Gigabit PON Upstream Transmission Feasibility - A Statistical Analysis Tool

Y. Lisa Peng  Kendall D. Musgrove
Corning Incorporated

and

Meir Bartur
Zonu Incorporated

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Introduction

• Various PON upstream transmission scenario were statistically modeled using Corning SMF fiber distributions and 1310nm FP laser distributions from a well-known Japanese laser manufacture
• Comprehensive system parameter inclusions
The Approach - General

• Define important fiber and FP laser link parameters
• Obtain their practical statistical distribution
• Compute the statistical link feasibility based on loss and dispersion limitations
• Evaluate the sensitivity of important link parameters such as split ratio, k factor and BER
The Approach - Important Link Parameters

- Statistical distributions of Corning SMF-28 fiber
  - zero wavelength, dispersion slope, loss
- Statistical distributions of 1310 FP laser
  - center wavelength, spectral width, transmitter power, receiver power,
- Other link parameter distributions
  - connector, splice, clock recovery, cabled attenuation adder
- Discrete parameters, Constants and assumptions
  - $k$ - discrete, pick from 0.3 to 0.8
  - MPN - allowance of 1 dB or 2 dB
  - data rate: 1.25 Gbps
  - System margin - 2 dB
  - laser temperature impact - will include later
  - split ratio - pick from p-t-p, 1x4, 1x8, 1x16 and 1x32
  - BER - pick from $10^{-9}$ to $10^{-12}$
The Approach - Calculations

Attenuation limit: 
\[ L = \frac{P_T - P_R - CR - Cxn - Splc - Splt - M}{\alpha} \]

Dispersion (Corning SMF-28): 
\[ D(\lambda) = \frac{S_0}{4} \left[ \lambda - \frac{\lambda_0^4}{\lambda^3} \right] \]

MPN limited length: 
\[ L = \frac{1}{\pi * D * \sigma_\lambda * B} \sqrt{\ln \left( \frac{k}{k - r_{mpn} \sqrt{2}} \right)} \]

Where \( r_{mpn} \) is calculated from: 
\[ r_{mpn} = \frac{1}{Q} \sqrt{\left( 1 - 10^{-\frac{\delta_{mpn}}{5}} \right)} \]

Assuming 1dB or 2dB \( \delta_{mpn} \) system impairment
Link Statistical Reach Example
-Link Length from Calculated from Dispersion

Forecast: Dispersion Link Length

100,000 Trials

Frequency Chart

25,545 Outliers

Probability

System Reach, km

BER = 10^-9
MPN = 1 dB
k = 0.5
Normal FP power
2dB margin
ST connector
Link Statistical Reach Example
-Link Length from Calculated from Loss

Forecast: Attenuation Link Length

100,000 Trials

842 Outliers

Frequency Chart

System Reach, km

BER = 10⁻⁹
MPN = 1 dB
k = 0.5
Normal FP power
2dB margin
ST connector
Link Statistical Reach Example
-Combined System Reach

Forecast: Link Length

100,000 Trials
Cumulative Chart

2 Outliers

Probabilty

Loss contribution

Dispersion contribution

System Reach, km

48% of simulations represents
L_{dispersion} < L_{attenuation}

BER = 10^{-9}
MPN = 1 dB
k = 0.5
Normal FP power
2dB margin
ST connector
Impact of Split Ratio on Link Failure Rate Probability

- BER = 10^{-9}
- MPN = 1 dB
- k = 0.5
- Normal FP power
- 2dB margin
- ST connector
## Dispersion and Loss Contributions of Normal Gigabit PONs

<table>
<thead>
<tr>
<th>PON Split</th>
<th>% Dispersion Limited</th>
<th>% Loss Limited</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point to Point</td>
<td>48</td>
<td>52</td>
</tr>
<tr>
<td>1x4</td>
<td>28</td>
<td>72</td>
</tr>
<tr>
<td>1x8</td>
<td>16</td>
<td>84</td>
</tr>
<tr>
<td>1x16</td>
<td>6</td>
<td>94</td>
</tr>
</tbody>
</table>

- BER = $10^{-9}$
- MPN = 1 dB
- $k = 0.5$
- Normal FP power
- 2dB margin
- ST connector
Impact of k Factor on Link Failure Probability

k factor significantly lowers the system reach

1x8 Split
BER = 10^{-12}
MPN = 1 dB
Normal FP power
2dB margin
ST connector

k increase from 0.5 to 0.8
Impact of k Factor on Link Failure Probability

k factor impact bigger in point-to-point systems

- P-t-P
- BER = $10^{-12}$
- MPN = 1 dB
- Normal FP power
- 2dB margin
- ST connector

k increase from 0.5 to 0.8
System Can be Strongly Dispersion Limited Even with High Power Lasers

High power laser
No loss margin
SC connector

BER = 10^{-12}
MPN = 1 dB
k=0.5
Regular FP LD utilization for high data-rates

- Statistical link power margin model
  - Adopted from AT&T paper ~1995
  - Factors all link parameters based on mean and standard deviation
  - Example (keeping fixed dispersion losses. Using statistical modeling for dispersion gives much better results). Link Margin difference in dB. FP @ -2dBm

- Link Budget Power Margin (dB)

<table>
<thead>
<tr>
<th>Mean – 3σ</th>
<th>Worst Case</th>
<th>(Mean – 2σ) – Worst Case</th>
<th>(Mean – 3σ) – Worst Case</th>
<th>Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.93</td>
<td>2.4</td>
<td>4.3</td>
<td>3.53</td>
<td>10 km 1:16</td>
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<tr>
<td>0.66</td>
<td>-3.2</td>
<td>4.68</td>
<td>3.86</td>
<td>20 km 1:16</td>
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<tr>
<td>2.78</td>
<td>-0.6</td>
<td>4.15</td>
<td>3.38</td>
<td>10 km 1:32</td>
</tr>
<tr>
<td>-2.49</td>
<td>-6.2</td>
<td>4.53</td>
<td>3.71</td>
<td>20 km 1:32</td>
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</table>
High Power FP LD utilization for high data-rates

- Statistical link power margin model
  - Same as previous slide except High Power FP @2dBm

- Link Budget Power Margin (dB)

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FP LD utilization for high data-rates

Recommendation:

- Strive for mean/STD data for key parameters.
- Employ Monte-Carlo simulation for dispersion statistics as an integral part of the tool.
- Adopt round-robin testing to reach consensus on MPN and test methodology for inclusion in PMD spec.
Conclusions

- Developed a statistical tool for PON link feasibility evaluation with the flexibility of adjusting various laser, fiber, and link architectural designs
- System capability can be enhanced with statistical design
- Gigabit PON systems may be dispersion limited due to MPN of FP1310 nm lasers at the ONU even at high split ratios and using high powered lasers