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XXXIV Cycle

Machine learning for Raman amplification design and prediction

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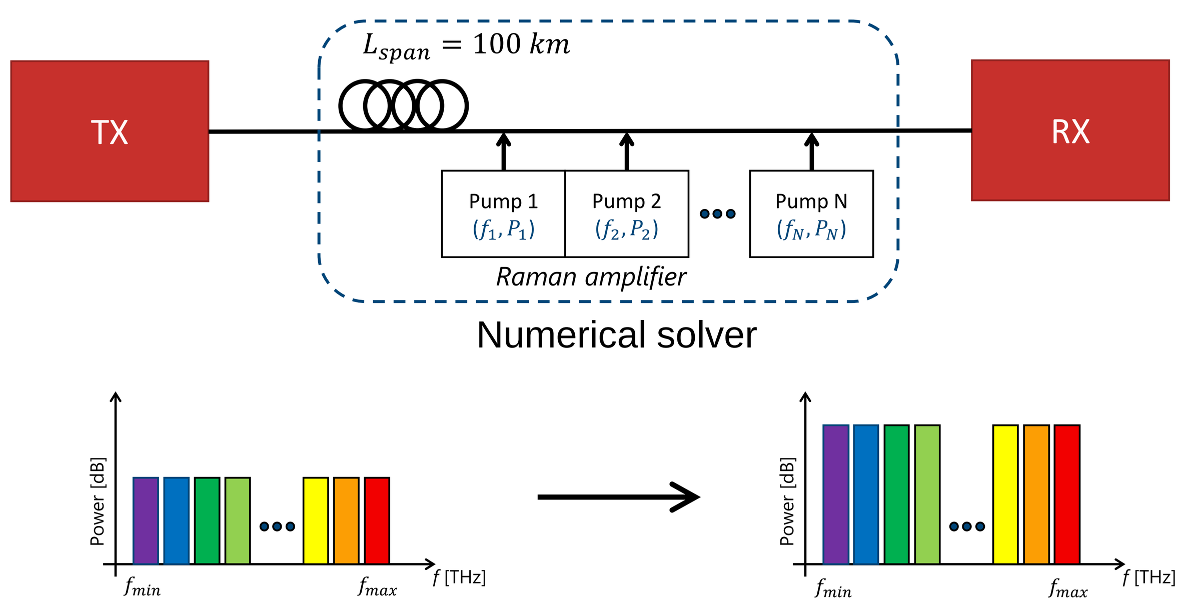
Research context and motivation

- Due to the continuous increasing of data traffic, in particular because of real-time applications and video streaming, more capacity will be needed in the near future. The *Shannon's law* gives the theoretical expression for the channel capacity:
$$C = B\, log_2\, (1 + SNR)$$
where B is the bandwidth and SNR the signal-to-noise ratio.
- To increase the capacity, next generation optical communication systems will require more bandwidth, up to considering the O+E+S+C+L bands.
- Simple EDFAs are suitable only in the C and L bands, therefore Raman amplifiers (RAs), based on Stimulated Raman Scattering (SRS), should be used thanks to their ability to provide gain and low-noise figure at any wavelength.
- Moreover, fast routing, deployment and data traffic optimization and low latency network automatization functions will be required by future autonoumus and self-adaptive optical networks.



Addressed research questions/problems

- Two main problems are addressed:
 - Fast evaluation of Raman amplification gain and noise figure profiles (direct problem)
 - Design of a Raman amplifier for a target gain profile (inverse problem)
 which both deal with the new operations supported by future optical networks.

- In general, given a set of pumps in terms of power and wavelength, to determine Raman amplification gain and noise figure profiles, a set of nonlinear ordinary differential equations (ODEs) have to be solved by a Raman solver, which is a time-consuming and computationally demanding operation.
- State-of-the-art Raman amplifier design is based on a Raman solver and consists in parameters optimization through genetic algorithms, resulting in high computational time.

- Available solutions are not suitable for fast and real-time network orchestration.

Novel contributions

- The use of Machine Learning (ML) is a promising alternative solution for both the two problems.
- According to the problem (direct or inverse), once the neural network (NN) has learnt the corresponding mapping/model ($f(\cdot)$ or $f^{-1}(\cdot)$), it can be used for fast/instantaneous predictions.

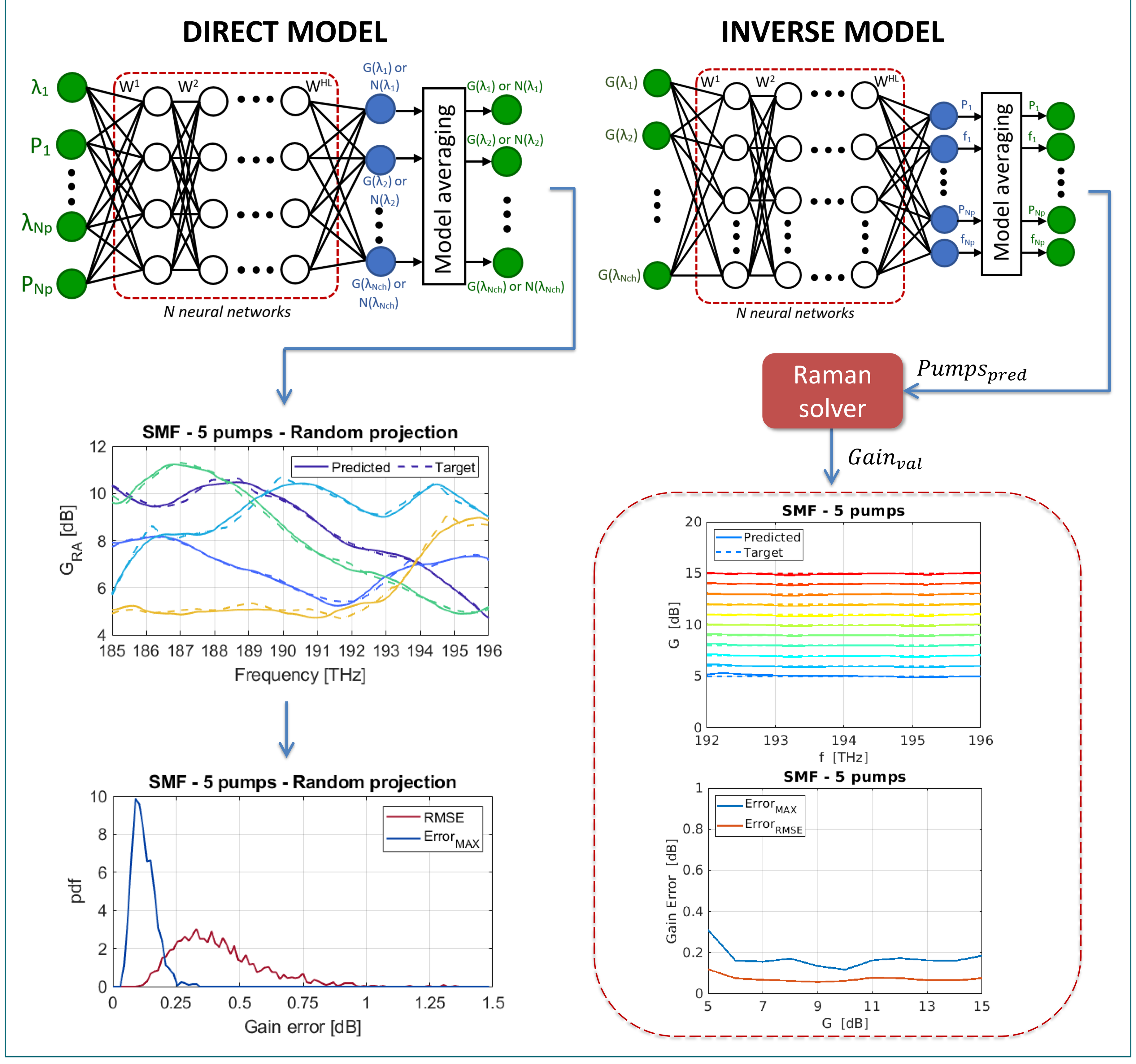
- The use of different training algorithms and the optimization of neural network hyperparameters are exploited to improve network performance.

Submitted and published works

- Rosa Brusin, A.M., Zibar D., Curri, V., and Carena, A., "*An ultra-fast method for gain and noise prediction of Raman amplifiers*", ECOC, Dublin, 2019, paper number 4456300
- Rosa Brusin, A.M., Guiomar, F.P., Lorences-Riesgo, A., Monteiro, P.P, and Carena, A., "*Enhanced resilience towards ROADM-induced optical filtering using subcarrier multiplexing and optimized bit and power loading*", Optics Express (Accepted for publication)
- Zibar, D., Rosa Brusin, A.M., de Moura, U.C., Da Ros, F., Curri, V., and Carena, A., "*Inverse System Design using Machine Learning: the Raman Amplifier Case*", submitted to Journal of Lightwave Technology

Adopted methodologies

- **Data-set generation**: training data-sets are randomly generated considering different number of pumps and different types of fibers using a Raman solver. This solver evaluates Raman gain profile and noise figure.
- **NN training**: the NN is trained using one of the generated training data-set depending on the parameters selection (number of pumps, type of fiber, etc). Different hyperparameters can be considered (activation function, # of hidden layers, # of hidden nodes, etc).
- **NN test & validation**: the trained NN is tested and validated and the error between target profile and predicted profile is evaluated.



Future work

- Experimental validation in the laboratory
- Further optimizations for the inverse model to improve predictions
- Extension of the framework considering Spatial Division Multiplexing (SDM)
- Extension of the framework exploiting multimode Raman scattering
- Joint optimization of hybrid Raman+EDFA amplifiers upgrading this framework
- Condsider other pumping schemes: forward and higher order Raman pumping (higher order Raman pumping is important in submarine cables with very long fiber spans)
- Integration in a network orchestrator to speed up and simplify propagation effects evaluation (e.g. nonlinear effects through GN-model)

Further work

- In parallel to the work here presented, I keep studing multi-subcarrier multiplexing (MSC) as a possible mitigation technique for filtering effects due to cascaded ROADMs.

List of attended classes

- 01QORRV – Writing Scientific Papers in English (21/02/2019, 3 cfu, 15 hrs)
- 01QRRRV – Advanced iterative techniques for digital receivers (25/06/2019, 4 cfu, 20 hrs)
- 01SWPRV – Time management (26/04/2019, 1 cfu, 2 hrs)
- 01TEVRV – Deep learning (didattica d'eccellenza) (04/06/2019, 6 cfu, 30 hrs)
- 02LWHRV – Communication (28/12/2018, 1 cfu, 5 hrs)

- OFC 2019 Short Courses (03/03/2019, 8 hrs)
- Subsea Optical Fiber Communication (OFC) Summer School, Finland (04-10/08/2019, 22 hrs)

POLITECNICO DI TORINO

PhD program in
Electrical, Electronics and Communications Engineering