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

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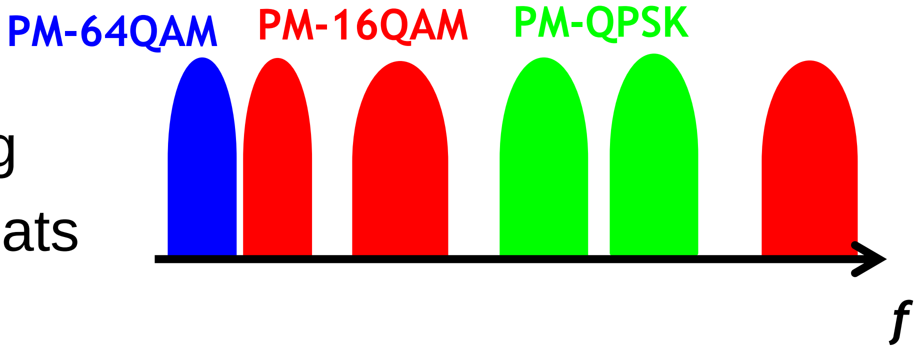
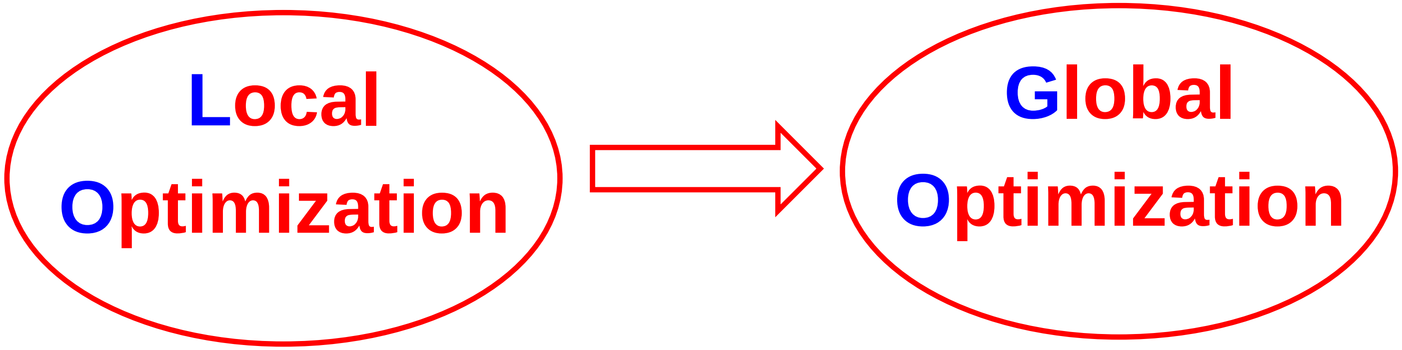
Motivations of this work

- Next generation “flexible” optical networks will be characterized by:
  - Variable
    - Channel spacing
    - Modulation formats
    - Symbol-rate



  - Coherent detection
  - No dispersion management → uncompensated transmission (best solution with coherent detection)

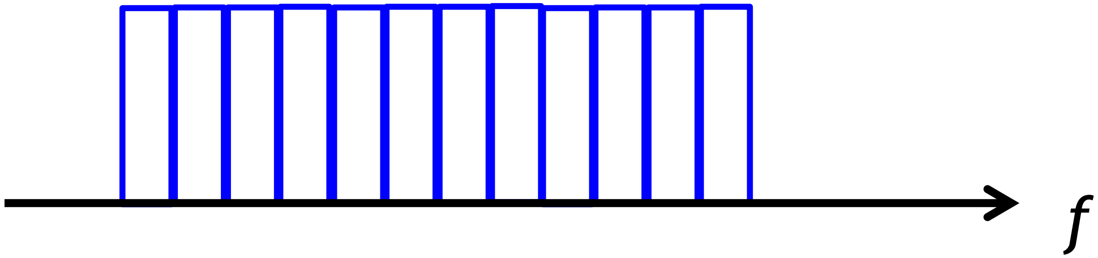
The LOGON strategy



Local Optimization → **Global Optimization**

LOGON

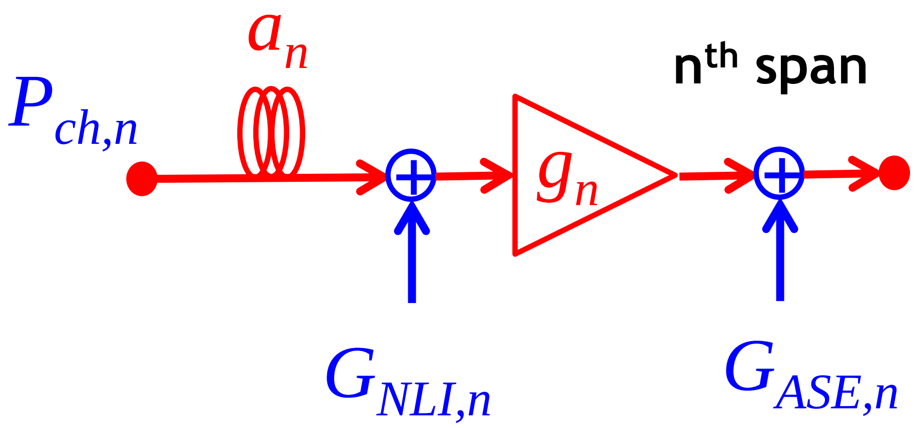
Nyquist-limit



Fundamental hypotheses

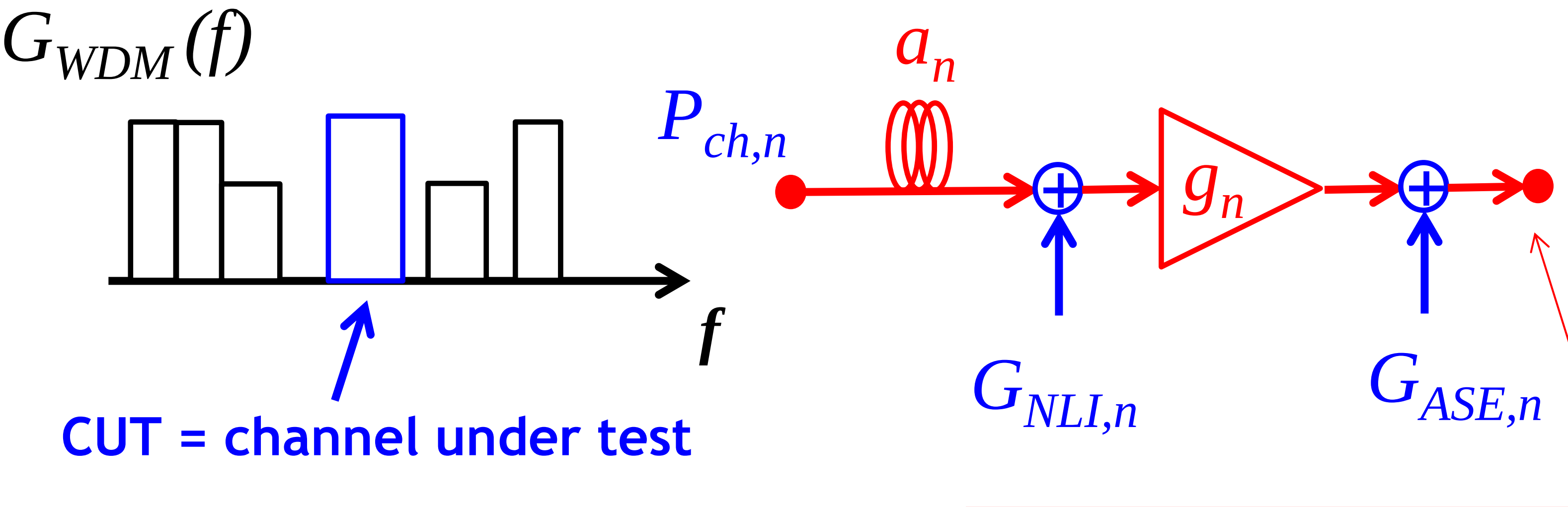
- Coherent detection
- Uncompensated transmission

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



[1] A. Carena at al, “Statistical characterization of PM-QPSK signals after propagation in uncompensated optical links”, ECOC 2010, p.P4.07

Non-linear interference modeling



CUT = channel under test

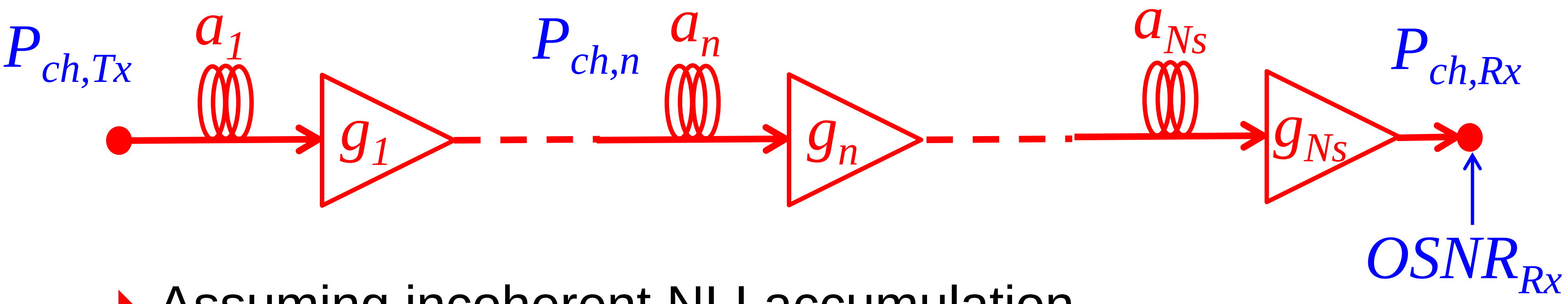
$$G_{ASE,n} = F_n h\nu(g_n - 1)$$
$$\approx F_n h\nu\, g_n$$

$$\boxed{osnr_n = \frac{P_{ch,n} \cdot a_n \cdot g_n}{\left(G_{ASE,n} + G_{NLI,n} \cdot g_n\right)B_N}}$$

$$G_{NLI,n} = f\left(\underbrace{\alpha_n, \gamma_n, \beta_{2,n}, L_{s,n}}_{\text{Fiber span parameters}}, G_{WDM,n}\right)$$

Power spectral density (PSD) of the WDM comb

Multi-span transmission

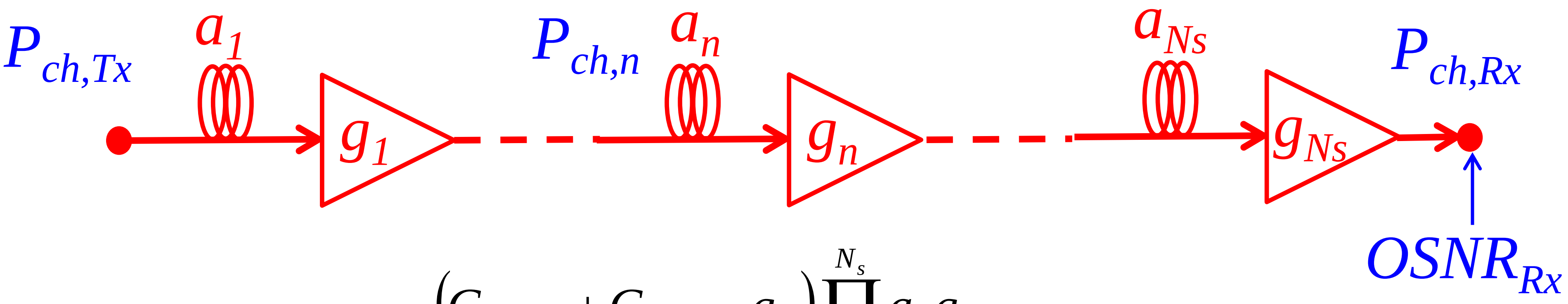


- Assuming incoherent NLI accumulation
  (in [2] it has been sown that this assumption is sufficiently accurate, especially in full C-band populated links):

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

[2] P. Poggiolini, “The GN model of non-linear propagation in uncompensated coherent optical systems”, JLT 2012, vol. 30, no.24.

Multi-span transmission



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

- Substituting: $P_{ch,Rx} = P_{ch,n} \prod_{k=n}^{N_s} a_k g_k = P_{ch,n} a_n g_n \prod_{k=n+1}^{N_s} a_k g_k$

$$\frac{1}{OSNR_{Rx}} = B_N \sum_{n=1}^{N_s} \frac{\left(G_{ASE,n} + G_{NLI,n} \cdot g_n\right)}{P_{ch,n} a_n g_n} = \sum_{n=1}^{N_s} \left[\underset{\mathbf{osnr}_n}{\boxed{\frac{P_{ch,n} a_n g_n}{B_N \left(G_{ASE,n} + G_{NLI,n} \cdot g_n\right)}}} \right]^{-1}$$

LOGO principle

LOGO

$$\boxed{\frac{1}{OSNR_{Rx}} = \sum_{n=1}^{N_s} \frac{1}{osnr_n}}$$

$$\boxed{osnr_n = \frac{P_{ch,n} \cdot a_n \cdot g_n}{\left(G_{ASE,n} + G_{NLI,n} \cdot g_n\right) B_N}}$$

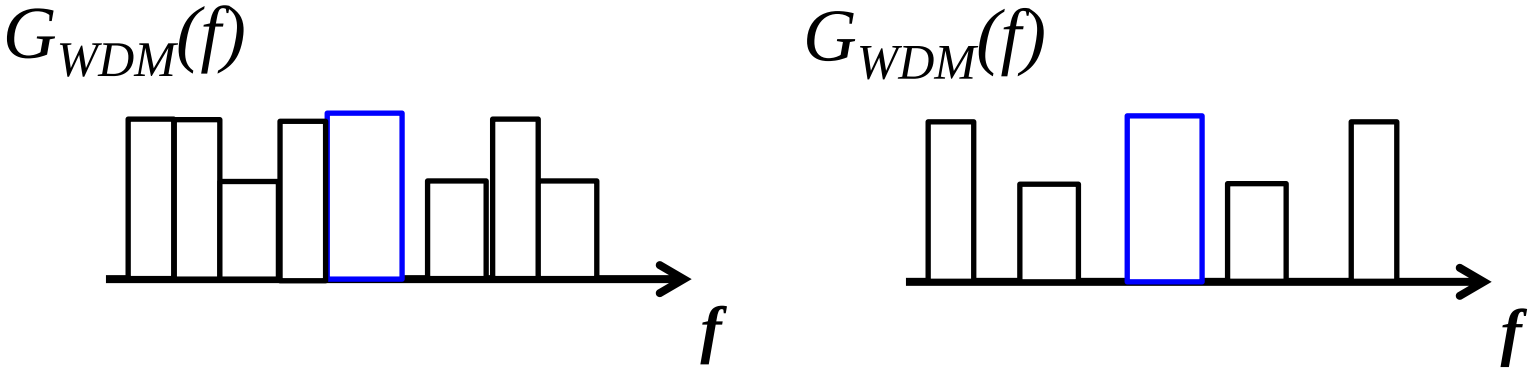
The OSNR at the Rx can be optimized by simply optimizing each one of the spans’ osnr individually, provided that they are independent of one another.

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:

$$\boxed{osnr_n = \frac{P_{ch,n} \cdot a_n \cdot g_n}{\left(G_{ASE,n} + G_{NLI,n} \cdot g_n\right) B_N}}$$

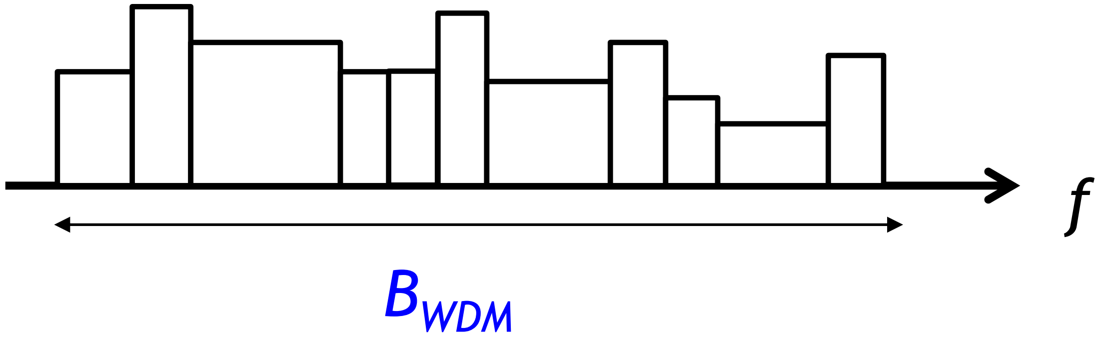
- The optimum launch powers depend on the spectral loading (all others parameters are fixed):



  - Full knowledge of bandwidth allocation required !

Full spectral loading assumption

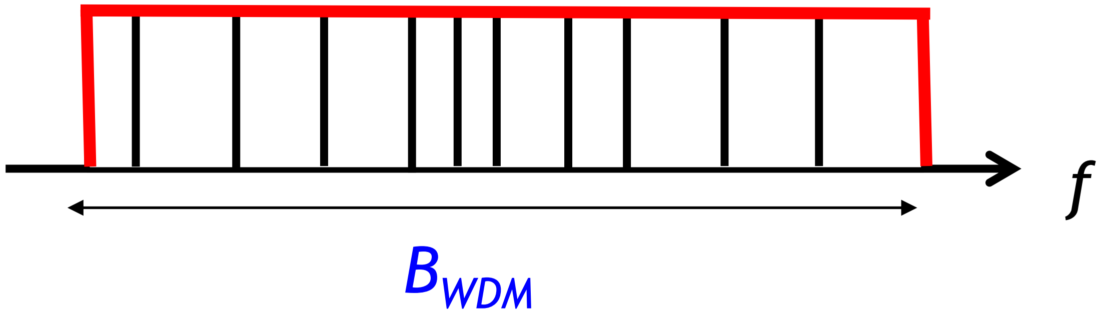
- Full spectral loading (worst case scenario) is ideally found when the full available optical bandwidth (B_{WDM}) is utilized at maximum spectral efficiency:



- 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

Optimization at Nyquist limit

- The GN-model [3] predicts that, at the Nyquist limit, osnr$_n$ is maximized by launching a uniform signal PSD across the WDM comb:



$$\boxed{G_{WDM,n}^{opt} = \sqrt{\frac{hnF_n}{2\rho_{NLI,n}}}} \quad \text{with} \quad \boxed{\rho_{NLI,n} = a_n \frac{16}{27} \frac{\alpha_n \gamma_n^2 L_{eff,n}}{\pi \beta_{2,n}} \operatorname{asinh}\left[\frac{\pi^2}{4\alpha_n} \beta_{2,n} B_{WDM}^2 \right]}$$

LOGON

[3] P. Poggiolini, Tutorial on "Modeling of Non-Linear Propagation in Uncompensated Coherent Systems", OFC 2013, OTh3G.1.

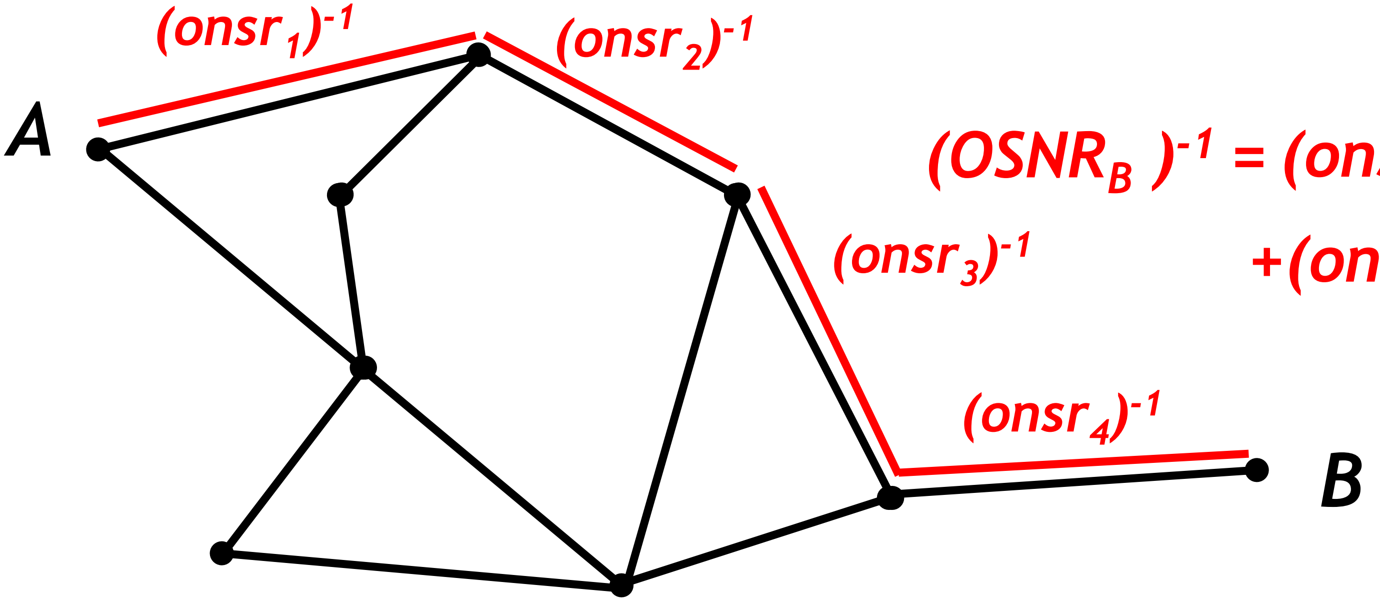
Pros of LOGON

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

- 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:

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

Pros of LOGON



$$(OSNR_B)^{-1} = (onsr_1)^{-1} + (onsr_2)^{-1} + (onsr_3)^{-1} + (onsr_4)^{-1}$$

- 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

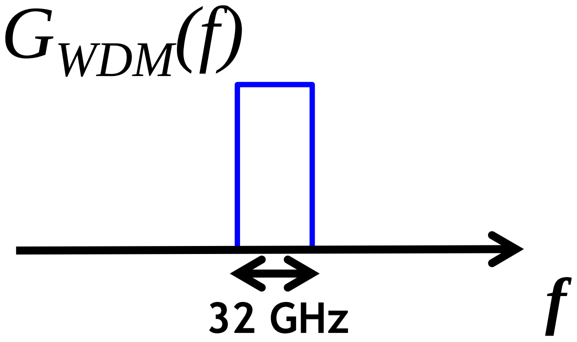
- By always assuming full spectral loading, when a lightpath travels across a sparsely populated network, its potential performance could be substantially underestimated → CP might act regeneration when not necessary

- EXAMPLE: single channel propagation over a multi-span system composed of 100-km spans of SSM fiber
  - R_s = 32 Gbaud
  - F = 6 dB
  - OSNR target: 13 dB

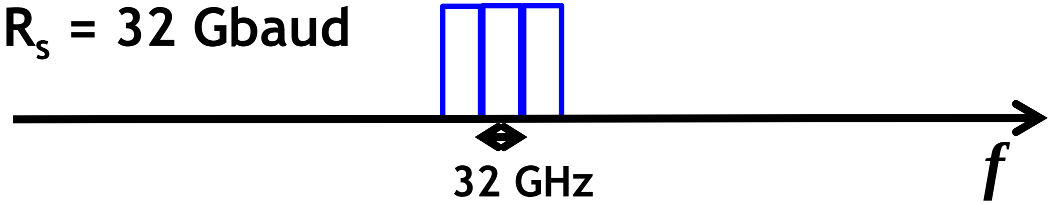
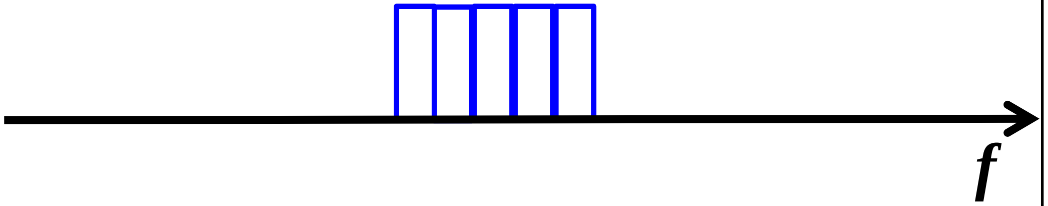
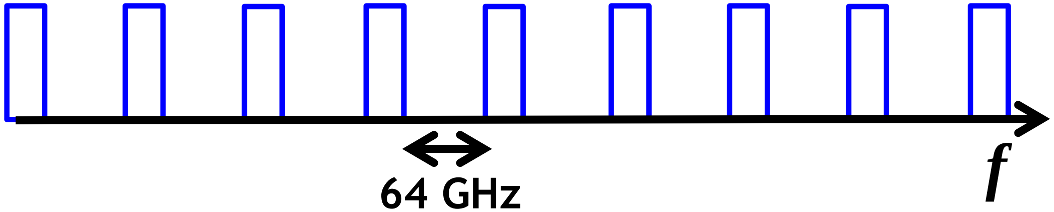
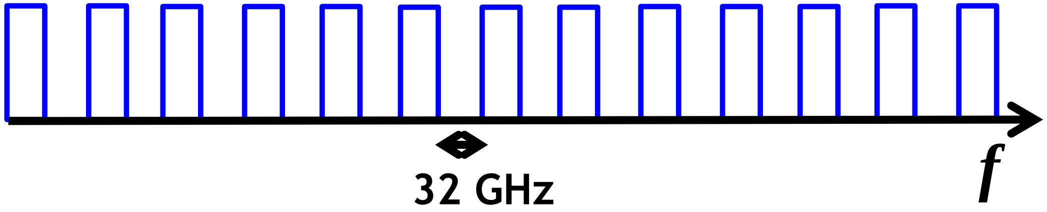
Actual maximum reach: **6000 km**

Maximum reach estimated by LOGON over entire C-band (5 THz): **4000 km**

Max reach prediction error: **-33%**
-1.75 dB



Loss of performance

Spectrum Filling	Max Reach Prediction Error
	- 23 % (-1.12 dB)
	-19 % (-0.92 dB)
	-27 % (-1.4 dB)
	-20% (-1.0 dB)

Conclusions

- 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 ~20% lightpath maximum reach underestimation when the network is lightly loaded.

Thank you!

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