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

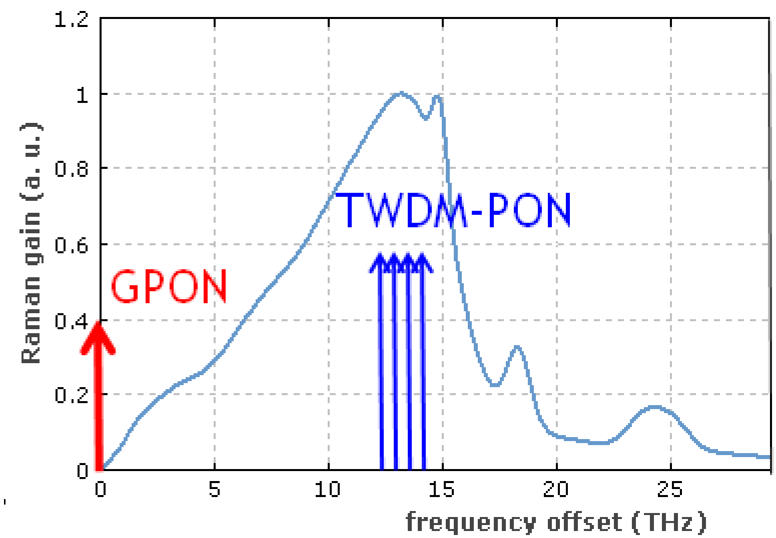
R. Gaudino[1], V. Curri[1], S. Capriata[2]

[1] Politecnico di Torino, Torino, Italy, roberto.gaudino@polito.it
[2] Telecom Italia, Torino, Italy, stefano.capriata@telecomitalia.it

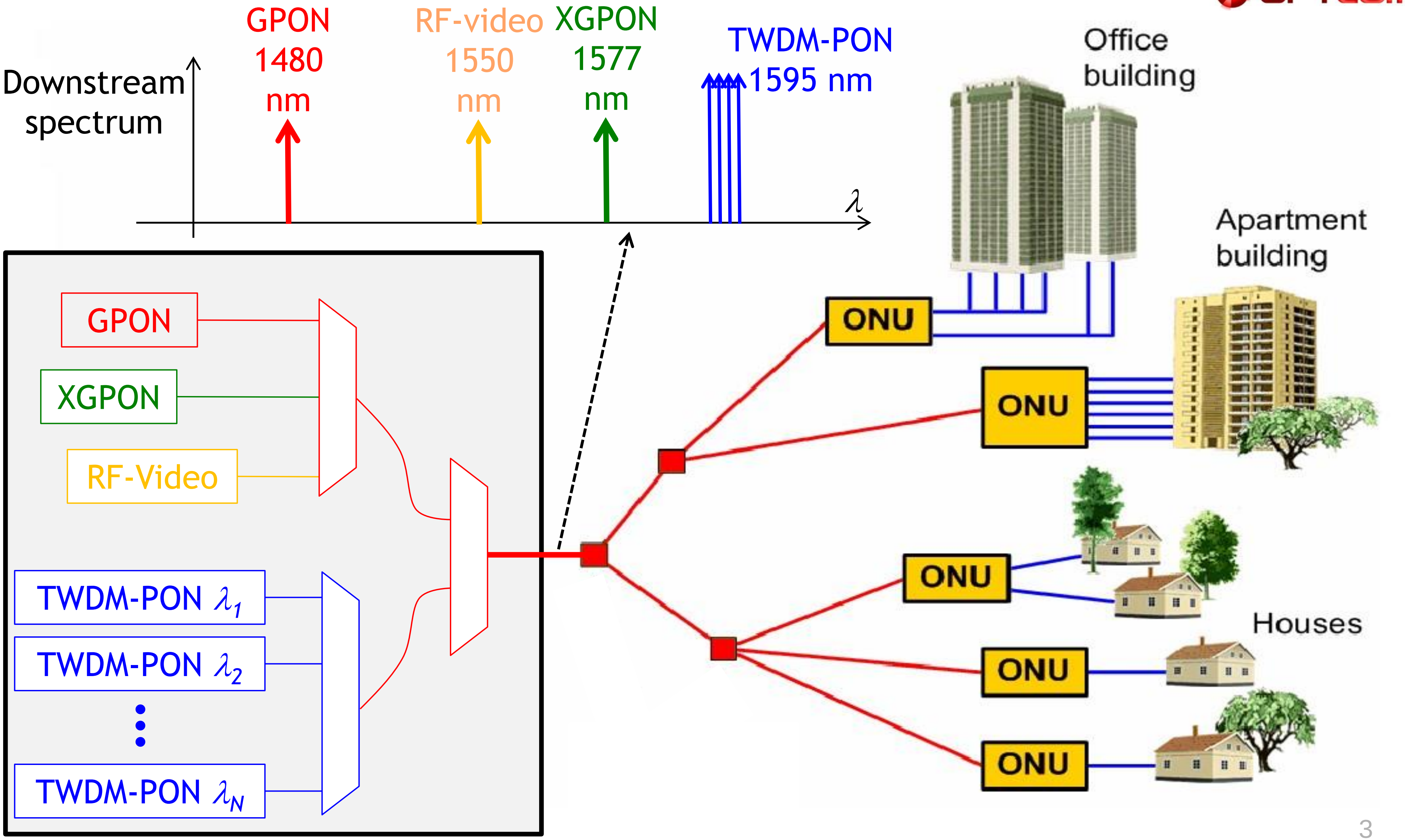
ECOC 2013 Paper P.6.19

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



Split-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.

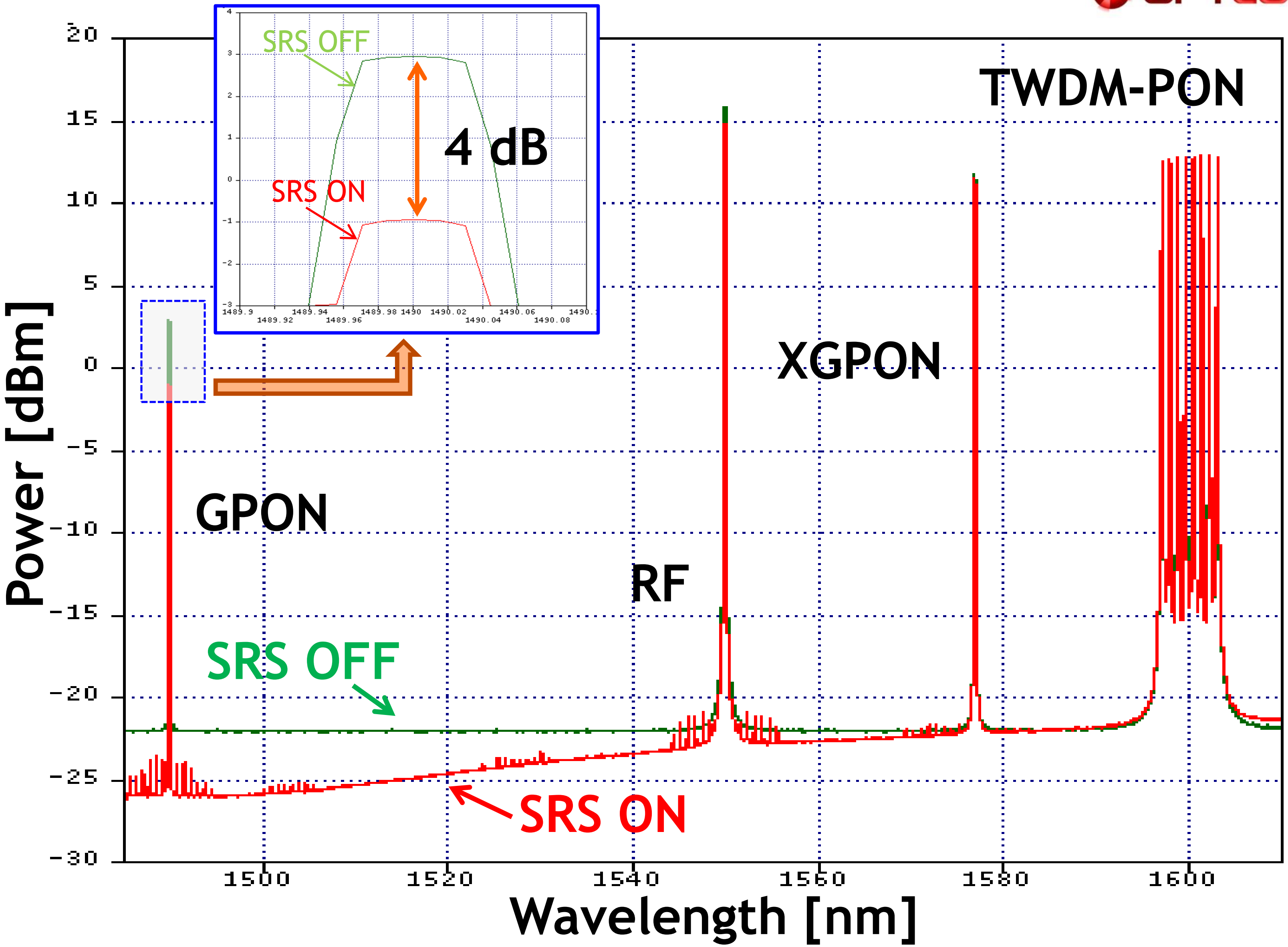
Simulative results: Rx spectrum

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

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

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

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

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

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

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

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

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

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

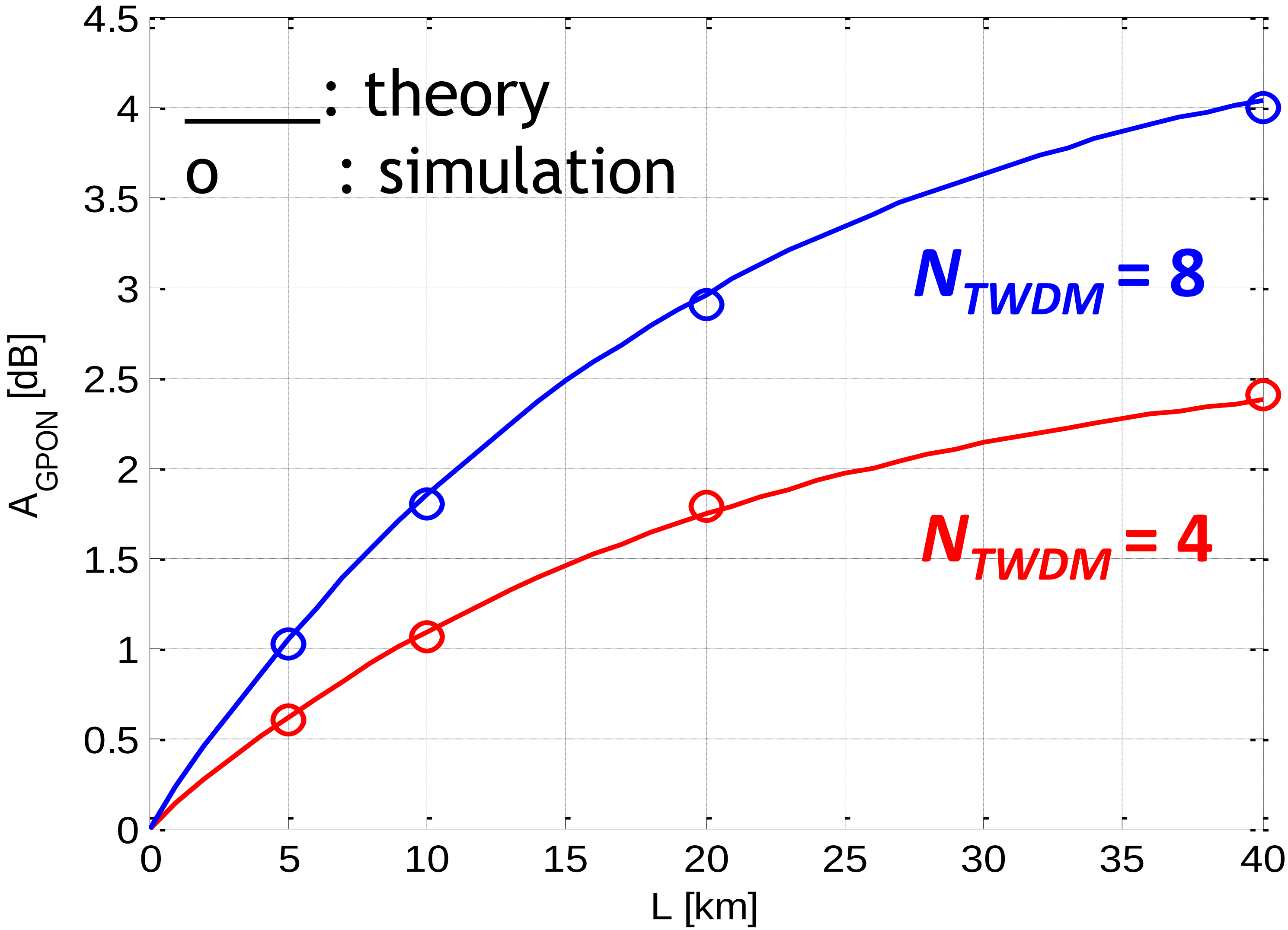
$$C_{R,\max} \cong 0.3\times 10^{-3} \quad \left[\frac{1}{\mathrm{mW}\cdot\mathrm{km}}\right]$$

$$A_{GPON}^{dB} = \left[10\log_{10}(\mathrm{e})\right]^2 \cdot \frac{\left(1-10^{-\frac{\alpha_{dB}}{10}L}\right)}{\alpha_{dB}} \cdot C_{R,\max} \cdot$$

$$\cdot\left(\tfrac{1}{2}P_{RF} + \tfrac{8}{9}P_{XGPON} + N_{TWDM}P_{TWDM}\right) \quad [\mathrm{dB}].$$

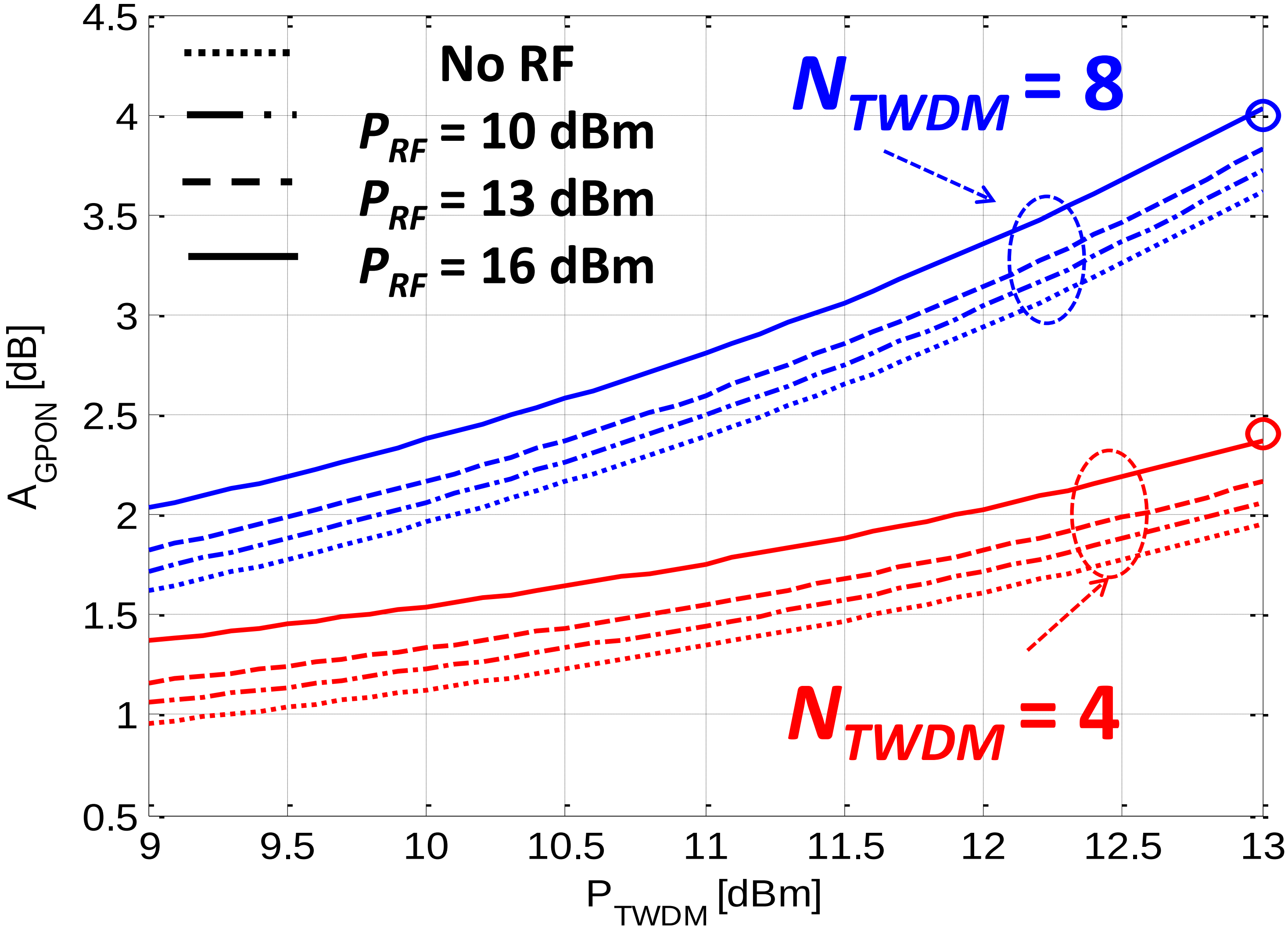
Theory vs. sim: A_{GPON} vs. L

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



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

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 value the SRS-induced GPON loss cannot exceed, we suppose the polarization of all channels is aligned along the entire fiber propagation
- In this case the Raman efficiency (in dB) is 2 times the polarization-averaged coefficients we considered
- Therefore, the resulting worst-case $A_{GPON,WC}$ is

$$A_{GPON,WC}^{dB} = \mathbf{2} \cdot A_{GPON}^{dB}$$

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

Comments

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

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

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

Acknowledgements

This work was supported by Telecom Italia

The simulator OptSim™ was supplied by Synopsys Inc.