Ultra-high Bitrates Next Generation Passive Optical Networks

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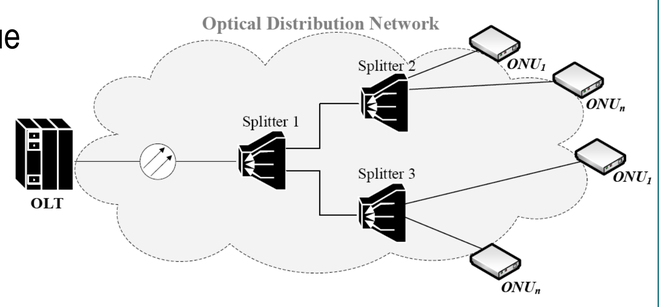
Research context and motivation

- Since early 2000s, **Passive Optical Networks** (PON) have been deployed on a massive scale for FTTH (700 million estimated users worldwide, growing)
- Increasing demand for **higher bitrates** due to emerging applications
  - 5G backhaul
  - Industrial and campus networks
  - Augmented and Virtual Reality (AR/VR)
- Main challenges for this kind of network:
  - Achieve **high link budgets**, to re-use already deployed networks
  - Keep total cost of the system low

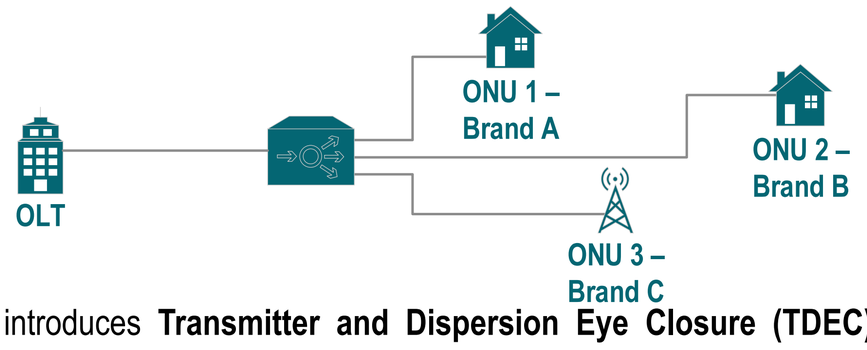


[1] Horvath, T. *et al.*, Passive Optical Networks Progress: A Tutorial. *Electronics* **2020**, *9*, 1081. https://doi.org/10.3390/electronics9071081

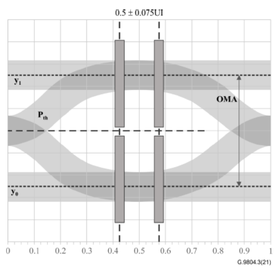
GPON (~1 Gbps) → EML, FEC → **XG-PON** (10 Gbps) → DSP, SOA → **50G-PON** (50 Gbps) → **What's next?**

Addressed research questions/problems

- **Introduction of DSP** in 50G-PON adds one potential issue: **how to ensure interoperability** among devices from different manufacturers?



- 50G-PON introduces **Transmitter and Dispersion Eye Closure (TDEC),** a metric to characterize the transmitter quality. Based on the theoretical amount of noise (2) a signal can tolerate to achieve a given Bit Error Rate (BER), TDEC (3) indicates **the penalty** when we compare it to the noise it's possible to add to the measured transmitted signal (1).



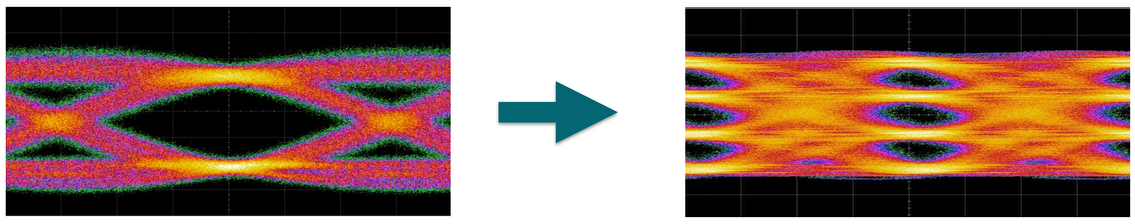
(1) $$\frac{1}{2}\left(\frac{\int f_u(y)Q\left(\frac{y-P_{th}}{C_{eq}\cdot\sigma_G(y)}\right)dy}{\int f_u(y)dy}\right)+\frac{1}{2}\left(\frac{\int f_l(y)Q\left(\frac{P_{th}-y}{C_{eq}\cdot\sigma_G(y)}\right)dy}{\int f_l(y)dy}\right)=\mathrm{BER}_{target}$$

(2) $$2\mathrm{BER}_{target}=Q\left(\frac{OMA}{2\sigma_{o,ideal}}\right)+Q\left(\frac{OMA}{2m\sigma_{o,ideal}}\right)$$

(3) $$TDEC=10\cdot\log_{10}\left(\frac{\sigma_{o,ideal}}{\sigma_{estimated\_DUT}}\right)$$

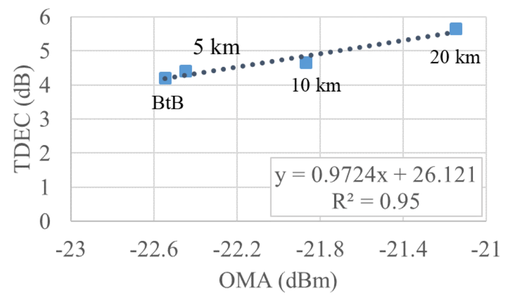
[2] ITU-T G.9804.3

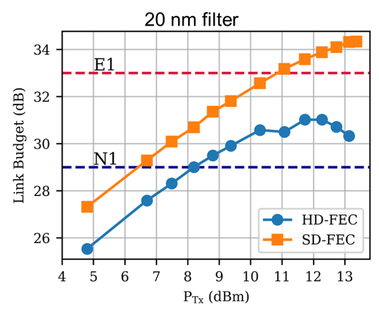
- For PONs with **bitrates higher than 50 Gbps**, one approach to keep using Intensity Modulation and Direct Detection (IMDD) is employing **multilevel modulation formats**



Novel contributions

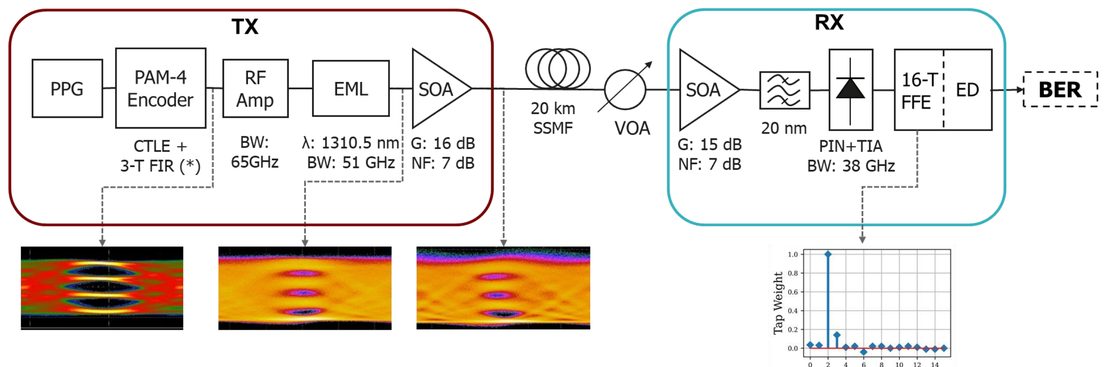
- Work on 50G-PON TDEC metric: **experimental proof** of linear correlation with:
  - **Accumulated chromatic dispersion** of the link
  - **Extinction ratio** of the optical transmitted signal signal
- Research on future PON led to achieving a the first **real-time PAM-4 100 Gbps** link with power budgets compatible with PON standard.





Adopted methodologies

- 50G-PON TDEC:
  - Theoretical study of this metric in presence of Avalanche Photodiode (APD) receivers and experimental verification with a variety of transmitters
- PAM-4 100G-PON:
  - Tx SOA allows to launch signal with high output power, while Rx PIN sensitivity is improved by the addition of SOA + Optical Filter
  - PAM-4 encoder with Continuous Time Linear Equalizer (CTLE) + Analog Finite Impulse Response (FIR) Filter and real-time BER Tester (BERT) allow fine-tuning of signal quality



Future work

- Avalanche photodiodes (APDs) have proven to be a key component for PONs. 25G-class devices have proven mature for use at 50 Gbps.
- Our open question on this: what kind of performance can be expected in a 100 Gbps PAM-4 link by **replacing the SOA+Filter+PIN with a 25G-APD**
- In parallel, 50G-PON is still under research, particularly the feasibility of a **50 Gbps upstream link.**
- Directly modulated lasers (DML) represent an interesting alternative to using external modulation in terms of lower cost and higher launch power.
- Research in progress on using **negative dispersion wavelengths** to counteract DML frequency chirp

Submitted and published works

- G. Caruso, I. N. Cano, R. Rosales, D. Nesset, G. Talli and R. Gaudino, "Enhanced Electrical Duobinary Decoder with Low-BW Based Receivers for Short Reach Indoor Optical Links," *2021 European Conference on Optical Communication (ECOC)*, 2021, pp. 1-4 – **(Accepted)**
- G. Caruso, I. N. Cano, D. Nesset, G. Talli, R. Gaudino, "Real-Time 100Gb/s Downstream PAM4 PON Link with 34 dB Power Budget," *2022 European Conference on Optical Communication (ECOC),* Basel, 2022 - **(Accepted)**
- C. Bluemm, H. von Kirchbauer, G. Caruso *et al.*, "FDMA Point-to-Multi-Point Fibre Access System for Latency Sensitive Applications," *2022 European Conference on Optical Communication (ECOC),* Basel, 2022 - **(Accepted)**
- I. N. Cano, G. Caruso, D. Nesset, G. Talli, "Relation Between TDEC, Extinction Ratio and Chromatic Dispersion in 50G PON", *13th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP),* Porto, 2022 - **(Accepted)**
- J. Potet *et al.*, "Real-Time DSP-Free 100 Gbit/s/λ PAM-4 Fiber Access Link Using EML and Direct Detection," in *IEEE Photonics Technology Letters*, vol. 34, no. 17, 2022, pp. 895-898 - **(Accepted)**

List of attended classes

- 01UMNRV – Advanced Deep Learning (didattica di eccellenza) (15/6/2021, 30 hours)
- 01TRLRV – Optical Transport Networks (23/7/2021, 30 hours)
- 01TCTRV – Photonext: Hands on course on Photonics for Fiber Transmission (29/10/2021, 30 hours)
- 02SFURV – Programmazione scientifica avanzata in MATLAB (25/5/2021, 30 hours)
- 01QAAAA – Semiconductor light sources for engineers (12/9/2022, 20 hours)
- OFC 2021 - Short Course - Hands-On: Laboratory Automation and Control using Python (Advanced) (7/6/2021, 4 hours)
- OFC 2021 - Short Course - Machine Learning in Optical Networks (7/6/2021, 4 hours)
- Soft Skill Courses: 40 hours

POLITECNICO DI TORINO

HUAWEI

Industrial PhD position - PhD program in
Electrical, Electronics and Communications Engineering