convergence for various Transmission Channels and Multi-Rate Upstream 50G-PON

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Abstract: We assess the feasibility of multiple transmission channel and multi-rate upstream 50G-PON. The TDEC shows that a unique preset filter may be used at both 50Gb/s and 25Gb/s to meet interoperability without adaptive equalization.

1. Introduction

Higher Speed Passive Optical Network (HS-PON) is the last set of PON standards released by ITU-T [1]. As for 10 Gb/s Symmetrical PON (XGS-PON), the first part of HS-PON, 50G-PON, is based on Time Division Multiplexing (TDM) in downstream (DS), and Time Division Multiple Access (TDMA) in upstream (US). 50G-PON assumes a line rate of 50 Gb/s in DS in Non-Return to Zero (NRZ) modulation format, and several bitrates in upstream, namely 12.5 Gb/s, 25 Gb/s, and 50 Gb/s, also in NRZ. Several wavelength options are considered: 1342+/-2 nm in DS and 1270+/-10 nm or 1300+/-10 nm in US. The constraints on components bandwidth (i.e. 25G-class receivers) and Chromatic Dispersion (CD) obliges the community to seek solutions to reach the optical budget (e. g. up to 29dB in N1 class) and sensitivity requirements of the HS-PON. For this reason, 50G-PON will be the first ITU-T technology requiring the use of Digital Signal Processing (DSP). This DSP can take several forms which are at vendor's discretion, but the baseline according to the standard, is the use of Feed-Forward Equalization (FFE). However, 50G-PON needs to meet the interoperability requirement to be successful. Regarding DSP, this means that the configuration must meet all possible combinations: an Optical Network Unit (ONU) from "vendor A" with specific characteristic must be able to communicate with an Optical Line Terminal (OLT) of "vendor B" (see Fig. 1) with other characteristics, independently from the transmitter/receiver bandwidth (or radio frequency (RF) path in general), or optical path (including dispersion load) as the propagation range can be from 0 to 20 km. Also, the TDMA assumes the transmission channel to evolve from burst to burst, in a few nanoseconds. In brief, the devices have no prior knowledge of the transmission channel, and a method to set the device to the optimal configuration is required. Moreover, in upstream, it is expected that the OLT can receive signals emitted from ONUs working at several line rates (12.5, 25 or 50 Gb/s) as it does for XGS-PON. Finally, for the sake of energy savings and component centralization, we assume that the FFE is located at the OLT side in upstream instead of the ONU side, as the Optical Distribution Network (ODN) may be shared among 64 or even 128 ONUs.

We propose in this paper to study the FFE performance in an unknown transmission channel context. To do so, we discuss on the convergence of a blind equalization algorithm, and on the impact on US burst mode at 50 Gb/s. We compare this solution to a configuration where the equalization parameters are pre-registered. Finally, we discuss the impact with a multi-rate system.

2. Experimental Setup and Methodology

The experimental setup is presented on Fig. 2. A Pulse Pattern Generator (PPG) generates a 2^{15}-1 Pseudo Random Binary Sequence (PRBS). Helped with an amplifier, it drives a 40 GHz bandwidth Mach-Zehnder Modulator (MZM), to modulate an optical signal emitted by an External Cavity Laser (ECL). The 50 Gb/s NRZ pulses propagates through 0, 10 or 20 km of Standard Single Mode optical Fiber (SSMF) links. The signal is detected by a 70 GHz PIN photodetector and a 200 GSa/s Digital Storage Oscilloscope (DSO), see Fig. 2. The data are normalized so that the low and high levels are aligned with -1 and +1 levels, respectively. No additional attenuation is used, and the input optical extinction Ratio exceeds 8 dB while the received power varies from -1.1 dBm to -7.4 dBm depending on the propagation in different lengths of SSMF.

The post-processing applied to the signal first consists in applying a 4th order 18.75 GHz Bessel-Thompson filter, which corresponds to the lowest bandwidth receiver according to the standards, a 25G class avalanche photodiode receiver. Once the signal is filtered (see Fig. 3.a), a T-spaced 13 "taps" coefficients FFE filter is applied (see Fig. 3.b), corresponding to the DS standard baseline. The solution selected to optimize the set of FFE's coefficient is a variant

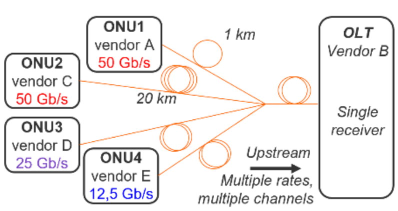

Fig. 1. 50G-PON system with multiple rates and multiple channels

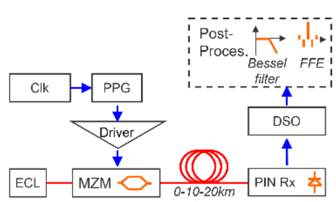

Fig. 2. Experimental setup

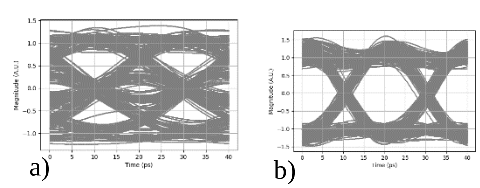

Fig. 3. 50Gb/s eye diagrams after 20km and 18.75 GHz filter (a), and after FFE (b)

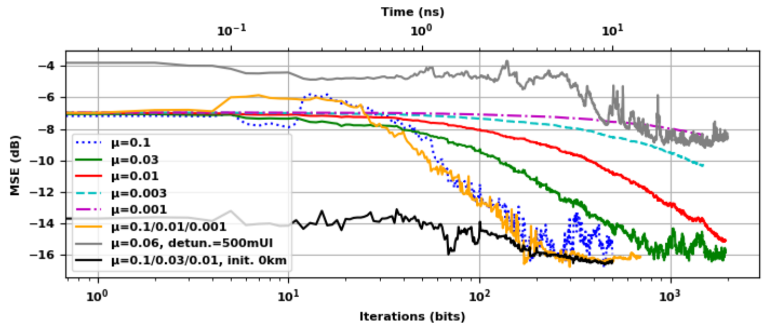

Fig. 4. MSE vs. iteration in various convergence contexts (1270nm)

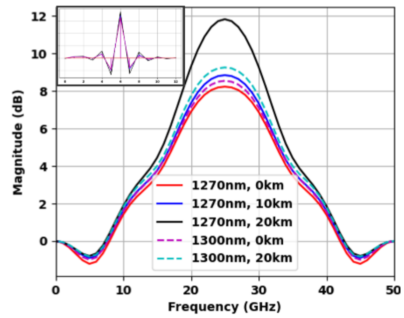

Fig. 5. DFTs of the processed FFE filters (top insight: time domain response)

of the well-known Least Mean Square (LMS) algorithm. In contrary to regular LMS, in case of blind equalization the Mean-Squared Error (MSE) is not computed comparing the equalized symbols with the reference sequence, as we assumed that no training sequence can be used since it is not agreed in the standard. The MSE here is the difference between the FFE output and the detected NRZ-OOK symbol after decision. The process is repeated at the line rate of 50 Gb/s, while the convergence rate depends on the step-size μ, to be discussed later. The initial FFE coefficients are set to zero, except for the middle one, set to one.

3. Results and discussion

We propose first to focus on the transient analysis of the step-size parameter μ. Fig. 4 shows the measured MSE depending on the LMS iterations for a signal which has propagated through 20 km at 1270 nm, while a set of μ varying from 0.1 to 0.001 is investigated. When μ is high (μ=0.1, blue dotted curve) the algorithm reaches an MSE of -16 dB, thus the steady state is reached in about 200 iterations, equivalent to 4 ns at 50 Gb/s. However, this is a high step-size value, since the MSE presents noisy fluctuation of several dBs. Reducing μ can help to reduce such variations, as shows green, red, cyan, and purple curves on Fig. 4. Unfortunately, the number of iteration and then the duration required to converge increases rapidly: more than 2000 bits (40 ns) required when μ=0.01 (red curve). A convenient way to improve the convergence is to use a variable step size [2]. The orange curve on Fig. 4 shows the MSE when μ=0.1 from 0 to 200 bits, then μ=0.01 from 200 to 300 bits, and finally μ=0.001 after. Doing so, the MSE variations remains at the end below 0.1dB while converging in about 200 iterations, and it can still adapt to slow transmission channel variation due for example to temperature drift impacting the components bandwidth. The LMS algorithm (whether blind or with training sequence) requires making decision on the received analog signal, i.e. needs the threshold and the decision moment (phase) to be correctly tuned. The grey curve on Fig. 4 shows the MSE failing to converge when the decision is taken 500 mUI (Units of Interval) away from the optimal point. In PON systems, the first nanoseconds of transmitted burst mode signal correspond to the preamble which helps the receiver to recover the phase and threshold. However, the preamble may not be exploitable if the FFE did not converged, and then, the LMS algorithm or any adaptive equalization algorithm cannot converge.

Fortunately, Fig. 4 shows that the algorithm always converges when the decision is correctly taken, i.e. the FFE converges to a similar frequency response. The coefficients (averaged over 10 measurements) and the corresponding Discrete Fourier Transform (DFT) appear on figure Fig. 5 (20 km: black curve). Similarly, the FFE coefficient and DFT were obtained for 0 km and 10 km transmission at 1270 nm (see Fig. 5). As expected, the results shows that the FFE tends to compensate the high frequency (>25 GHz) losses induced by CD when the transmission length increases. As those three sets of coefficients cover the range of transmission (0 to 20 km), it can be more convenient to initiate the FFE to one of them. The black curve on Fig. 4 shows the MSE convergence when the FFE is initialized with the same values of the 0 km filter, while the equalized signal propagated through 20 km at 1270 nm. The MSE convergence is reached with almost the same speed, about 200 bits (or 4 ns), but with less noisy fluctuation.

Finally, considering this study, only the first 4 ns of the preamble would be impacted. As 50 Gbs/s US specification is for further study, it should be noted that the preamble at 12.5 Gb/s and 25 Gb/s US is specified to last about 150 ns in both cases. Using the FFE set of coefficients of one of the propagation lengths (0, 10 or 20 km) seems to be sufficient to recover both phase and threshold, but also to optimize the FFE with the LMS, while it was demonstrated in [3] that 200 ns where in practice required.

Instead of using an adaptive algorithm such as the LMS, which requires computing resources and energy, we can also consider simply using a single pre-registered FFE profile, without LMS nor another adaptive algorithm. To study this, we propose to exploit the Transmitter and Dispersion Eye Closure (TDEC), a new metric used in HS-PON

TDEC (dB) at 1270 nm	Data: 0km	Data: 10km	Data: 20km
Filter: 0km (*Ceq*:1.74 dB)	2.21	2.30	3.14
Filter: 10km (*Ceq*:1.93 dB)	2.37	2.43	3.21
Filter: 20km (*Ceq*:2.73 dB)	3.25	3.19	3.32

Table 1. TDEC measurements for 50 Gb/s data at 1270 nm, when different filters are applied

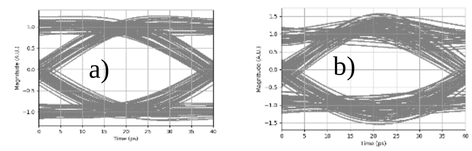

Fig. 6. 25Gb/s eye diagrams without FFE (a), and with the 50Gb/s FFE (b)

specification [1]. TDEC exploits eye diagrams to estimate the penalty induced by a transmitter compared to an ideal one. In DS HS-PON, the TDEC is assumed to directly estimate the impact of the transmitter quality to the sensitivity: a transmitter showing 1 dB TDEC more than another would lead to 1 dB worst sensitivity.

We showed in [4] that the main contribution to TDEC is the noise enhancement factor noted *Ceq*, caused by the FFE. We then propose to measure the TDEC for 0, 10 and 20 km propagation length, in varying the FFE combinations. The results, averaged over 10 measurements to reduce the standard deviation below 0.1 dB, are showed in Table 1. The 20 km filter provides an important *Ceq* of 2.73 dB, which dominates the 3.32 dB of TDEC when the signal propagated through 20 km, because the filter matches the channel, but amplifies noise at high frequency. On the other side, the 0 km filter brings less noise (*Ceq*=1.74 dB) but the 20 km signal suffers more from the CD, providing a worst eye diagram than in the 20 km filter case. At the end, it appears that the 20 km signal shows similar TDEC for the three filters: from 3.14 dB to 3.32 dB. Such results tend to demonstrate that using a single pre-registered FFE profile without adaptive algorithm would provide similar performances, while saving energy and cost. The 0 km filter shows the best TDEC performances for the 3 propagation lengths, thus suggesting using it as the reference. The process was repeated at 1300 nm (the other US wavelength range) and the 0 km filter at that wavelength (see Fig. 5, magenta dashed line) is very close to that of the 1270 nm wavelength (as there is no CD), confirming that a single set of parameters could be used for the different wavelength ranges. In case that the receiver bandwidth is higher, it could also be assumed that the FFE (located at receiver side) would be adapted to its bandwidth as both will be part of the same OLT, relaxing the FFE work and corresponding noise, while improving the transmissions performances compared to an 18.75 GHz bandwidth receiver.

Finally, the question remains about the multi-rate behavior of such 18.75 GHz receiver associated with 50 Gb/s T-spaced FFE. While the TDEC is not defined at 25 Gb/s, it can be assumed that the noise enhancement factor *Ceq* of the FFE will remain the same. The TDEC is then computed using the same process regarding the relative position of the histograms in the eye diagram in terms of units of interval. We first assume a receiver not requiring FFE at 25 Gb/s: *Ceq*=0 dB (by definition) and the TDEC is 0.22 dB, a normal result considering the use of a 25G class receiver (18.75 GHz bandwidth) on a 25 Gb/s signal. Then, the previously obtained 0 km (50Gb/s) filter is applied (red curve on Fig. 5). The measured TDEC is 2.24 dB, which is slightly higher than the *Ceq* (1.74 dB): while the FFE introduces overshoots on the eye diagram (see Fig. 6) the eye remains quite open and close to an ideal one. A similar behavior is expected at 12.5 Gb/s. Then, this confirms that using a pre-registered FFE profile, as the one obtained from the "50 Gb/s, 1270 nm, 0 km" configurations are compatible with different rates, wavelength ranges and reaches of the US 50G-PON, assuming less than 2.5 dB impact on the optical modulation amplitude.

4. Conclusions

We investigated on the equalization of the 50G-PON upstream to meet the various transmission channels and multi-rate system interoperability requirements where the signal path varies from burst to burst in a few nanoseconds. We showed that at least 4 ns were required for an adaptive blind equalizer to converge, thus impacting the performance of the preamble of burst-mode systems, but also that the decision instant and the algorithm convergence were inter-dependent. To speed-up the convergence, we suggested to preset the FFE coefficients to the filter obtained without propagation (0km), thus meeting the two 50G-PON wavelength ranges. We also discussed avoiding the use of adaptive equalization and using only the preset filters. The results suggest that the FFE filter obtained with the 50 Gb/s signal has a limited impact (below 2.5 dB) on the 25 Gb/s sensitivity.

5. Acknowledgments

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6. References

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