Various approaches to 10GEPON PHY issues and tradeoffs

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S. Pato, P. Monteiro, H. Silva, "Uplink Performance Evaluation of the Physical Layer for 10 Gbit/s EPONs", *13th International Conference on Telecommunications (ICT'06)*, Funchal, Madeira, 9-12 May, 2006.

S. Pato, P. Monteiro, H. Silva, "Performance Evaluation of the Physical Layer for 10 Gbit/s Ethernet Passive Optical Networks", *First International Conference on Access Networks (AccessNets'06)*, Athens, Greece, 4-6 Saptember, 2006.

Objectives

- Maintain the specifications of the existing EPON standard (IEEE 802.3 - 2005).
- Modifications only in the shared elements of the network (OLT) for economical reasons – ONUs stay the same (as in 1 G EPON systems).
- Feasibility of the 10GEPON system, allowing for higher network capacity, by applying the proposed solutions.

Problems to overcome

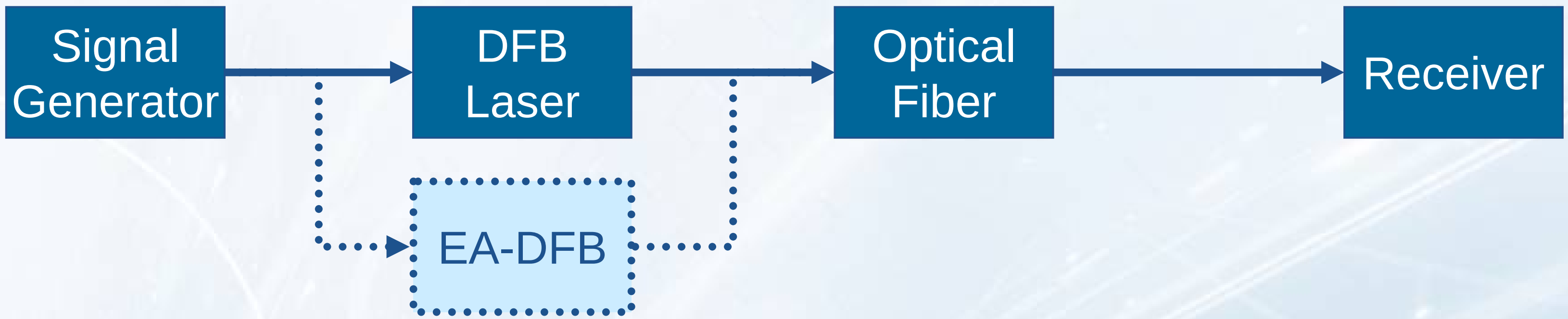
- Degradation in sensitivity of OLT receiver
  - due to bursy nature of upstream traffic;
  - increased data rate ⇨ lower sensitivity;
  - affects also ONU receivers, though OLT RX is more problematic due to burst more transmission.
- Increase of dispersion penalties
  - mainly affecting downstream channel;
  - upstream channel relatively safe if operated near the zero-dispersion wavelength (1310nm);
  - actual conditions depend on the selection of upstream/downstream wavelengths (if necessary).

Proposed solutions

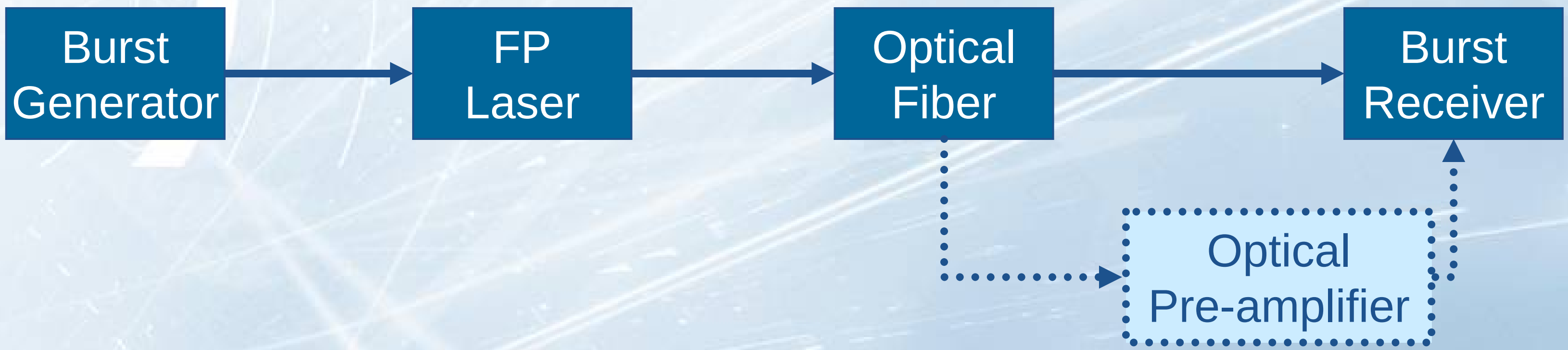
- Upstream channel
  - optical pre-amplification using SOAs;
  - application of APD receiver at the OLT (shared);
  - target ⇨ minimize OLT RX module sensitivity degradation due to higher data rate.
- Downstream channel
  - application of Electro-Absorption Modulator integrated with a DFB laser (EA-DFB) in the OLT TX module;
  - target ⇨ mitigate the increase in the dispersion penalties in 1550 nm transmnission window.

Physical Layer Simulator

Downstream transmission channel



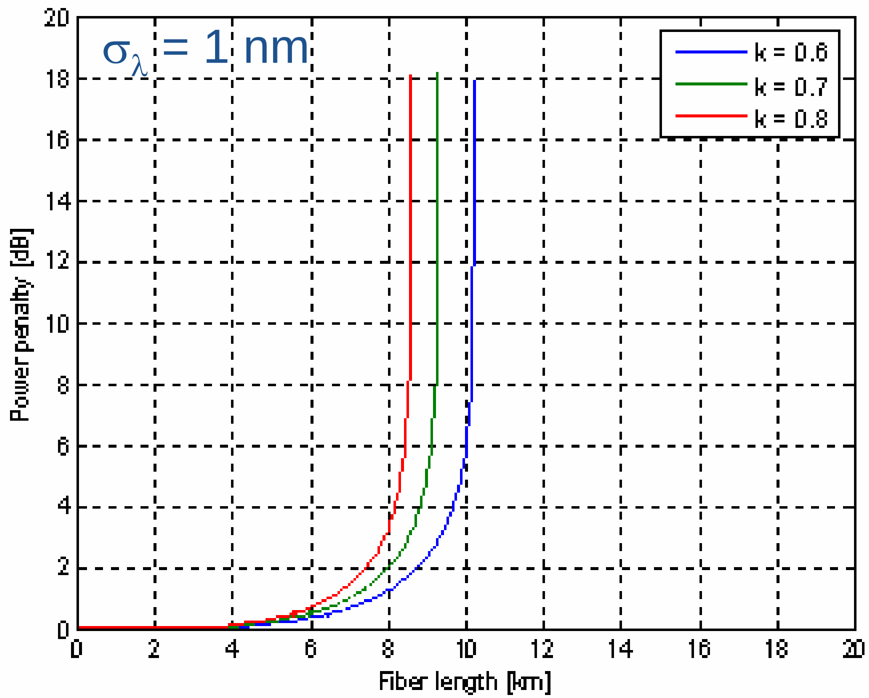
Upstream transmission channel

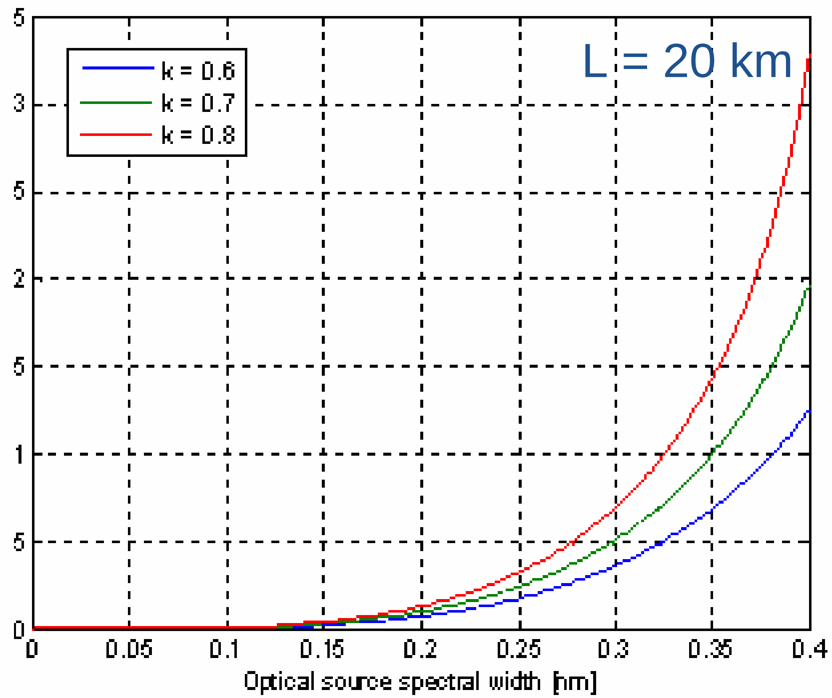


Physical Layer Simulator

- Exact mathematical models were applied to characterize each sub-system;
- Semi-analytic simulator: noise is described analytically, assuming a Gaussian distribution;
- Gaussian approximation is used to estimate the effective bit error rate (BER) at PHY level;
- Main limitation: optical source noise is not considered ⇨ further analysis of its impact is required (Mode Partition Noise – MPN).

MPN Penalty (upstream channel)





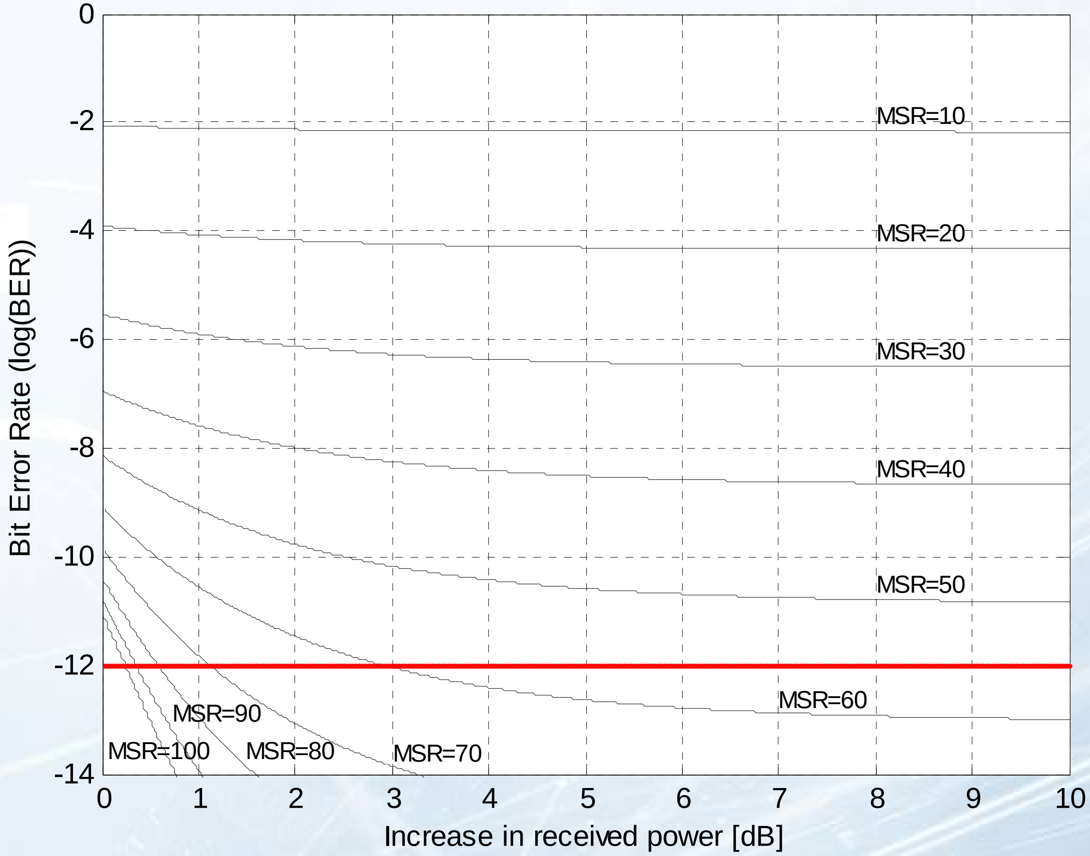
k: mode partion noise coefficient

MPN penalty = 0.5 dB

$L_{max} \approx$ 6 km (σ_λ = 1 nm)

L = 20 km $\Rightarrow \sigma_\lambda \approx$ 0.3 nm

MPN Penalty (downstream channel)



Mode-Suppression Ratio (MSR) < 56

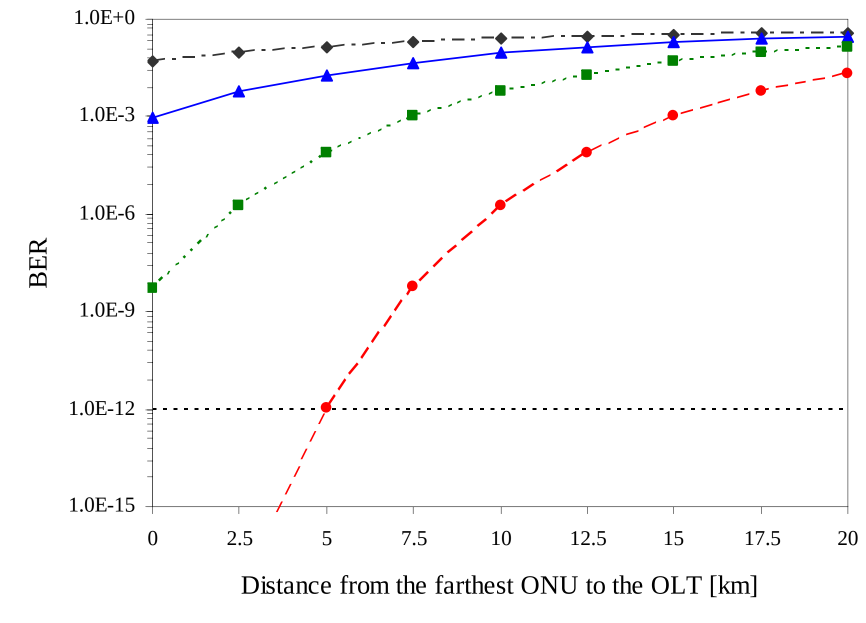
Infinite MPN penalty !

MPN penalty = 0.5 dB

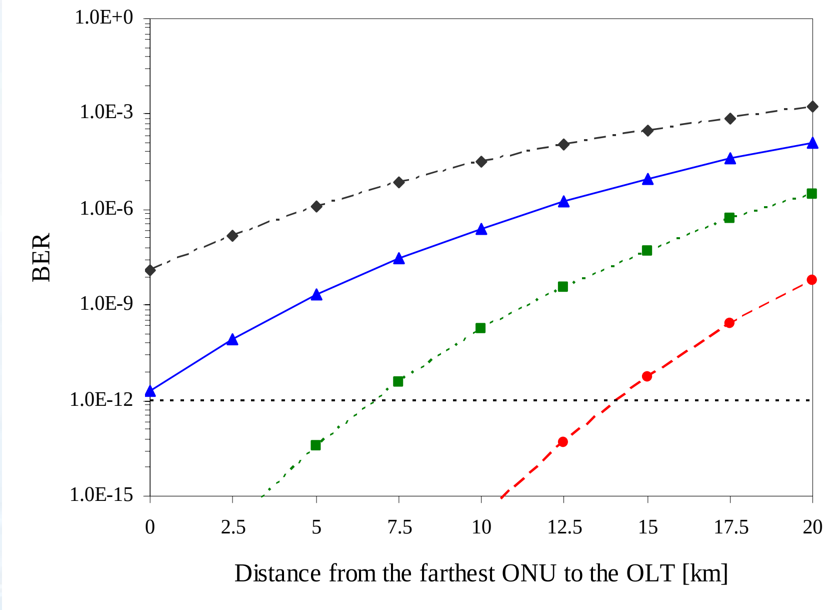
MSR ≈ 19 dB

10G EPON Upstream with SOA preamp [1]

Low launch power (P_{tx} = -1dBm & ER = 6dB)



Standard configuration

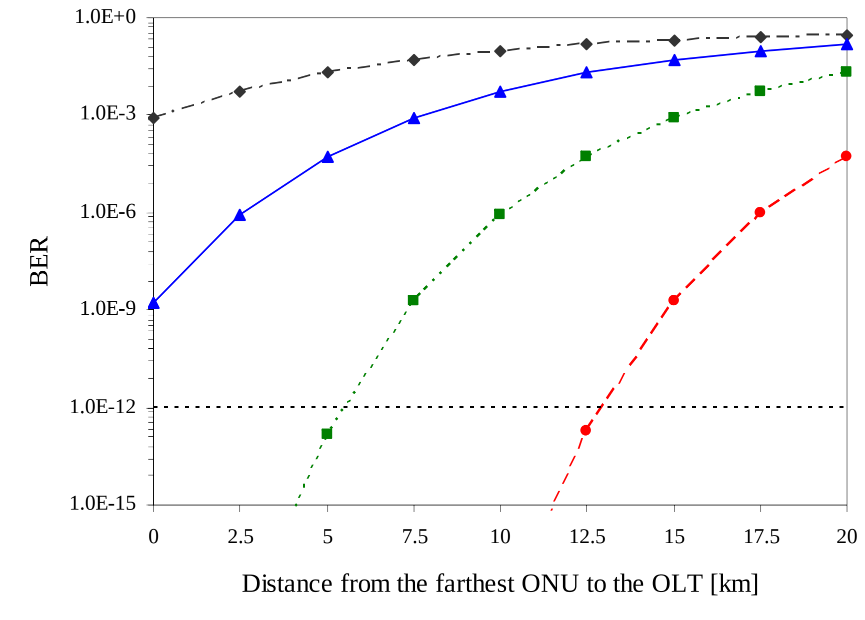


Configuration with SOA preamp

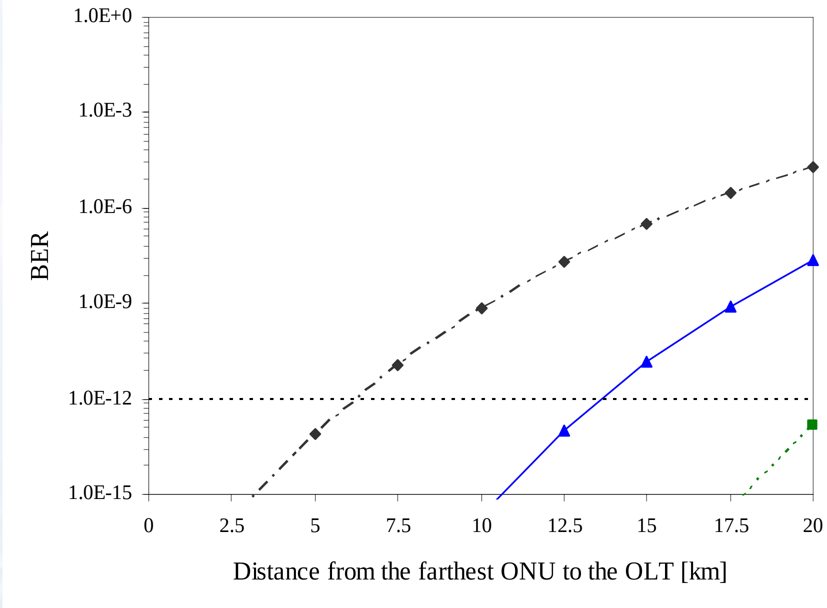
BER = 10^{-12}	16 ONUs	32 ONUs	64 ONUs	128 ONUs
Standard configuration	L < 5 km	✗	✗	✗
Pre-amplified system	L < 15 km	L < 7.5 km	✗	✗

10G EPON Upstream with SOA preamp [2]

Medium launch power (P_{tx} = 2dBm & ER = 6dB)



Standard configuration

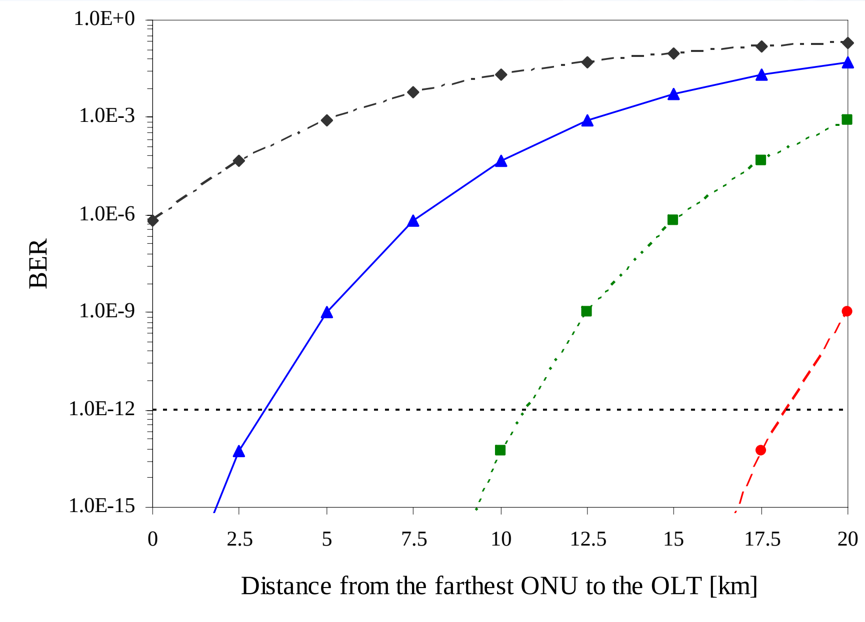


Configuration with SOA preamp

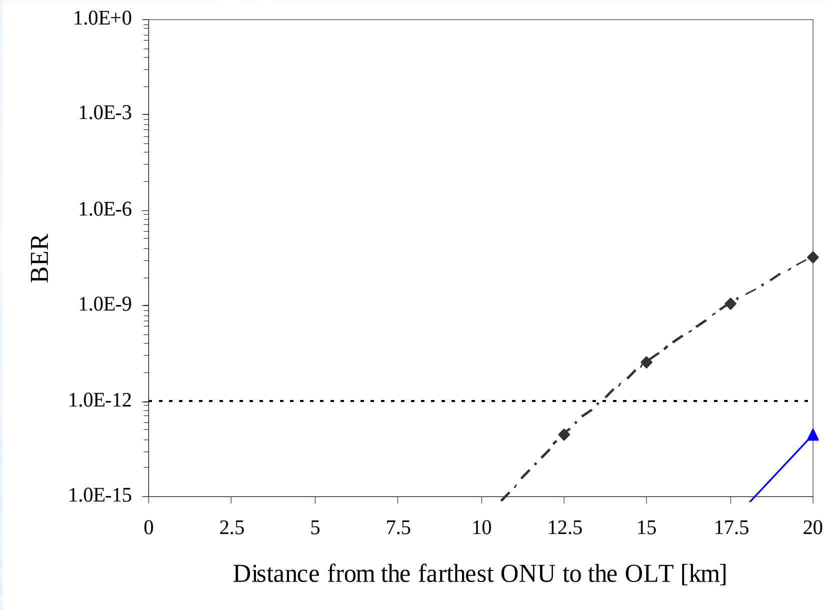
BER = 10^{-12}	16 ONUs	32 ONUs	64 ONUs	128 ONUs
Standard configuration	L < 12.5 km	L < 5 km	✗	✗
Pre-amplified system	✓	✓	L < 12.5 km	L < 5 km

10G EPON Upstream with SOA preamp [3]

High launch power (P_{tx} = 4dBm & ER = 6dB)



Standard configuration



Configuration with SOA preamp

BER = 10^{-12}	16 ONUs	32 ONUs	64 ONUs	128 ONUs
Standard configuration	L < 17.5 km	L < 10 km	L < 2.5 km	✗
Pre-amplified system	✓	✓	✓	L < 12.5 km

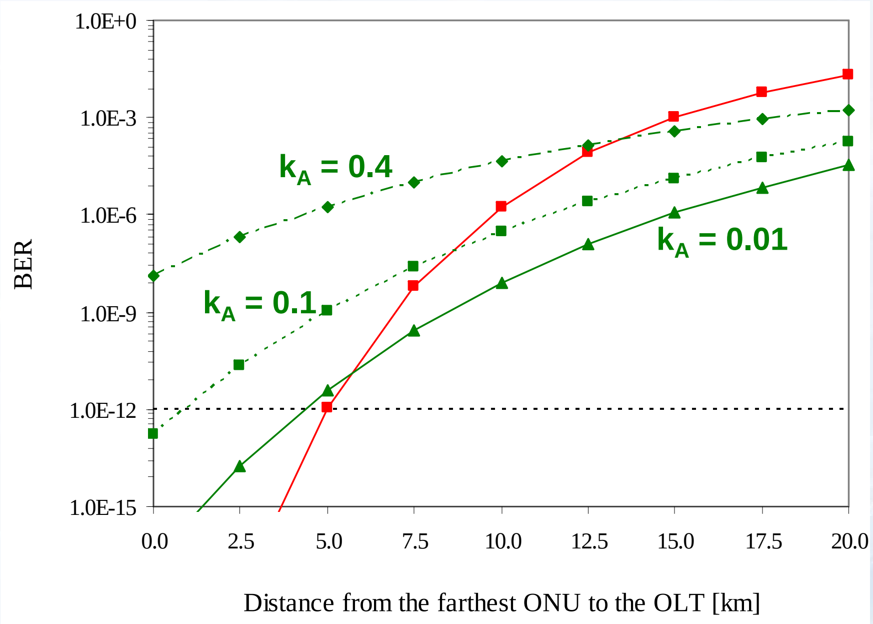
10G EPON Upstream with SOA preamp [4]

- SOA parameters:
  - amplification gain ⇨ + 15 dB
  - noise figure ⇨ 9 dB
- Issues originating from application of high power levels
  - saturation region of the optical amplifier
  - increased of ASE noise figure
- Optical pre-amplification in the OLT RX module:
  - target ⇨ minimize RX module sensitivity impairment @ 10 G
  - upgraded EPON system parameters: longer network reach and / or higher split count;
  - more economical approach ⇨ OLT cost is shared between *N* subscribers

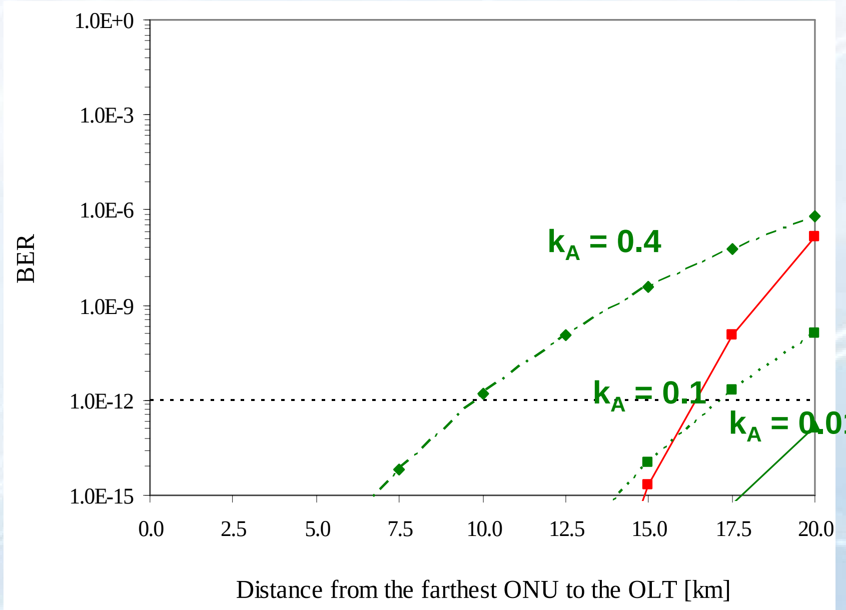
10G EPON Upstream with APD RX [1]

16 ONUs

P_{tx} = -1dBm & ER = 6dB



P_{tx} = 2dBm & ER = 10dB

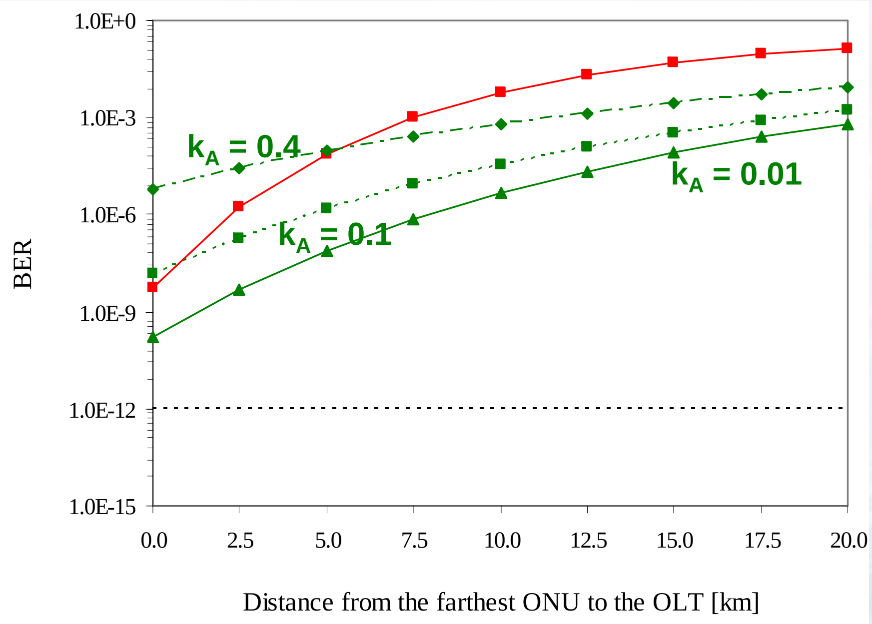


- PIN receivers outperform commercially available APD at short reach
- L = 20 km reached with P_{tx} = 2dBm using an APD with low k_A (ionization coefficient ratio)

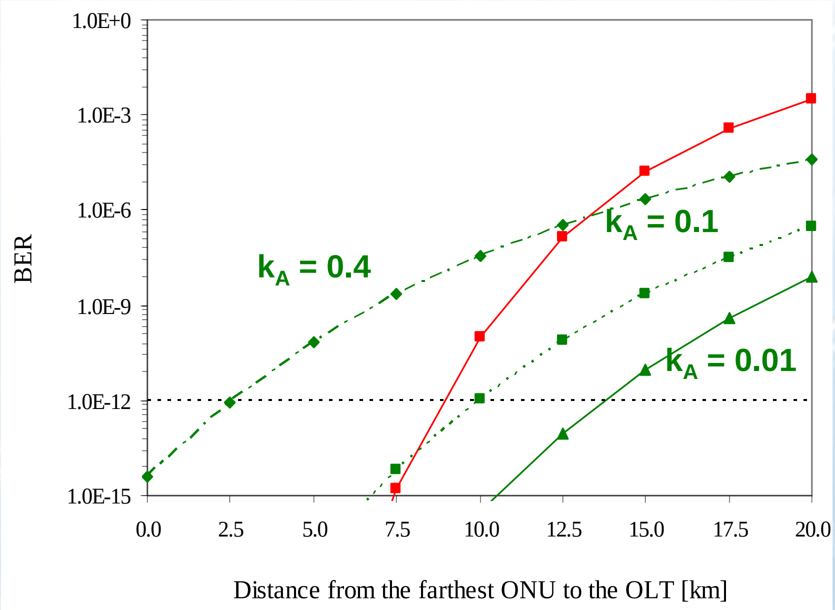
10G EPON Upstream with APD RX [2]

32 ONUs

P_{tx} = -1dBm & ER = 6dB



P_{tx} = 2dBm & ER = 10dB

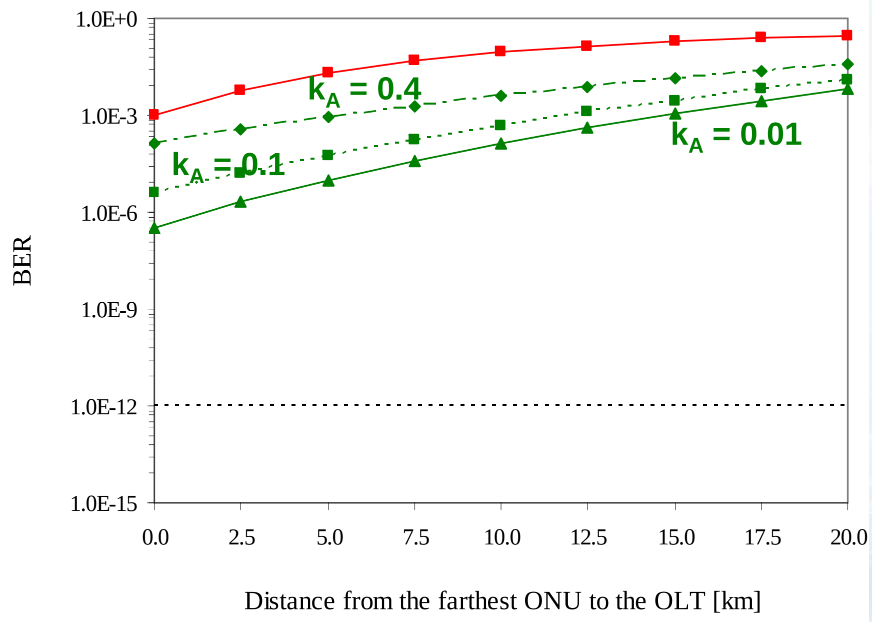


- performance improvement with the APD not enough to increase network capacity or reach
- larger network diameter only when P_{tx} = 2dBm using an APD with low k_A (ionization coefficient ratio)

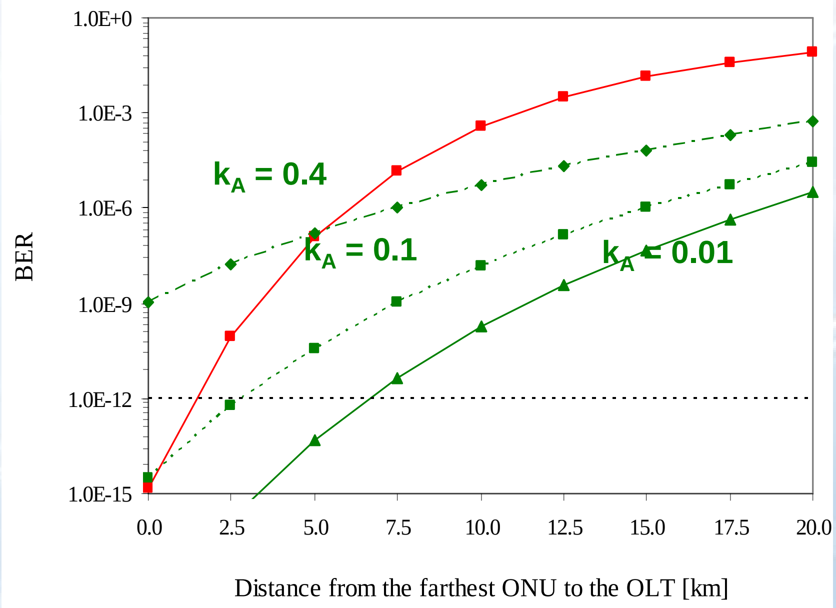
10G EPON Upstream with APD RX [3]

64 ONUs

P_{tx} = -1dBm & ER = 6dB



P_{tx} = 2dBm & ER = 10dB



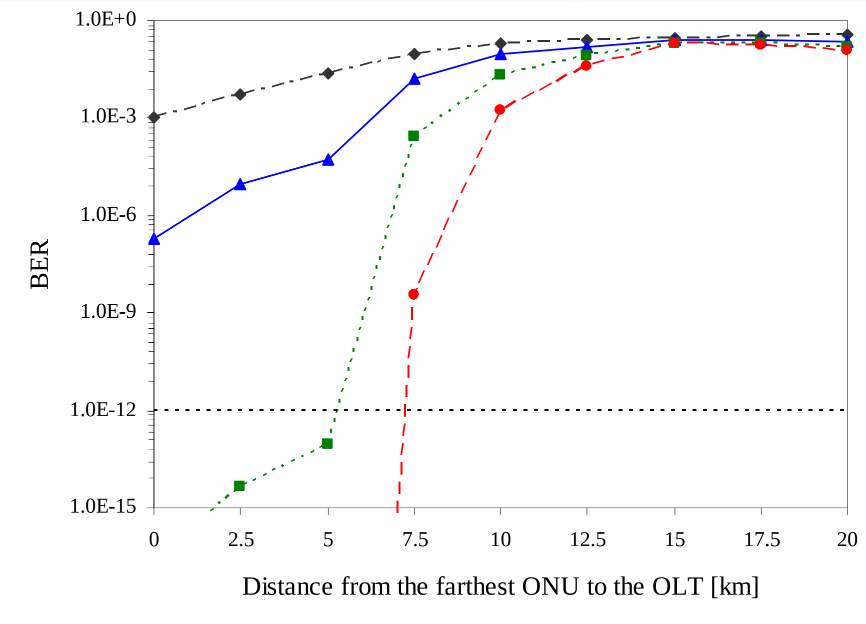
- performance improvement with the APD not enough to increase network capacity or reach
- larger network diameter only when P_{tx} = 2dBm using an APD with low k_A (ionization coefficient ratio)

10G EPON Upstream with APD RX [4]

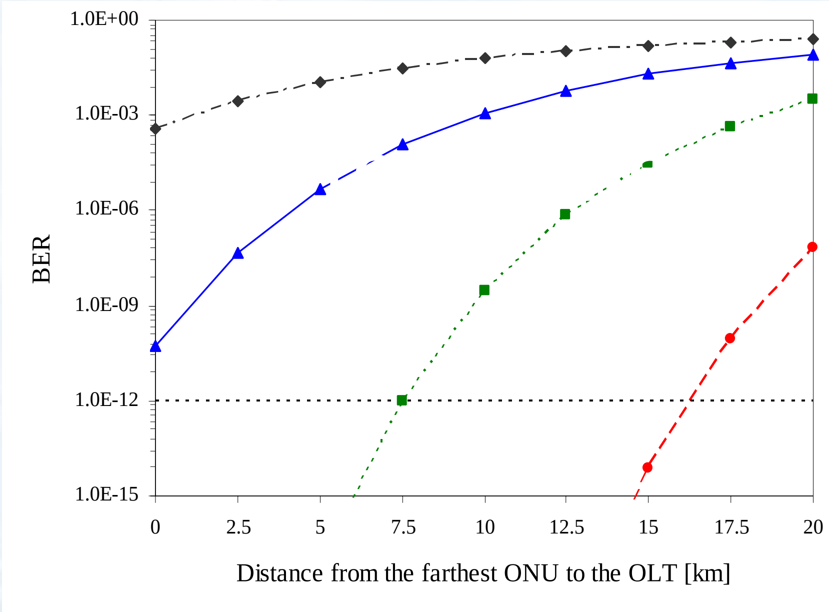
- demonstrated results for an APD with an average avalanche gain of 10 and a responsivity of 7 A/W;
- globally better performance with a PIN receiver, when compared with the APD receiver:
  - potential S/N degradation, due to APD operation far from the optimum gain.
- advantages of replacing the PIN receiver by an APD receiver are marginal:
  - trade-off should be considered in detail – increased cost of the examined APD does not seem to justify its application over PIN.
- PIN RX with a SOA preamp performs better than APD RX with a SOA preamp:
  - additional noise added to the system when optical pre-amplification is employed together with an APD receiver.

10G EPON Downstream with EA-DFB [1]

Low launch power (P_{tx} = 2dBm & ER = 6dB)



DFB

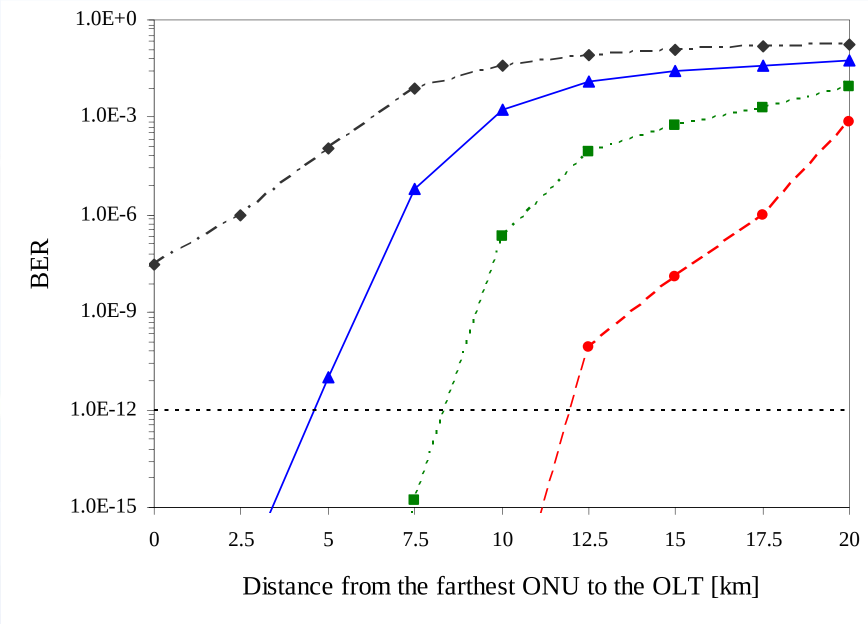


EA-DFB

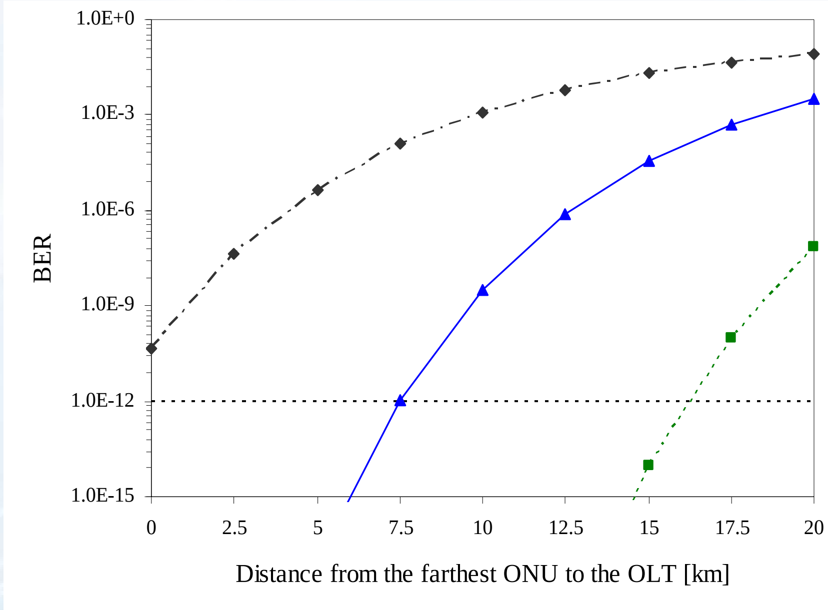
BER = 10^{-12}	16 ONUs	32 ONUs	64 ONUs	128 ONUs
DFB	L < 7.5 km	L < 5 km	×	×
EA-DFB	L < 15 km	L < 7.5 km	×	×

10G EPON Downstream with EA-DFB [2]

Medium launch power (P_{tx} = 5dBm & ER = 6dB)



DFB

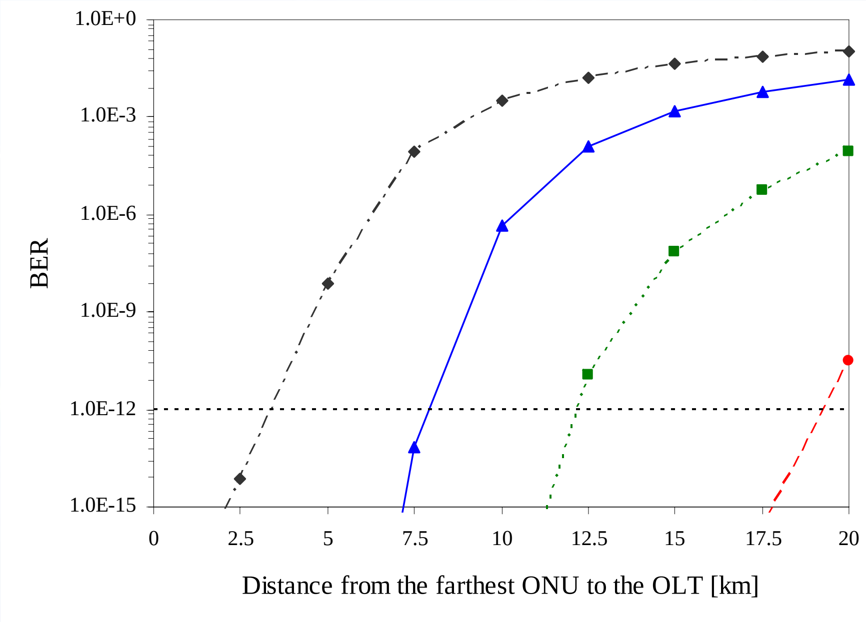


EA-DFB

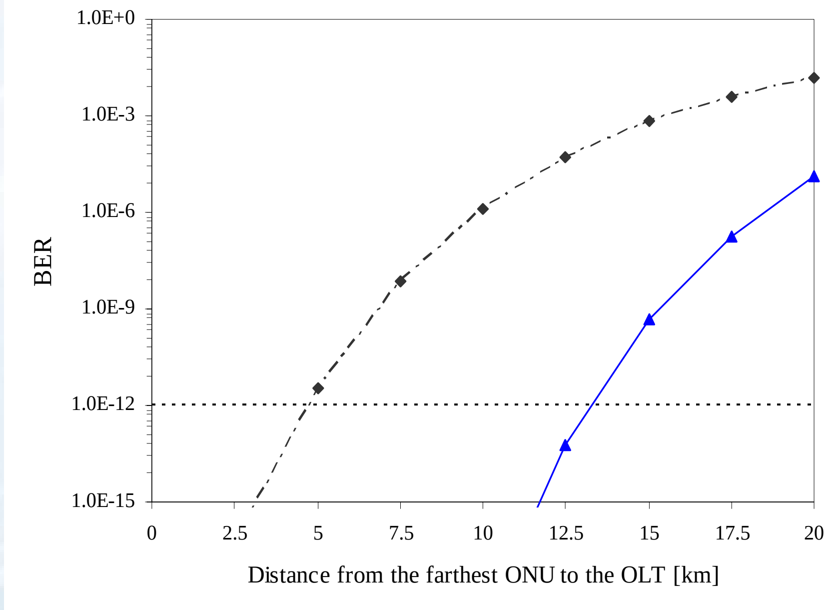
BER = 10^{-12}	16 ONUs	32 ONUs	64 ONUs	128 ONUs
DFB	L < 12.5 km	L < 7.5 km	L < 5 km	✗
EA-DFB	✓	L < 15 km	L < 7.5 km	✗

10G EPON Downstream with EA-DFB [3]

High launch power (P_{tx} = 7dBm & ER = 6dB)



DFB



EA-DFB

BER = 10^{-12}	16 ONUs	32 ONUs	64 ONUs	128 ONUs
DFB	L < 17.5 km	L < 12.5 km	L < 7.5 km	L < 2.5 km
EA-DFB	✓	✓	L < 12.5 km	L < 5 km

10G EPON Downstream with EA-DFB [4]

- EA-DFB lasers used at the OLT:
  - significant reduction of dispersion penalty for the downstream channel;
  - support reasonable network reach and/or split ratio, depending on the targeted parameter.
- Sensitivity reduction in ONU RX module:
  - uncompensated, un-amplified PIN diodes are used;
  - SOA based booster amplifier at OLT may be a solution;
  - SOA can be integrated with EA-DFB module.

Power Budget (20 km)

	16 ONUs	32 ONUs	64 ONUs	128 ONUs
Fiber loss	8 dB	8 dB	8 dB	8 dB
Splitter loss	13.5 dB	16.5 dB	19.5 dB	22.5 dB
Total loss	21.5 dB	24.5 dB	27.5 dB	30.5 dB
Amplifier gain	15 dB	15 dB	15 dB	15 dB
Power budget	6.5 dB	9.5 dB	12.5 dB	15.5 dB

- Attenuation parameter = 0.4 dB/km (splices and connectors losses included in the attenuation parameter);
- Splitter loss = $10\log_{10}(N)$ + excess loss.