Impact of Low-OSNR Operation on the Performance of Advanced Coherent Optical Transmission Systems

P. Poggiolini(1), A. Carena(1), Y. Jiang(1), G. Bosco(1), V. Curri(1), F. Forghieri(2)

(1) DET, Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129, Torino, Italy
(2) Cisco Photonics Italy srl, Via Santa Maria Molgora 48C, 20871, Vimercate, Italy

www.optcom.polito.it
Recent progress in forward error-correcting codes permits to increase the pre-FEC BER threshold

- 20% overhead LDPC convolutional codes requires \( \text{BER}_{\text{th}} = 2.7 \cdot 10^{-2} \)
- Operation with such FEC allows to operate links at very low OSNRs

ASE noise impact on non-linear effects may become substantial
Outline

- Observing simulation results
- The Enhanced-GN model
- Accounting for ASE-generated NLI noise
- Considering signal-power depletion
- Conclusions
We choose to use a relatively high-non-linearity fiber with long spans to limit the reach and get manageable simulation times.
In simulations ASE noise can be injected at each EDFA or at the end of the link.
NZDSF - $\Delta f=33.6$ GHz

Simulation results

- $N_{\text{adds}}$
- $P_{\text{TX}}$ [dBm]

$3 \cdot 10^{-4}$

- ASE RX-loading
- ASE In-line
Simulation results

- ASE RX-loading
- ASE In-line

\( \Delta f = 33.6 \text{ GHz} \)

\( N_{\text{add}} \) vs. \( P_{\text{TX}} \) [dBm]
NZDSF - $\Delta f = 33.6$ GHz

Simulation results

- $3 \times 10^{-3}$
- $1 \times 10^{-3}$
- $3 \times 10^{-4}$

- ASE RX-loading
- ASE In-line
NZDSF - $\Delta f = 33.6$ GHz

Simulation results

- □ ASE RX-loading
- ○ ASE In-line

![Graph showing simulation results with markers at 1 $\times 10^{-2}$, 3 $\times 10^{-3}$, and 3 $\times 10^{-4}$]
Simulation results

- ASE RX-loading
- ASE In-line

NZDSF - $\Delta f = 33.6$ GHz
Simulation results

Gap: 3 spans 10% of reach (0.4 dB)

□ ASE RX-loading
○ ASE In-line

NZDSF - Δf=33.6 GHz
The Enhanced GN-model (EGN)

- Non-linear propagation in uncompensated links can be studied using the GN-model.

- GN-model is based on three ingredients:
  - Signal is Gaussian distributed.
  - Nonlinear Interference is Gaussian distributed and additive.
  - Nonlinear Interference is perturbative.

- EGN model removes the Gaussian distribution assumption.
  - Higher complexity.
  - Modulation format dependency of some terms.

- NZDSF
- PM-QPSK
- $R_s=32$ Gbaud
- 15 channels
- $\Delta f=33.6$

\[ P_{NL} = \eta P_{ch}^3 \]

\[ OSNR_{NL} = \frac{P_{ch}}{P_{ASE} + P_{NL}} \]

\[ BER = f(OSNR_{NL}) \]

Rigorous modeling is possible, in principle, but it may be quite complex

We propose a simple coarse model

\[ P'_{NL} = \sum_{n=1}^{N_{span}} \eta(n) \left[ P_{ch} + P_{ASE}(n) \right]^3 \]

\[ OSNR_{NL} = \frac{P_{ch}}{P_{ASE} + P'_{NL}} \]
Max Reach Penalty due to ASE

Model

Simulation

PM-BPSK

PM-QPSK

log_{10}(BER)

Max Reach Penalty [dB]
NZDSF - $\Delta f=33.6$ GHz
NZDSF - $\Delta f=33.6$ GHz

SIMULATION
- ASE RX-loading
- ASE In-line

MODEL
- EGN
- EGN with ASE-generated NLI
During propagation along the link there is a gradual signal depletion in favor of NLI noise.

Heuristically, we can consider that the actual useful signal power is reduced by $P_{NLI}$.

\[ OSNR_{NL} = \frac{P_{ch} - P_{NLI}}{P_{ASE} + P'_{NLI}} \]

- $P_{ch}$: Signal generated
- $P_{ASE}$: Signal + ASE generated
- $P_{NLI}$: Signal + ASE generated
NZDSF – $\Delta f=33.6$ GHz

SIMULATION
- ASE In-line

MODEL
- EGN
- EGN with ASE-generated NLI
- EGN with ASE-generated NLI and signal depletion
The trend towards more powerful FECs allows to operate system at very low OSNR

Some of the advantages of such high-performance FECs are thwarted by effects that are negligible at high OSNR

- ASE-generated NLI and signal depletion

To avoid performance overestimations:

- In modeling, even using the accurate EGN model, some coarse heuristic corrections are needed
- In simulation it is necessary to include in-line injection of ASE noise
The OptSim simulator was supplied by Synopsys Inc.

This work was supported by CISCO Systems within a SRA contract.

andrea.carena@polito.it
www.optcom.polito.it