**AI-Enabled Optical Receiver (*AI\_Receiver*)**

**Coding Skills Required: Beginner/Intermediate**

## Goals

The goal of this project is to develop a machine learning based receiver for optical communication systems, focusing on using a AI model to equalize linear and nonlinear distortions caused by linear and nonlinear distortions that occur due to propagation in optical fibers. In this project, you will explore the use of machine learning and neural networks to build a receiver that equalized the the received data in an accurate and efficient manner.

You will investigate two type of data:

1. Single channel (single wavelength) coherent (QAM) data transmission.
2. wavelength-division multiplexing (WDM) intensity-modulated (IM) data transmission. For this, you may want to consider convolutional LSTM models. Other AI algorithms can also be investigated.

## Introduction

As signals traverse the optical communication channel, they encounter non-idealities such as noise and inter-symbol interference, leading to degradation in their quality. The task of a receiver is to decipher the transmitted information by deducing the intended bits from the received signals. Traditionally, this has been addressed through the incorporation of an "Equalizer" in the receiver architecture. The Equalizer mitigates the effects of noise and interference, enabling the receiver to make informed decisions about whether a “0” or a “1” was originally transmitted (in context of binary data). Effectively, the receiver transforms into a classifier, capable of categorizing the received bits into their respective binary states.

Wavelength Division Multiplexing (WDM) serves as a crucial technology in ultra-high-capacity links, forming the backbone of the internet. This technique involves numerous data channels, each operating at a distinct wavelength, traveling through a single fiber. The primary challenge in data transmission lies in the optical crosstalk between channels induced by the inherent nonlinearity of the fiber. Traditional methods for mitigating the reduction in the bit error rate caused by the crosstalk include numerical backpropagation and nonlinear Volterra filter, both implemented in the digital domain at the receiver. However, they are not ideal solutions for high data rates due to the expensive computational cost. In this project, you will investigate the use of neural networks for accurately and efficiently recovering the transmitted data from the distorted output signal.

## A WDM transmission systemA diagram of a computer Description automatically generated

## Tasks

## Understand the WDM data

You will be provided with a starting dataset. The data is a multidimensional time series consisting of the input (TX) and output (RX) data for the optical communication link. Data is in .csv format with file name TX (or RX) lambda + number.csv. The input to the link is the binary data to be transmitted are stored in files named after “TX”, and the output is the received data stored in files named after “RX”. The number after “lambda” is the channel where data is transmitted through. We have two sets of received data, one is corrupted by noise, dispersion, and optical nonlinearities, and other impairments, another is corrupted by just noise and dispersion. For each, you have the transmitted data (ground truth) and the received data, for each wavelength (lambda).

A screenshot of a computer

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## 3. Preprocess and visualize the data

The WDM data provided to you is non-return to zero (NRZ) binary data and the Bitrate (symbol rate) is 25Gbps, and data is sampled at 400Gpbs. Plot the TX and RX of data vs. time for each channel on one plot (show the first 30 bits). Calculate the period of one bit (symbol). Then calculate the number of samples corresponding to one bit. Organize and reshape your data for the neural network training and inference.

## 4. Implement and train the AI model

For this dataset, your objective is to predict whether each received bit was a 0 or 1 by using an AI model. The recommended course is to start with a CNN model first then try the convolutional LSTM model. You use the TX as the label (“ground truth”) and RX as the data to be classified as “0” or “1”. You can compare your results with different conventional machine learning algorithms of your choice (such as SVM, logistic regression, decision tree). For neural networks, experiment with different receptive field sizes applied to the received data.

## 5. Evaluate the accuracy, efficiency, and robustness of the proposed receivers

Evaluate the decoding accuracy and runtime of different types of receivers. Investigate their robustness against sampling rate and quantization.

* **Quantization**: The data provided to you is not digitized. For the TX data, you can do a 1-bit quantization, i.e. assign high values to one and low values to zero. For the RX data You can generate multiple copies of it, each digitized with a different number of bits. It is recommended that you use 6bit, 4bit and 2bit. You can then show the classification accuracy vs. number of quantizer bits as well as the original analog version.
* **Sampling Rate:** the data is oversampled by 16x, i.e. each bit is sampled 16 times. You should compute the classification accuracy vs. number of samples per bit. You can do this by using decimation. Try 16, 8, 4, 2 decimation factors.
* **Receptive Field:** Instead of operating on a single received bit, you can operate on a received receptive field to consider the memory effect. Plot the accuracy vs. the size of the receptive field.

**6. Repeat steps 1-4 for single channel coherent (QAM) transmission data**

## Deliverables

PowerPoint slides, final presentation, Colab notebook, and GitHub repository.

## Contact

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## References

You can find many papers on this topic by searching “machine learning for optical communication” in Google Scholar. Here are a couple of examples:

<https://www.spiedigitallibrary.org/conference-proceedings-of-spie/11703/1170319/Optical-nonlinearity-compensation-based-on-machine-learning-technology/10.1117/12.2578197.full> - This is an SPIE conference paper and **the link includes a video**

Zibar, Darko, et al. "Machine learning techniques in optical communication." *Journal of Lightwave Technology* 34.6 (2015): 1442-1452.

Khan, Faisal Nadeem, et al. "An optical communication's perspective on machine learning and its applications." *Journal of Lightwave Technology* 37.2 (2019): 493-516.