Propagation impairments due to Raman effect on the coexistence of GPON, XG-PON, RF-video and TWDM-PON

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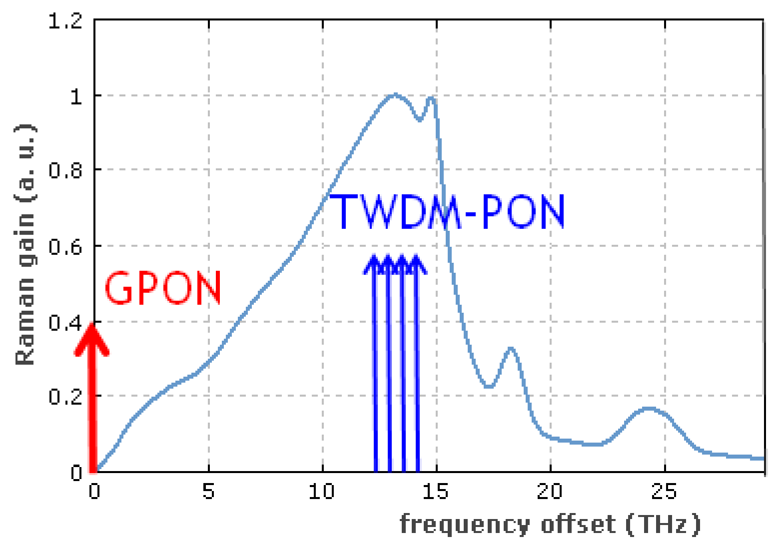
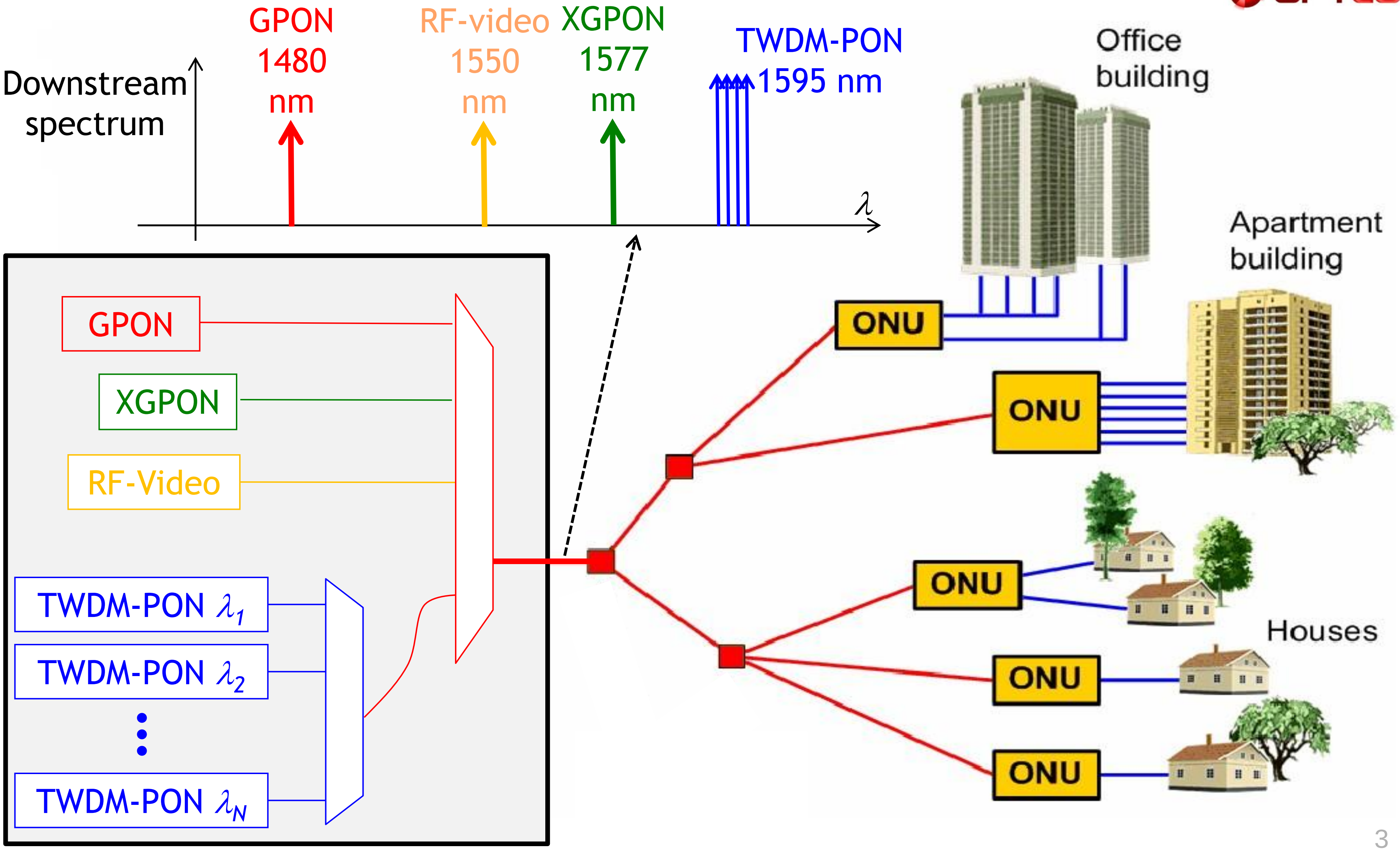
Effects of SRS in TWDM-PON and GPON

- **TWDM-PON wavelength allocation for the downstream**
  - 4-8 wavelengths around 1600 nm
  - Approximately 110 nm distance from GPON at 1490 nm
- **The problem**: the spectral distance is exactly at the maximum efficiency of Raman crosstalk
  - Strong TWDM-PON signals can **deplete** GPON signal in the downstream due to RAMAN nonlinearity
  - We show that this problem sets a **maximum Tx power level** for TWDM-PON signals



Full coexistence scenario



Spilt-step simulations

Main parameters

- Up to L_{feed}=40 km of G.652 (SSMF) feeder fiber
  - α_{dB} = 0.22 dB/km, D = 16 ps/nm/km,
  - δ_{PMD} = 0.1 ps/sqrt(km), A_{eff} = 80 μm^2
- GPON:
  - 1490 nm, 2.5 Gbit/s, NRZ, power: +3 to +7 dBm
- RF-video
  - 1555 nm, up to +16 dBm
- XG-PON:
  - 1577 nm, 10 Gbit/s, NRZ, power:+8 to +12 dBm
- TWDM-PON: Δf=100 GHz, 1595-1600nm first four λ's,
  - 1600-1605 nm for the possible upgrade to other four λ's, launched power per channel from +9 to +13 dBm.

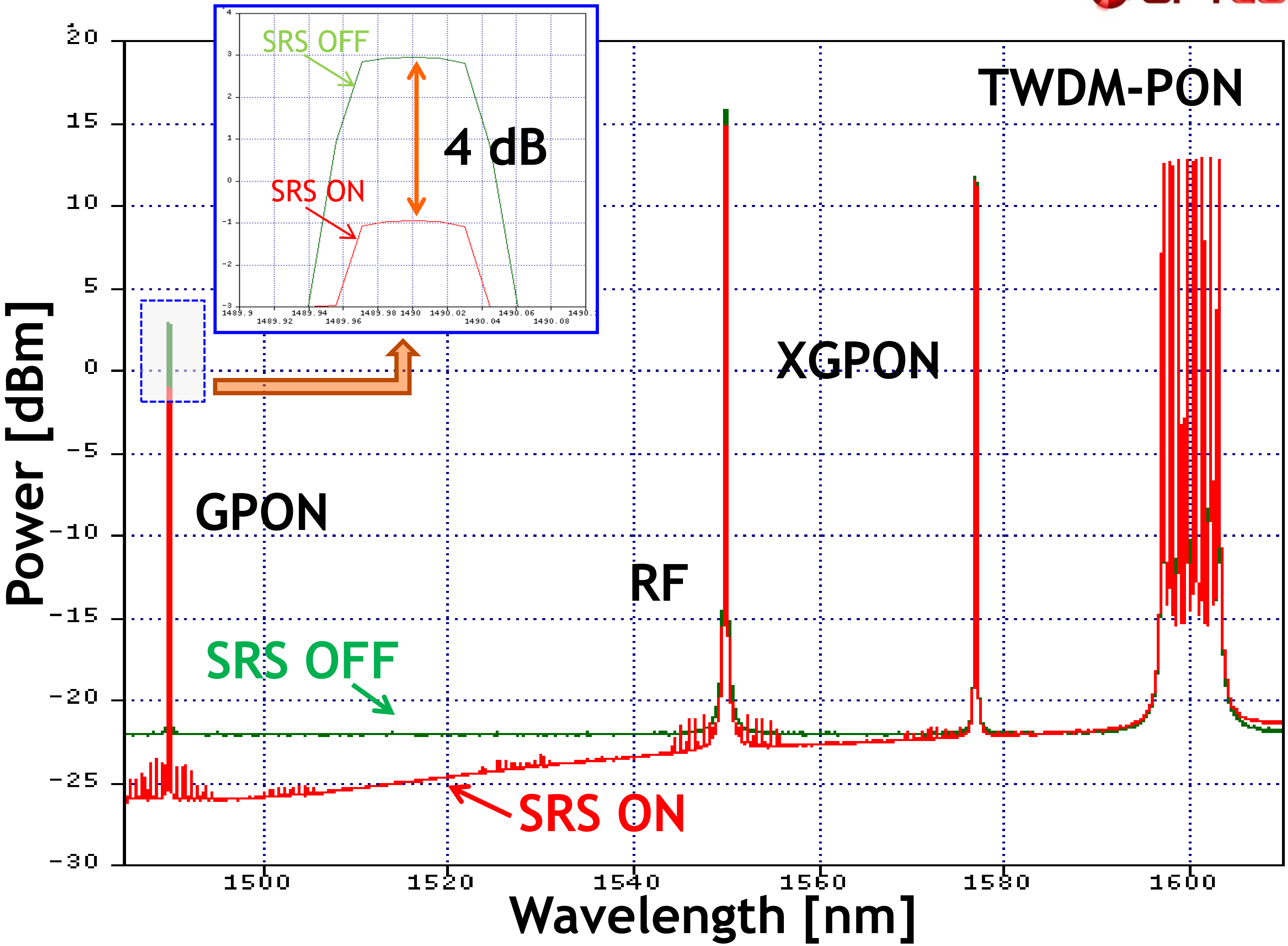
Simulative results: Rx spectrum

L= 40 km

P_{RF} = 16 dBm

P_{XGPON} = 12 dBm

P_{TWDM} = 13 dBm



Simulative results

- **Progressively turning on propagation effects we observed:**
  - **Linear effects ON** (loss, dispersion, PMD): only attenuation observed, no significant signal distortion
  - **Kerr effect ON**: no extra penalty
  - **SRS ON**: **extra loss on GPON observed (A_{GPON})**, no signal distortion

P_{RF} = 16 dBm

P_{XGPON} = 12 dBm

P_{TWDM} = 13 dBm

N_{TWDM}	A_{GPON} [dB]			
	5 km	10 km	20 km	40 km
4	0.6	1.1	1.8	2.4
8	1.0	1.8	2.9	4.0

Simulative analysis: conclusions

- We **did not observe** any time-dependent intra- or inter-**channel distortion** effects due to linear (chromatic dispersion) or nonlinear (Kerr effect and SRS) phenomena
- We estimated an **extra attenuation A_{GPON}** on GPON channel due to SRS-induced power transfer from GPON channel to the channels at lower frequencies
- **SRS-induced gain** on channels at lower frequencies (i.e. higher wavelengths) is practically **irrelevant**

- **We propose an analytical model for this transmission scenario taking into account only fiber loss and GPON depletion due to SRS**

A simple analytical model

We assume that RF, XG-PON and TWDM-PON channels experience fiber loss only , while GPON is affected by SRS depletion as well. So, supposing relative depolarization among channels (*$DOP_{TX}=0$*) in fiber propagation, the evolution of GPON power P_{GPON} with z is given by

$$\frac{\partial P_{GPON}(z)}{\partial z} = -\{\alpha_{GPON} + C_{R,XGPON} P_{XGPON}(z) + C_{R,RF} P_{RF}(z) + N_{TWDM} C_{R,TWDM} P_{TWDM}(z)\} P_{GPON}(z)$$

$$\text{with } P_i(z) = P_i e^{-\alpha_i z}$$

where α_{GPON} is the fiber loss [1/km] at the GPON λ, $C_{R,i}$ [1/km/mW] are polarization-averaged SRS efficiencies at (λ_i - λ_{GPON}) and P_i are the power levels [mW] per channel, with *i* = XGPON, RF, TWDM.

The SRS-induced GPON extra loss

The equation has a simple analytical solution, so the SRS-induced GPON extra loss can be written as

$$A_{GPON}^{dB} = 10\log_{10}(\mathrm{e}) \begin{Bmatrix} C_{R,RF} L_{e,RF} P_{RF} + C_{R,XGPON} L_{e,XGPON} P_{XGPON} + \\ + C_{R,TWDM} L_{e,TWDM} N_{TWDM} P_{TWDM} \end{Bmatrix} \text{ [dB]}$$

where $L_{e,i}$ are the effective lengths at different λ's

$$L_{e,i} = 10\log_{10}(\mathrm{e}) \frac{1-10^{-\frac{\alpha_{dB,i}}{10}L}}{\alpha_{dB,i}} \text{ [km]}$$

and $C_{R,i}$ are the polarization-averaged SRS efficiencies at different spectral spacing

$$C_{R,i} = C_R\left(\lambda_i - \lambda_{GPON}\right) \quad \left[\frac{1}{\mathrm{mW}\cdot\mathrm{km}}\right]$$

A_{GPON} for G.652 fiber

Considering the spectral placing of the DS channels and the λ dependence of the $C_{R,i}$ coefficients:

$$C_{R,TWDM} \cong C_{R,\max} \qquad C_{R,XGPON} \cong \tfrac{8}{9} C_{R,\max} \qquad C_{R,RF} \cong \tfrac{1}{2} C_{R,\max}$$

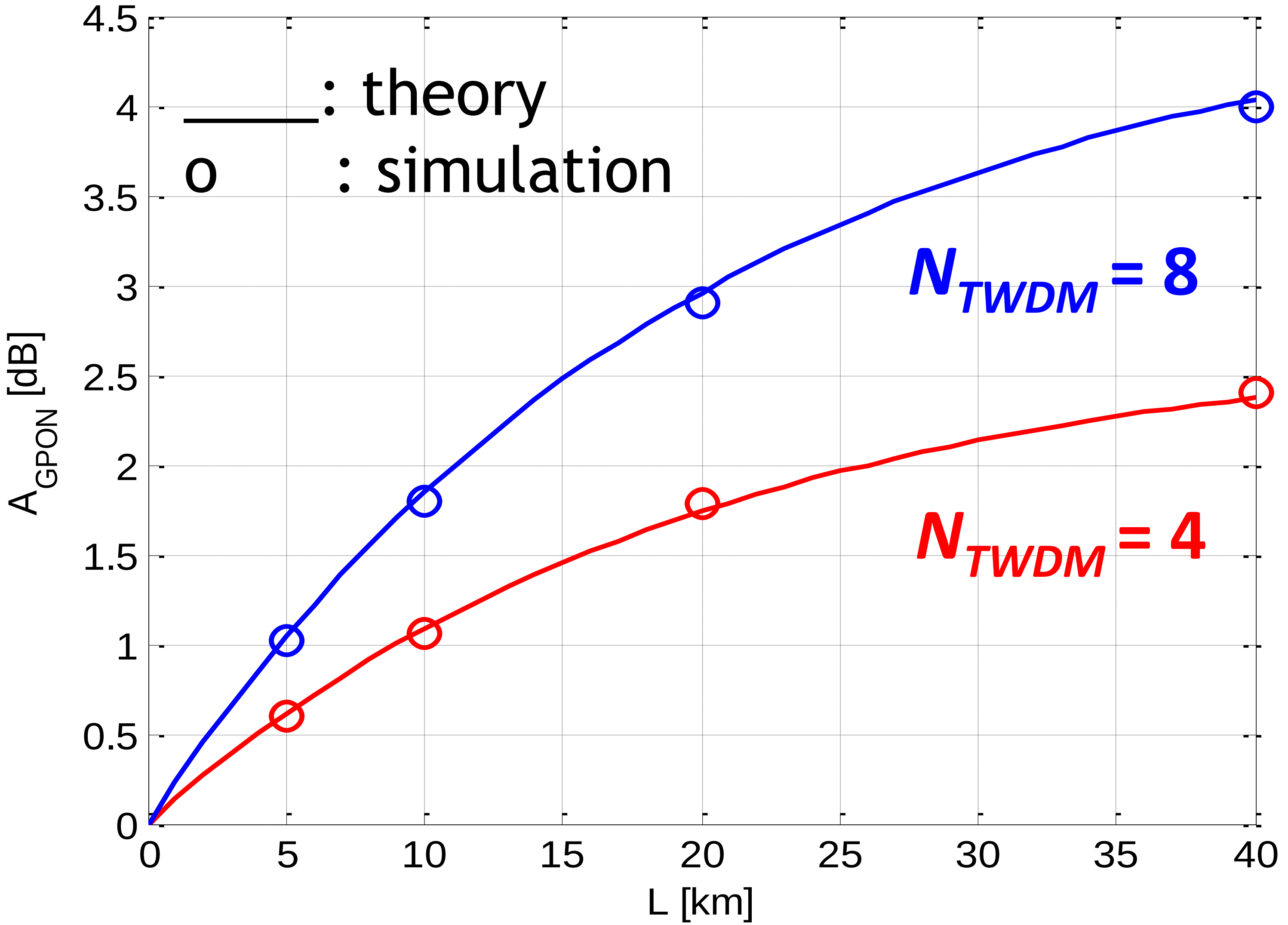
For the G.652 (SSMF) fiber and mutually depolarized signals

$$C_{R,\max} \cong 0.3\times10^{-3} \quad \left[\frac{1}{\mathrm{mW}\cdot\mathrm{km}}\right]$$

$$A_{GPON}^{dB} = \left[10\log_{10}(\mathrm{e})\right]^2 \cdot \frac{\left(1-10^{-\frac{\alpha_{dB}}{10}L}\right)}{\alpha_{dB}} \cdot C_{R,\max} \cdot \\ \cdot\left(\tfrac{1}{2} P_{RF} + \tfrac{8}{9} P_{XGPON} + N_{TWDM} P_{TWDM}\right) \quad [\mathrm{dB}].$$

Theory vs. sim: A_{GPON} vs. L

P_{RF}=16 dBm, P_{XGPON}=12 dBm, P_{TWDM}=13 dBm



Theory vs. sim: A_{GPON} vs. P_{TWDM}

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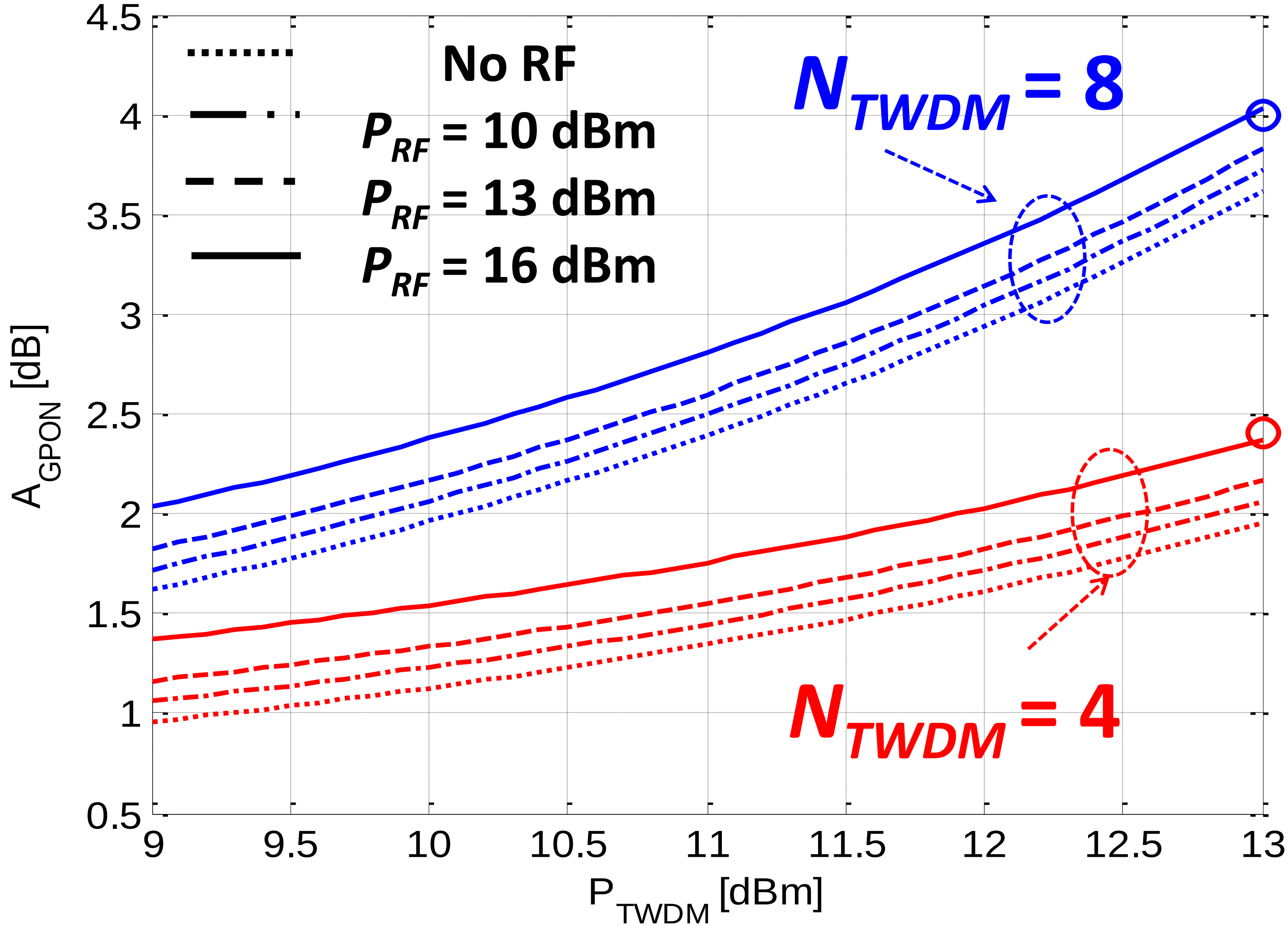
L = 40 km, P_{XGPON}=12 dBm



Requirements for *DOP = 0*

- The proposed simple analytical model demonstrated excellent agreement with simulation results
- It holds provided that the relative degree of polarization among channels is null along the fiber
- This requirement is satisfied if:
  - The fiber PMD is "large enough" ($\delta_{PMD} \geq 0.1$ ps/sqrt(km))

    AND/OR
  - DOP=0 (relative to GPON) for all channels at the transmitter
- **In general A_{GPON} is a random process whose average value can be calculated by the simple model we proposed**

Worst-case analysis: *DOP* = 1

- In order to **evaluate the upper-bound for A_{GPON}**, we suppose the polarization of all channels is aligned along the entire fiber propagation
- In this case the Raman efficiency is 2 times the polarization-averaged coefficients we considered
- Therefore, **the resulting worst-case $A_{GPON,WC}$ is two times the average A_{GPON} in dB units**

$$A_{GPON,WC}^{dB} = \mathbf{2} \cdot A_{GPON}^{dB} \quad [\mathrm{dB}]$$

$$A_{GPON,WC}^{dB} = 2 \cdot \left[10\log_{10}(\mathrm{e})\right]^2 \cdot \frac{\left(1-10^{-\frac{\alpha_{dB}}{10}L}\right)}{\alpha_{dB}} \cdot C_{R,\max} \cdot \left(\tfrac{1}{2} P_{RF} + \tfrac{8}{9} P_{XGPON} + N_{TWDM} P_{TWDM}\right) \quad [\mathrm{dB}]$$

Comments

- GPON power depletion due to the effects of SRS arising from the presence of RF, XGPON and TWDM-PON signals may induce relevant system impairments in case of high TWDM-PON power

This effect sets a “fundamental” upper-bound for the power level of TWDM-PON channels (especially in the full coexistence scenario)

- The upper-bound depends on the ODN parameters as well as on the maximum acceptable power penalty on GPON (likely of the order of 1dB)

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