The LOGON Strategy for Low-Complexity Control Plane Implementation in New-Generation Flexible Networks

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Motivations of this work

- Next generation “flexible” optical networks will be characterized by:
  - Variable channel spacing
  - Modulation formats
  - Symbol-rate
  - Coherent detection
  - No dispersion management $\rightarrow$ uncompensated transmission (best solution with coherent detection)
The LOGON strategy

Local Optimization $\rightarrow$ Global Optimization

LOGON

Nyquist-limit

$f$
Coherent detection

Uncompensated transmission

In such a scenario, the interference due to non-linear effects (NLI) acts as additive Gaussian noise [1]:

\[ P_{ch,n} + a_n + G_{NLI,n} + G_{ASE,n} \]

\[^{n}\text{th span}\]

\[ g_n \]

Non-linear interference modeling

\[ G_{WDM}(f) \]

\[ P_{\text{ch},n} \]

\[ \alpha_n \]

\[ g_n \]

\[ \text{CUT} = \text{channel under test} \]

\[ G_{\text{ASE},n} = F_n h \nu (g_n - 1) \]
\[ \approx F_n h \nu g_n \]

\[ G_{\text{NLI},n} = f(\alpha_n, \gamma_n, \beta_{2,n}, L_s, n, G_{WDM,n}) \]

\[ o\text{snr}_n = \frac{P_{\text{ch},n} \cdot \alpha_n \cdot g_n}{(G_{\text{ASE},n} + G_{\text{NLI},n} \cdot g_n)B_N} \]

Fiber span parameters

Power spectral density (PSD) of the WDM comb
Multi-span transmission

Assuming incoherent NLI accumulation (in [2] it has been sown that this assumption is sufficiently accurate, especially in full C-band populated links):

\[
OSNR_{Rx} = \frac{P_{ch,Rx}}{B_N \sum_{n=1}^{N_s} \left( G_{ASE,n} + G_{NLI,n} \cdot g_n \right) \prod_{k=n+1}^{N_s} a_k g_k}
\]

Multi-span transmission

Substituting:

\[
P_{ch,Rx} = P_{ch,n} \prod_{k=n}^{N_s} a_k g_k = P_{ch,n} a_n g_n \prod_{k=n+1}^{N_s} a_k g_k
\]

\[
\frac{1}{OSNR_{Rx}} = B_N \sum_{n=1}^{N_s} \left( G_{ASE,n} + G_{NLI,n} \cdot g_n \right) \prod_{k=n+1}^{N_s} a_k g_k
\]
The OSNR at the Rx can be optimized by simply optimizing each one of the spans’ osnr individually, provided that they are independent of one another.

\[
\frac{1}{OSNR_{Rx}} = \sum_{n=1}^{N_s} \frac{1}{osnr_n}
\]

\[
osnr_n = \frac{P_{ch,n} \cdot a_n \cdot g_n}{\left( G_{ASE,n} + G_{NLI,n} \cdot g_n \right) B_N}
\]
Local optimization

Once the link has been set up, the only quantities that can be adjusted to maximize the osnr\(_n\) are the individual channel launch powers:

\[
osnr_n = \frac{P_{ch,n} \cdot a_n \cdot g_n}{(G_{ASE,n} + G_{NLI,n} \cdot g_n)B_N}
\]

The optimum launch powers depend on the spectral loading (all others parameters are fixed):

\[G_{WDM}(f)\]

\[G_{WDM}(f)\]

Full knowledge of bandwidth allocation required!
Full spectral loading (worst case scenario) is ideally found when the full available optical bandwidth \((B_{WDM})\) is utilized at maximum spectral efficiency:

- We assume that:
  - channel spectra are rectangular, with bandwidth equal to the symbol rate
  - channel spacing is such that channel spectra touch but do not overlap
  - channels may have different symbol rate and modulation format
The GN-model [3] predicts that, at the Nyquist limit, $\text{osnr}_n$ is maximized by launching a uniform signal PSD across the WDM comb:

$$G_{WDM,n}^{opt} = \sqrt{\frac{hnF_n}{2\rho_{NLI,n}}}$$

with

$$\rho_{NLI,n} = a_n \frac{16 \alpha_n \gamma_n^2 L_{eff,n}}{27 \pi \beta_{2,n}} \text{asinh} \left[ \frac{\pi^2}{4\alpha_n} \beta_{2,n} B_{WDM}^2 \right]$$

Pros of LOGON

\[ G_{WDM,n}^{opt} = \sqrt{\frac{hnF_n}{2\rho_{NLI,n}}} \]

with

\[ \rho_{NLI,n} = a_n \frac{16}{27} \frac{\alpha_n \gamma^2 L_{eff,n}}{\pi \beta_{2,n}} \text{asinh}\left[ \frac{\pi^2}{4\alpha_n} \beta_{2,n} B_{WDM}^2 \right] \]

- The optimum values of \( G_{WDM,n} \) are completely static (dependent on fiber and EDFA parameters only) and link spectral load independent:
  - The evaluation of \( G_{WDM,n}^{opt} \) (and osnr_n) could be done by a dedicated hardware, w/o any CP intervention
  - CP can perform dynamic estimation of signal degradation simply using:

\[ \frac{1}{OSNR_{Rx}} = \sum_{n=1}^{N_s} \frac{1}{osnr_n} \]
By always assuming full spectral loading, the insertion of one or more channels in an already populated link cannot cause any disruption nor does it require any re-routing of channels already present.
Cons of LOGON

- By always assuming full spectral loading, when a lightpath travels across a sparsely populated network, its potential performance could be substantially underestimated → CP might act regeneration when not necessary

- EXAMPLE: single channel propagation over a multi-span system composed of 100-km spans of SSM fiber
  - $R_s = 32 \text{ Gbaud}$
  - $F = 6 \text{ dB}$
  - OSNR target: $13 \text{ dB}$
  - $G_{WDM}(f)$

Actual maximum reach: $6000 \text{ km}$

Maximum reach estimated by LOGON over entire C-band (5 THz): $4000 \text{ km}$

Max reach prediction error: $-33\%$ $-1.75 \text{ dB}$
### Spectrum Filling

<table>
<thead>
<tr>
<th>Rs = 32 Gbaud</th>
<th>Max Reach Prediction Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>32 GHz</td>
<td>- 23% (-1.12 dB)</td>
</tr>
<tr>
<td></td>
<td>-19% (-0.92 dB)</td>
</tr>
<tr>
<td>64 GHz</td>
<td>-27% (-1.4 dB)</td>
</tr>
<tr>
<td>32 GHz</td>
<td>-20% (-1.0 dB)</td>
</tr>
</tbody>
</table>

**Legend**:
- f: Frequency
- Rs: Symbol rate
- 32 GHz: Frequency range
- 64 GHz: Frequency range
Under the assumption of uncompensated transmission and coherent detection, local optimization at each span leads to global optimization (LOGO).

A local optimization based on full Nyquist spectral loading assumption (LOGON) leads to very simple and computationally effective optimization results, with the drawback of \( \sim 20\% \) lightpath maximum reach underestimation when the network is lightly loaded.
Thank you!

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