Impact of the Transmitted Signal Initial Dispersion Transient on the Accuracy of the GN-Model of Non-Linear Propagation

A. Carena[1], G. Bosco[1], V. Curri[1], P. Poggiolini[1], F. Forghieri[2]
[1] DET, Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129, Torino, Italy
[2] Cisco Photonics Italy srl, Via Philips 12, 20900, Monza, Italy.

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Motivation

- Non-linear propagation in uncompensated links can be studied using the GN-model
- GN-model ingredients:
  - Signal is Gaussian distributed
  - Nonlinear Interference is Gaussian distributed and additive
  - Nonlinear Interference is perturbative
- First ingredient is not verified at system input: it takes some accumulated dispersion to turn the signal into Gaussian noise
- This work investigates the error introduced by the Initial Dispersion Transient (IDT) with respect to prediction of the GN-model

Outline

- A quick recap of the GN-model
- NLI estimation technique
- Simulation setup
  - Reference system description
- Results
  - Impact on system performance prediction
- Conclusions

GN-model

$$G_{NLI}(f) = \frac{16}{27}\gamma^2 \cdot \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} G_{Tx}(f_1)G_{Tx}(f_2)G_{Tx}(f_1+f_2-f) \cdot \left| \frac{1-e^{-2\alpha L_S} e^{j4\pi^2|\beta_2|L_S(f_1-f)(f_2-f)}}{2\alpha - j4\pi^2|\beta_2|(f_1-f)(f_2-f)} \right|^2$$

$$\cdot \frac{\sin^2\left(2N_S\pi^2(f_1-f)(f_2-f)|\beta_2|L_S\right)}{\sin^2\left(2\pi^2(f_1-f)(f_2-f)|\beta_2|L_S\right)} df_1 df_2$$

N_s

$$\sigma^2_{NLI} = \eta P^3_{ch}$$

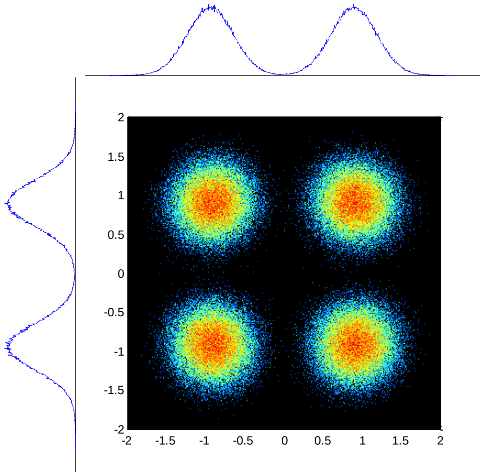
Coherent NLI accumulation $\sigma^2_{NLI} = \sigma^{2\,(1span)}_{NLI} \cdot N_s^{1+\varepsilon}$

Incoherent NLI accumulation $\sigma^2_{NLI} = \sigma^{2\,(1span)}_{NLI} \cdot N_s$

A. Carena et. al, "Modeling the impact of nonlinear propagation effects in uncompensated optical coherent transmission links", IEEE/OSA Journal of Lightwave Technology, vol. 30, no. 10, 15 May 2012, pp. 1524-1539.

NLI estimation technique

- NLI variance was estimated directly on the scattering diagram by averaging σ of all points
- Noiseless simulations with:
  - non-linearity turned on → σ^2_{tot}
  - non-linearity turned off → σ^2_{lin}



- The NLI variance was found as:

$$\sigma^2_{NLI} = \sigma^2_{tot} - \sigma^2_{lin}$$

and η as

$$\eta = \frac{\sigma^2_{NLI}}{P^3_{ch}}$$

Reference system: Tx & Rx

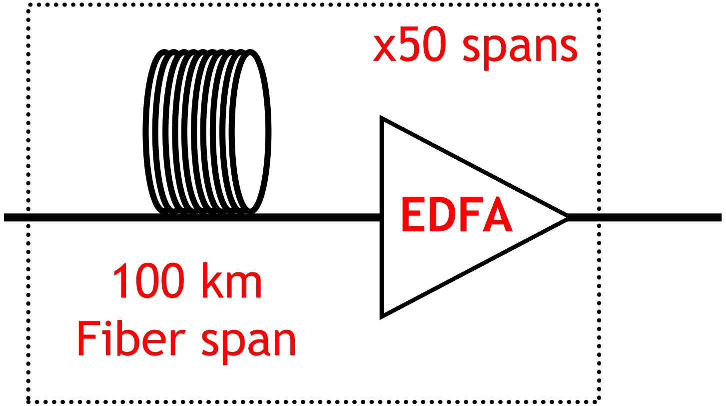
TRANSMITTER

- R_S=32 Gbaud
  - 128G PM-QPSK
  - 256G PM-16QAM
- Nyquist-WDM
  - DSP spectral shaping
    - roll-off=0.02
  - Δf=33.6 GHz
- WDM
  - 9 channels

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

Reference system: Link

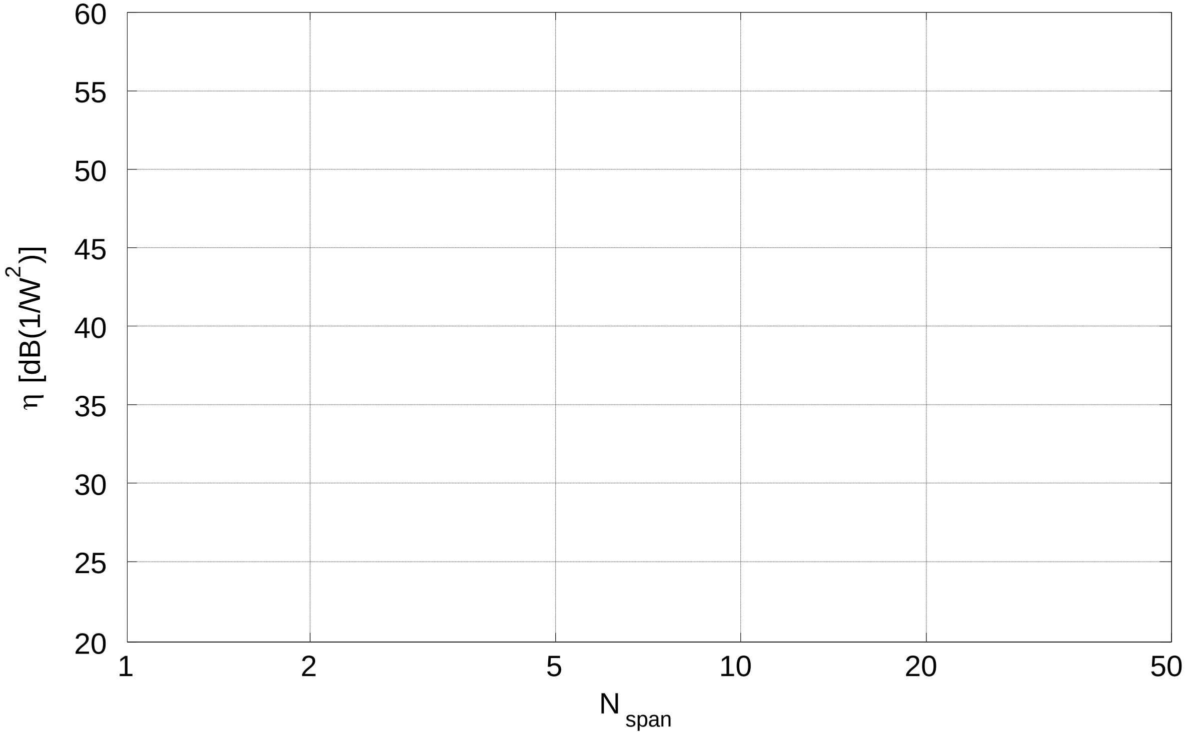


SMF
- Attenuation
  - α=0.2 [dB/km]
- Non-linearity
  - γ=1.3 [1/W/km]
- Dispersion
  - D=16.7 [ps/nm/km]

NZDSF
- Attenuation
  - α=0.22 [dB/km]
- Non-linearity
  - γ=1.5 [1/W/km]
- Dispersion
  - D=3.8 [ps/nm/km]

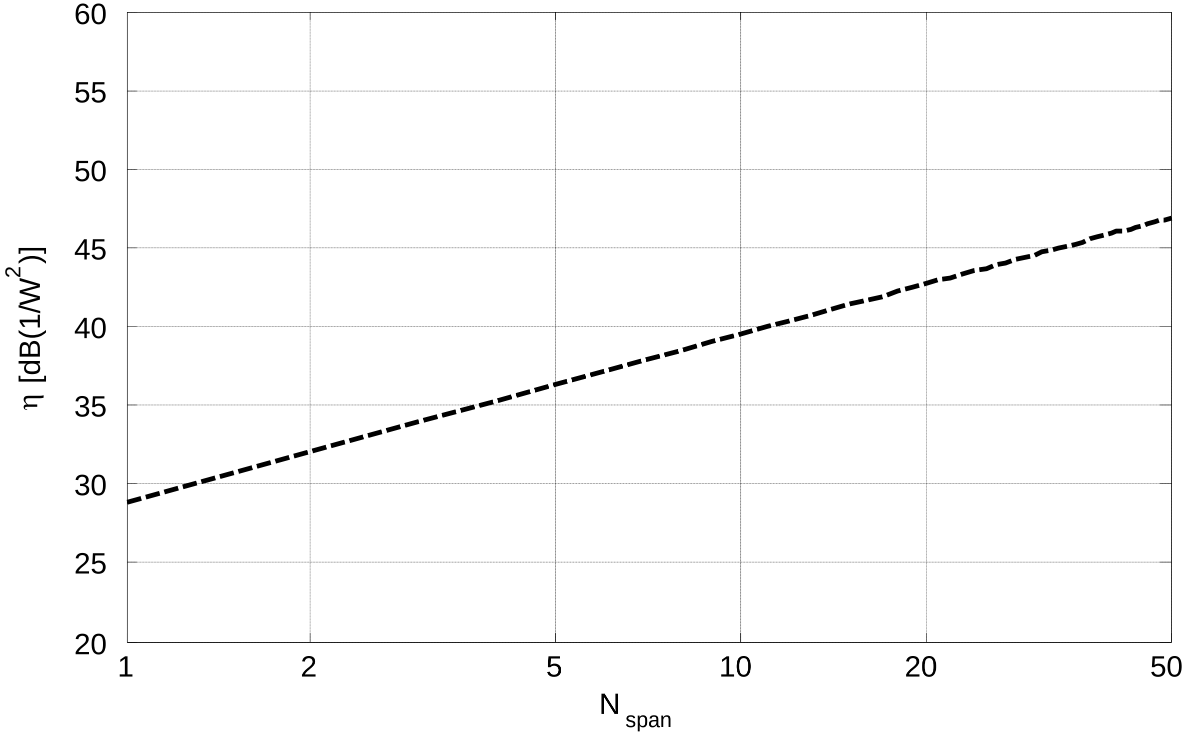
SMF

PM-QPSK



SMF

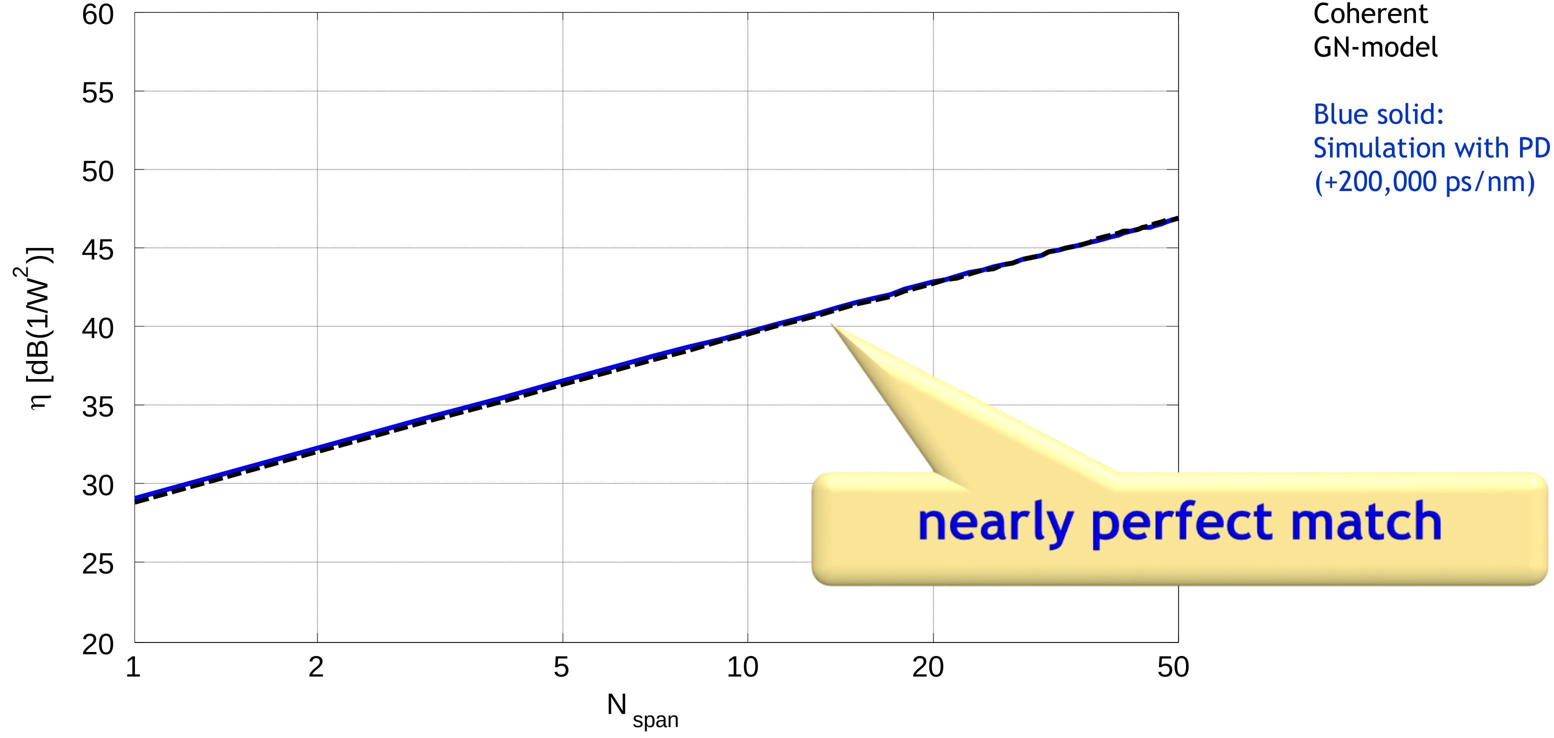
PM-QPSK



Black dashed:
Coherent
GN-model

SMF

PM-QPSK

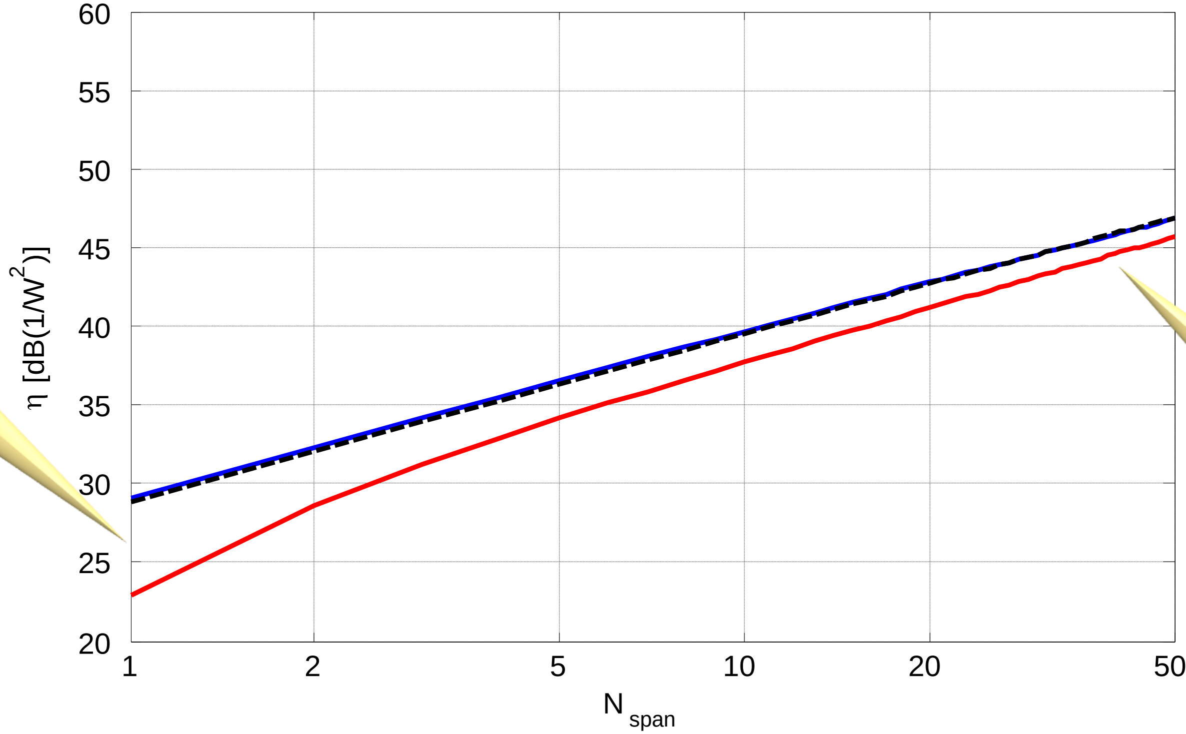


Black dashed:
Coherent
GN-model

Blue solid:
Simulation with PD
(+200,000 ps/nm)

SMF

PM-QPSK



6 dB gap after 1 span

<1.5 dB gap at Max Reach

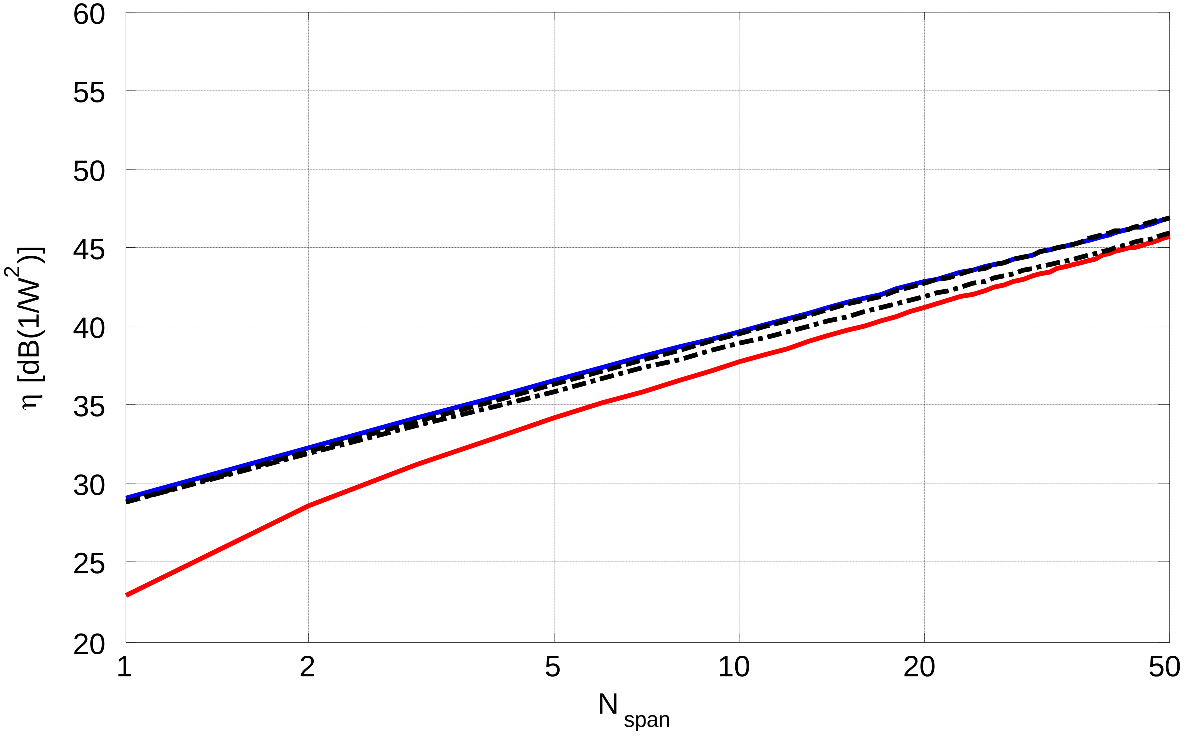
Black dashed: Coherent GN-model

Blue solid: Simulation with PD (+200,000 ps/nm)

Red solid: Simulation NOPD

SMF

PM-QPSK



Black dashed:
Coherent
GN-model

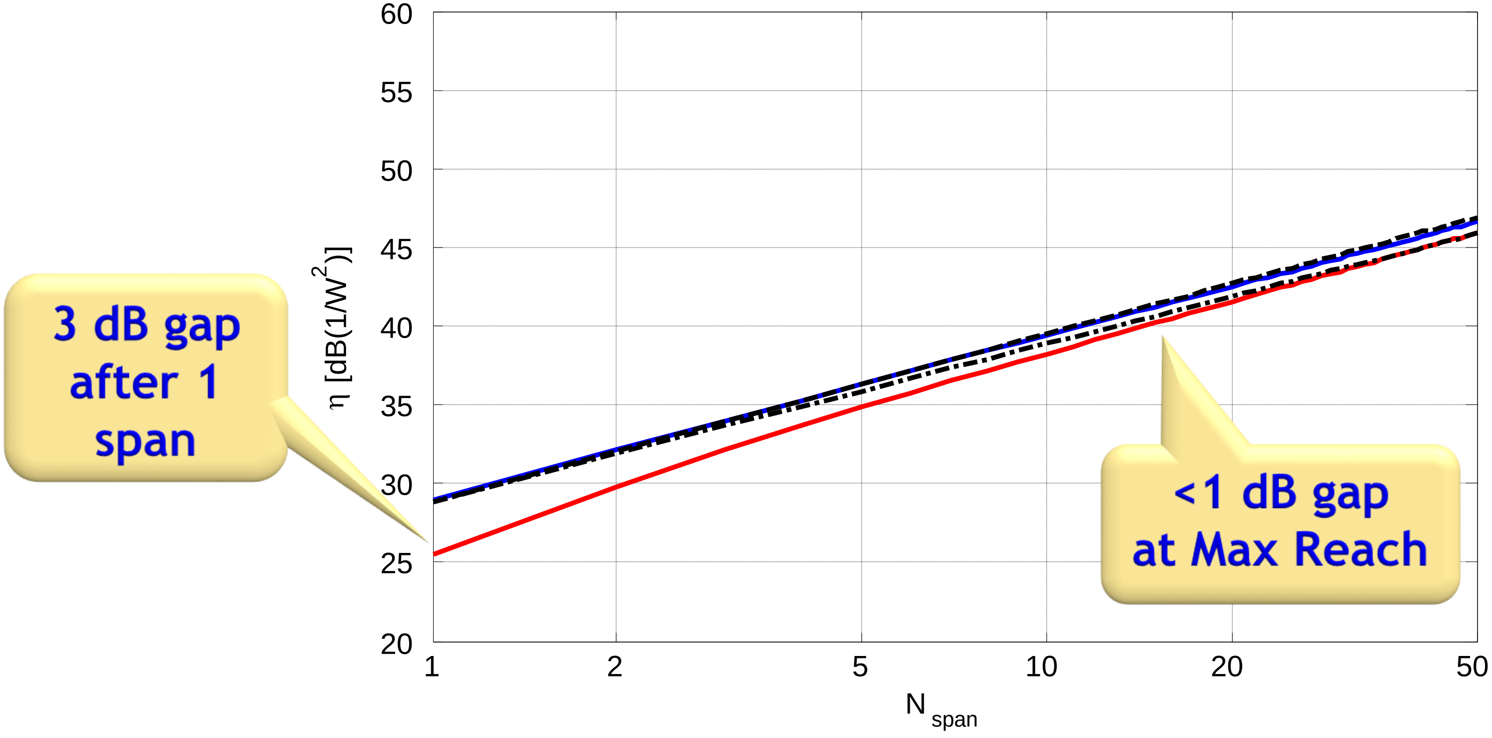
Blue solid:
Simulation with PD
(+200,000 ps/nm)

Red solid:
Simulation NOPD

Black dash-dotted:
Incoherent
GN-model

SMF

PM-16QAM



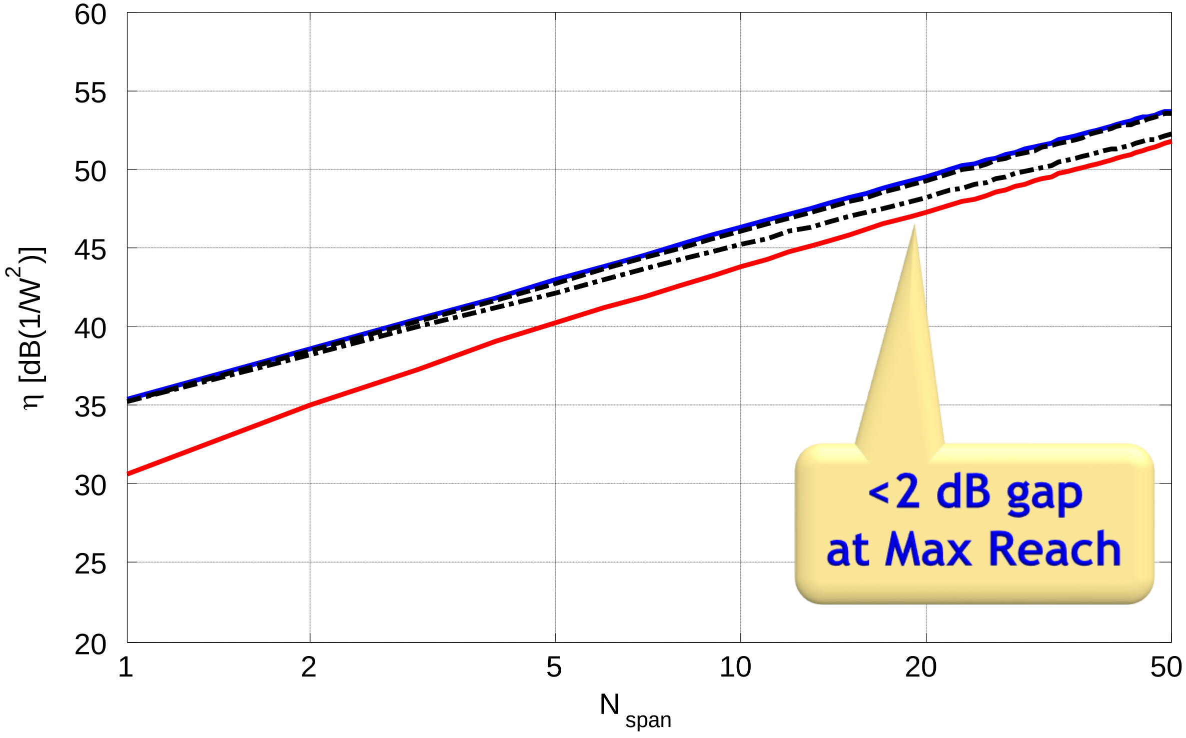
Black dashed: Coherent GN-model

Blue solid: Simulation with PD (+200,000 ps/nm)

Red solid: Simulation NOPD

Black dash-dotted: Incoherent GN-model

PM-QPSK



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GN-model

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Simulation with PD
(+200,000 ps/nm)

Red solid:
Simulation NOPD

Black dash-dotted:
Incoherent
GN-model

System impact: Max Reach

$$N_{span,MAX} \propto \sqrt[3]{\frac{1}{\eta}}$$

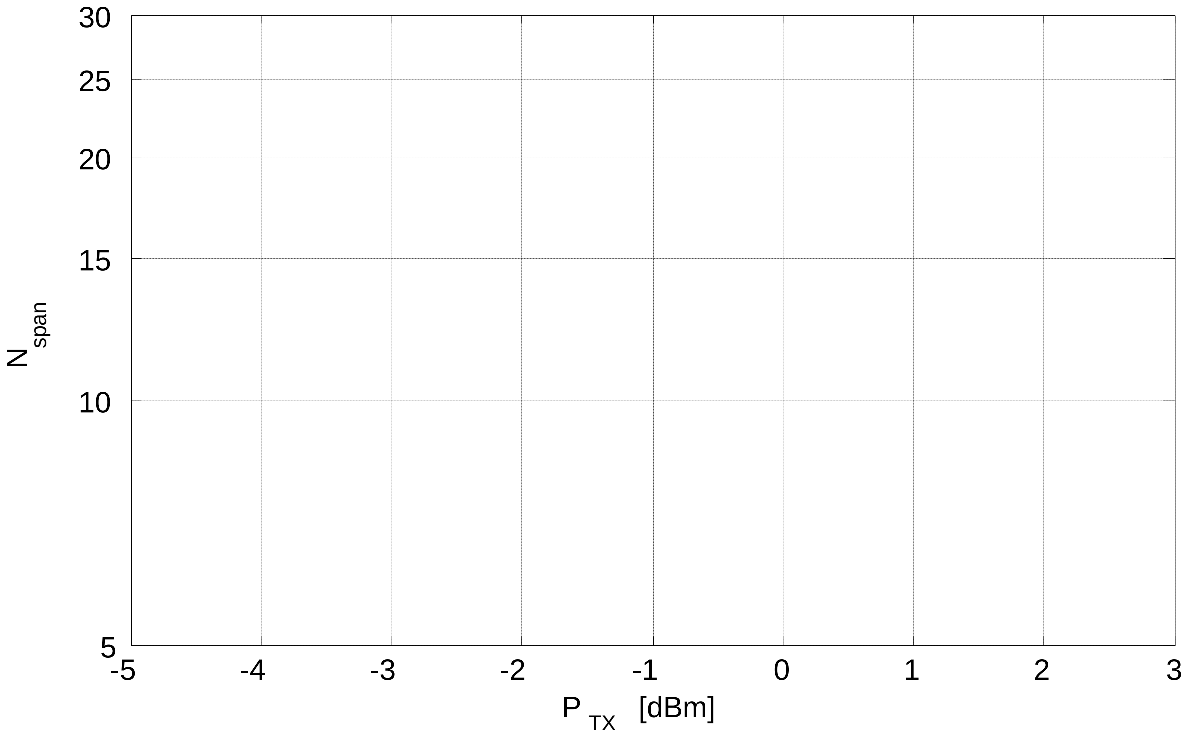
$$\Downarrow$$

$$\Delta N_{span,dB} = -\frac{1}{3}\Delta\eta_{dB}$$

Inaccuracies in η estimation are mitigated by 1/3

System impact

$BER_{target} = 10^{-3}$

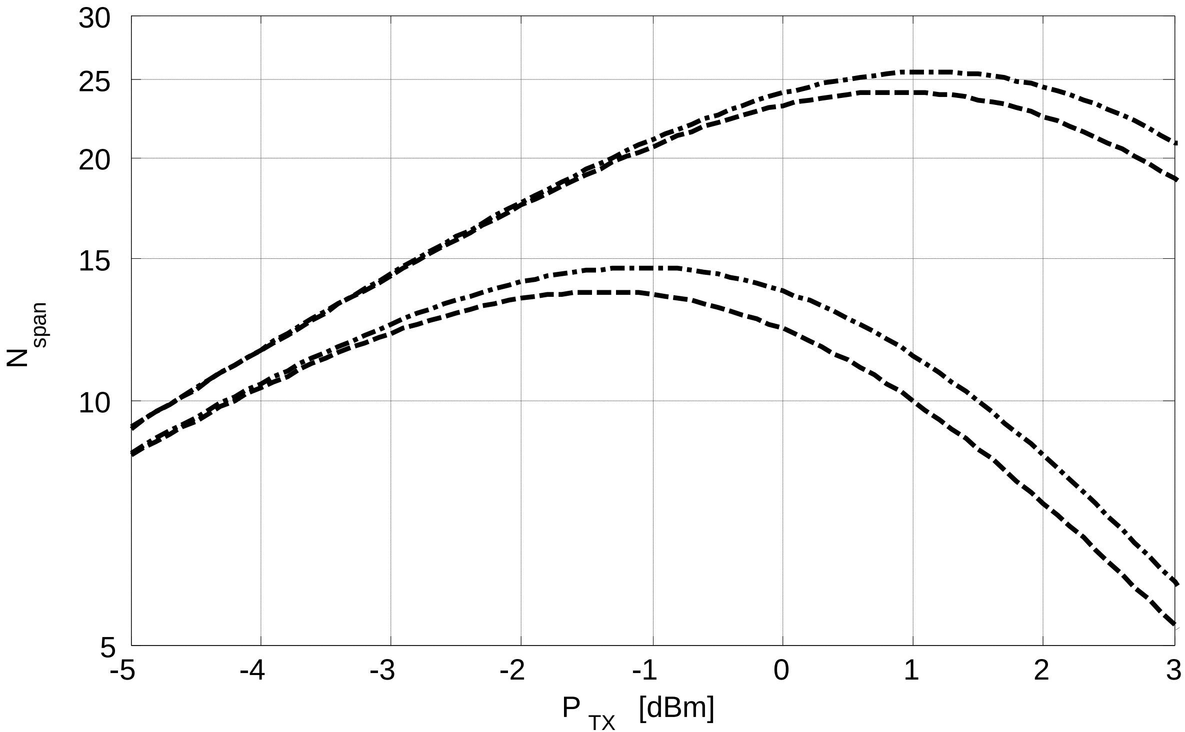


PM-QPSK
L_{span}=110 km

PM-16QAM
L_{span}=80 km

System impact

$BER_{target} = 10^{-3}$



PM-QPSK
L_{span}=110 km

PM-16QAM
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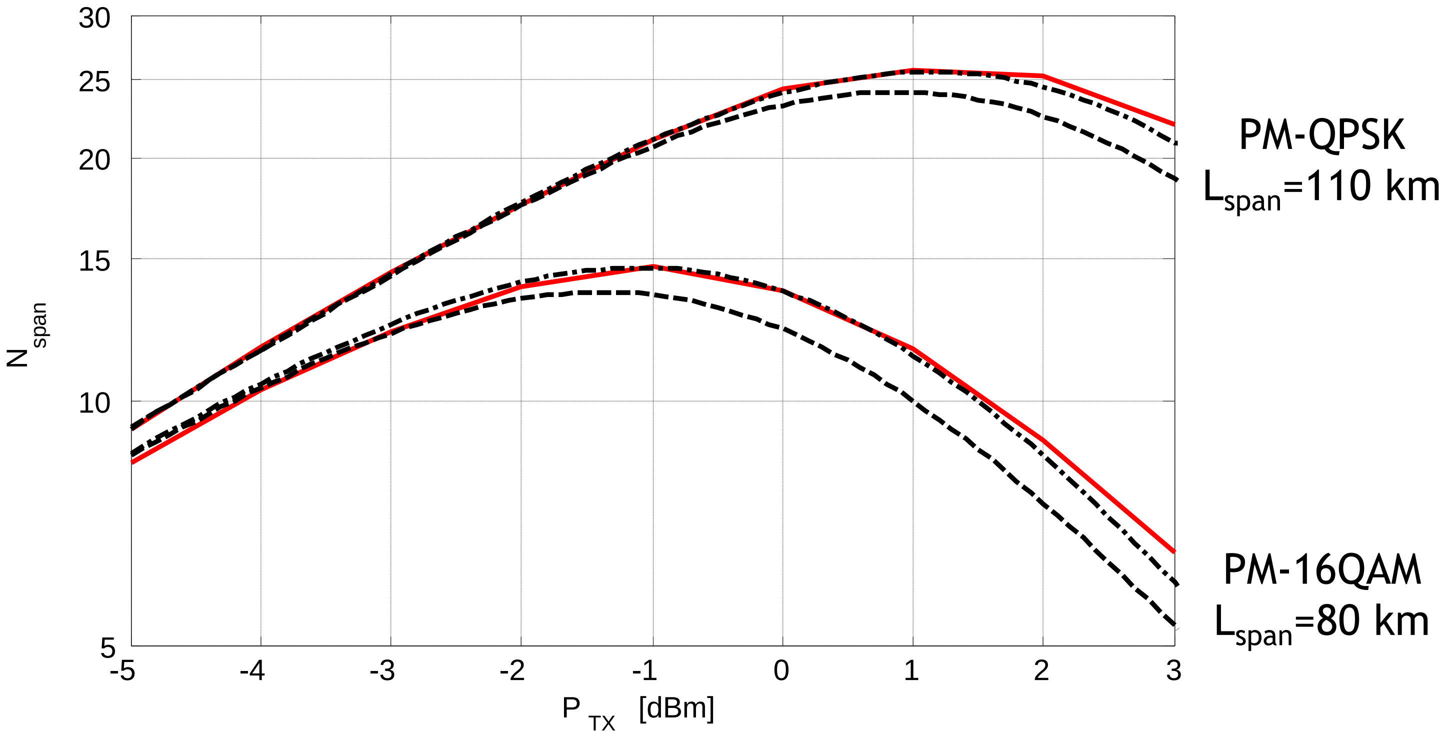
Black dashed:
Coherent
GN-model

Black dash-dotted:
Incoherent
GN-model

System impact

$BER_{target} = 10^{-3}$



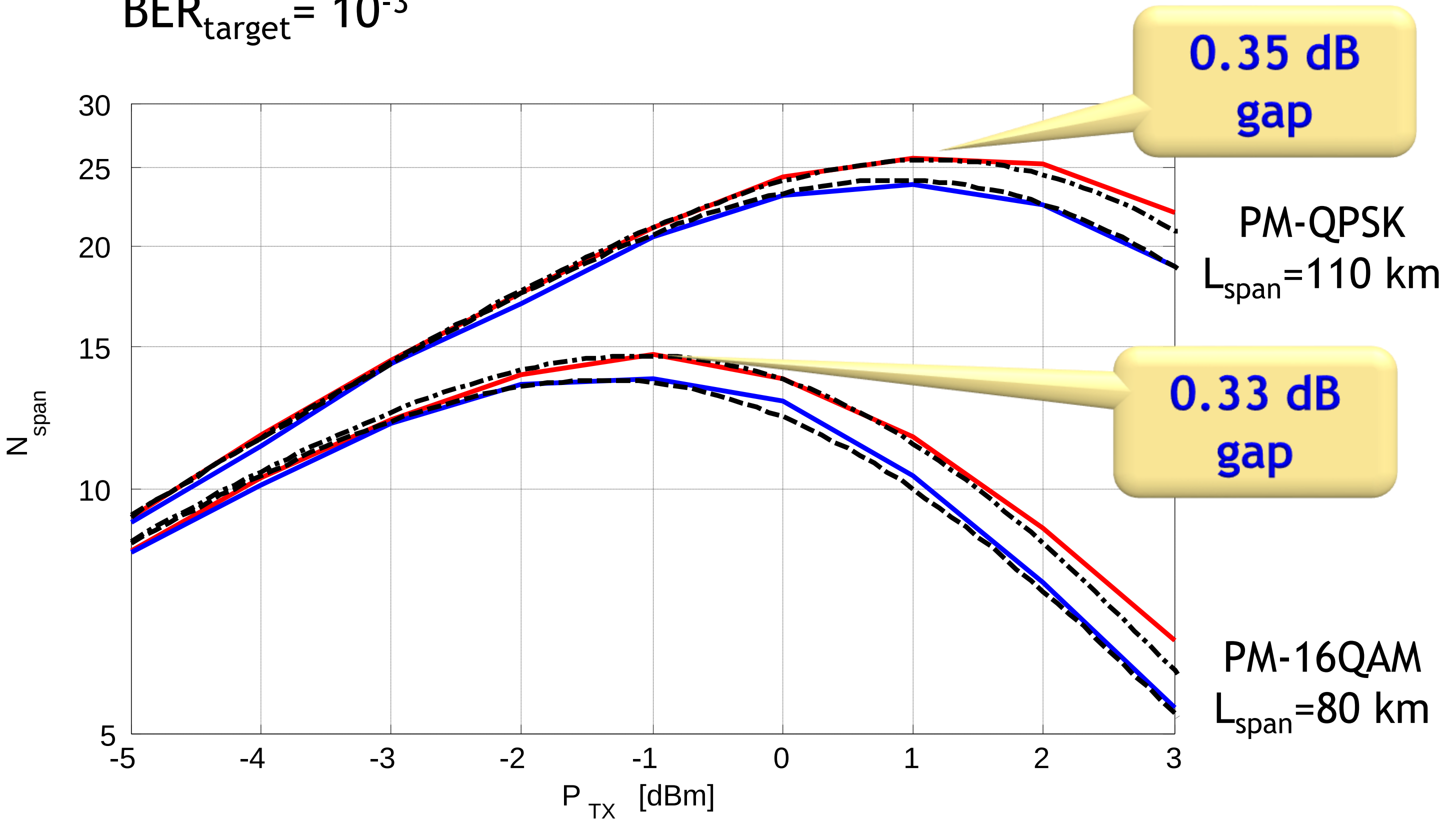
Black dashed:
Coherent
GN-model

Black dash-dotted:
Incoherent
GN-model

Red solid:
Simulation NOPD

System impact

$BER_{target} = 10^{-3}$



Black dashed: Coherent GN-model

Black dash-dotted: Incoherent GN-model

Red solid: Simulation NOPD

Blue solid: Simulation with PD (+200,000 ps/nm)

Conclusions

- The Initial Dispersion Transient does have some impact on the accuracy of the GN-model
- With QAM constellations, the Coherent GN-model always provides a lower bound to system performances
  - High-order constellations show better accuracy because they are closer to Gaussian distribution already at transmitter (higher PAPR)
- The Incoherent GN-model typically delivers good prediction
  - It is not a more faithful modeling, two approximations tend to cancel each other out

Acknowledgments

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