Modelling Coherent Transmission over Passive Optical Networks for 5G/6G Mobile Fronthauling

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ABSTRACT

We present a software modelling tool developed inside the EU MSCA project EWOC that predicts the physical layer performance of coherent transmission in a metro-access converged network. Our frequency-resolved tool considers a generic 2 × 2 optical frequency-dependent channel matrix together with typical coherent receiver impairments expected to limit ultra-high date-rate links required for 5G/6G fronthaling. The simulator can be used as a basis for network planning tools and scalability studies considering the physical layer parameters with a high accuracy and less time and CPU consumption compared to extensive time-domain simulations.

1. INTRODUCTION

Developing accurate models for optical transmission physical layer is a crucial step towards an intelligent and highly reconfigurable optical networks and their digital twins [1], in particular for future 5G/6G increasingly demanding and dynamic mobile fronthauling based on 7.x functional split. Therefore, we introduce in this paper a frequency-resolved model and consequently a simulation tool for ultra-high speed transmission converged metro-access network allowing to predict performance of coherent passive optical network (PON). The model is an evolution of the work presented in [2], which was carried out to estimate analytically the signal-to-noise ratio (SNR) at the output of a coherent receiver adaptive equalizer. In our upgraded model, several receiver impairments, which are paramount for high data-rates and advanced modulation formats, are included in the performance prediction based on coherent receiver physical specifications [3]. Moreover, the “so-called” widely-linear representation described in [4] is deployed to include both In-phase/quadrature (IQ) phase/amplitude imbalances and time skew. In particular, the simulator model considers optical filtering, optical noise, polarization multiplexing and polarization dependent loss in addition to the coherent receiver various imperfections, i.e. electrical frequency responses, noises and IQ imbalances. These physical layer attributes are inputted to the model to predict the SNR performance at the output of the DSP-based receivers using a sufficiently long feed-forward 4 × 4 adaptive equalizer. Other performance metrics can then be easily evaluated from SNR, such as bit error rate (BER) as shown in [2].

2. COHERENT TRANSMISSION OVER PON SETUP AND RESULTS

The simulation setup presented in Fig 1.(a) assumes several physical layer parameters that are realistic for coherent transmission in a metro + PON environment, assuming an all-optical connection between the two network segments using reconfigurable optical add-drop multiplexers (ROADMs). We used this setup for validating the analytical developed frequency-resolved simulator while comparing its output results with those coming from a very-detailed time-domain simulator as described in [2].

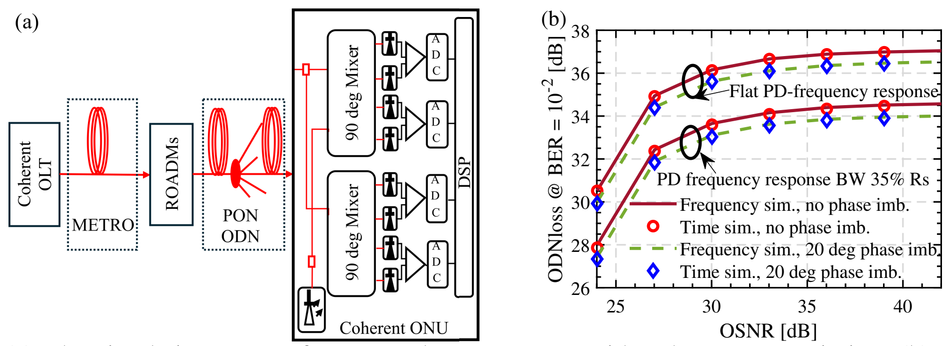

Figure 1: (a) The simulation setup of converged metor-access with coherent transmission. (b) ODNLoss at a BER of 10^{-2} corresponding to OSNR assumed on a 0.1 nm bandwidth for several physical layer parameters.

The transmitted signal is a dual-polarization (DP) M-quadrature amplitude modulation (M-QAM) signal shaped by a square-root raised cosine filter with a roll-off factor of 0.2. The signal then propagates through the optically amplified metro segment represented by the concatenation of 5 ROADMs, each with 2 wavelength selective switches with a super-Gaussian profile of a 60 GHz bandwidth. Optical colored noise is loaded on the signal, together with random unitary Jones matrix and polarization dependent loss of 1 dB. At the coherent receiver, various impairments may be considered in the developed model, however, only the mentioned imperfections are observed in the following test cases while other physical parameters are considered ideal. We start by analyzing the simulator performance in a back to back scenario with optical noise and several coherent receiver imperfections, in particular electrical bandwidth, transimpedance amplifier thermal noise and IQ phase mismatch. Figure 1.(b) illustrates the maximum optical distribution network (ODN) loss allowed to achieve a BER of the value of 10^{-2} for various optical to signal ratio (OSNR), when the transmitted signal is a 50 Gbaud DP 16-QAM (i.e, 400 Gbps) with an average transmitted power of 11 dBm. Two photodiode (PD) electrical bandwidths are addressed with and without an IQ phase-imbalance of 20 degrees with a thermal noise PSD of $N_0 = 2 \times 10^{-18}$ W/Hz. The frequency simulator is validated with respect to extensive time-domain simulations with a 4 × 4 real-valued adaptive equalizer deploying least mean square (LMS) algorithm. For the examined impairments, the frequency-domain simulator results are consistent with its time-domain counterpart as shown in Fig 1(b). At an OSNR of 40 dB, it can be seen that a PD electrical bandwidth with 35% of the symbol rate introduces a penalty of around 3 dB compared to the no-filter case, and considering a 20 degrees phase imbalance worsens this penalty by 0.5 dB. The excellent agreement between simulators is attained with a large reduction in time and CPU-processing required for time-domain-based simulator. To further investigate the simulator accuracy, performance with regards to IQ phase and amplitude imbalances is presented by Q^2 -factor in Fig. 2. Here, we study the proposed simulator accuracy with the previously described optical channel scenario (5 ROADMS and polarization multiplexing) together with optical noise. The frequency-domain simulator predicted Q^2 -factor together with the measured one through time-simulations are illustrated for a 50 Gbaud DP 16 (64)-QAM modulated signal in Fig. 1 (a) and (b), respectively. Two types of receiver equalizers, i.e. the 2 × 2 complex-valued and the 4 × 4 real-valued equalizers, are considered in the time simulations. The Q^2-factor of both simulators are in accordance with each other when deploying the real-valued equalizer in time simulations. However, the complex-valued equalizer output shows a degraded performance with higher IQ impairments in comparison to the real-valued one. This is explained by the complex equalizer inability to account for differences between I and Q paths in the coherent receiver front-end. Moreover, higher modulation orders are more prone to IQ imbalances. Finally, we point out that the required time to obtain the predicted Q^2 in the frequency simulator is faster than the time-domain one by around 90%, which can be valuable for fast and reliable network planning tools in future coherent PONs.

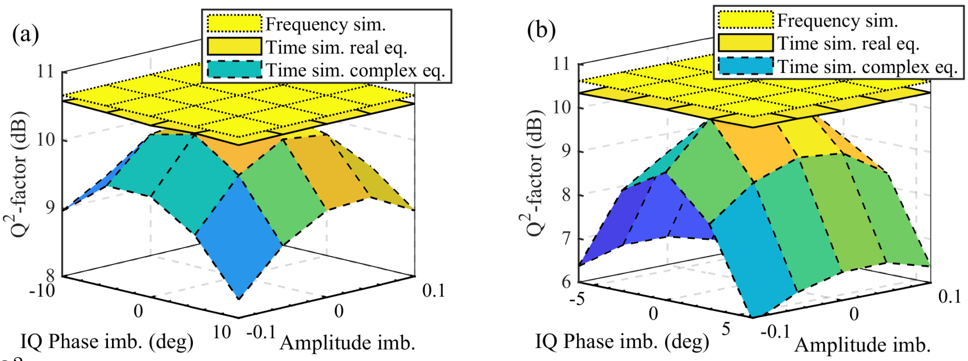

Figure 2: Q^2 -factor for a coherent receiver corresponding to IQ imbalances considering frequency- and time-domain simulator for a 50 Gbaud DP (a) 16-QAM and 24 dB of OSNR, and (b) DP 64-QAM with a 30 dB of OSNR defined assuming a 0.1 nm bandwidth.

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