Fibre Optic Nonlinear Technologies [FONTE]

- A European Industrial Doctorate [GA766115]

Document Details

Title	Deliverable 3.3 Performance analysis of monitoring techniques based on machine learning
Deliverable number	D3.3
Deliverable Type	Report (public)
Deliverable title	Performance analysis of monitoring techniques based on machine learning
Work Package	WP3 – Machine learning techniques for fibre-optic channel
Description	Report about optical performance monitoring focusing on the pre-processing stage
Deliverable due date	31/05/2020
Actual date of submission	19/05/2020
Lead beneficiary	DTU
Version number	V1.3
Status	FINAL

Dissemination level

PU	Public	X
CO	Confidential, only for members of the consortium (including Commission Services	

Project Details

Grant Agreement	766115
Project Acronym	FONTE
Project Title	Fibre Optic Nonlinear Technologies
Call Identifier	H2020-MSCA-ITN-2017
Project Website	fonte.astonphotonics.uk
Start of the Project	1 June 2018
Project Duration	48 months

Consortium

Aston University
NOKIA Bell Labs
TELECOM ParisTech
TU Delft
DTU Technical University of Denmark

EC Funding

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 766115

Executive Summary

The constant increase in information due to inventions coming from internet-of-things, autonomous cars, and others, forces the network to re-inventing itself to keep demand efficiently. Optical performance monitor (OPM) techniques ensure that communication in an optical link, where most of the information goes through, is reliable. The current OPM techniques require full signal demodulation, which is too complex and expensive [1,2]. Therefore, it is desirable to create a simple and cheaper mechanism to extract the necessary information.

Using only photodetectors (PDs) to measure the power of the signal might be an alternative solution. However, due to the square-law detection, the phase information is lost in the process. In this scenario, machine learning (ML) techniques might be used to overcome this challenge. ML working as regression is a powerful tool that can determine a nonlinear relationship between input and output. Hence, a good promise in learning the relationship between the power signal and the channel parameters.

In this report, we show some of the state-of-art solutions to address the topic highlighted previously and report a new approach using an optoelectronic receiver with ML to mitigate the CD in the direct detected system. Although this technique is used for mitigation, the idea of using an optical pre-processing might be extendable to OPM.

The optoelectronic receiver consists of slicing the spectrum and detecting each of them with a photodetector, followed by an ML technique to reconstruct the transmitted information. Through this process, our previous works showed an increase in the transmission reach compare to a single PD receiver [3,4].

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ACRONYMS

AiPT	Aston Institute Of Photonic Technologies
EC	European Commission
EID	European Industrial Doctorates
ESR	Early Stage Researcher
FONTE	Fibre Optic Nonlinear Technologies
OPM	Optical performance monitoring
ML	Machine learning
DD	Direct detection
NN	Neural network
OSNR	Signal-to-noise ratio
CD	Chromatic dispersion
PMD	Polarization-mode-dispersion
OOK	On-off keying

1. INTRODUCTION

Optical fiber communication has several parameters that need to be measured to guarantee a reliable system. Using a direct detection scheme to determine them is a challenging process, due to not having access to the phase information. To address this complicated mapping from the power spectrum to the channel parameter, we can consider the use of ML techniques. However, ML algorithms can easily get complex either in the structure or in the training process.

One of the most important features of ML is the input data. Applying a pre-processing stage to highlight the necessary feature for the ML algorithm can reduce its complexity. Therefore, also reducing the cost.

This report is organized as follows. Section 2 will highlight some of the works in the literature for OPM. The section will be mainly focused on the pre-processing stage that is applied together with the ML. Section 3 will describe the optical pre-processing technique that is used to improve the mitigation of CD in the direct detection system. Section 4 shows the conclusion of the report.

2. OPTICAL PERFORMANCE MONITOR TECHNIQUES WITH MACHINE LEARNING

The work on [5] shows the numerical and experimental analyses on the identification of the optical signal-to-noise ratio (OSNR), chromatic dispersion (CD), and polarization-mode-dispersion (PMD) for a 40 Gb/s on-off keying (OOK) and a differential phase-shift-keying signal. In the receiver, a PD together with a 2-layer feedforward neural network (FNN) is used to identify those parameters. An eye-diagram is computed from the received signal (pre-processing stage) and four features are extracted to feed the FNN. The parameters are the Q-factor, eye closure, root-mean-square jitter, and crossing amplitude. Using 12 neurons in the hidden layer they successfully identified the desired parameters.

Alternatively, the work on [6] shows a deep neural network without pre-processing. The output of the digital-to-analog scope is directly used to identify the channel parameter. In this case, however, a coherent receiver is used instead. Even considering a more complex receiver, in which the phase is available in the digital domain, the authors used 5-layers with 500 neurons each to identify the OSNR.

These two works were highlighted here to show that using a pre-processing stage might reduce the complexity of the following algorithm. In this case, might reduce the complexity of the ML technique for OPM. The works on [1,2] have a more detailed analysis of comparing OPM techniques in general.

3. OPTOELECTRONIC RECEIVER FOR DIRECTLY DETECTED SYSTEMS

In [3,4] we proposed an optical pre-processing technique to improve the transmission reach of direct detection systems with machine learning. The optical pre-processing consists of filtering (slicing) the received spectrum and detecting each slice with a PD. Fig. 1 describes the simulation setup to validate the proposal. Fig. 1(a) shows the simulation setup without the pre-processing stage and Fig. 1(b) with it.

A random bit sequence with 32 GBd OOK is generated, shaped by a root raised cosine (RRC) filter with 0.1 of roll-off, and ideally modulated by a Mach–Zehnder modulator (MZM). The optical signal goes throw an optical fiber with the only impairment being the CD. White Gaussian noise is added to the signal to simulate the pre-amplifier stage and it is adjusted to the desired SNR. The signal is then filtered, considering the pre-processing stage (Fig. 1(b)), and each is detected by a PD. In the case without pre-processing the signal is only detected by a unique PD (Fig. 1(a)). Digital signal processing (DSP) is only composed of a fixed filter (RC) or a machine learning algorithm (FNN or reservoir computing). Finally, the number of errors is counted and the bit error rate (BER) is calculated.

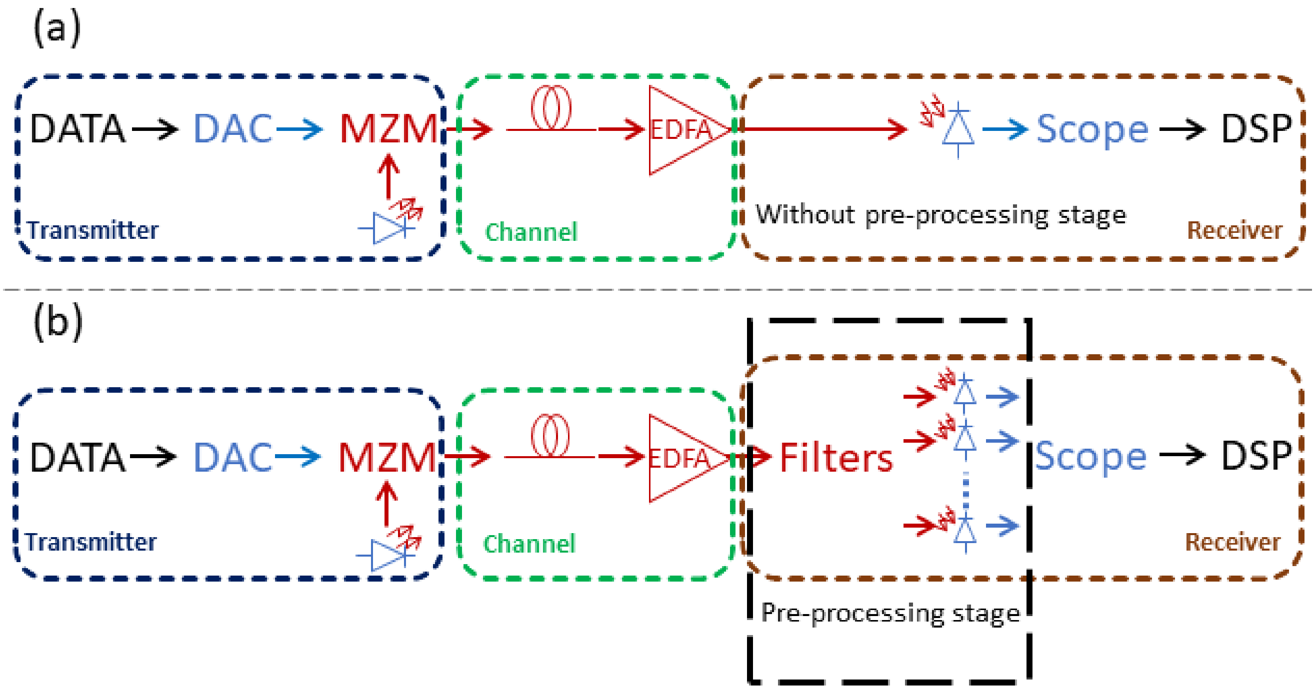

Figure 1 - Simulations setup. (a) Without pre-processing. (b) With pre-processing. DAC: Digital-to-analog converter. MZM: Mach–Zehnder modulator. EDFA: erbium-doped fiber amplifier. DSP: Digital signal processing.

Fig. 2 shows the simulation result of the structured present before. The performance metric considered is the received SNR required for a BER at the KP4 forward error correction (FEC) threshold (BER = 2.24 x 10^{-4}). The results will be present considering the SNR penalty, i.e., the difference in required receiver SNR, with respect to a simple reference receiver (Fig. 1(a) with RRC filter and no additional processing).

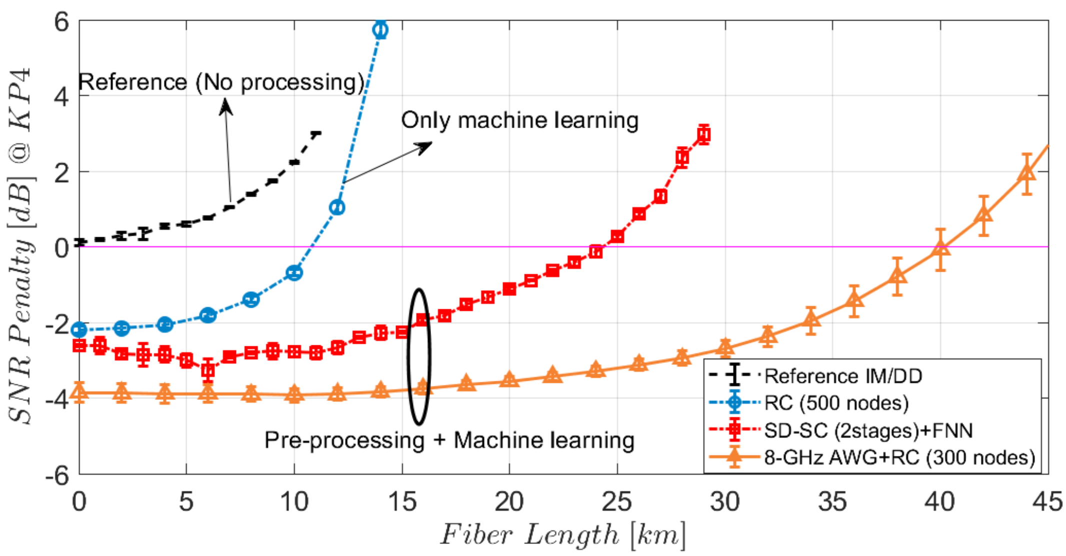

Figure 2 - Simulation results.

The dashed black curve shows the performance of the benchmark receiver. A distance of 10 km with a 2 dB penalty at KP4 FEC is calculated without any equalizer algorithm or pre-processing stage. The blue curve (circles) shows the results of using only ML algorithm (reservoir computing [4]), without any pre-processing. The results show an improvement compared to the benchmark receiver. The negative penalties indicate that the machine learning algorithm converged to a better equalizer compared to the RRC filter used in the benchmark. This is because the direct detection system does not have a known matched filter and using a fixed filter might imply some penalty. The red curve (square) shows the results using an optical pre-processing with 4 slices, simulated with Mach-Zehnder delay interferometer (SD-SC 2-stages) together with a machine learning algorithm (FNN) [3]. In this case, 28 km were simulated considering the same penalty as before, 2 dB in the KP4 FEC. The yellow curve (triangles) shows another optical pre-processing with 5 slices, simulated with arbitrary waveguide grating (AWG) together with a machine learning algorithm (reservoir computing) [4]. In this case, 44 km were simulated with the same penalty as before.

In summary, using an additional pre-processing stage together with the machine learning algorithm showed improvement in the transmission reach.

4. Conclusions

This report describes a comparison between two papers in the area of OPM to highlight the difference in the number of neurons used in the machine learning algorithm to identify the OSNR of the system. The one with an additional pre-processing stage uses 12 neurons in the hidden layer of a 2-layer FNN. In contrast, 5-layers FNN with 500 neurons in each layer is necessary for the case without any pre-processing. In other words, an additional pre-processing stage might reduce the necessary number of neurons of the machine learning algorithm for OPM. Therefore, reducing complexity and cost.

Additionally, this report shows a technique of optical pre-processing for the mitigation of CD for short-reach distances. It is based on slicing the received signal and detecting each with a PD, followed by a stage of ML. The results show a transmission reach of 40 km with this method, while a 10 km transmission reach is showed for the single PD scenario, considering 0 dB penalty compared to a back-to-back simulation at KP4 FEC. Although these results are for mitigation, the optical pre-processing technique might be extendable to OPM.

References

[1] F. Musumeci et al., "An Overview on Application of Machine Learning Techniques in Optical Networks," in IEEE Communications Surveys & Tutorials, vol. 21, no. 2, pp. 1383-1408, Second quarter of 2019.

[2] Z. Dong, et al., Optical performance monitoring: A review of current and future technologies. Journal of Lightwave Technology, 34(2), 525-543. 2015.

[3] S. M. Ranzini et al., "Tunable Optoelectronic Chromatic Dispersion Compensation Based on Machine Learning for Short-Reach Transmission." Applied Sciences 9.20. 4332. 2019.

[4] F. Da Ros, et al., "Reservoir-computing based equalization with optical pre-processing for short-reach optical transmission." IEEE Journal of Selected Topics in Quantum Electronics. 2020.

[5] X. Wu, et al., “Applications of artificial neural networks in optical performance monitoring,” IEEE/OSA Journal of Lightwave Technology, vol. 27, no. 16, pp. 3580–3589, 2009.

[6] T. Tanimura, T. Hoshida, J. C. Rasmussen, M. Suzuki, and H. Morikawa, “OSNR monitoring by deep neural networks trained with asynchronously sampled data,” in OptoElectronics and Communications Conference (OECC) 2016. IEEE, Oct. 2016, pp. 1–3.