LEVERAGING MACHINE LEARNING FOR ENHANCED PERFORMANCE OF OPTICAL AND WIRELESS COMMUNICATION SYSTEMS

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by

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Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the

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To my parents and brother,

for being my biggest cheerleaders.

Certificate

I hereby certify that the work which is being presented in the thesis entitled "**LEVERAGING MACHINE LEARNING FOR ENHANCED PERFORMANCE OF OPTICAL AND WIRELESS COMMUNICATION SYSTEMS**" except Chapter 3 in the fulfillment of the requirements for the award of the degree of **Doctor of Philosophy** and submitted to the Bharti School of Telecommunication Technology and Management, Indian Institute of Technology Delhi, is an authentic record of my own work carried out during the time period from November 2019 to September 2023 under the supervision of Prof. Brejesh Lall and Prof. Amol Choudhary from the Department of Electrical Engineering, Indian Institute of Technology Delhi, India.
The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute and any collaboration with other students with their contributions has been clearly highlighted. Any work that has been published is mentioned under the "List of Publications".

Naveenta Gautam

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

Prof. Brejesh Lall	Prof. Amol Choudhary
Professor	Associate Professor
Department of Electrical Engineering	Department of Electrical Engineering
Indian Institute of Technology Delhi	Indian Institute of Technology Delhi

1st September 2023

To whom it may concern

This is to certify that Chapter 3 entitled *"Leveraging Transfer Learning for 5G Slicing in Industrial Networks"* contained in the thesis entitled *"LEVERAGING MACHINE LEARNING FOR ENHANCED PERFORMANCE OF OPTICAL AND WIRELESS COMMUNICATION SYSTEMS"* being submitted by NAVEENTA GAUTAM to the Bharti School of Telecommunication Technology and Management, Indian Institute of Technology Delhi, for the award of the degree of Doctor of Philosophy is the record of the bona-fide research work carried out by her during the internship at Nokia Bell Labs, Stuttgart, Germany during June-September 2022 under the supervision of myself and Nokia colleagues.

The results contained in this thesis have not been submitted either in part or in full to any other university or institute for the award of any degree or diploma.

Best regards,

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Naveenta Gautam

Abstract

Telecommunication systems, integral to modern society, facilitate seamless information transmission across vast distances via wired and wireless networks. The surge in data demand, fueled by smartphone adoption, IoT devices, and streaming services, has expanded the role of these systems beyond communication to encompass critical information access, business operations, and entertainment [1].

As data demands soar, telecommunication providers confront challenges meeting user requirements. This compels substantial investments in network capacity, 5G technology deployment, and existing infrastructure optimization for enhanced data transmission efficiency [1]. Amid these challenges, machine learning (ML) emerges as a potent tool to transform telecommunication performance. ML techniques, applicable in signal processing, network optimization, security enhancement, and personalized services [2], are reshaping telecommunication systems. This ongoing integration promises continuous technological advancement in communication.

We harness the power of machine learning to address critical challenges spanning wireless and optical communications domain. We explore innovative methodologies, algorithms, and techniques that can elevate the performance and signal quality of communication networks. In the first part of our research we explore the use of transfer learning and reinforcement learning for network slicing in industrial scenarios. Here, we seek to optimize resource allocation and network management, ensuring

efficient and adaptable communication systems for diverse industrial applications [3]. Transitioning our focus to optical fiber communication systems, which serve as the fundamental backbone for the burgeoning 5G networks, our primary objective is to tackle the formidable challenge posed by nonlinear effects. These nonlinear phenomena have emerged as a critical bottleneck impeding the realization of high-speed optical communications [4]. Through machine learning techniques, we aim to mitigate these nonlinearities, unlocking the potential for faster and more reliable data transmission. As we delve deeper into the intricacies of optical fiber systems, we explore the dynamic behavior of ultrashort pulses within nonlinear fibers [5]. Leveraging neural networks, we develop models capable of predicting and reconstructing these intricate pulse dynamics. This breakthrough not only enhances our understanding of pulse dynamics but also facilitates the design of more robust optical communication systems [6]. In the final phase of our research journey, we tackle the challenge of deploying deep neural networks within real-time systems. To this end, we propose a model compression method utilizing knowledge distillation. This innovative approach allows us to distill the vast knowledge contained within our deep neural networks into more compact architectures, enabling their seamless integration into real-world latency-sensitive communication systems [7].

In summary, the combination of telecommunication systems and machine learning has the potential to reshape communication technology fundamentally. As ML techniques continue to advance and become more seamlessly integrated into telecommunication networks, we can expect improved performance, enhanced user experiences, and a transformative impact on how information is transmitted, received, and utilized in our increasingly connected world. Our work explores some facets of the same and the findings are encouraging.

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List of Abbreviations

BiLSTM Bidirectional long short term memory. 9, 95, 128

CaNN Cascade Neural Network. 128

CNN Convolutional Neural Network(s). 18, 24, 128

DBP Digital Backpropagation. 8, 55, 95

DDPG Deep Deterministic Policy Gradient. 32, 34, 72, 85

DNN Deep Neural Network(s). 169

DRL Deep Reinforcement Learning. 7, 80, 92

DSP Digital Signal Processing. 8, 14, 47, 51

EVM Error Vector Magnitude. 114

FCNN Fully connected neural network. 9, 128

FPGA Field-Programmable Gate Array. 69, 195

FWM Four Wave Mixing. 4, 49

GRU Gated Recurrent Unit. 128

GVD Group Velocity Dispersion. 129

KD Knowledge Distillation. 18, 170

LSTM Long short term memory. 128

ML Machine Learning. vi, 21, 125

NLC Nonlinear compensation. 54

NLSE Nonlinear Schrodinger equation. 15, 128, 170

NN Neural Network. 15

QAM Quadrature Amplitude Modulation. 3

RNN Recurrent Neural Network. 24, 140

SPM Self Phase Modulation. 4, 48, 99

TL Transfer Learning. 7, 37, 72, 89

WDM Wavelength Division Multiplexing. 3, 98, 99

XPM Cross Phase Modulation. 4, 49, 99