OFC 2018
MAR 12TH, 2018 - SAN DIEGO
PRESENTATION #M1D.2

MODELLING THE IMPACT OF SRS ON NLI GENERATION IN COMMERCIAL EQUIPMENT: AN EXPERIMENTAL INVESTIGATION

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OUTLINE

- QoT Estimations in Wideband Optical Systems
- Experimental Reference Results
- Assessment of Modeling Options for Wideband QoT-E
- Conclusions

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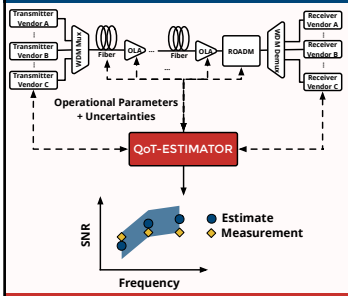
QUALITY OF TRANSMISSION ESTIMATION IN OPTICAL SYSTEMS

MOTIVATIONS AND CHALLENGES

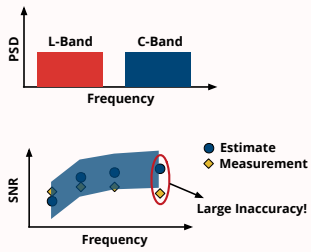
QOT-E: MODELING OPTIONS AND EXPECTED ACCURACY



- **Vendor agnostic Quality-of-Transmission Estimators (QoT-Es)** are nowadays **developed for multi-vendor network design** and network management and **orchestration**
- Many **QoT-E** are **based** on existing models such as the **Gaussian Noise (GN) model**
- Several **validation efforts made with with commercial equipment** showed that GN-model based **QoT-Es yield** good accuracy (**+/- 0.5 dB SNR uncertainty**) at the **center of the WDM comb with good knowledge of operational parameters of the devices**[1-2]
- Can we **keep such accuracy level across the full WDM comb?**

1. M. Filer *et al.*, "**Multi-vendor Experimental Validation of an Open Source QoT Estimator for Optical Networks**," JLT, 2018
2. G. Grammel *et. al.*, "**Physical Simulation Environment of the Telecommunications Infrastructure Project (TIP)**," OFC 2018, M1D.3

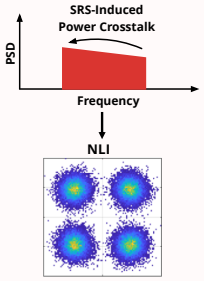
WHY WIDEBAND QOT-E?



- **C+L Systems** are getting traction as a possible **solution to capacity crunch**
- **QoT-Es** operating in such scenarios need **to keep constant accuracy levels across the full WDM comb**
- **NLI generation is not bandwidth limited** for spectral occupations **up to 10s of THz**[1-2]**, also in presence of strong PMD**[2]
- Other wideband effect such as **Stimulated Raman Scattering (SRS) must be taken into account**

1. G. Saavedra *et al.*, "**Experimental Analysis of Nonlinear Impairments in Fibre ...**," JLT, Oct. 2017
2. M. Cantono *et al.*, "**Observing the Interaction of PMD with Generation of NLI in Uncompensated Amplified Optical Links**", OFC 2018, W1G.4

GOAL OF THIS PAPER

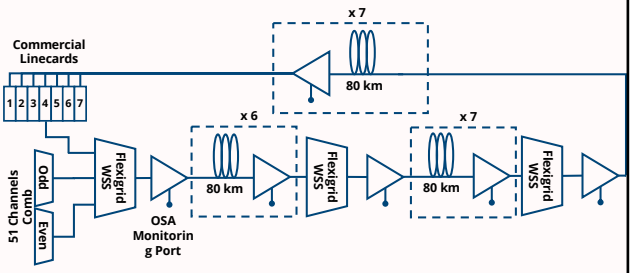


- We aim at **comparing different QoT-E oriented NLI modeling approaches in presence of SRS**
- This is **critical** in wideband scenario in order **to**
  - **Deliver consistent QoT estimations** across the full spectral comb
  - **Improve design** of wideband systems where the **impact of SRS on NLI** is often **masked by large margins or** line management strategies yielding **QoT-suboptimal spectrum flattening**

EXPERIMENTAL SETUP

REFERENCE SCENARIO

THE ORANGE LAB TESTBED

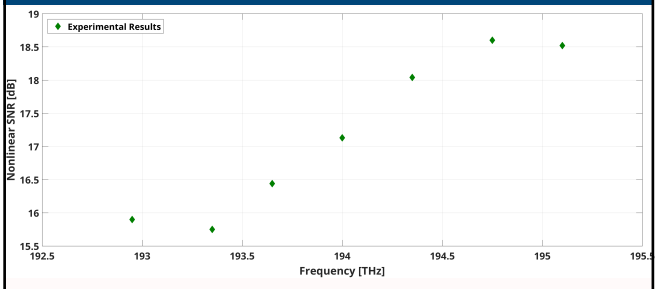


THE ORANGE TESTBED

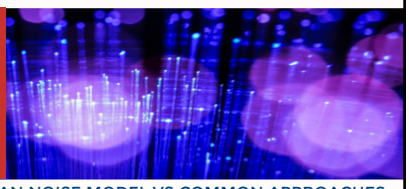
- **20x80km** Corning SMF-28e+
- **58 channels**
  - **7 commercial 32 GBaud PM-QPSK** 100 Gbps Transceivers (**CUTs**)
  - 51 lab 28 GBaud PM-QPSK 100 Gbps Transceivers
- Launch Power = **+0.4 dBm** per channel
- **Linear OSNR measurement performed through OSA** after each amplifier
- Measured **Q-factor** were mapped **to SNR values** exploiting **back-to-back measurements**

$$\mathrm{SNR_{NLI}} = \left[\frac{1}{\mathrm{SNR_{GEN}}} - \frac{1}{\mathrm{OSNR_{LIN}}}\right]^{-1}$$

REFERENCE EXPERIMENTAL RESULTS

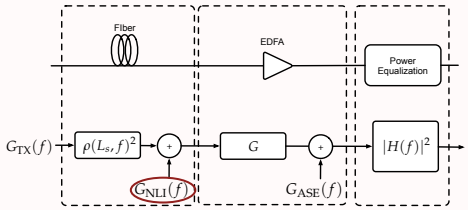


MODELING OPTIONS FOR WIDEBAND QOT ESTIMATION



THE GENERALIZED GAUSSIAN NOISE MODEL VS COMMON APPROACHES

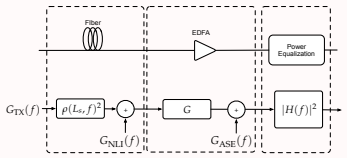
EQUIVALENT SPAN MODEL FOR QOT-E



SOURCE OF UNCERTAINTIES IN QOT-E

- For the considered setup the **main source of uncertainty** is represented by the **connector loss** of each span.
- **Nominal** SNR estimations are obtained assuming **0.75 dB connector loss**
- **Typical values in between 0.5 and 1 dB** have been considered as well, yielding **variations in the nonlinear SNR estimations** of the order of **+/- 0.5 dB**.
- If **experimental SNR values fall within this range** from the nominal estimation, the **modeling** option **is successful in performance estimation**.

OPTION 1: THE GN-MODEL



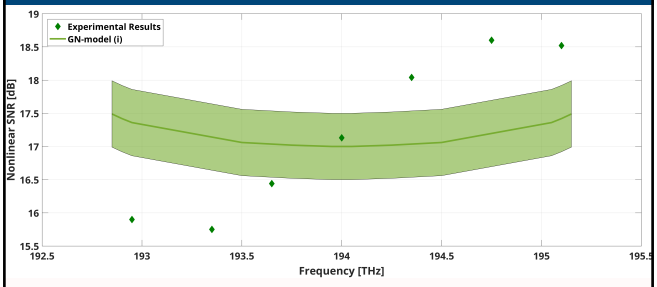
- The PSD of NLI noise is evaluated via the **incoherent GN model**[1]
- **No SRS-induced tilt** assumed in the fiber, i.e.

$$\rho(L_s,f)^2 = e^{-2\alpha L_s}$$

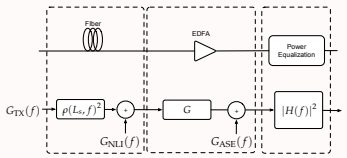
$$G_{NLI}(z,f) = \frac{16}{27}\gamma^2\rho(z,f)^2 \iint_{-\infty}^{+\infty} G_{TX}(f_1)G_{TX}(f_2)G_{TX}(f_1+f_2-f)\left|\frac{1-e^{-2\alpha L_s+j4\pi^2\beta_2 L_s(f_1-f)(f_2-f)}}{2\alpha-j4\pi^2\beta_2 L_s(f_1-f)(f_2-f)}\right|^2 \mathrm{d}f_1\mathrm{d}f_2$$

1. P. Poggiolini *et al.*, "**The GN-model of Fiber…** ," JLT, vol. 32, no. 4, Feb. 2014

OPTION 1: THE GN-MODEL



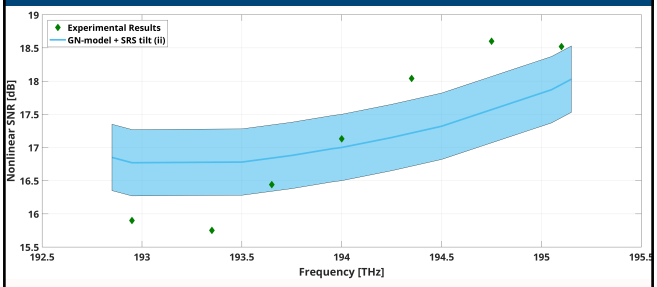
OPTION 2: THE GN-MODEL + SRS TILTING



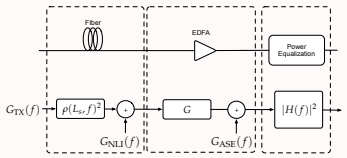
- The PSD of NLI noise is evaluated via the **incoherent GN model**[1]
- **SRS-induced tilt** is **computed numerically** via the pump-and-probe equations
- **SRS and NLI** generation are **assumed as two independent effects**

1. P. Poggiolini *et al.*, "**The GN-model of Fiber…** ," JLT, vol. 32, no. 4, Feb. 2014

OPTION 2: THE GN-MODEL + SRS TILTING



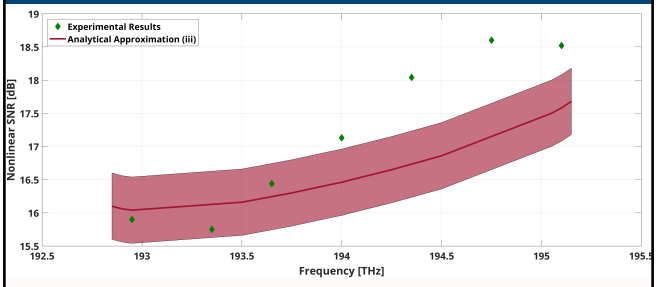
OPTION 3: THE GN-MODEL W/ FREQUENCY-DEPENDENT EFFECTIVE LENGTH



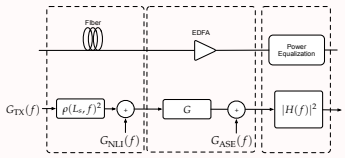
- The PSD of NLI noise is evaluated via the analytical approximation of the incoherent GN model[1]
- **SRS-induced tilt** is **computed numerically** via the pump-and-probe equations
- **SRS tilt** is used to compute **frequency dependent effective lengths** that are **plugged into GN-model** calculations

1. P. Poggiolini *et al.*, "**The GN-model of Fiber…** ," JLT, vol. 32, no. 4, Feb. 2014

OPTION 3: THE GN-MODEL W/ FREQUENCY-DEPENDENT EFFECTIVE LENGTH



OPTION 4: THE GENERALIZED GAUSSIAN NOISE MODEL

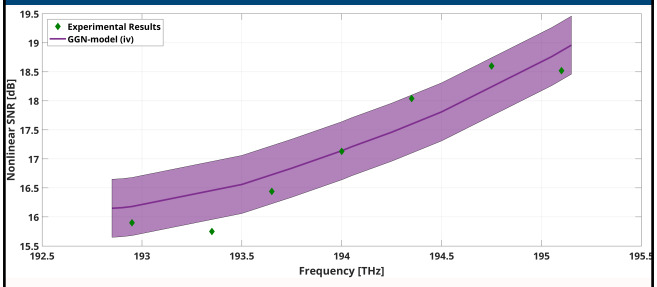


- The **PSD of NLI noise is evaluated via the incoherent GGN model**[1]
- **SRS-induced tilt** is **computed numerically** via the pump-and-probe equations

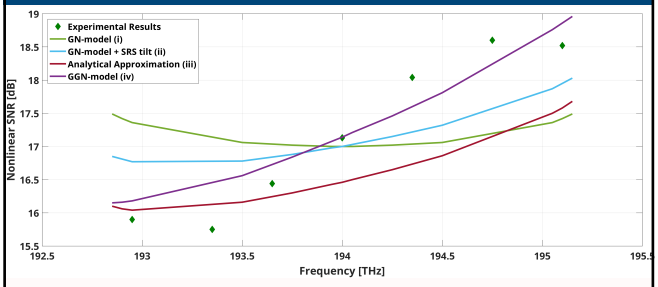
$$G_{\mathrm{NLI}}(z,f)=\frac{16}{27}\gamma^2\rho(z,f)^2\iint_{-\infty}^{+\infty}G_{\mathrm{TX}}(f_1)G_{\mathrm{TX}}(f_2)G_{\mathrm{TX}}(f_1+f_2-f)\left|\int_0^z e^{+j\Delta\beta(f,f_1,f_2)\zeta}\cdot\Delta\rho(f,f_1,f_2,\zeta)\mathrm{d}\zeta\right|^2\mathrm{d}f_1\mathrm{d}f$$

1. M. Cantono *et al.*, "On the Interplay of Nonlinear Interference Generation with Stimulated Raman Scattering for QoT Estimation ", JLT, March 2018, 10.1109/JLT.2018.2814840

OPTION 4: THE GENERALIZED GAUSSIAN NOISE MODEL



SUM UP



CONCLUSIONS

- Assessing the **interplay between SRS and NLI generation is fundamental for wideband QoT Estimation**
- **Commonly used approaches** and models can be used to deliver **good QoT estimations at the center of the WDM comb**
- The same approaches **fail in delivering consistent estimation across the full comb**, with estimation errors larger than +/- 0.5 dB
- The recently introduced **Generalized GN model** instead represents a good option to overcome such limitation as it is able to **reliable estimate QoT across the full WDM comb**.

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QUESTIONS? THANK YOU

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