University College London

Department of Electronic and Electrical Engineering

Final Project Proposal Draft

Team Member Names	*Student Numbers*
An Vo	00000000
Mindaugas Jarmolovičius	17139494
Oliver Jaison	00000000
Tharmetharan Balendran	17011729

Supervisor
Prof. Robert Killey

ELEC0118 Fourth Year MEng Project

October 7, 2020

***Abstract* — Write me last...**

1 Introduction

Optical Fibres are a staple medium for fast communication systems all over the globe. They allow for light speed transfer of bits between two stations which has numerous applications in today's society. However, they are not perfect. They can suffer from a few issues such as Additive White Gaussian Noise (AWGN) and Shot Noise from Photo-Diodes as well as chromatic dispersion. This project will be addressing a method to mitigate the adverse of effects of non-linearities in the optical fibre cables. In particular, the effect of implementing neural networks in both the transmitter and receiver of a communication system to enable "end to end deep learning" will be observed and improved upon with the use of Field Programmable Gate Arrays (FPGAs).

2 Aims and Objectives

The main objective of this project is to design a suitable neural network to optimize the transmission of data via a communication channel and implement it on a FPGA hardware. The channel that will be of primary focus is the optical fibre communication channel where non-linearities introduced by chromatic dispersion and photodiode detection is a major problem that needs to be overcome. The project can be broken down into individual objectives that will need to be achieved, which are described in following sections.

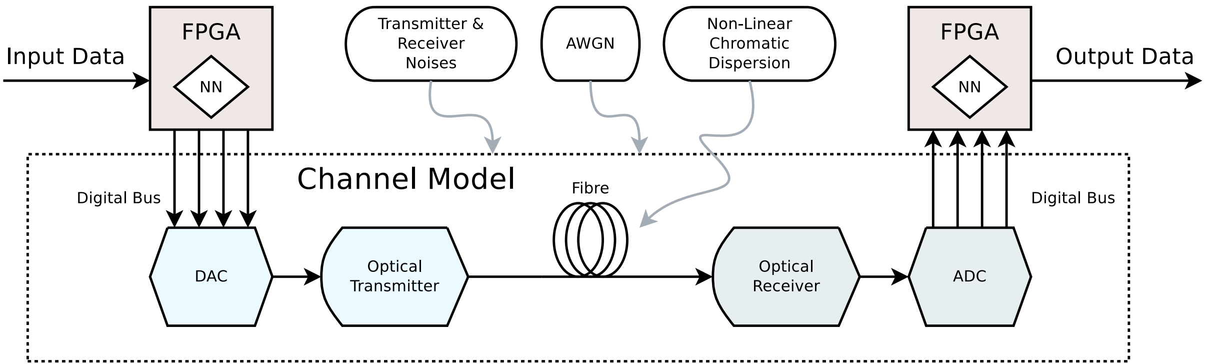

Figure 2.0.1: *Simplifier overall system diagram without inside FPGA Neural Network (NN) back-propogation learning.*

2.1 Choosing an Appropriate Neural Network Architecture

The modulation scheme as well as the encoding of the bits will be learned for the specific communication channel by a neural network at the transmitter. Likewise, at the receiving end of the communication system, a separate neural network will decode the received signal into a stream of bits. A suitable neural network architecture must be chosen for each of the applications.

The study carried out in [1] features a Convolutional Neural Network (CNN) at the transmitting and receiving end of the communication system. Similar to our own project, the paper describes an end to end neural network implementation for the communication system. The channel used in the simulations is an Additive White Gaussian Noise (AWGN) model and does not consider potential non-linearities introduced in the channel. On the contrary, [2] describes a Multi-Layer Perceptron (MLP) based Non-Linear Equalizer(NLE) at the receiver for an optical communication system. As this paper, clearly discusses the optical communication channel, it may be useful in deciding on a suitable neural network at the transmitter. It should be noted that the paper describes an equalizer and not a demodulator/decoder.

Further research and literature review needs to be done into different architectures that are available and the requirements that need to be met by the transmitter and receiver of the communication channel. Depending on the chosen neural network architecture, a suitable FPGA will need to be decided on as well. Different architectures may demand different levels of hardware resources.

2.2 Simulating the Communication Channel and Proposed Transmitter/Receiver

The transmitting and receiving end as well as the channel itself need to be simulated as a channel model. The neural networks will most likely be implemented using the TensorFlow package with python. The different characteristics of the channel need to be included in the model to ensure that it sufficiently represents how a transmitted signal would be altered by a real optical fibre communication channel. [3] describes a potential model for the optical communication system. This model includes a low-pass filter (LPF) to account for the finite bandwidth of read hardware, a digital to analogue converter (DAC), an analogue to digital converter (ADC), a Mark-Zehnder modulator (MZM), photo-conversion by a photodiode, Gaussian noise as well as the optical fibre transmission itself. We will need to decide on the communication channel configuration that we wish to simulate as well as the data-rate of the communication system.

This simulation could replace channel model which would look as a back box while training Neural Networks.

2.3 Implementing the Neural Networks on a FPGA

Implementing Neural Network on FPGA raises multiple problems that need to be solved.

2.3.1 Floating-point vs fixed-point arithmetic

FPGA internal data structure has number of trade-off that need to be decided on

- **Floating-point** - allows high precision however are slower are require more resources. Native to other neural networks implemented in software.
- **Fixed-point** - introduce quantisation noise. Might be insufficient with very small or large values. Also requires deciding on sufficient bits size.

Preliminary research shows that fixed-point neural network implementation on FPGA achieves over 12x greater in speed, over 13x smaller in area, therefore allows far greater processing density [4]. Therefore, further investigation needs to be done in order to determinate if fixed-point data structure is sufficient.

2.3.2 Required FPGA resources

Depending on implemented Neural Network, its size, used data structure, a suitable FPGA board needs to selected.

Option to use multiple FPGA boards that would be linked with fast communication protocols will be also considered, including overall board architecture.

2.3.3 Neural Network optimisations in FPGA

There are a number of research papers that include some optimisations to implement Neural Networks on FPGA:

- Feed forward ANN on FPGA [5]
- ANN based PID controller on FPGA [6]

Further research will be done to find optimal implementation of Neural Network in HDL.

2.4 Training and Testing the System using an Optical Fibre Communication System

If time and circumstance permits the project could conclude by testing the designed system using an experimental setup to simulate the communication channel as opposed to a computer model. This would bring light to discrepancies between the real-life setup and the simulated model. As well as that, it would validate that the design works as well in an experimental setup as it does in simulation. The neural network could be trained at different lengths of fibre and observed to see how the learned parameters as well as the bit error rate differ to traditional methods of encoding/decoding.

2.5 Project Schedule

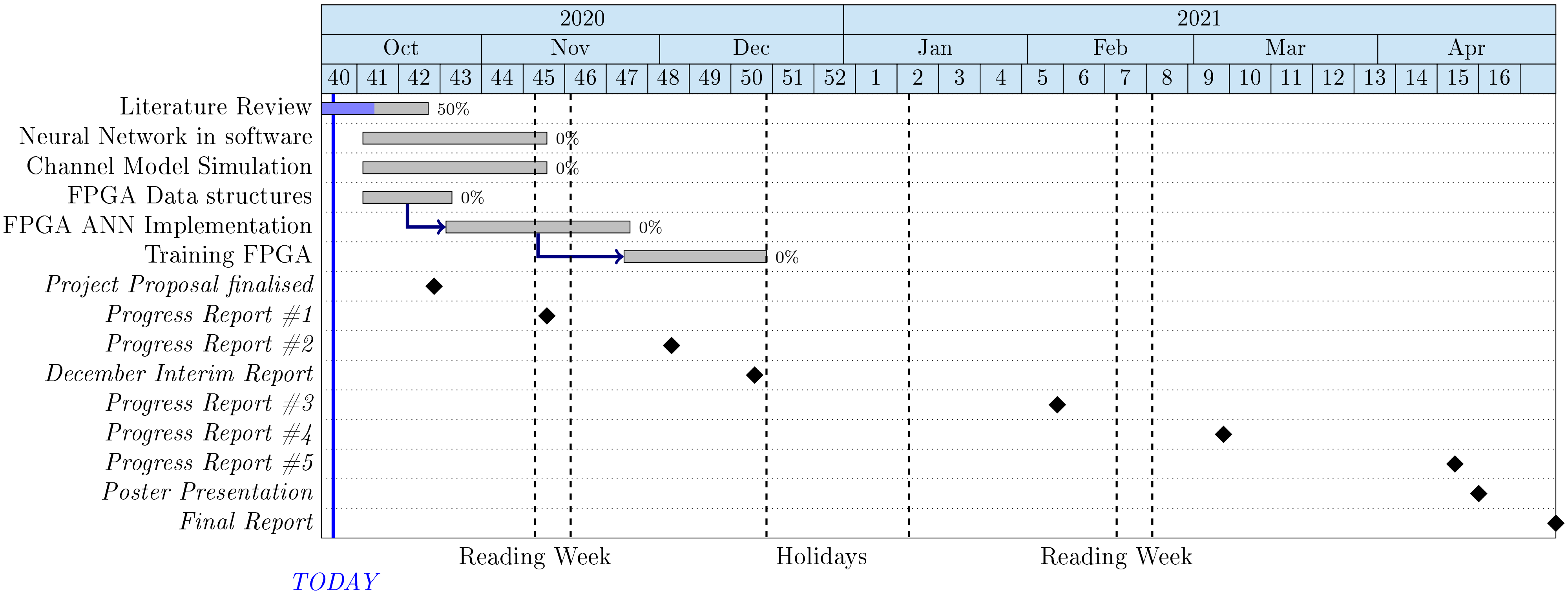

Table 2.5.1: *Project schedule and deadlines in a Gantt chart*

3 Preliminary Assessment of Risks

3.1 Safety Risks

- Bad Posture / RSI
- Eye-strain
- Burns from hot ICs

3.2 Failure Risks

- **Delayed/Cancelled arrival of Ordered goods (FPGA board)**

  Ordered goods such as the FPGA required for the project may not arrive on time and in such a case an FPGA available to us (DE0 Nano or Xilinx Spartan-6) may be utilized as a substitute. The compromises with choosing a less powerful FPGA should be considered.

- **Lack of time to complete all goals of project**

  There always exists the risk that a chosen project turns out to be more complex than initially expected. This may result in the project not progressing as quickly as planned and ultimately in the project not being completed in time. If the project should start to fall behind schedule the goals of the project should be altered to allow us to produce a completed system by then end even if it doesn't have all the functionality initially planned.

References

[1] B. Zhu et al. "Joint Transceiver Optimization for Wireless Communication PHY Using Neural Network". In: *IEEE Journal on Selected Areas in Communications* 37.6 (2019), pp. 1364–1373. ISSN: 1558-0008. DOI: 10.1109/JSAC.2019.2904361.

[2] M. A. Jarajreh et al. "Artificial Neural Network Nonlinear Equalizer for Coherent Optical OFDM". In: *IEEE Photonics Technology Letters* 27.4 (2015), pp. 387–390. ISSN: 1941-0174. DOI: 10.1109/LPT.2014.2375960.

[3] B. Karanov et al. "End-to-End Deep Learning of Optical Fiber Communications". In: *Journal of Lightwave Technology* 36.20 (2018), pp. 4843–4855. ISSN: 1558-2213. DOI: 10.1109/JLT.2018.2865109.

[4] Amos R Omondi and Jagath Chandana Rajapakse. *FPGA implementations of neural networks*. Springer, 2006, p. 56.

[5] P. Dondon et al. "Implementation of a feed-forward Artificial Neural Network in VHDL on FPGA". In: *12th Symposium on Neural Network Applications in Electrical Engineering (NEUREL)*. 2014, pp. 37–40. DOI: 10.1109/NEUREL.2014.7011454.

[6] V. Gupta, K. Khare, and R. P. Singh. "FPGA Design and Implementation Issues of Artificial Neural Network Based PID Controllers". In: *2009 International Conference on Advances in Recent Technologies in Communication and Computing*. 2009, pp. 860–862. DOI: 10.1109/ARTCom.2009.182.