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Machine Learning Assisted Model of QoT Penalties for Photonics Switching Systems

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Abstract: We propose a data-driven approach to provide augmented knowledge of the QoT impairments of photonic switches in a software-defined networking context. The proposed framework is topological and technological agnostic and can be operated in real-time.
Keywords- *Machine learning, Photonic integrated circuit, Open optical networks, QoT, Software-defined networking*

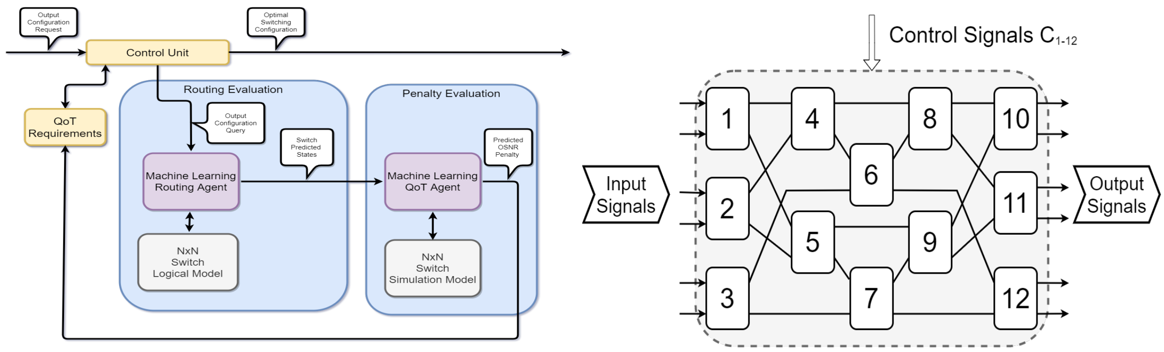
1. Introduction

In the past few years, core optical networks and data centers heavily exploited photonic integrated circuits (PICs) to perform multiple complex operations at the photonic level, thus eliminating the bottleneck introduced by the opto-electronic conversion. Besides this, the modern-day optical networks are rapidly progressing towards implementing the Software-Defined Networking (SDN) paradigm down to the transport layer for the flexible and dynamic management of the network infrastructure. Optical SDN is based on modeling control states and quality of transmission degradation of each network element to enable a full abstraction of WDM optical transport [1].

In this work, we extended our previous demonstration to model the control states of a PIC $N \times N$ photonic switching system with a completely agnostic approach based on Machine Learning (ML) methods [2]. Here we introduce an additional ML network that can provide an accurate model of Quality of transmission (QoT) impairments due to the switching element. The control unit, depicted in Fig. 1a, can predict the states for a given output permutation request, while the proposed ML agent can handle the QoT penalty estimation in order to evaluate the optimal solution. We focus on predicting the transmission penalties of the $N \times N$ photonic switching systems to be used for a more accurate estimation of the QoT of lightpaths within a transparent optical network. The switching topology considered in this analysis to validate the proposed ML-based technique is constructed using the concept presented in [3].

2. Simulation Model & Dataset Analysis

The system under analysis consists of a 6×6 Beneš switch routing WDM channels centered in the C-band, each carrying a PM-64QAM modulation. The device has been modeled and characterized through the Synopsys© Photonic Circuits Design Suite [4], with the routing control provided through MATLAB© scripting [5]. The Beneš switch under analysis, shown in Fig. 1b, is controlled by twelve binary control signals which determine the behavior of the internal switching elements, allowing the routing of all permutations of the input signals to the output ports of the device.



(a) Control unit proposed model

(b) 6×6 Beneš switching network

Fig. 1: System Model and Switching Device.

Optical Beneš switches exhibit path-dependent transmission performances and logically equivalent routing states for each target configuration. As such, the training dataset for the ML agent was obtained through simulation of 1000 unique random binary control signals, allowing repetition of the same output permutation. The Bit Error Rate (BER) at the receiver of each output port was evaluated for a range of different OSNR (Optical Signal-to-Noise Ratio). The data has been successively processed to obtain OSNR-Penalties referred to the predefined BER value of $BER_{th} = 4 \cdot 10^{-3}$.

3. Machine Learning Black Box

The proposed ML technique, particularly deep neural network (DNN), is built in such a way to perform a parallel operation, using TensorFlow© framework that comprises of 1 hidden-layers having 11 neuron units. The ReLU is considered an activation function that performs the mapping of the given input features into a response variable of our point of interest with less complexity. The proposed parallel DNN approach is assessed by mean square error (MSE) as a loss function. The model is tuned for training, validation, and testing by the conventional rule 70/15/15 with training steps of 100 and a learning rate of 0.001. The training set for the current setup comprises 700 realizations, while the test set consists of 300 realizations. The engineered features in the suggested scenario include the M controls states. At the same time, the utilized response variable is the OSNR penalty of the specific output port.

4. Results & Conclusion

We analyzed the performance of the proposed ML module in the prediction of the QoT in terms of $\text{OSNR}_{Penalty}$ for each port of the Beneš switch. The metric used to evaluate the accuracy of the ML model is an absolute OSNR difference, defined as ΔOSNR = abs ($\text{OSNR}_{Penalty,Predicted}$- $\text{OSNR}_{Penalty,Actual}$). The module's reliability is cross-

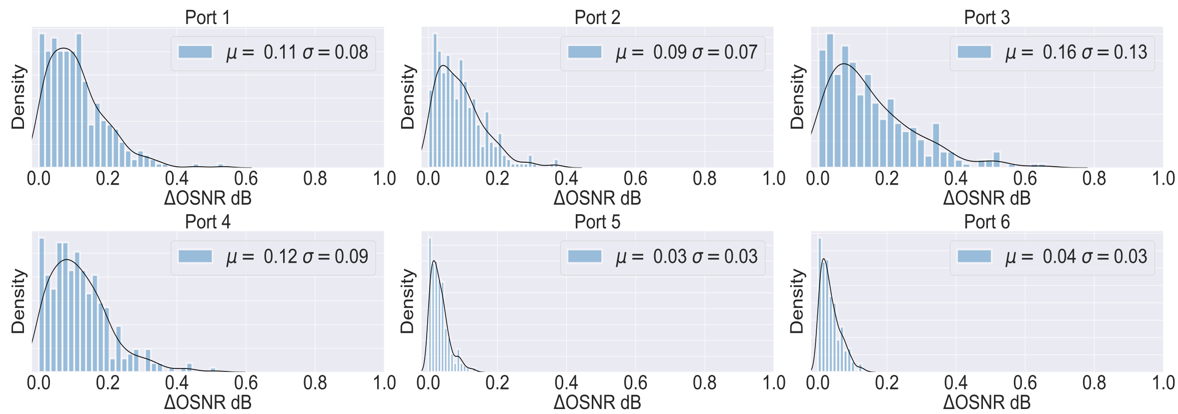


Fig. 2: Probability density functions of ΔOSNR for each port of the 6x6 Beneš switch.

verified by analyzing it on all the six ports of Beneš switch. The distribution of all the six ΔOSNRs along with the mean (μ) and standard deviation (σ) statistics are reported in Fig. 2. Examining the values of μ and σ, we can observe the high level of accuracy achieved by the ML agent. In the worst-case (port 3), the average ΔOSNR is only 0.16 dB, while the maximum absolute error is less than 0.7 dB.

In conclusion, we have demonstrated that the proposed ML framework can provide the complete abstraction of any $N \times N$ photonic switching system, playing a promising role in delivering an accurate prediction of QoT impairments. The delivered augmented knowledge is used to characterize and operate the PIC providing the full software abstraction down to layer-0.

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