POLITECNICO DI TORINO

ON THE ACCUMULATION OF NON-LINEAR INTERFERENCE IN MULTI-SUBCARRIER SYSTEMS

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OUTLINE

- History and Motivation
- Observation of experimental results and comparison with EGN model predictions
- Extension to general cases
- Conclusions

HISTORY

- Accumulation of non-linear interference (NLI) is an “old” topic
  - A. Carena et al., "Evaluation of the dependence on system parameters of non-linear interference accumulation in multi-span links ", ECOC 2012 Proceedings, paper We.2.C.6.

- Super-linear growth of NLI was found
  - Controversial results over the rate of accumulation
  - F. Vacondio et al., "On nonlinear distortions of highly dispersive optical coherent systems", Optics Express, vol. 20, no. 2, 16 Jan. 2012, pp. 1022-1032.
  - O.V. Sinkin et al., "Scaling of nonlinear impairments in dispersion-uncompensated long-haul transmission", OFC 2012 Proceedings, paper OTuAA.2.
  - G. Bosco et. al, "Experimental investigation of nonlinear interference accumulation in uncompensated links", IEEE Photonics Technology Letters, vol. 24, no. 14, 15 July 2012, pp. 1230-1232.

What has changed meanwhile?

MOTIVATION

- The Enhanced GN model (EGN) has been introduced
- EGN shows that Symbol-Rate Optimization can reduce NLI
  - Optimal symbol-rate are in the range of 2 to 4 Gbaud
- Multi-Subcarrier system is a promising technique to implement SRO reducing non-linear propagation impact
  - Recent experiment have demonstrated that SRO can be achieved

What happens to NLI when a MSC signal is propagated?

NLI ACCUMULATION

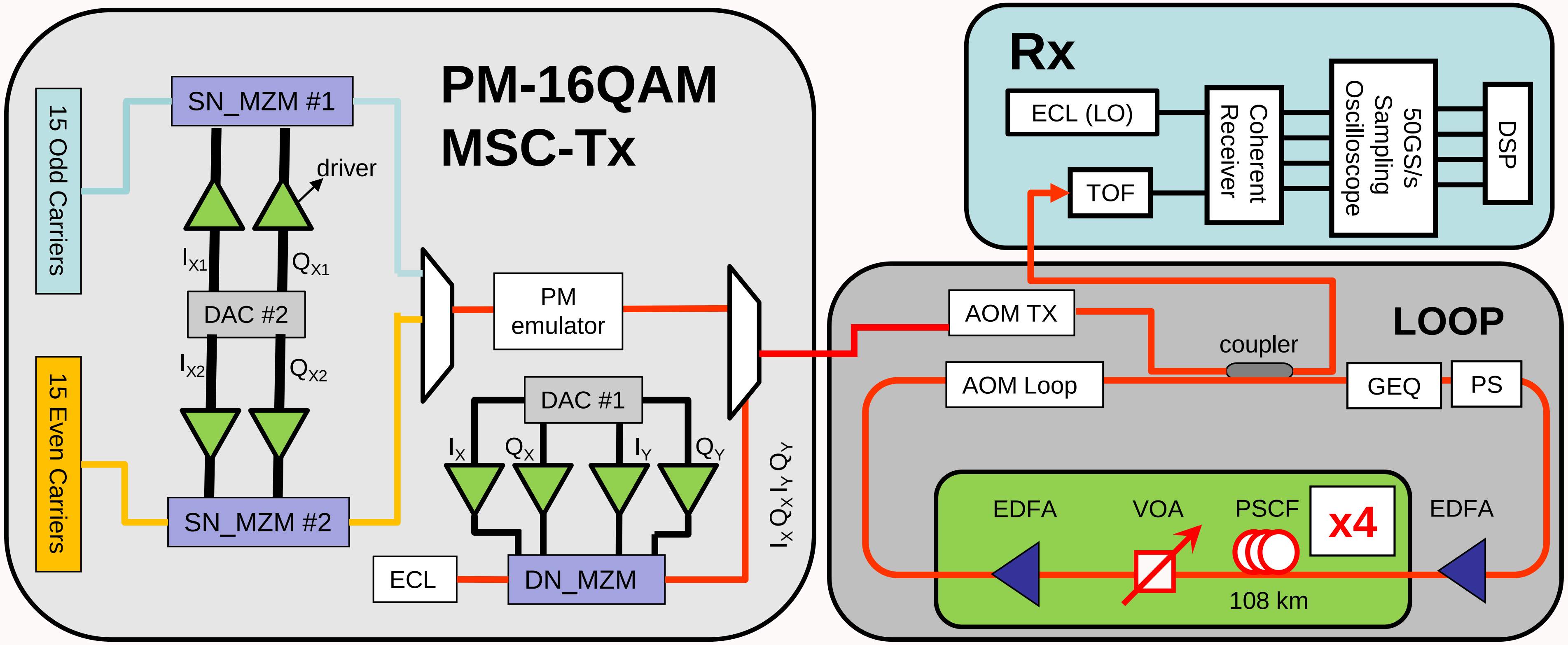
- The GN model predicts a coherent interaction between NLI generated in each span

- Accumulation of NLI in multi-span links predicted by GN model shows a super-linear growth

$$P_{NLI} \approx P_{NLI}^{(1)} \cdot N_{span}^{1+\varepsilon}$$

- EGN-model properly consider the initial dispersion transient
  - NLI accumulation does not exactly follow this law

TRANSMISSION EXPERIMENT SETUP



SN_MZM: single-nested Mach-Zehnder mod.
DN_MZM: double-nested Mach-Zehnder mod.

GEQ: Gain Equalizing programmable filter
PS: synchronous Polarization Scrambler
AOM: Acousto-Optic Modulator (used as switch)
TOF: Tunable Optical Filter
VOA: Variable Optical Attenuator

F. Guiomar et al., "Effectiveness of symbol-rate optimization with PM-16QAM subcarriers in WDM transmission", OFC 2017 Proceedings, paper WE.J.3.
F. Guiomar et al., “Nonlinear mitigation on subcarrier-multiplexed PM-16QAM optical systems”, Optics Express, vol. 25, No. 4, 20 Feb. 2017.

SYSTEM PARAMETERS

- TRANSMITTER
  - Nyquist-WDM PM-16QAM
  - 31 channels – Δf= 28 GHz
  - Aggregated R_S=24 Gbaud
  - MSC transmission from 1 carrier to 12 carriers
    - 1x24 Gbaud
    - 2x12 Gbaud
    - 4x6 Gbaud
    - 6x4 Gbaud
    - 8x3 Gbaud
    - 12x2 Gbaud

- LINK
  - PSCF fiber
  - L=108 km
  - D=20.12 ps/nm/km
  - α=0.162 dB/km

- RECEIVER
  - Ideal CPE → EGN-QPSK
    - All details on cited papers
  - Measurements from 3^{rd} to 10^{th} recirculation

MEASUREMENT OBSERVATION: FROM BER TO P_{NLI}

- From BER to SNR

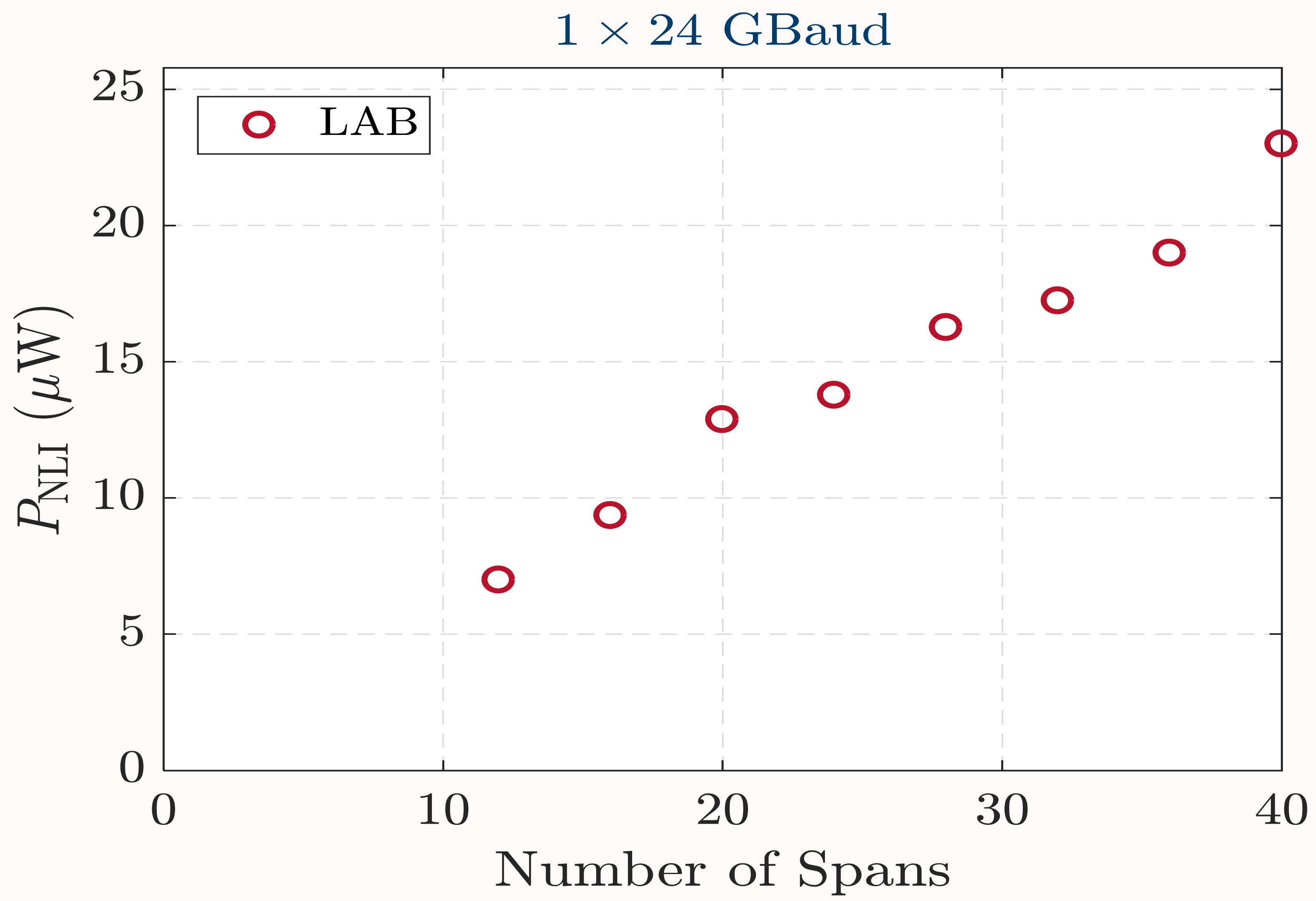
$$SNR_{meas} = \Psi^{-1}(BER)$$

- From SNR to P_{NLI}

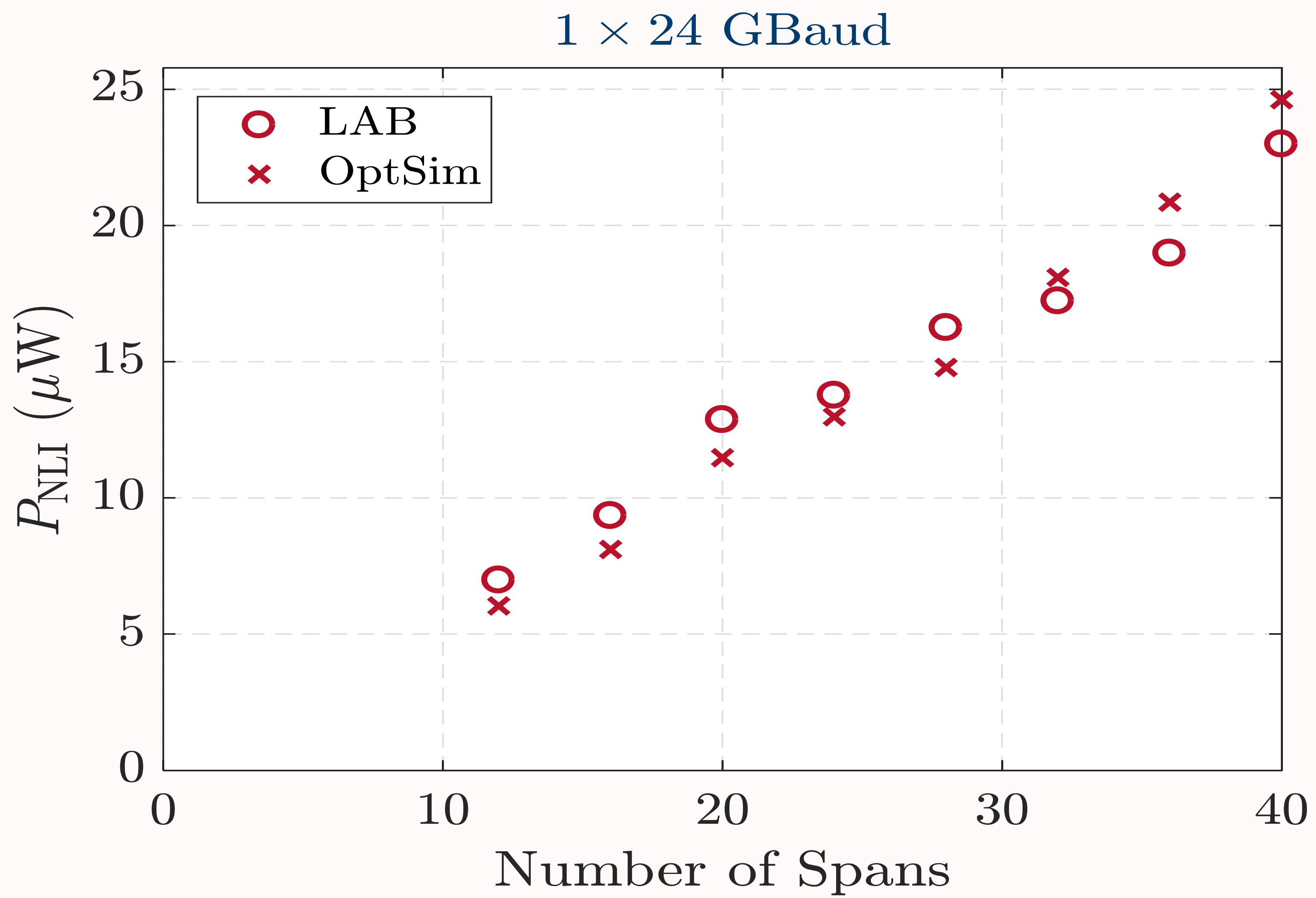
$$SNR_{meas} = \frac{P_{TX}}{P_{ASE} + P_{B2B} + P_{NLI}}$$

P_{B2B} takes into account back-to-back penalties

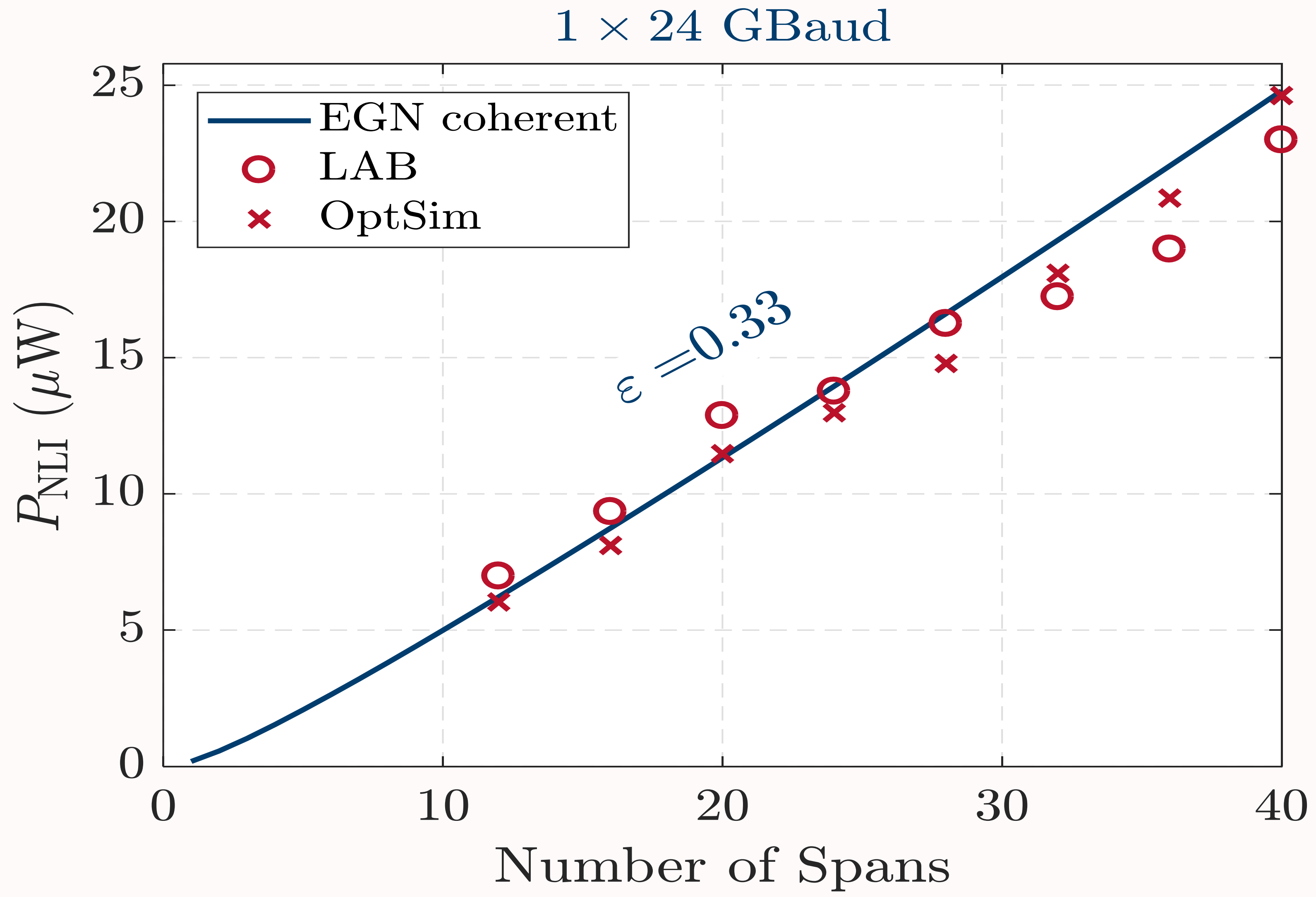
P_{NLI} vs N_{span}: Single Carrier



P_{NLI} vs N_{span}: Single Carrier



P_{NLI} vs N_{span}: Single Carrier



$$P_{NLI} \approx P_{NLI}^{(1)} \cdot N_{span}^{1+\varepsilon}$$

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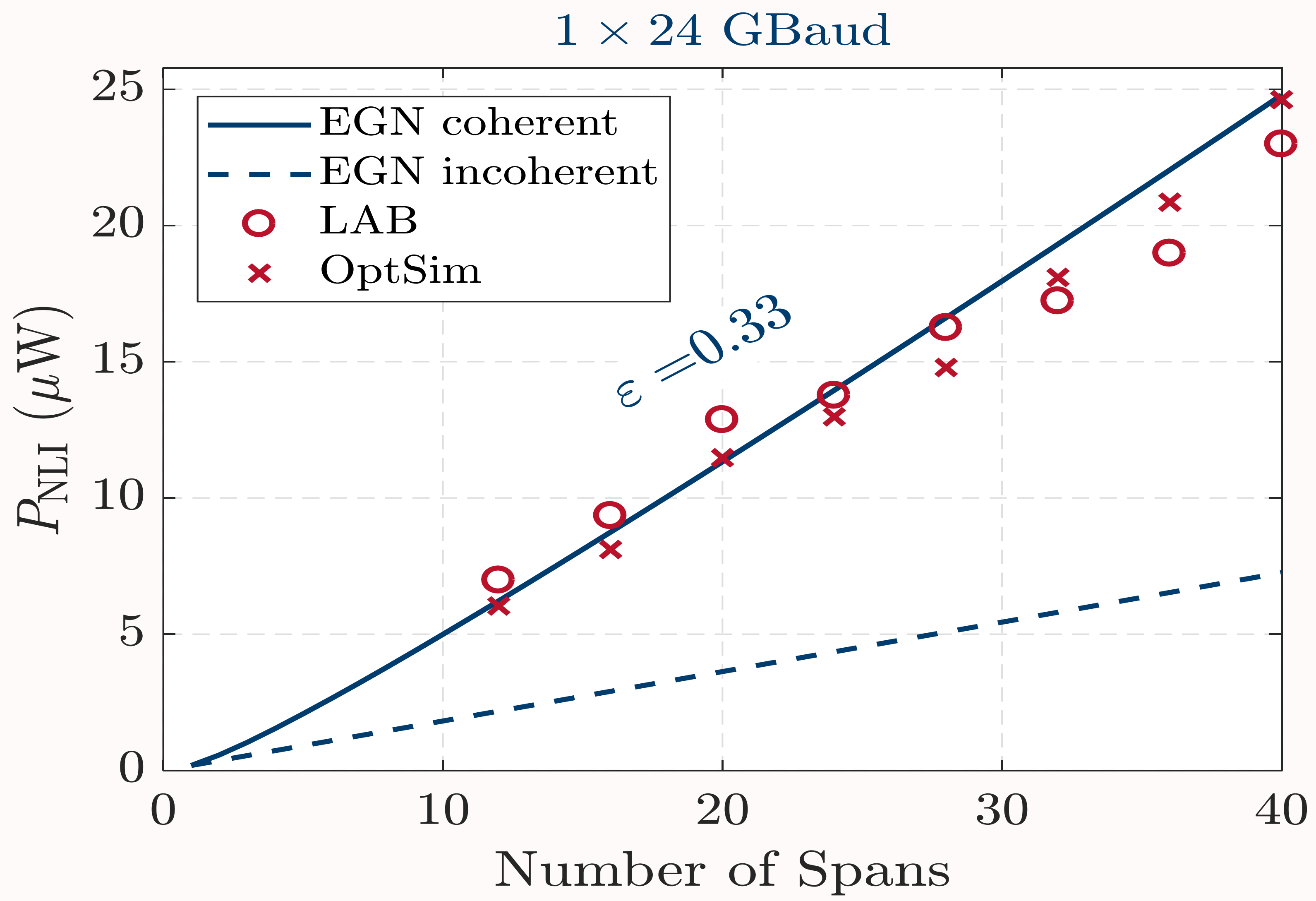
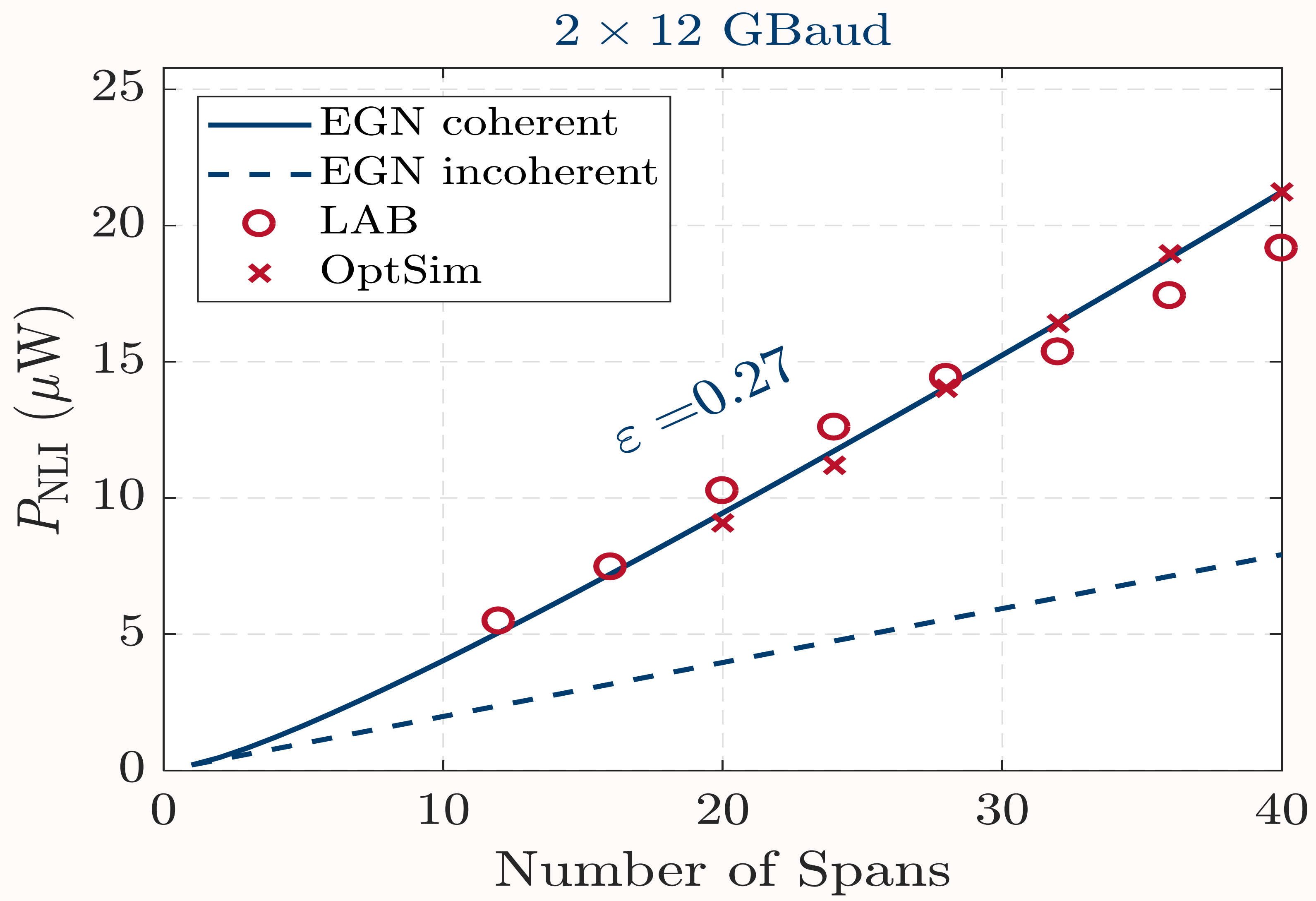
P_{NLI} vs N_{span}: Single Carrier



EGN incoherent

$$P_{NLI} \approx P_{NLI}^{(1)} \cdot N_{span}$$

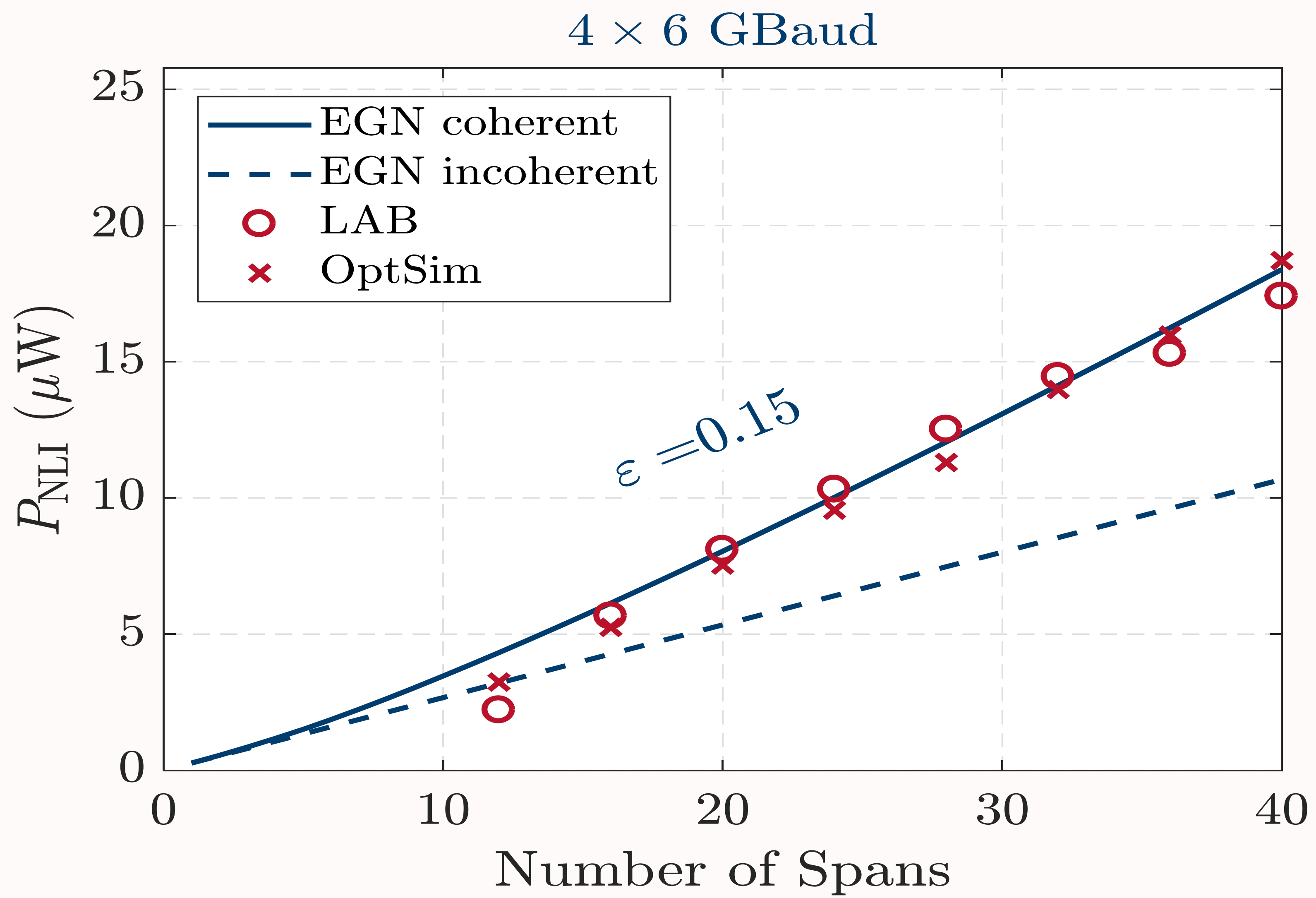
P_{NLI} vs N_{span}: 2 Sub-Carriers



EGN incoherent

$$P_{NLI} \approx P_{NLI}^{(1)} \cdot N_{span}$$

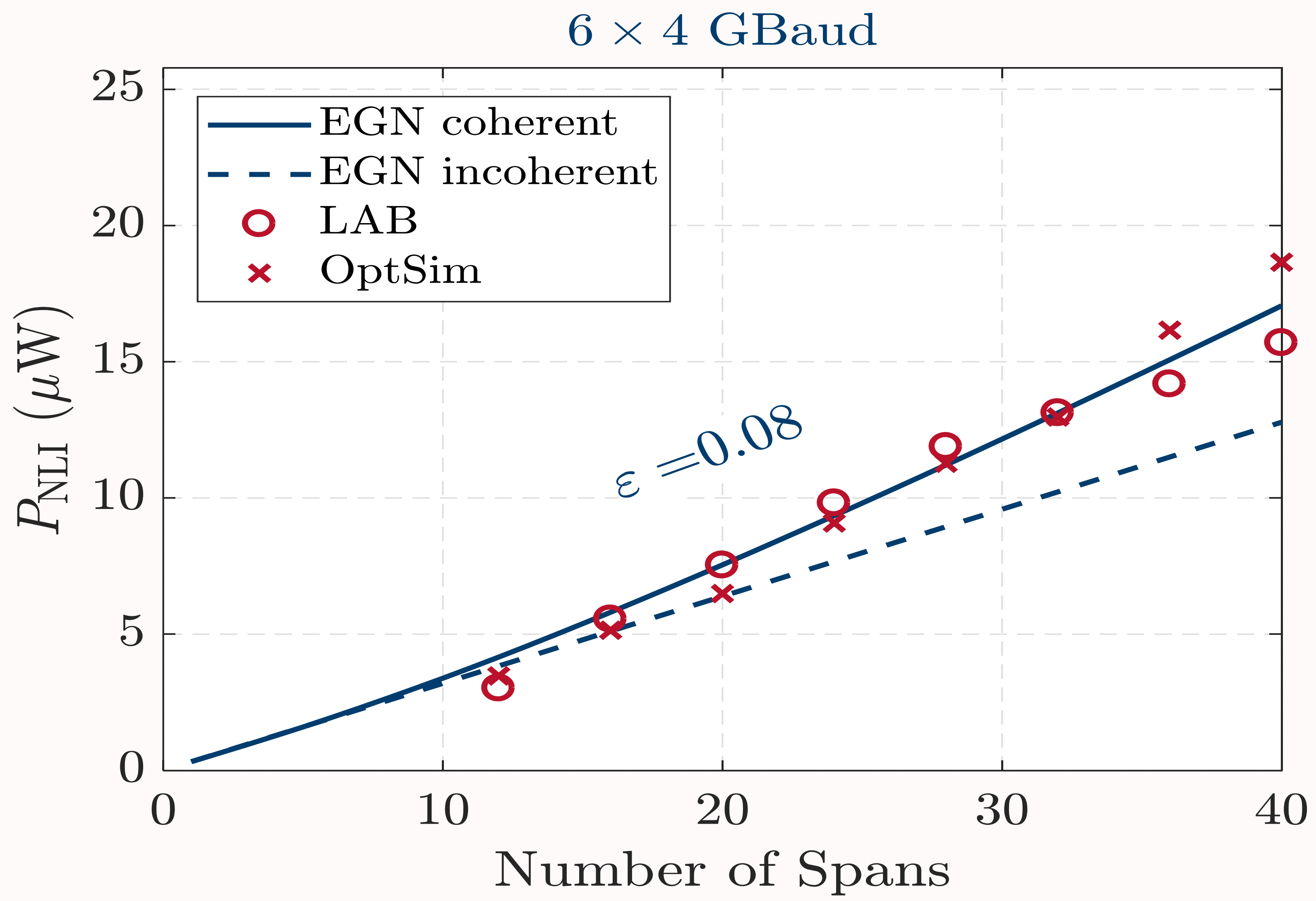
P_{NLI} vs N_{span}: 4 Sub-Carriers



EGN incoherent

$$P_{NLI} \approx P_{NLI}^{(1)} \cdot N_{span}$$

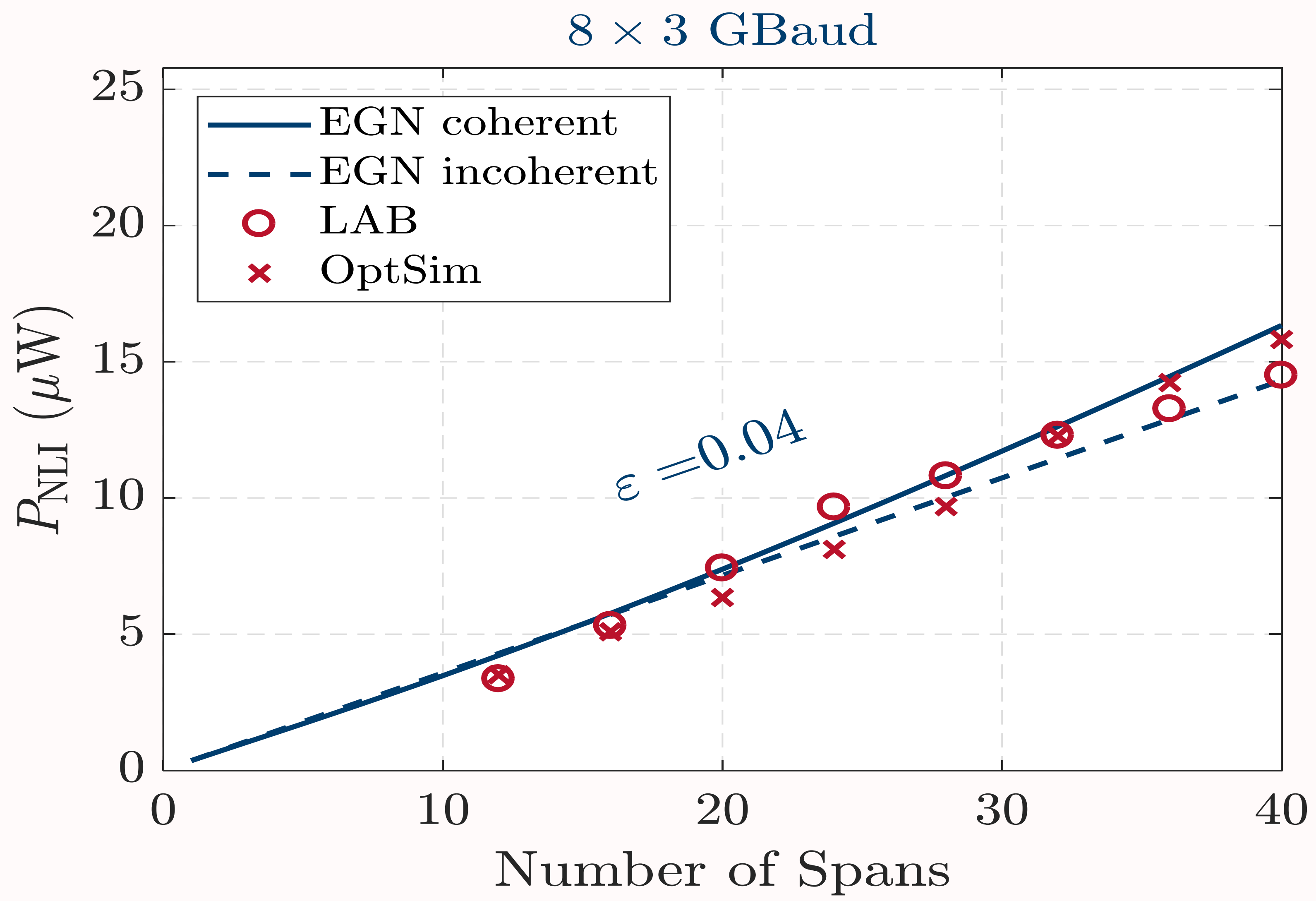
P_{NLI} vs N_{span}: 6 Sub-Carriers



EGN incoherent

$$P_{NLI} \approx P_{NLI}^{(1)} \cdot N_{span}$$

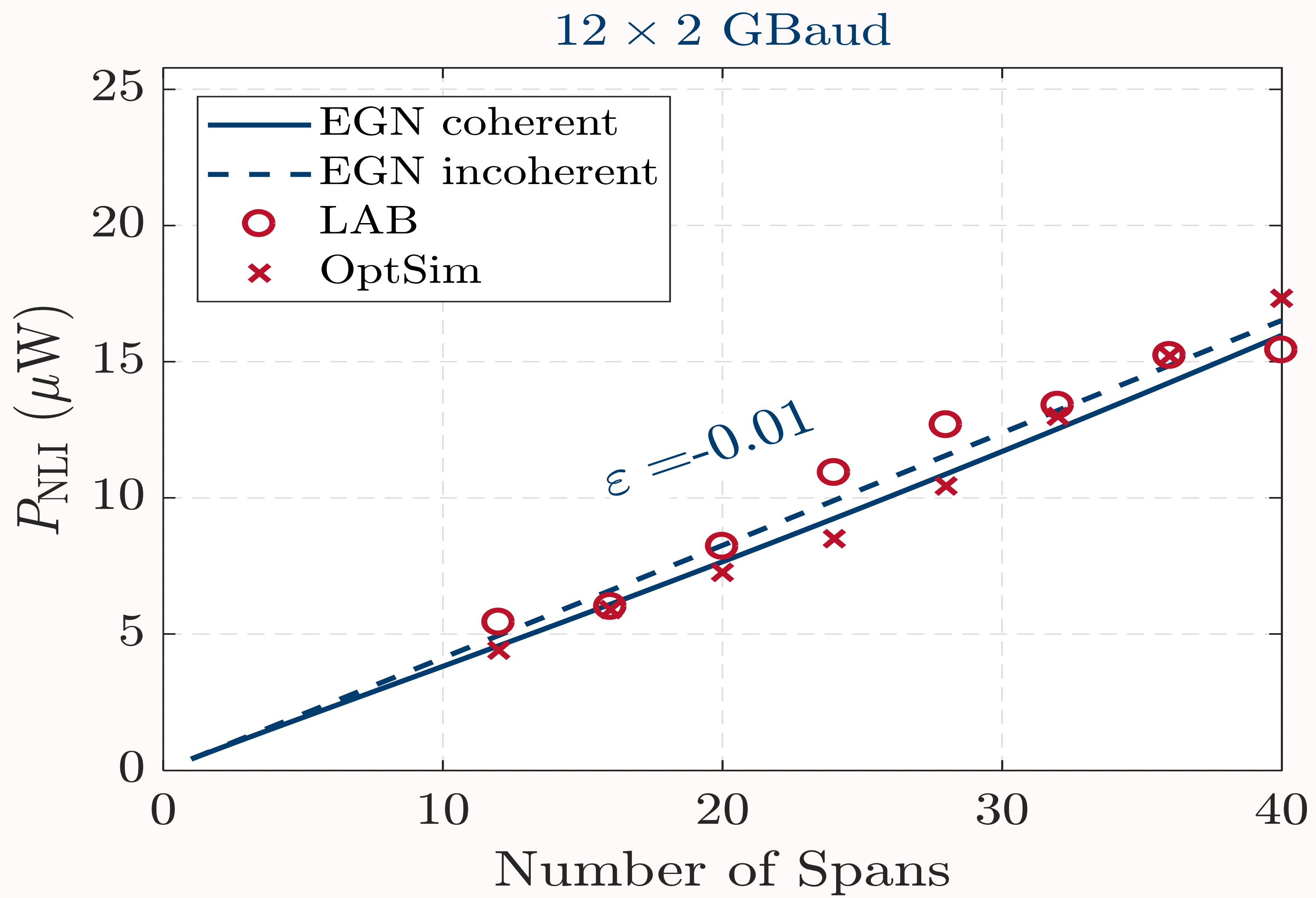
P_{NLI} vs N_{span}: 8 Sub-Carriers



EGN incoherent

$$P_{NLI} \approx P_{NLI}^{(1)} \cdot N_{span}$$

P_{NLI} vs N_{span}: 12 Sub-Carriers



EGN incoherent

$$P_{NLI} \approx P_{NLI}^{(1)} \cdot N_{span}$$

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EXTENSION TO GENERAL CASES

- What happen when varying the number of channels?
- What happen when varying channel spacing?
- What happen when changing fiber type?

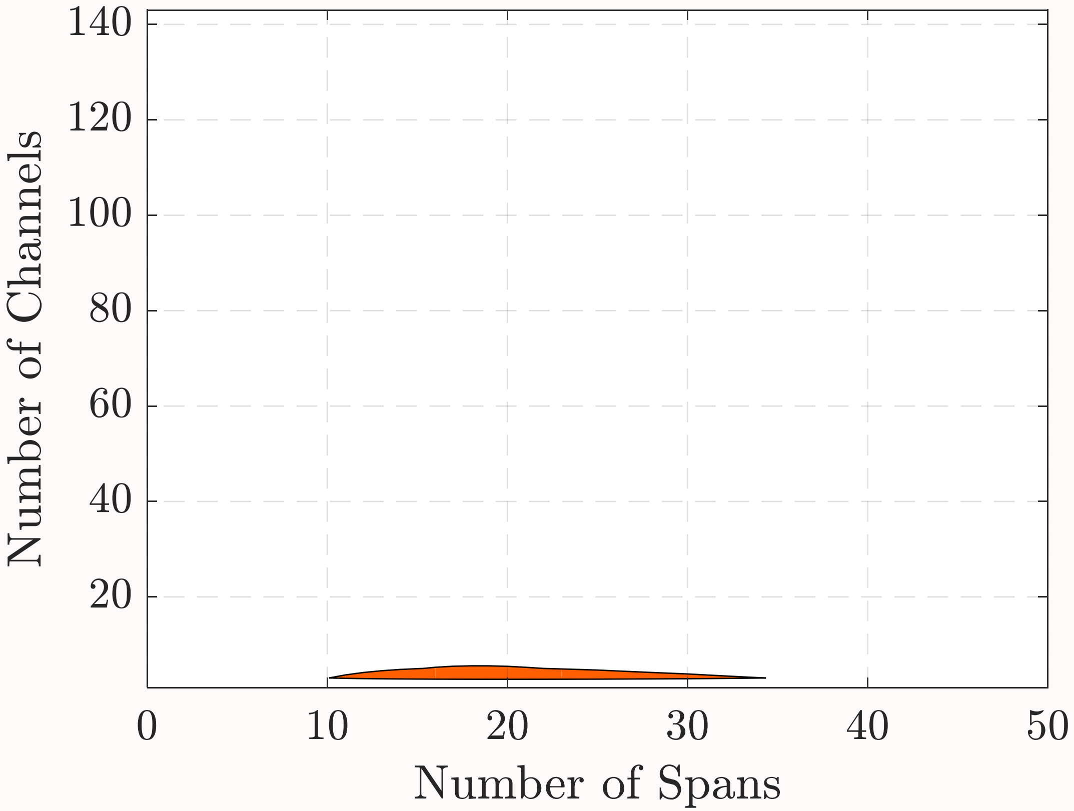
- We need an error parameter to characterize the difference between EGN coherent and EGN incoherent

$$\text{Error} = 10 \cdot \log_{10}\left(\frac{P_{NLI,EGNcoh}}{P_{NLI,EGNinc}}\right)$$

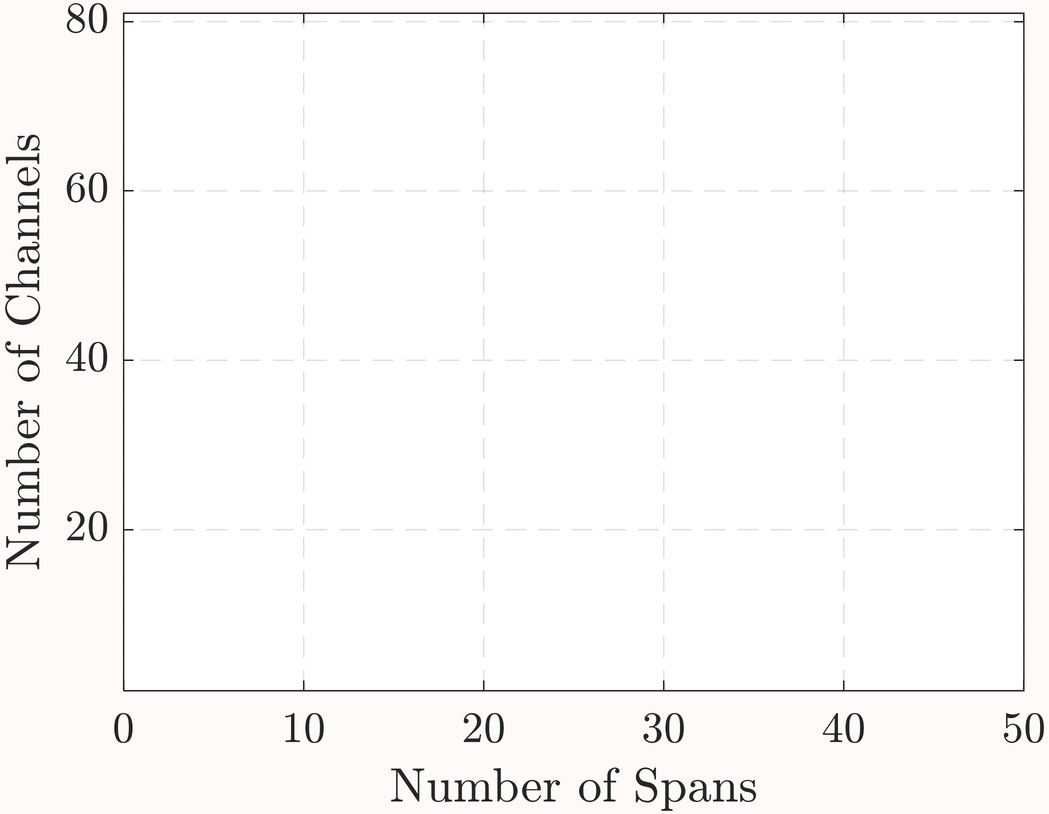
abs(Error) < 0.5 dB: PSCF

12 Sub-Carriers

Δf=28 GHz

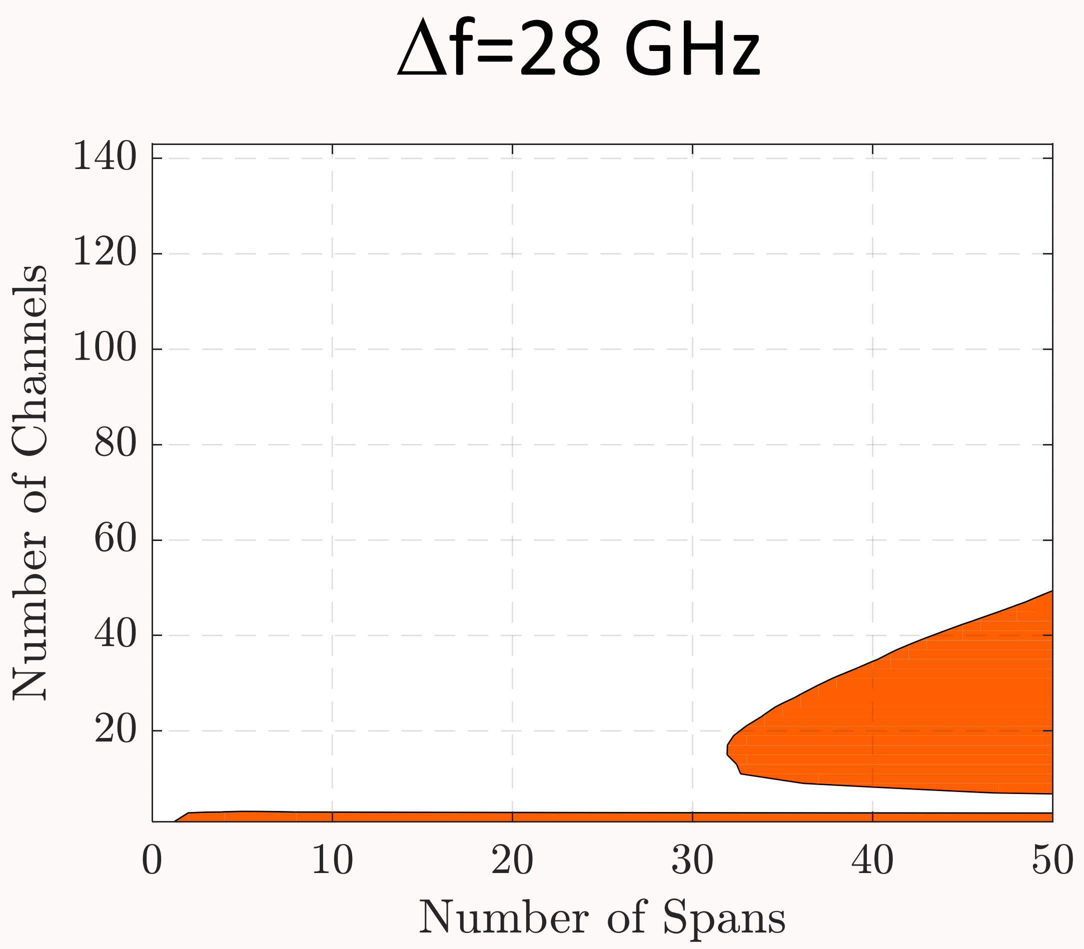


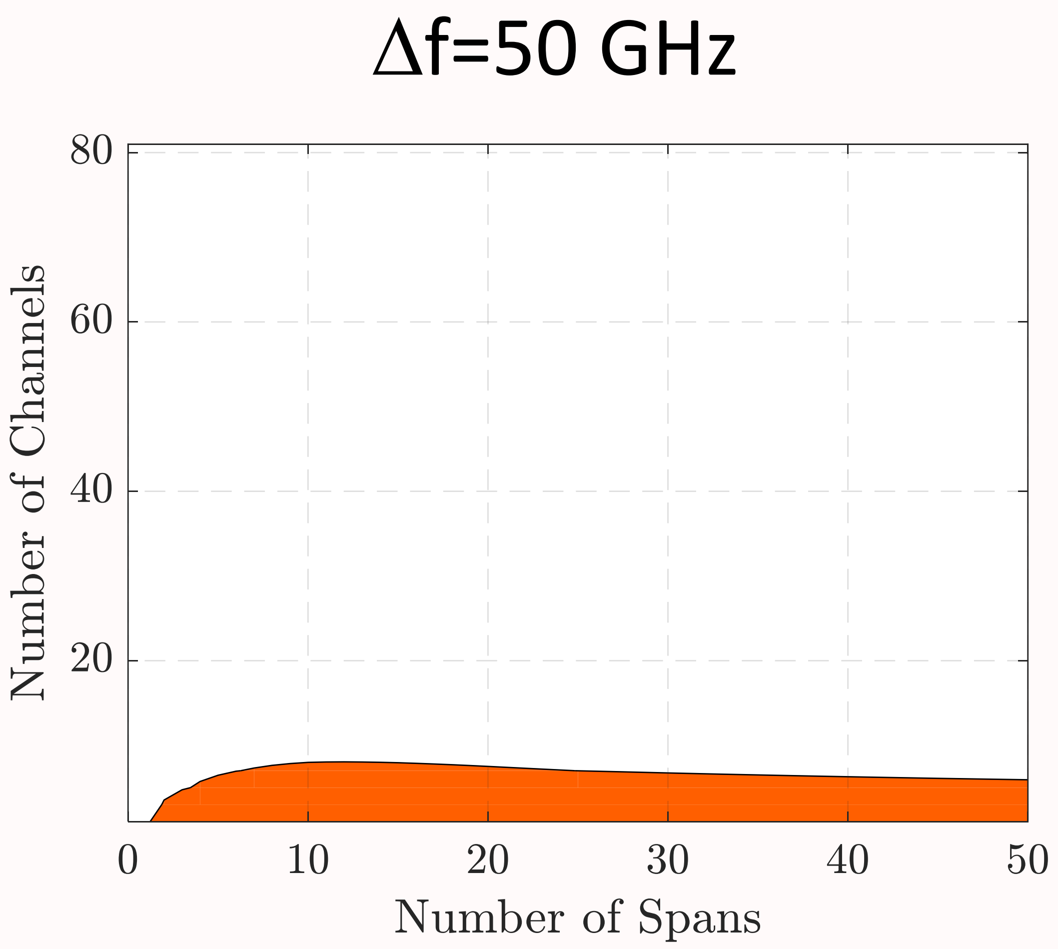
Δf=50 GHz



abs(Error) < 0.5 dB: NZDSF

12 Sub-Carriers





IMPACT ON SYSTEM PERFORMANCE

- MAXIMUM REACH

$$L_{MAX} \propto \sqrt[3]{\frac{1}{P_{NLI}}} \Rightarrow \Delta L_{MAX,dB} = -\frac{1}{3}\Delta P_{NLI,dB}$$

- OSNR MARGIN

$$OSNR_{MAX} \propto \sqrt[3]{\frac{1}{P_{NLI}}} \Rightarrow \Delta OSNR_{MAX,dB} = -\frac{1}{3}\Delta P_{NLI,dB}$$

P_{NLI} error [dB]	System performance [dB]
0.5	0.17

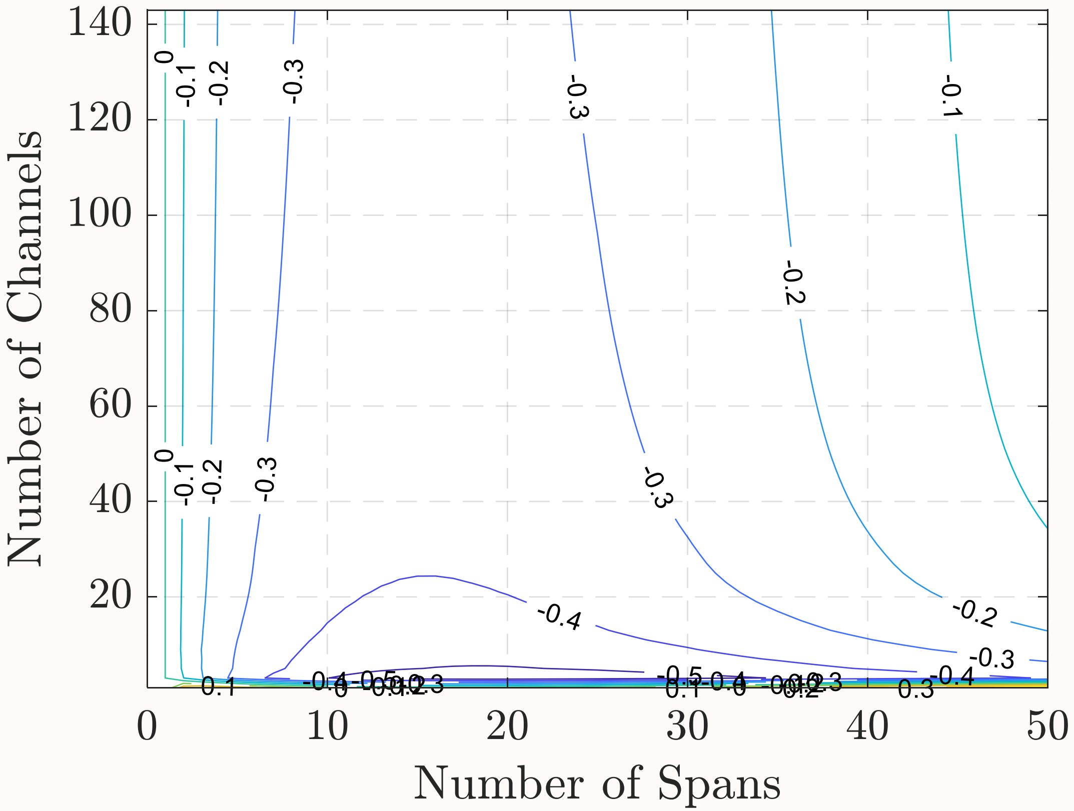
↓ 4%

Inaccuracies in NLI estimation are mitigated by a factor of 1/3 when used to determine system performances

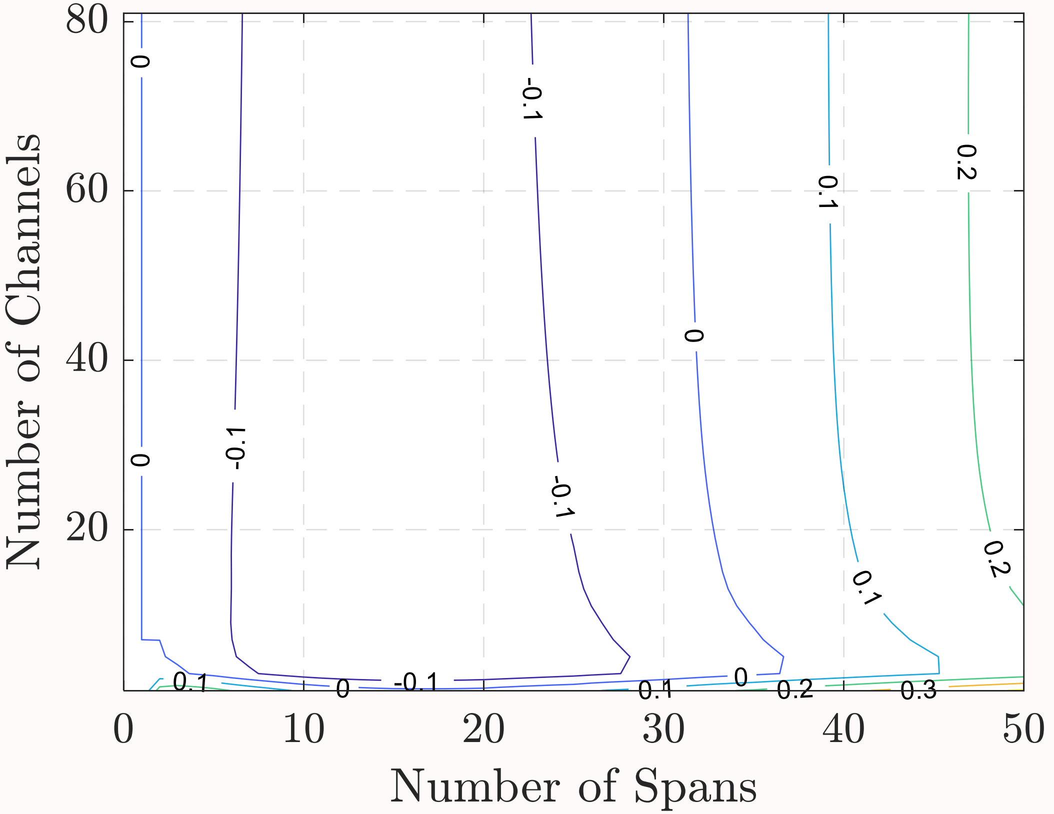
Error : PSCF

12 Sub-Carriers

Δf=28 GHz



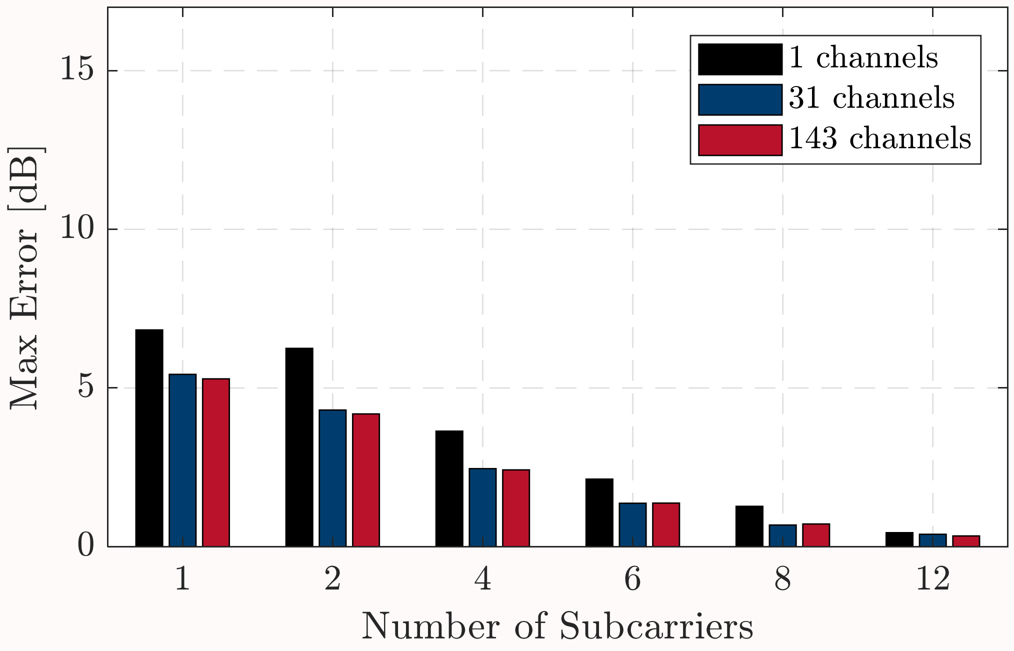
Δf=50 GHz



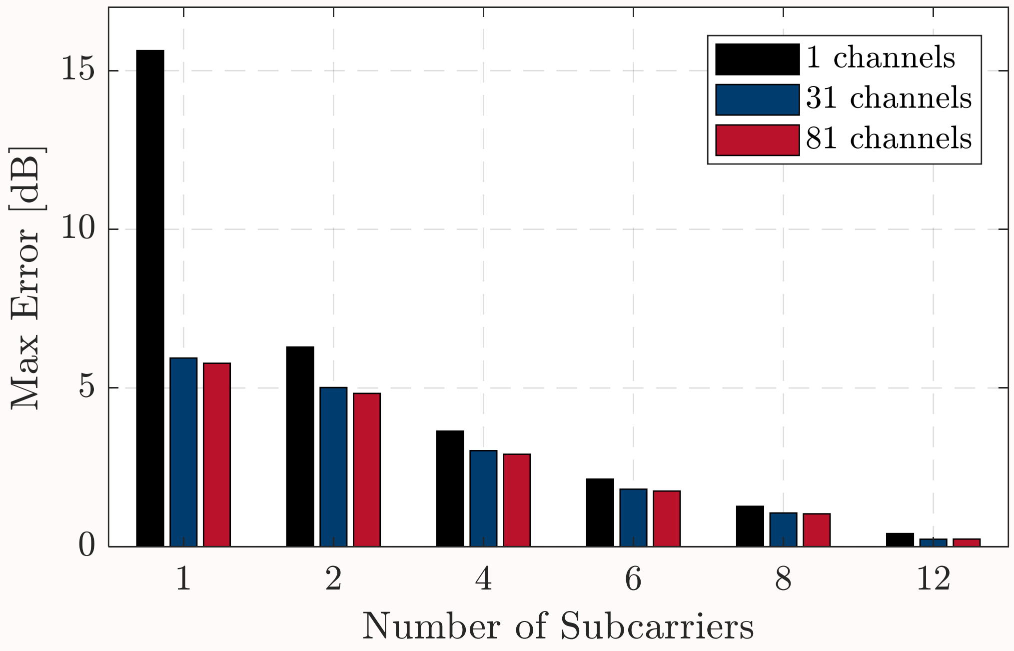
PSCF Fiber: Max Error

$$\text{Max Error} = \max_{N_{span}} \left[|\text{Error}| \right]$$

Δf=28 GHz



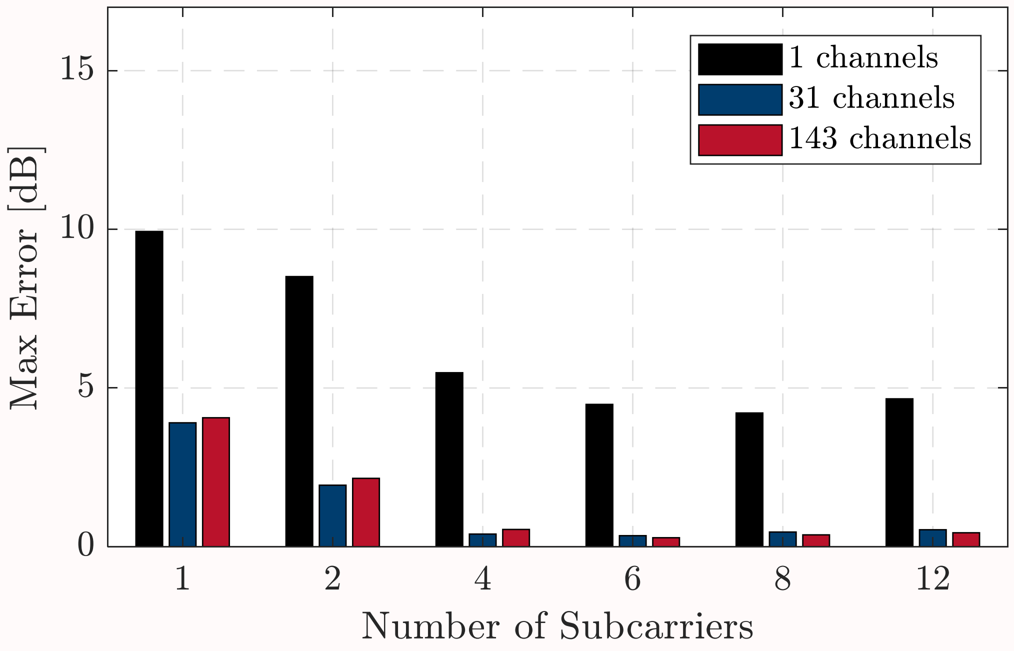
Δf=50 GHz



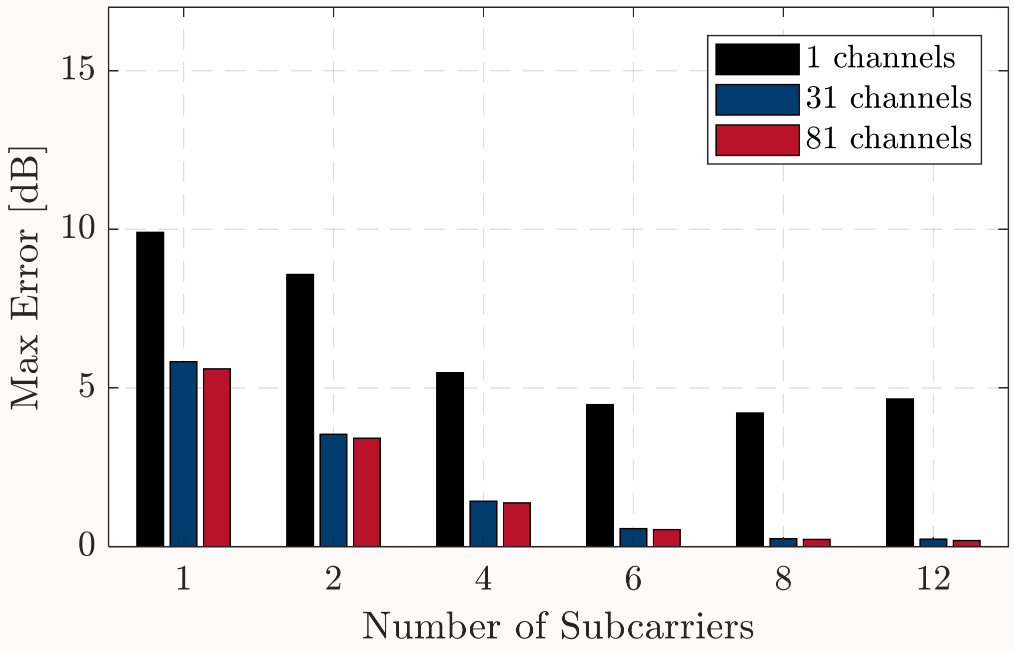
NZDSF Fiber: Max Error

$$\text{Max Error} = \max_{N_{span}} \left[\left| \text{Error} \right| \right]$$

Δf=28 GHz



Δf=50 GHz



CONCLUSIONS

- Experimental observations show that NLI accumulation in multi-subcarrier system with low symbol-rate is almost incoherent (linear)
- The "EGN-incoherent" model can predict NLI with good approximation
  - For high dispersion and high channel count it overestimate P_{NLI}
- This behavior allows for a simplified NLI evaluation
  - Faster evaluation based on single span EGN model
  - It could be employed in physical layer aware network planning tools

Acknowledgments

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