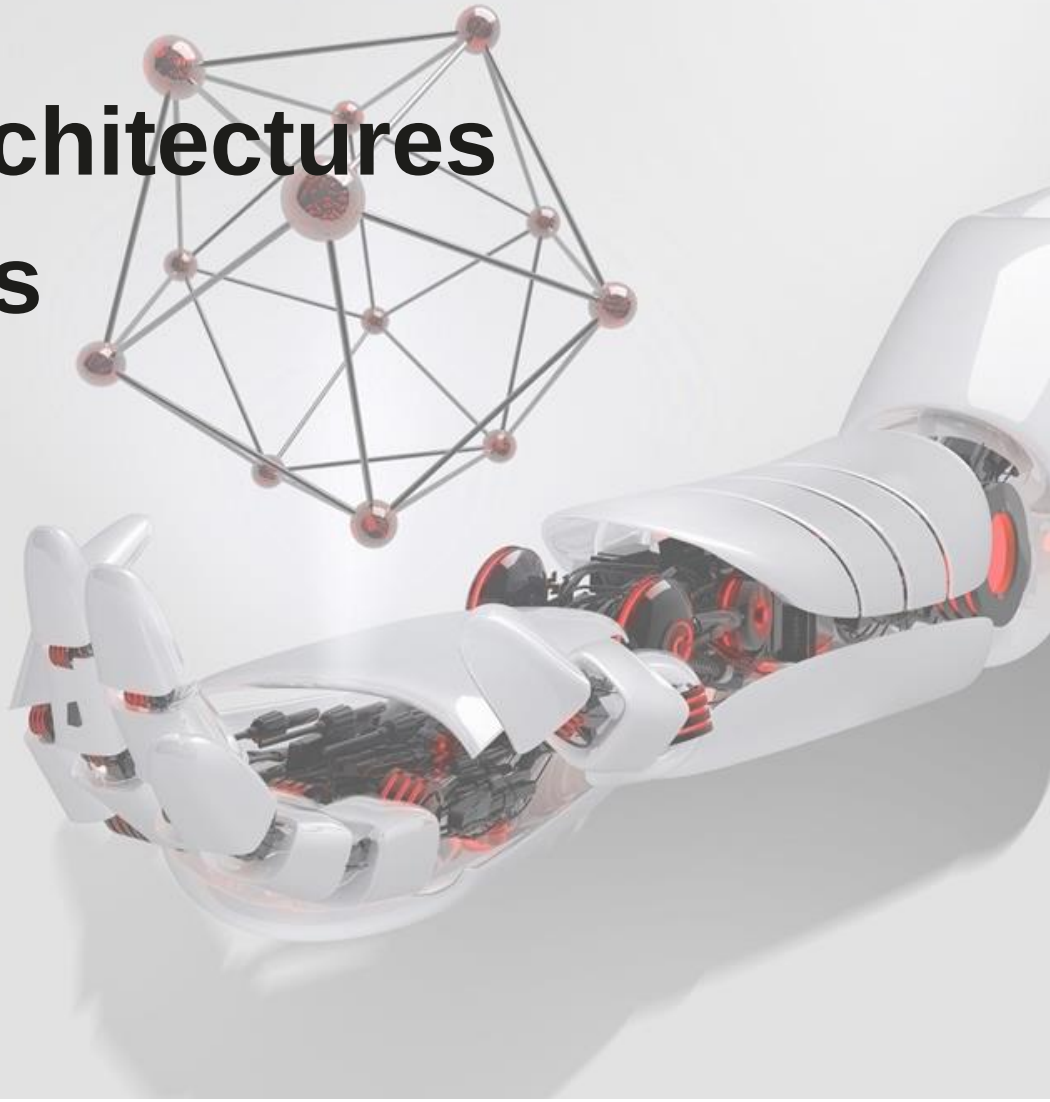
Ultra-high bitrates Optical Architectures and Passive Optical Networks



Giuseppe Caruso

1° PhotoNext Researcher's Day
Torino, 19/06/2023

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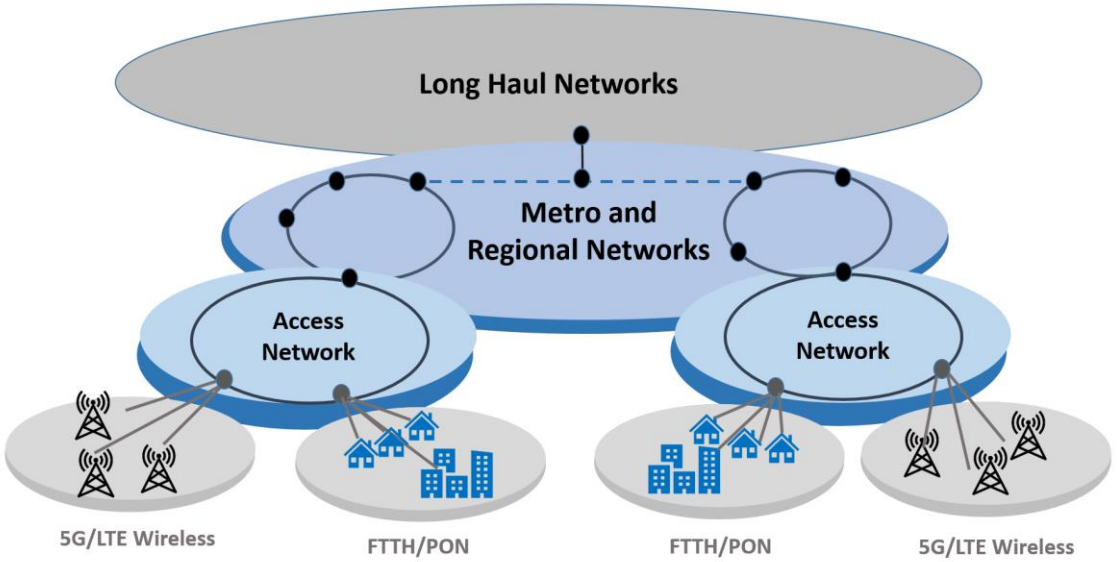
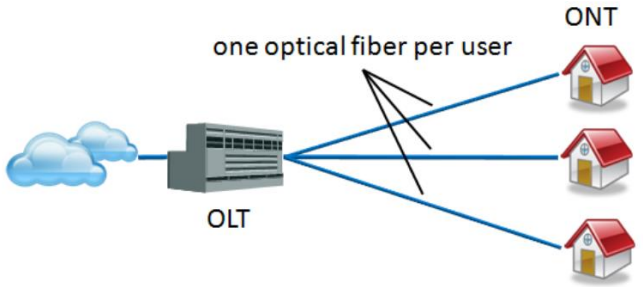
Optical Access Networks

- What is an access network?
  - It is a type of network that connects the **end user** to the **service provider**
  - **optical** when the medium transporting the information is an optical fiber

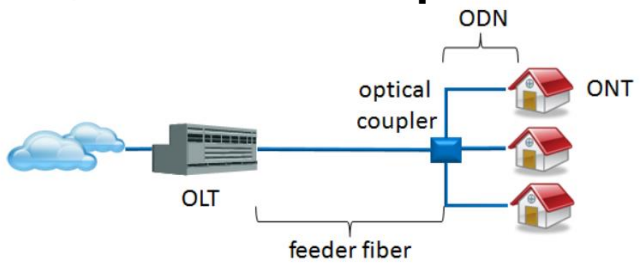


- Two topologies are mainly deployed:

Point to point



Point to multipoint, aka **Passive Optical Networks (PON)**



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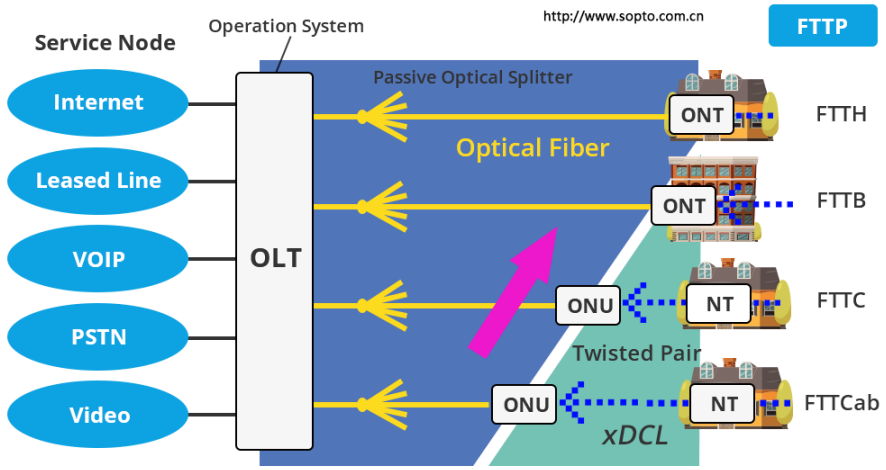
Optical Access Networks

- Main (but not the only) use case for **PONs** is to provide Fiber-to-the-x services **(FTTx)**
- In Italy, **10.2 milion** households are connected via FTTx connection, with maximum speed of 2.5 Gbps
- In 2023, 10 Gbps services for private users start to be commercially available



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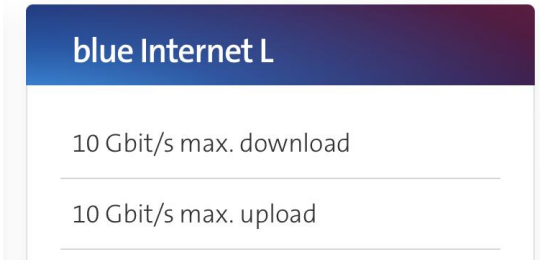

Orange ES

- In September 2021, **50G-PON** was standardized by ITU-T

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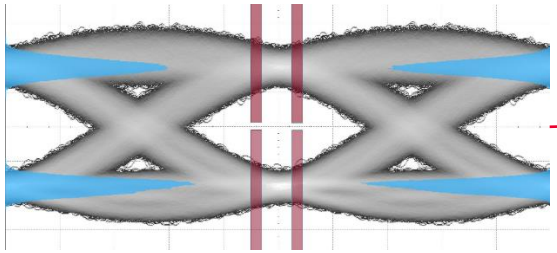
50G-PON: ensuring interoperability

- 50G-PON foresees the use of 25G-class receivers, including **DSP** to compensate for impairments

- How to make sure that transmitters from different manufacturers can work in a PON network?

- Introduction of the **Transmitter Dispersion Eye Closure (TDEC)** metric
  - Based on eye diagram observation
  - Tells us a penalty compared to an ideal NRZ signal



$$TDEC = 10 \cdot log\left(\frac{\sigma_{ideal}}{\sigma_G}\right).$$

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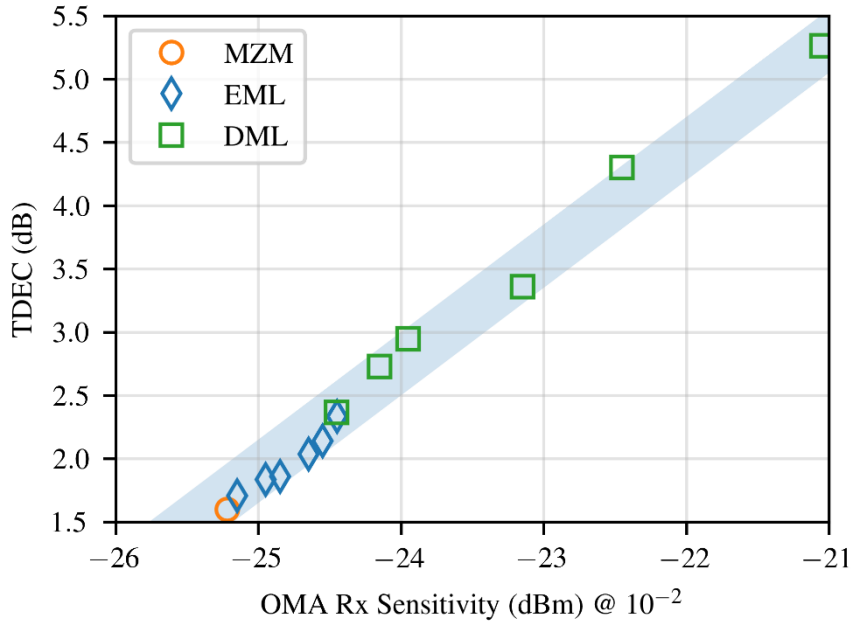
TDEC metric

We demonstrated in multiple works that TDEC is able to predict **RX sensitivity variations** with high accuracy

- For different kind of **transmitters**:
  - Mach Zehnder Modulators (MZM)
  - Electroabsorption-Modulated Lasers (EML)
  - Directly Modulated Lasers (DML)

- Due to different impairments, e.g.:
  - variation of Tx **Extinction Ratio**
  - Penalties from **chromatic dispersion**. (both in the positive and negative dispersion regime)



TDEC metric in 50G-PON: analytical and experimental investigation on several implementation aspects

MARIACRISTINA CASASCO[1,5], GIUSEPPE CARUSO[1,2,5], IVAN N. CANO[2], DEREK NESSET[3], MAURIZIO VALVO[4], VALTER FERRERO[1], AND ROBERTO GAUDINO[1]

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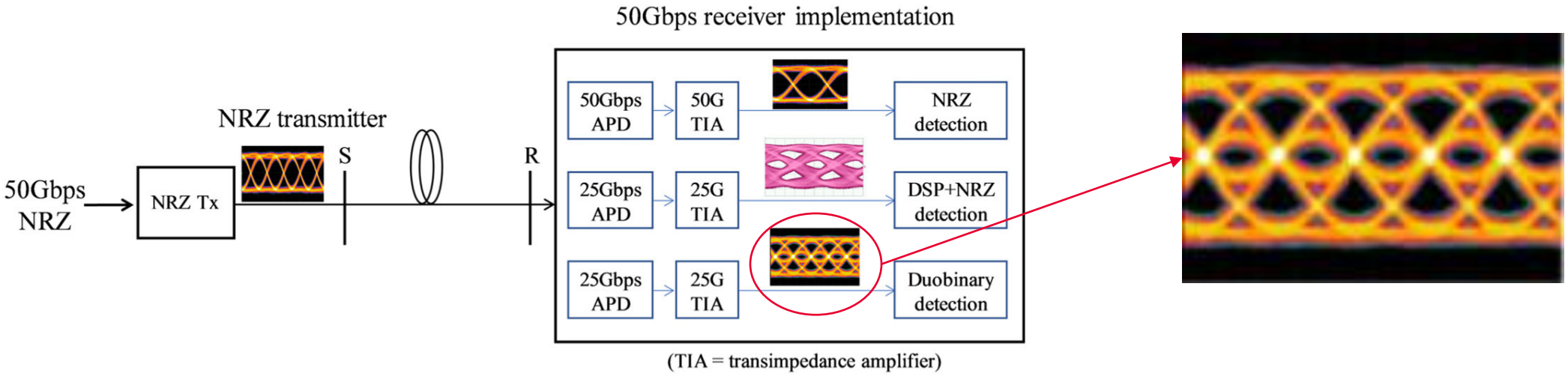
Alternative techniques for impairments mitigation

- With limited RX bandwidth, the other main issue in PON networks is **chromatic dispersion.**
- After 20 km, the transmitted signal can be **heavily degraded**



- Received binary signal becomes almost a three-level signal, similar to an **electrical Duobinary sequence**

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Enhanced Electrical Duobinary

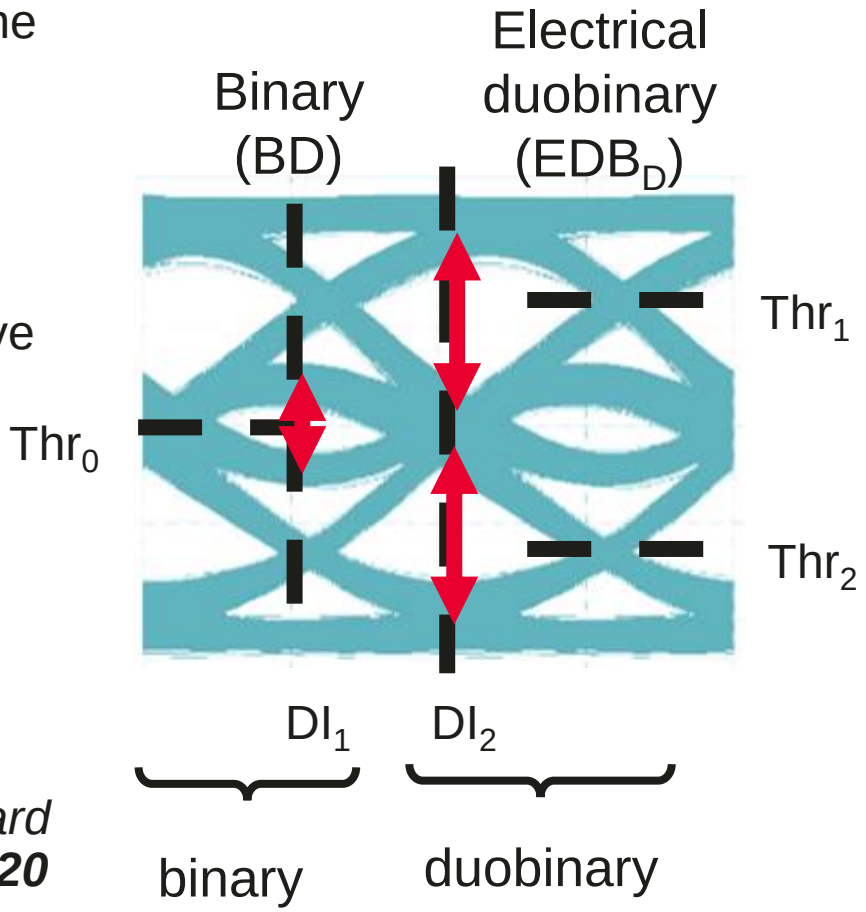
- **Idea:** Detect symbols in **both** the eye opening (binary, BD) and in the crossing point section (electrical duobinary, EDB_D)
- They are related by

$$EDB_C[i] = BD[i] + BD[i-1]$$

- We compare the detected EDB_D with EDB_C computed with the above equation.

- One wrong bit in BD produces **two errors** in EDB_C
- When two consecutive errors are detected, $BD[i]$ is inverted

- *At ECOC 2021, we showed that this technique, compared to standard binary detection, improves RX sensitivity* ***by more than 3 dB after 20 km*** *of single mode fiber*



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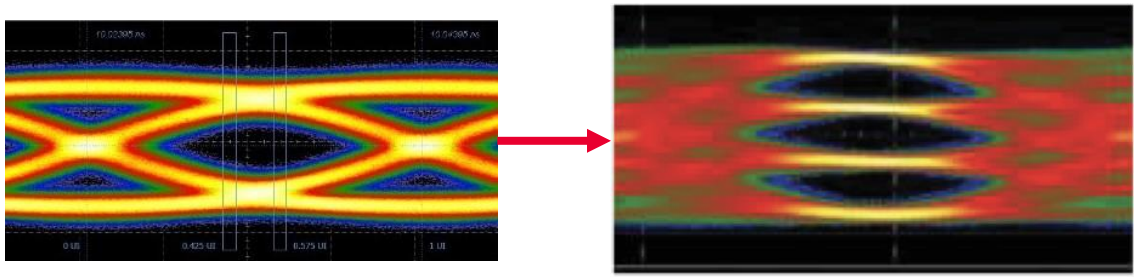
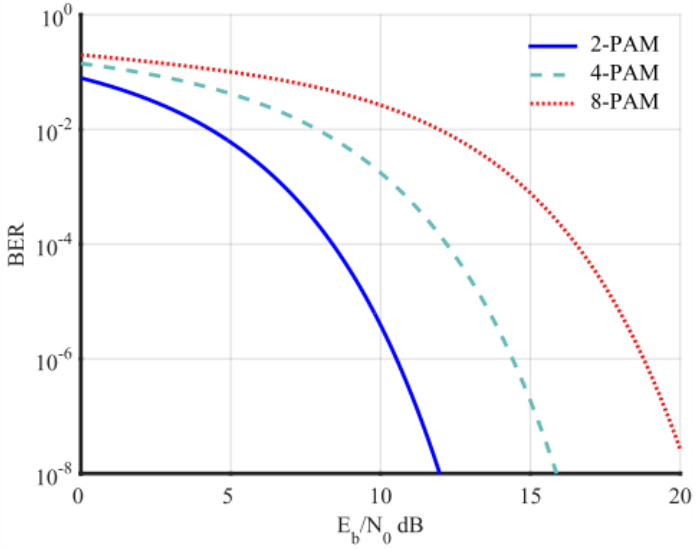
Going beyond 50 Gbps

- Research is already active for achieving **beyond 50 Gbps** optical access networks
- In this direction, we tried to increase bitrate by **changing modulation format**
- 50 Gbps NRZ to 100 Gbps PAM-4: double bitrate, same electrical bandwidth
- Main challenge: achieve **high link budgets required** by PON networks (> 29 dB)





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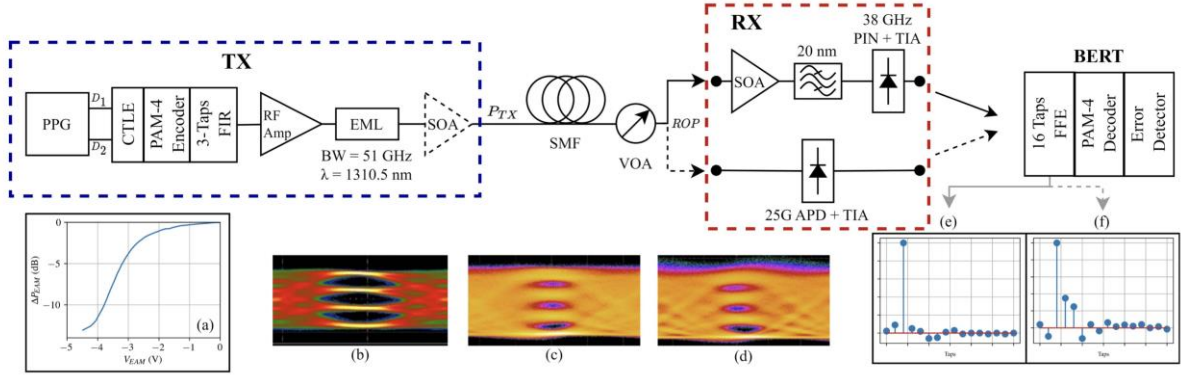
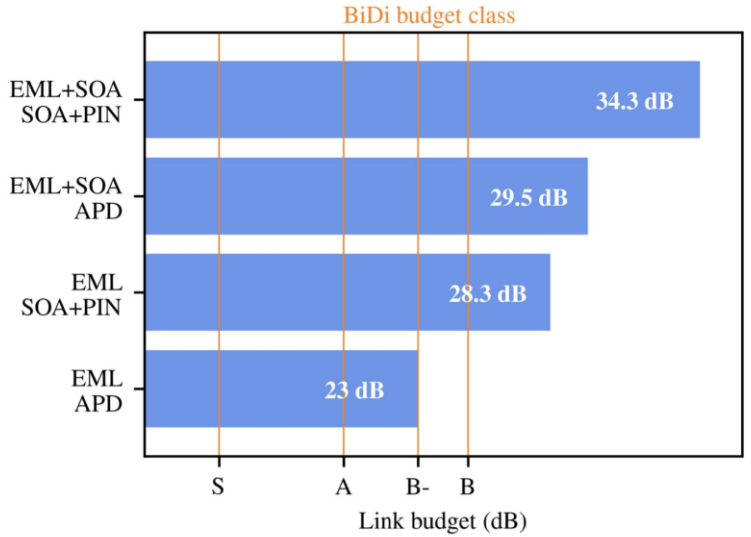
Going beyond 50 Gbps

- We investigated **potential and limitations** of this kind of systems
- A **real-time setup** was implemented, with amplified and non-amplified transceivers
- A record link budget of **34.3 dB** was achieved (presented at ECOC 2022 and published in JLT)





Publications

- On TDEC:
  - I. N. Cano, G. Caruso, D. Nesset and G. Talli, "Relation Between TDEC, Extinction Ratio and Chromatic Dispersion in 50G PON," *CSNDSP 2022,* Porto, Portugal
  - G. Caruso, I. N. Cano, G. Talli, D. Nesset and R. Gaudino, "Study of TDEC for 50G-PON Upstream at 50 Gb/s in Negative Dispersion Regime using 25G-class Transceivers," *2023 Optical Fiber Communications Conference and Exhibition (OFC)*, San Diego, CA, USA, 2023
  - M. Casasco, G. Caruso *et al.*, TDEC metric in 50G-PON: analytical and experimental investigation on several implementation aspects, **accepted for JOCN**
  - *M. Casasco, G. Caruso, I. Cano, A. Pagano, R. Mercinelli, M. Valvo, V. Ferrero, and R. Gaudinol,* TDEC metric for 50G-PON using optical amplification, **to be presented at ICTON 2023**

- On EEDB:
  - 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)*, Bordeaux, France, 2021.

- On 100 Gbit PAM-4:
  - 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, pp. 895-898, 1 Sept.1, 2022, doi: 10.1109/LPT.2022.3191460.
  - G. Caruso, I. N. Cano, D. Nesset, G. Talli and R. Gaudino, "Real-Time 100Gb/s Downstream PAM4 PON Link with 34 dB Power Budget," *2022 European Conference on Optical Communication (ECOC)*, Basel, Switzerland, 2022, pp. 1-4.
  - G. Caruso, I. N. Cano, D. Nesset, G. Talli and R. Gaudino, "Real-Time 100 Gb/s PAM-4 for Access Links With up to 34 dB Power Budget," in *Journal of Lightwave Technology*, vol. 41, no. 11, pp. 3491-3497

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Thank you.

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