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

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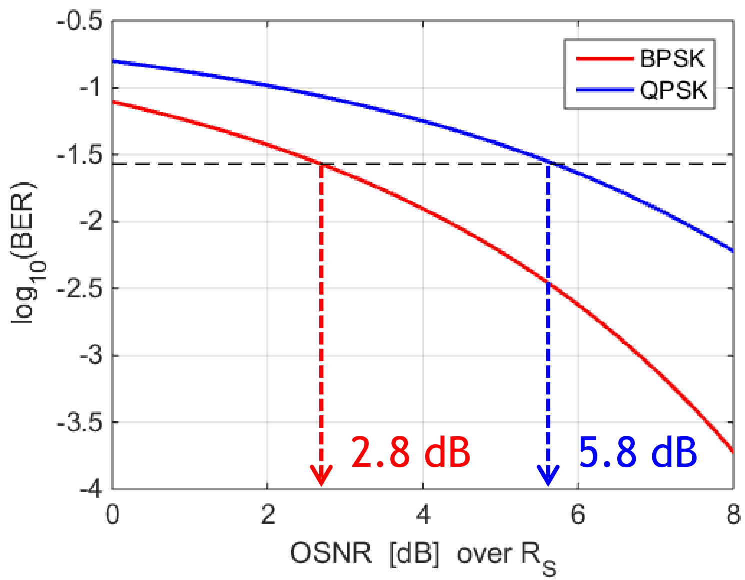
Motivation

OPTCOM

- Recent progress in forward error-correcting codes permits to increase the pre-FEC BER threshold
  - 20% overhead LDPC convolutional codes requires $BER_{th}=2.7 \cdot 10^{-2}$
- Operation with such FEC allows to operate links at very low OSNRs

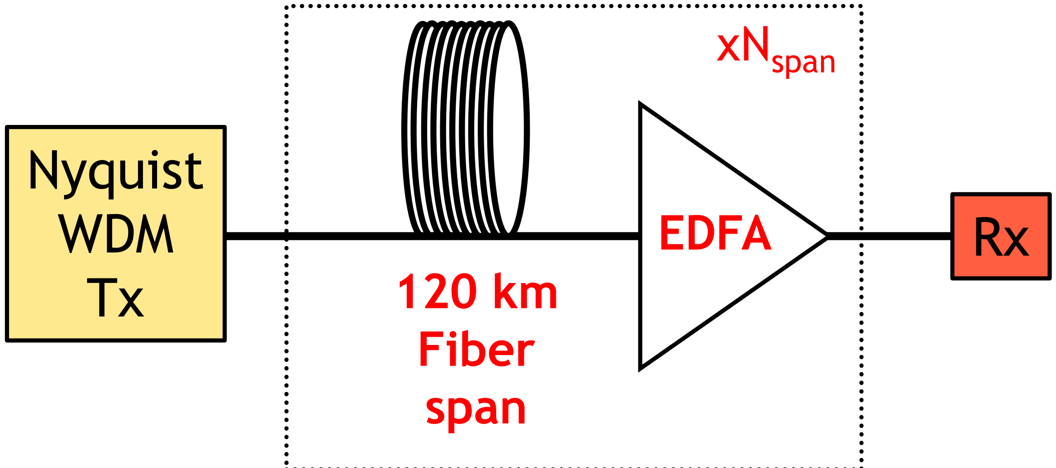


- ASE noise impact on non-linear effects may become substantial

Outline

- Observing simulation results
- The Enhanced-GN model
- Accounting for ASE-generated NLI noise
- Considering signal-power depletion
- Conclusions

System analyzed



TRANSMITTER
- R_S=32 Gbaud
  - 128G PM-QPSK
- Nyquist-WDM
  - DSP spectral shaping
  - Roll-off=0.05
  - Δf=33.6 GHz
  - 15 channels

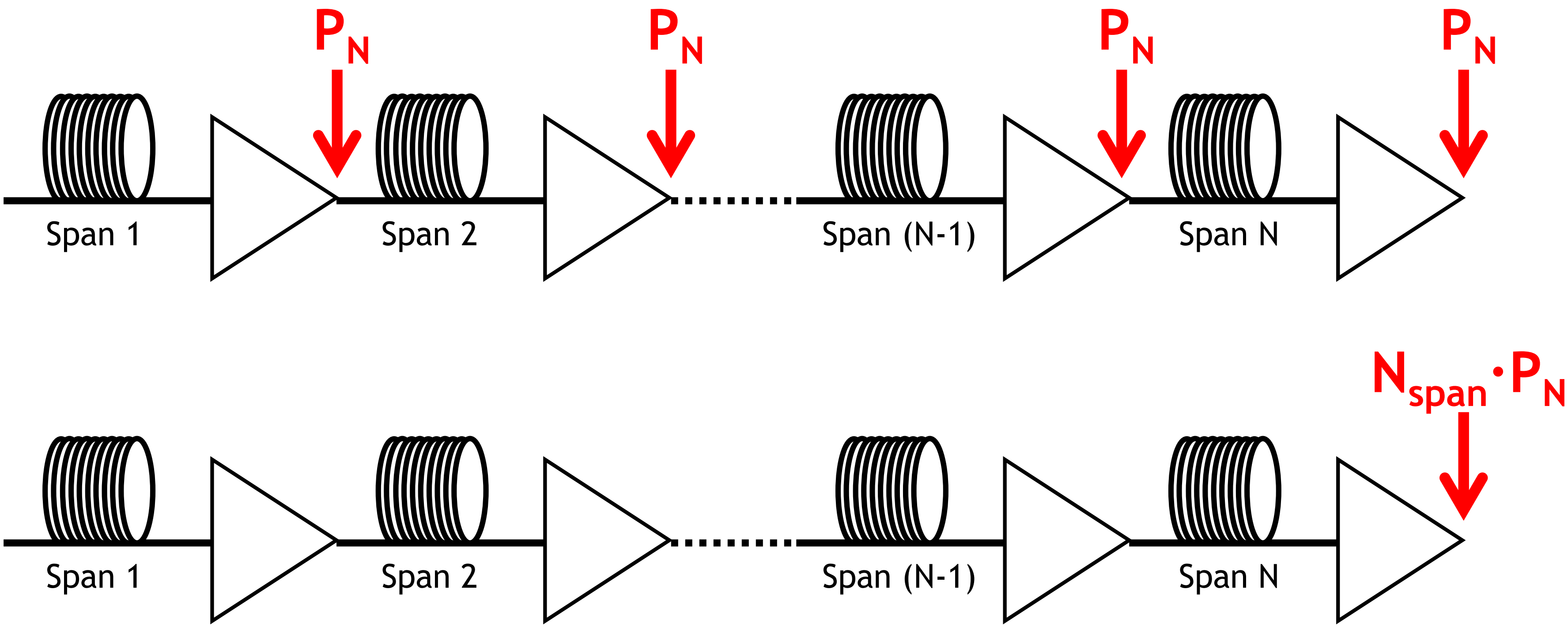
LINK
- Fiber: NZDSF
  - α=0.22 [dB/km]
  - γ=1.5 [1/W/km]
  - D=3.8 [ps/nm/km]
- EDFA
  - Gain recover fiber loss
  - F=5 dB

RECEIVER
- Coherent receiver
- Electrical bandwidth
  - $B_{elt}=0.5\cdot R_S$=16.0 GHz
- ADC
  - 2 SpS
- DSP
  - LMS with training sequence
  - 51 taps

We choose to use a relatively high-non-linearity fiber with long spans to limit the reach and get manageable simulation times

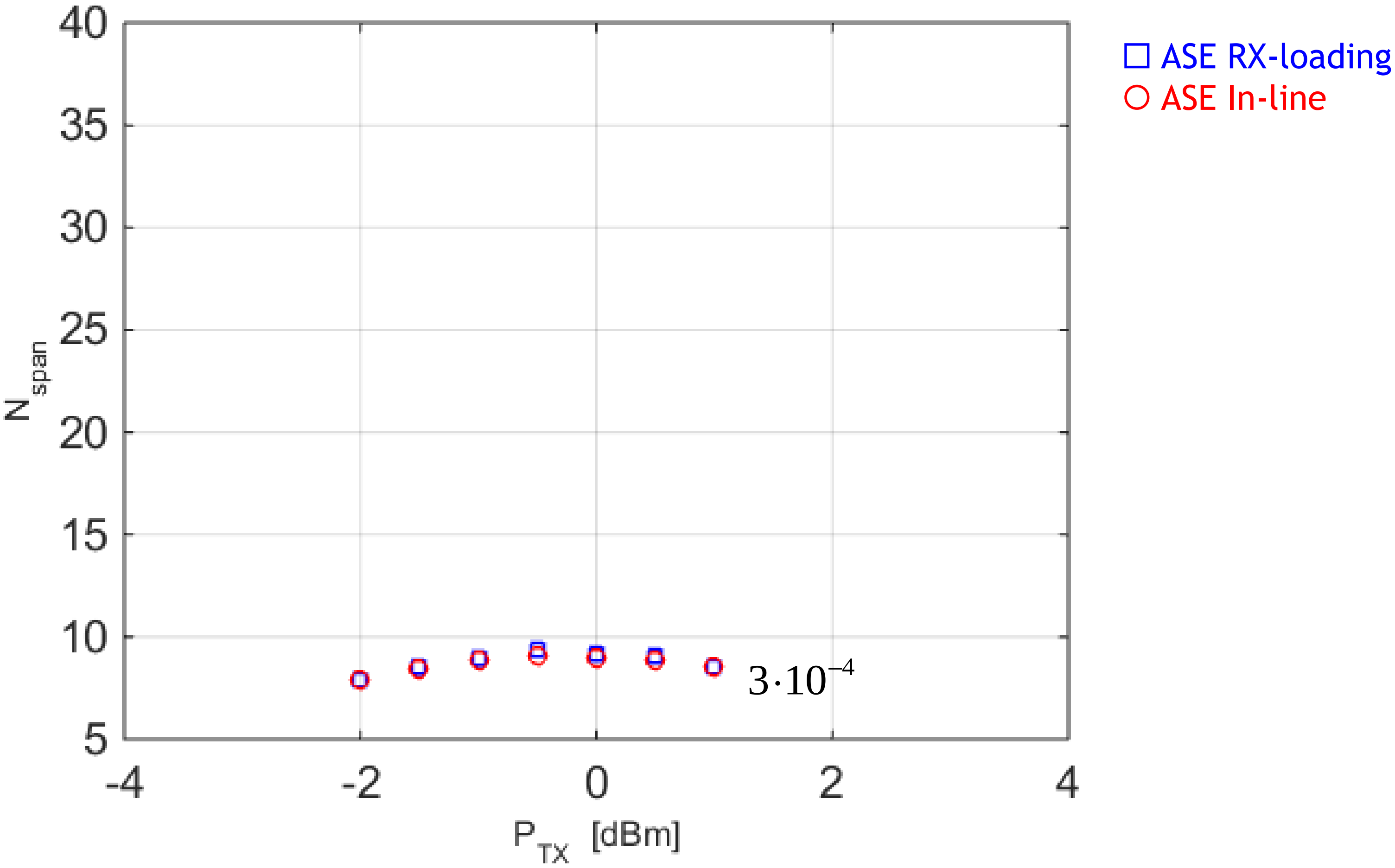
ASE injection: Rx-loading vs. In-line

- In simulations ASE noise can be injected at each EDFA or at the end of the link



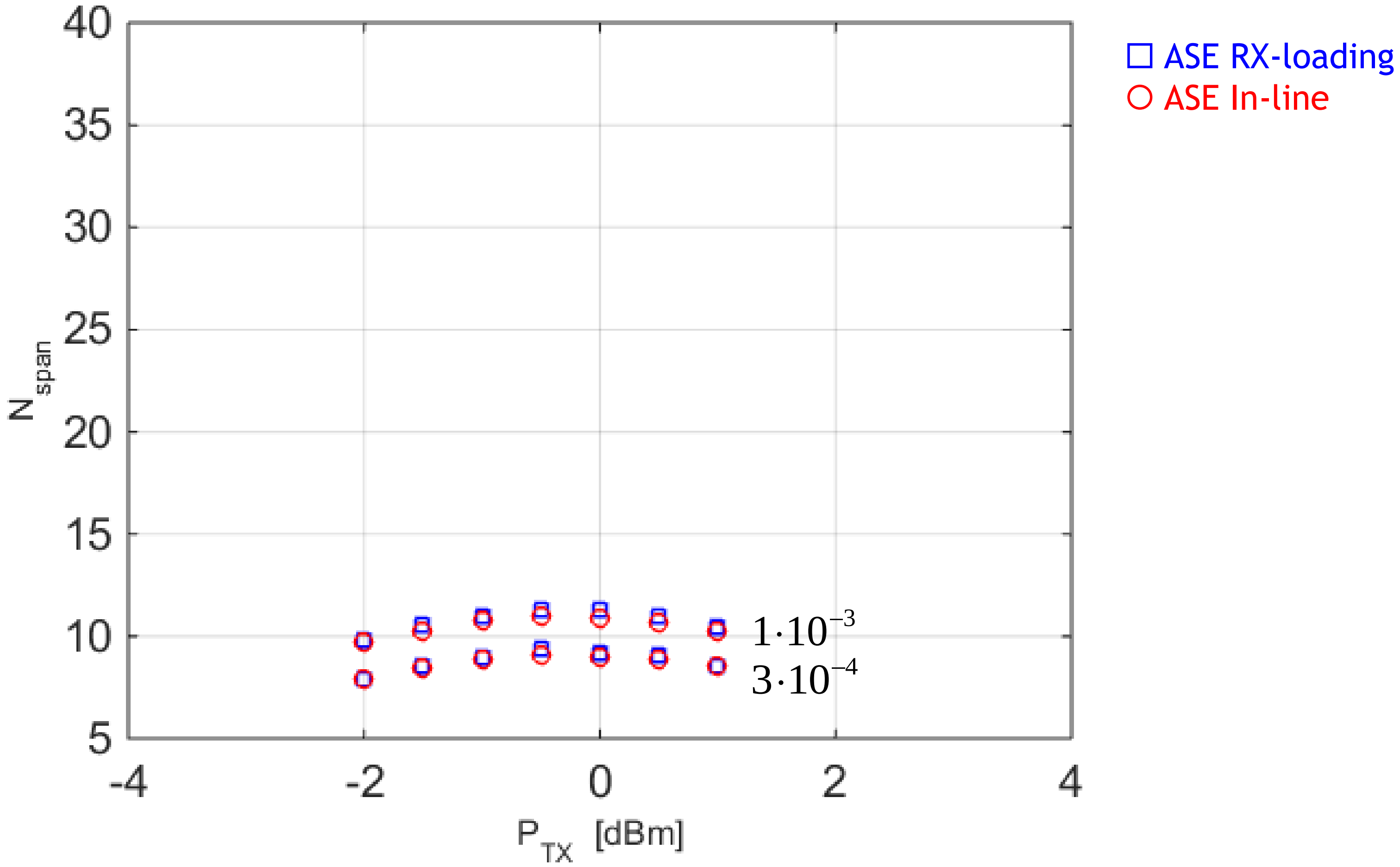
NZDSF - Δf=33.6 GHz

Simulation results



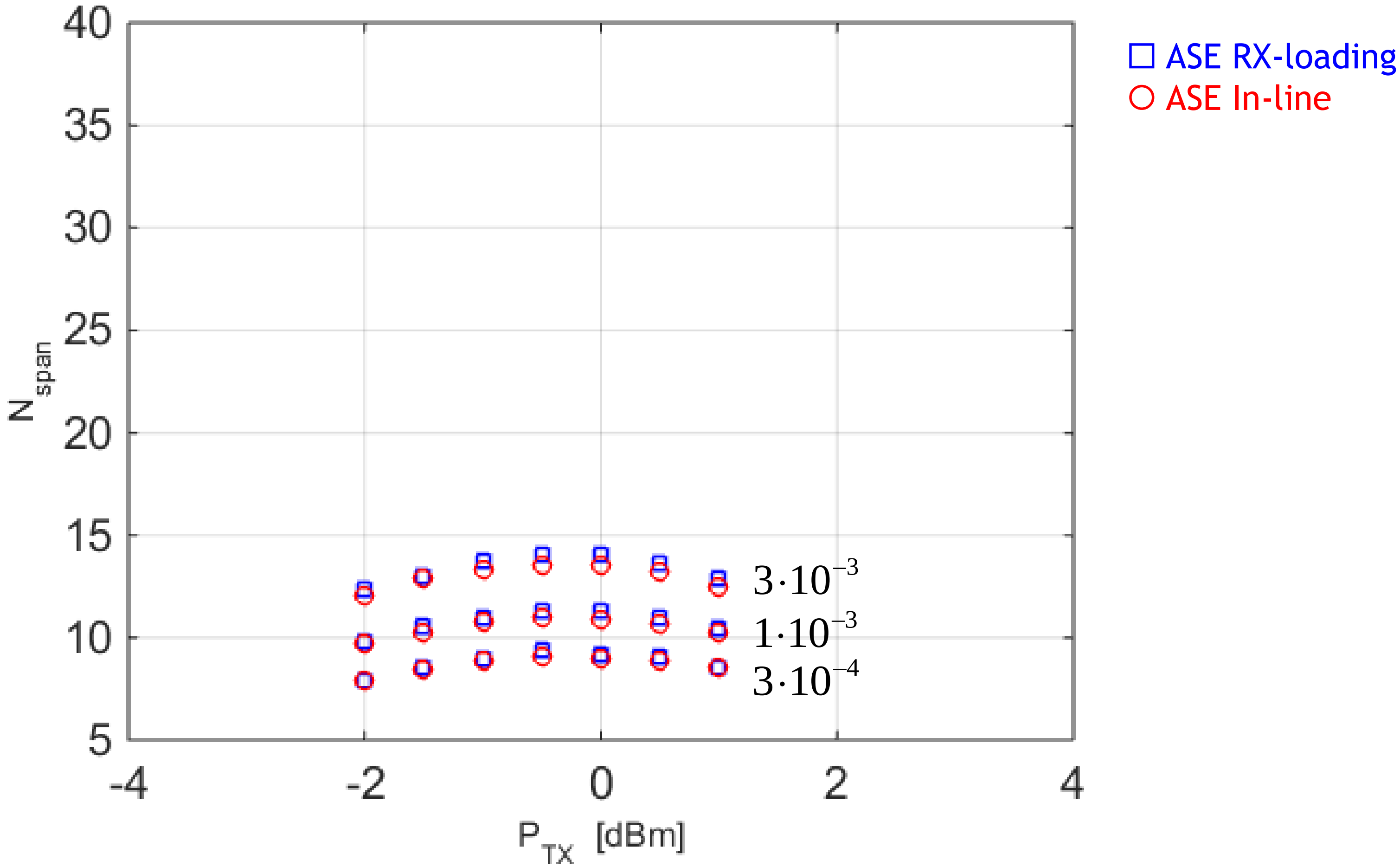
NZDSF - Δf=33.6 GHz

Simulation results



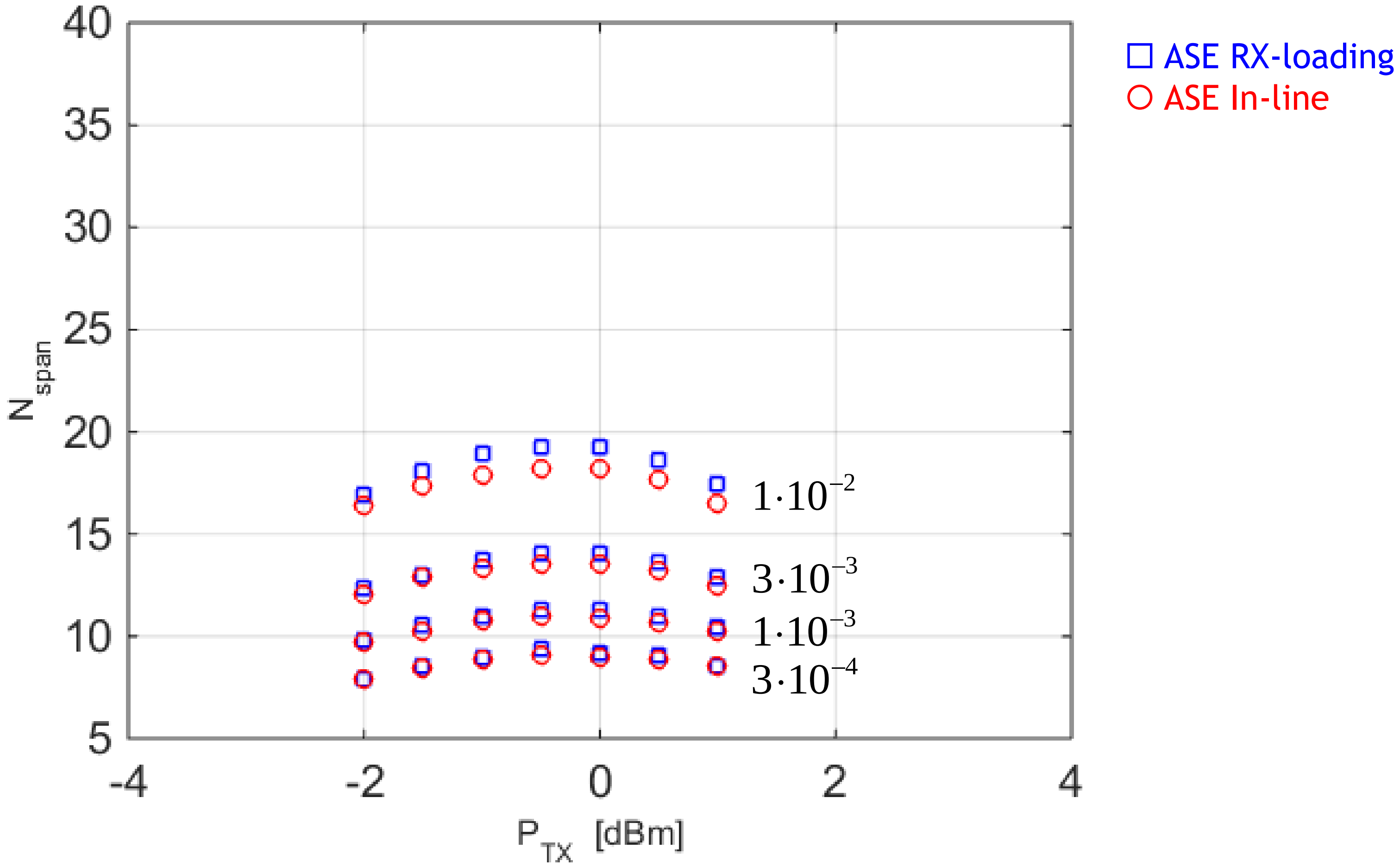
NZDSF - Δf=33.6 GHz

Simulation results



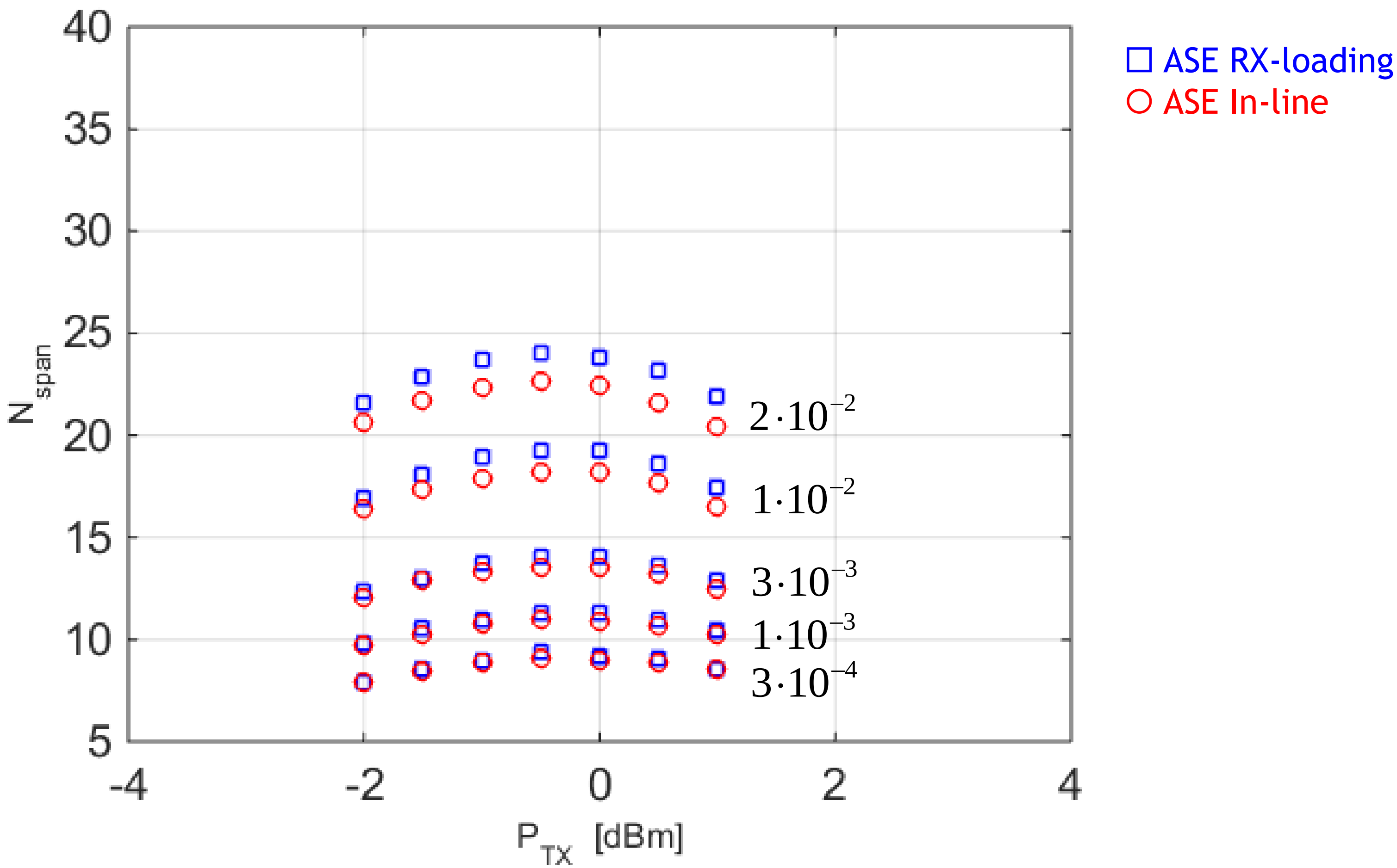
NZDSF - Δf=33.6 GHz

Simulation results



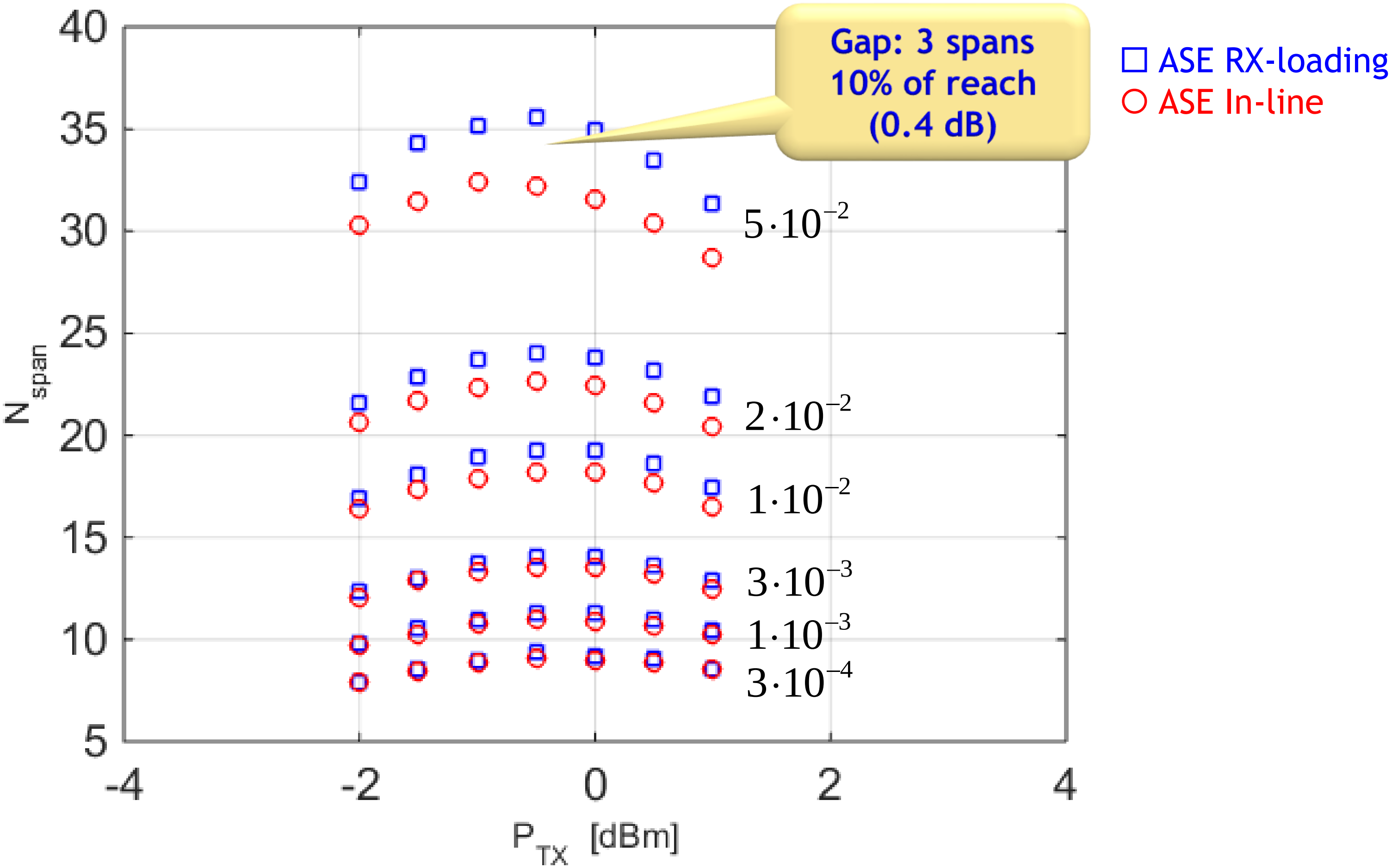
NZDSF - Δf=33.6 GHz

Simulation results



NZDSF - Δf=33.6 GHz

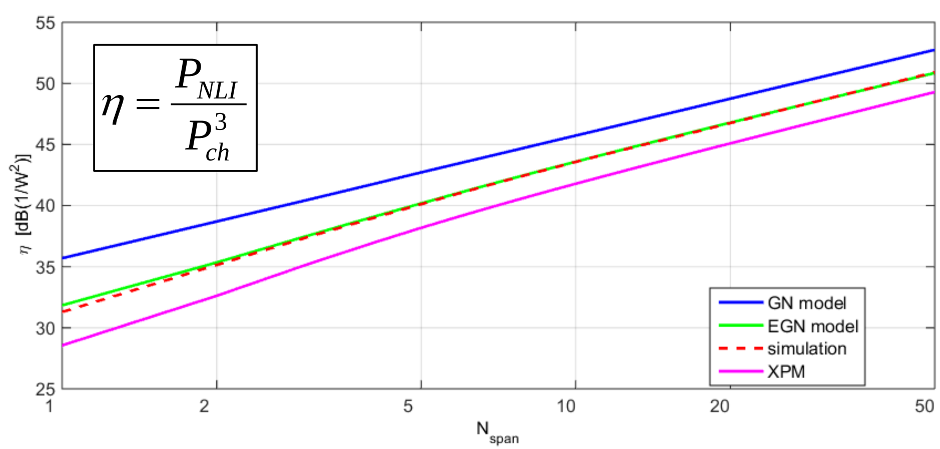
Simulation results



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
- Δf=33.6



$$P_{NLI} = \eta P_{ch}^3$$

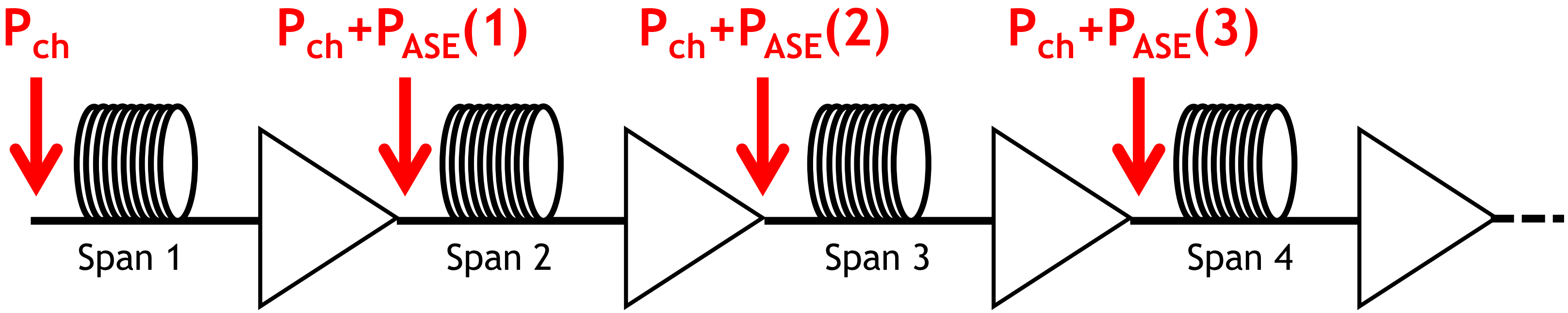
$$OSNR_{NL} = \frac{P_{ch}}{P_{ASE} + P_{NLI}}$$

$$BER = f\,(OSNR_{NL})$$

A. Carena, G. Bosco, V. Curri, Y. Jiang, P. Poggiolini, F. Forghieri, "EGN model of non-linear fiber propagation," Optics Express, vol. 22, no. 13, pp. 16335-16362, June 2014.

ASE-generated NLI

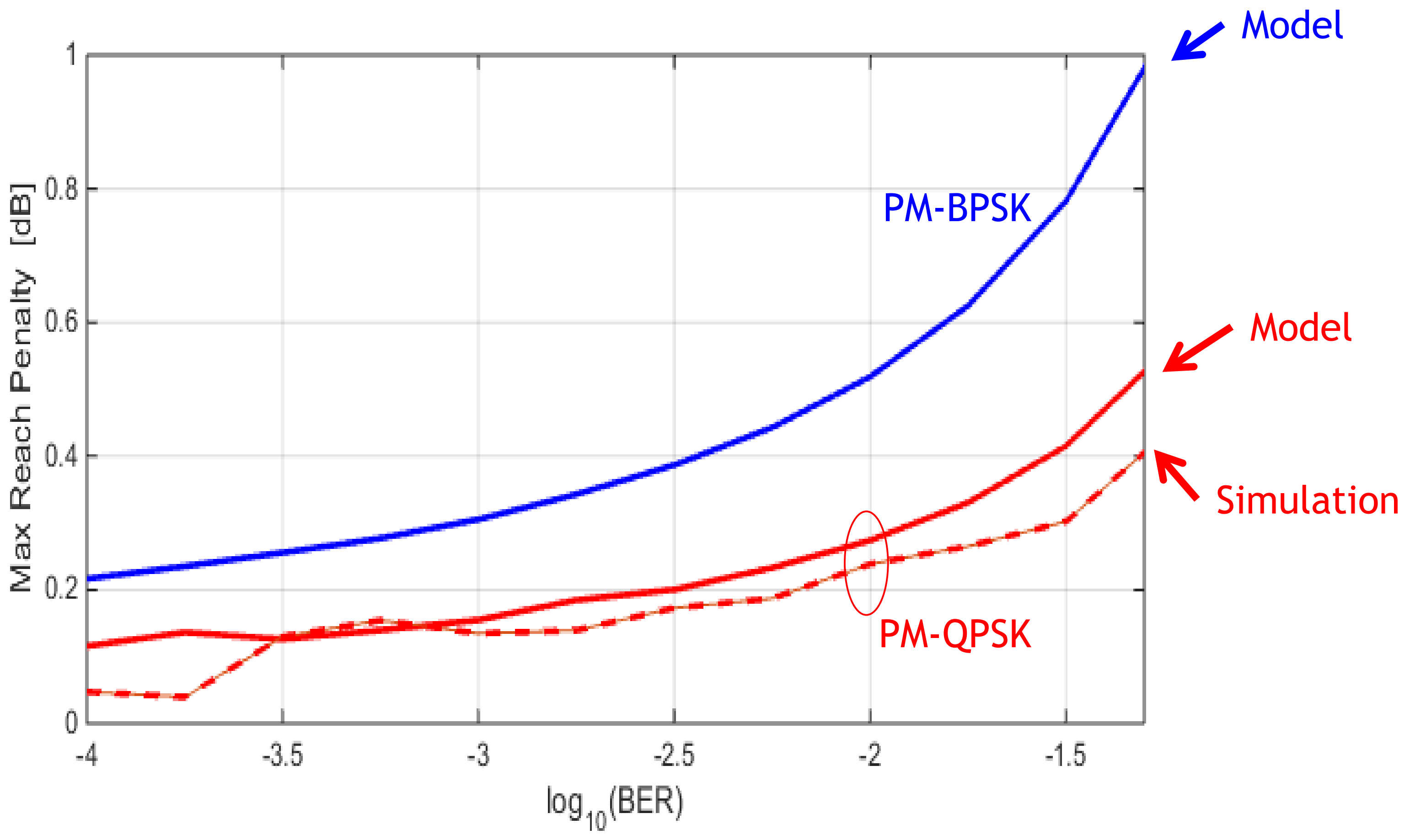
- Rigorous modeling is possible, in principle, but it may be quite complex
- We propose a simple coarse model



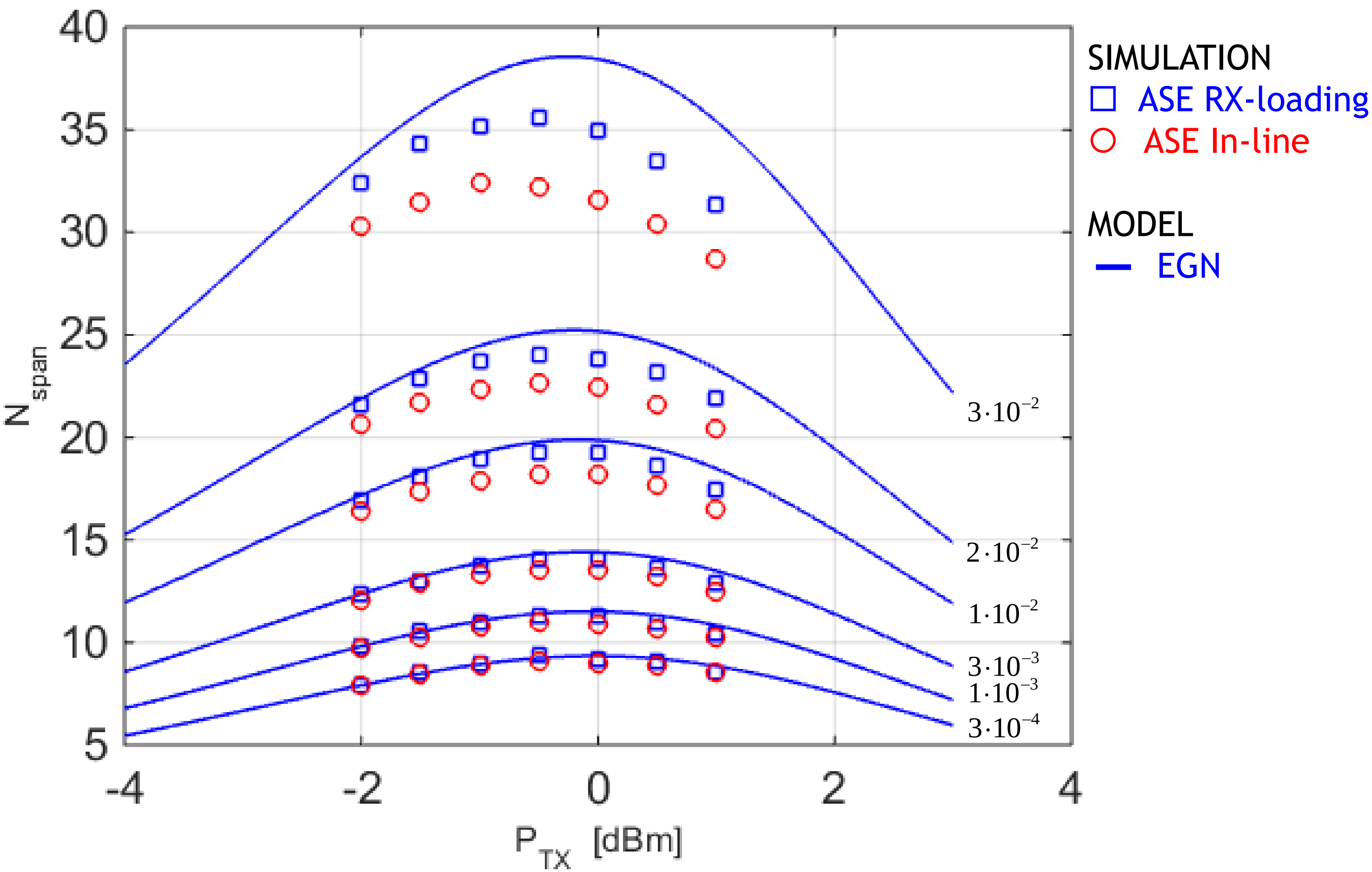
$$P'_{NLI} = \sum_{n=1}^{N_{span}} \eta(n) \left[P_{ch} + P_{ASE}(n) \right]^3$$

$$OSNR_{NL} = \frac{P_{ch}}{P_{ASE} + P'_{NLI}}$$

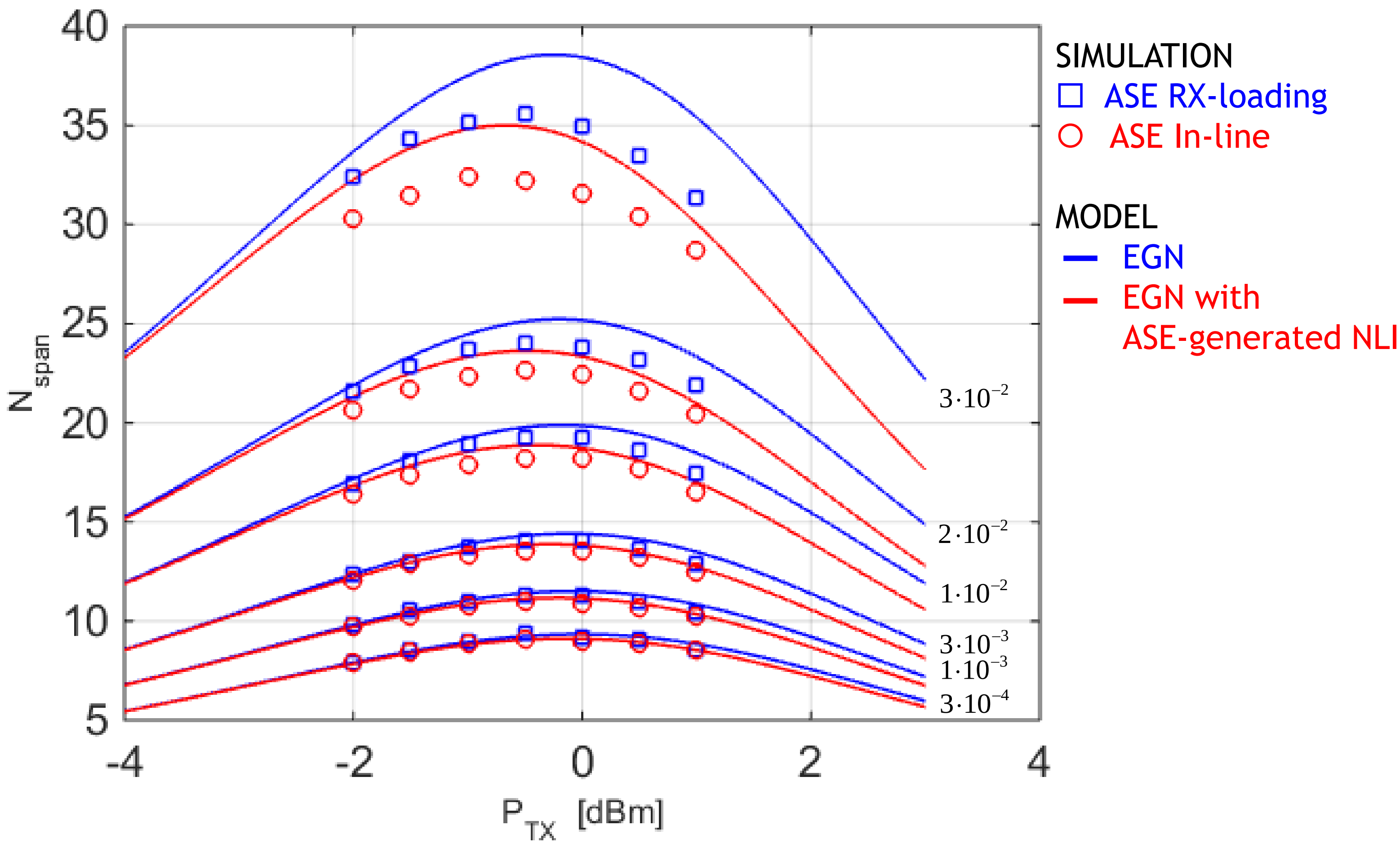
Max Reach Penalty due to ASE



NZDSF - Δf=33.6 GHz

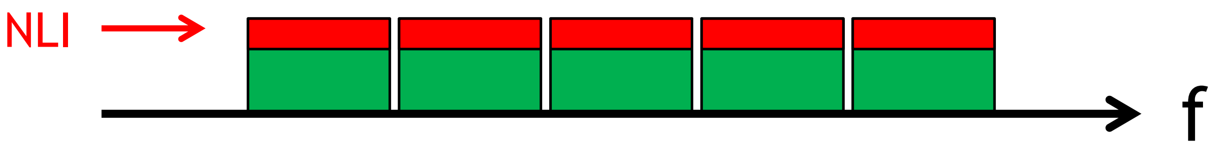


NZDSF - Δf=33.6 GHz



Non-linear signal-power depletion

- During propagation along the link there is a gradual signal depletion in favor of NLI noise



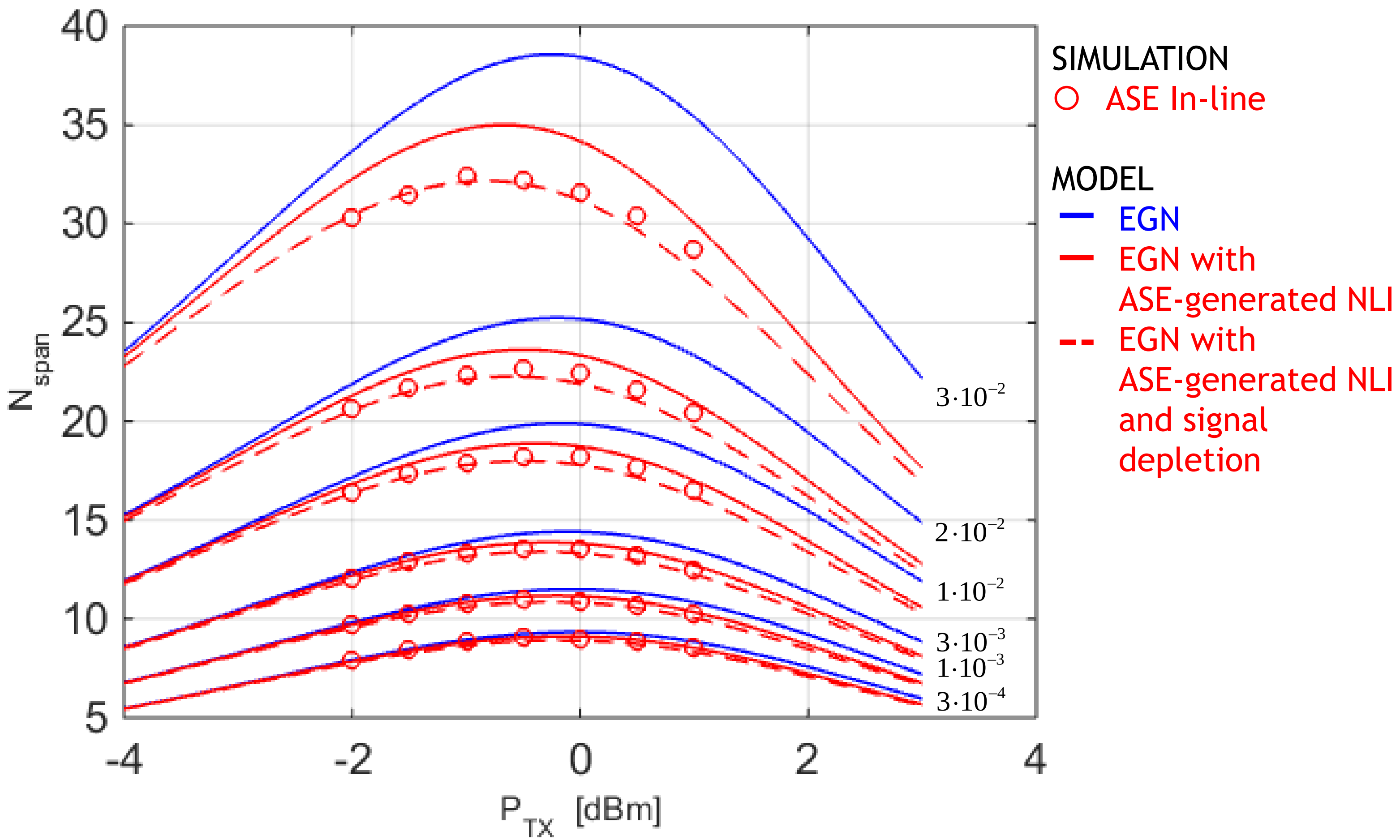
- Heuristically, we can consider that the actual useful signal power is reduced by P_{NLI}

signal generated

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

signal+ASE generated

NZDSF - Δf=33.6 GHz



Conclusions

- 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

Acknowledgments

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