Various approaches to 10GEPON PHY issues and tradeoffs

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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 bursty 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 minimizes 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 mitigates the increase in the dispersion penalties in 1550 nm transmission window.
Downstream transmission channel

Upstream transmission channel
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)

\[ \sigma_\lambda = 1 \text{ nm} \]

\[ L_{\text{max}} \approx 6 \text{ km (} \sigma_\lambda = 1 \text{ nm)} \]

\[ L = 20 \text{ km } \Rightarrow \sigma_\lambda \approx 0.3 \text{ nm} \]

\[ k \text{: mode partition noise coefficient} \]

MPN penalty = 0.5 dB
MPN Penalty (downstream channel)

Mode-Suppression Ratio (MSR) < 56

Infinite MPN penalty!

MPN penalty = 0.5 dB

MSR ≈ 19 dB
Low launch power \( (P_{tx} = -1\text{dBm} \& \text{ER} = 6\text{dB}) \)

### Standard configuration

<table>
<thead>
<tr>
<th>BER = (10^{-12})</th>
<th>16 ONUs</th>
<th>32 ONUs</th>
<th>64 ONUs</th>
<th>128 ONUs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard configuration</td>
<td>(L &lt; 5\text{ km})</td>
<td>(\times)</td>
<td>(\times)</td>
<td>(\times)</td>
</tr>
<tr>
<td>Pre-amplified system</td>
<td>(L &lt; 15\text{ km})</td>
<td>(L &lt; 7.5\text{ km})</td>
<td>(\times)</td>
<td>(\times)</td>
</tr>
</tbody>
</table>
Medium launch power ($P_{tx} = 2$dBm & ER = 6dB)

**Standard configuration**

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</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard configuration</strong></td>
<td>L &lt; 12.5 km</td>
<td>L &lt; 5 km</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td><strong>Pre-amplified system</strong></td>
<td>✓</td>
<td>✓</td>
<td>L &lt; 12.5 km</td>
<td>L &lt; 5 km</td>
</tr>
</tbody>
</table>
High launch power ($P_{tx} = 4$dBm & $ER = 6$dB)

<table>
<thead>
<tr>
<th>Distance from the farthest ONU to the OLT [km]</th>
<th>BER</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10^15</td>
</tr>
<tr>
<td>2.5</td>
<td>10^12</td>
</tr>
<tr>
<td>5</td>
<td>10^-9</td>
</tr>
<tr>
<td>7.5</td>
<td>10^-6</td>
</tr>
<tr>
<td>10</td>
<td>10^-3</td>
</tr>
<tr>
<td>12.5</td>
<td>10^0</td>
</tr>
<tr>
<td>15</td>
<td>10^3</td>
</tr>
<tr>
<td>17.5</td>
<td>10^6</td>
</tr>
<tr>
<td>20</td>
<td>10^9</td>
</tr>
</tbody>
</table>

Standard configuration

- **BER = 10^{-12}**
  - 16 ONUs: $L < 17.5$ km
  - 32 ONUs: $L < 10$ km
  - 64 ONUs: $L < 2.5$ km
  - 128 ONUs: X

Pre-amplified system

- ✓ ✓ ✓ ✓ $L < 12.5$ km

Configuration with SOA preamp

- 2
- L < 2.5 km
- L < 10 km
- L < 17.5 km
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
- PIN receivers outperform commercially available APD at short reach
- $L = 20$ km reached with $P_{tx} = 2$ dBm using an APD with low $k_A$ (ionization coefficient ratio)
32 ONU

\( P_{tx} = -1 \text{dBm} \& ER = 6 \text{dB} \)

\( P_{tx} = 2 \text{dBm} \& ER = 10 \text{dB} \)

- performance improvement with the APD not enough to increase network capacity or reach
- larger network diameter only when \( P_{tx} = 2 \text{dBm} \) using an APD with low \( k_A \) (ionization coefficient ratio)
10G EPON Upstream with APD RX [3]

64 ONUs

- $P_{tx} = -1\, \text{dBm} \, \& \, ER = 6\, \text{dB}$
- $P_{tx} = 2\, \text{dBm} \, \& \, ER = 10\, \text{dB}$

- Performance improvement with the APD not enough to increase network capacity or reach.
- Larger network diameter only when $P_{tx} = 2\, \text{dBm}$ using an APD with low $k_A$ (ionization coefficient ratio).

![Graph showing BER vs. distance for different $k_A$ values.](#)
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 ($P_{tx} = 2$dBm & ER = 6dB)

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<tr>
<th>BER = $10^{-12}$</th>
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<tbody>
<tr>
<td>DFB</td>
<td>L &lt; 7.5 km</td>
<td>L &lt; 5 km</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>EA-DFB</td>
<td>L &lt; 15 km</td>
<td>L &lt; 7.5 km</td>
<td>✗</td>
<td>✗</td>
</tr>
</tbody>
</table>
10G EPON Downlink Performance (P_{tx} = 5dBm & ER = 6dB)

Medium launch power

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

### EA-DFB
- ✓
- L < 15 km
- L < 7.5 km
- ✓
**High launch power ($P_{tx} = 7\text{dBm} \& \text{ER} = 6\text{dB}$)**

**DFB**

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<tr>
<td>DFB</td>
<td>$L &lt; 17.5 \text{ km}$</td>
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<td>$L &lt; 7.5 \text{ km}$</td>
<td>$L &lt; 2.5 \text{ km}$</td>
</tr>
<tr>
<td>EA-DFB</td>
<td>✓</td>
<td>✓</td>
<td>$L &lt; 12.5 \text{ km}$</td>
<td>$L &lt; 5 \text{ km}$</td>
</tr>
</tbody>
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**10G EPON Downstream with EA-DFB** [3]
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)

<table>
<thead>
<tr>
<th></th>
<th>16 ONUs</th>
<th>32 ONUs</th>
<th>64 ONUs</th>
<th>128 ONUs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber loss</td>
<td>8 dB</td>
<td>8 dB</td>
<td>8 dB</td>
<td>8 dB</td>
</tr>
<tr>
<td>Splitter loss</td>
<td>13.5 dB</td>
<td>16.5 dB</td>
<td>19.5 dB</td>
<td>22.5 dB</td>
</tr>
<tr>
<td>Total loss</td>
<td>21.5 dB</td>
<td>24.5 dB</td>
<td>27.5 dB</td>
<td>30.5 dB</td>
</tr>
<tr>
<td>Amplifier gain</td>
<td>15 dB</td>
<td>15 dB</td>
<td>15 dB</td>
<td>15 dB</td>
</tr>
<tr>
<td>Power budget</td>
<td>6.5 dB</td>
<td>9.5 dB</td>
<td>12.5 dB</td>
<td>15.5 dB</td>
</tr>
</tbody>
</table>

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