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Mini Review

Machine learning methods for optical communications

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Introduction

Radio over Fiber (RoF) technology has been realized in different forms ranging from analog to more complex forms [1-6]. The enhancement of capacity and wireless coverage has posed significant challenges to the existing optical and wireless access networks. Machine Learning (ML) methods have given a new direction to meet the ever-increasing challenges in fiber-optic communications. Since, ML-based methods are well known to perform exceptionally well in scenarios where it is too difficult to explicitly describe the underlying physics and mathematics of the problem and the numerical procedures available require significant computational resources/time.

Before the introduction of ML in this field, the reduction of nonlinearities was carried out through different methodologies that were proposed during last 10 years via Optical and Electrical domain methods, with latter getting more attention. Digital Predistortion (DPD) has gained immense attention and therefore it is still looked to be an important methodology [1,7-9]. However, these DPD based linearization techniques are not so straight forward and are rather complex, time consuming and adds extra over heads [10]. Similarly, these methodologies require an extra feedback mechanism which is achievable but increases the complexity of the system. Therefore, reducing such nonlinearities in optical communication links effectively is still a bottle neck in efficient deployment of optical communication systems.

Recent advancements in ML technology have further motivated the researchers to explore true potential of this emerging field in optical communication systems. Firstly, we review some significant research ideas pertaining to the use of ML algorithms in fiber-optic communications.

Then, a experimental study is presented for the mitigation of nonlinear impairments by comparing Reinforcement Learning (RL) based machine learning method with Support Vector Machine (SVM) method and conventional methods. In the proposed system, 10-Gb/s with 256 quadrature amplitude modulation (QAM) signal is injected into distributed feedback (DFB) laser for 50 km single mode fiber transmission. It causes signal to suffer from nonlinearities due to opto-electronic devices in the RoF link as the ideal decision boundary is no longer linear.

Machine learning applications in optical communication system

The application of optical communication systems can be divided with three main subcategories:

i. Nonlinearity Mitigation

ii. Performance Monitoring

iii. Smart Decision/ Prevention

The mitigation of nonlinearities in optical communications with ML is the most important application these days. Recently, RL-SARSA based ML method has been evaluated in [11-12] while SVM and K-Nearest Neighbours (KNN) based ML methods have been utilized too in [13-15]. SBP method has also been evaluated for reducing the impairments in optical communication systems [16].

Optical communication researchers are no strangers to regressions and classifications. Over the last decade, coherent detection and digital signal processing (DSP) techniques have been the cornerstone of optical transceivers in fiber-optic communication systems. Advanced modulation formats such as 256 quadrature amplitude modulation (256-QAM) and above together with DSP-based estimation and compensation of various transmission impairments such as laser phase noise have become the key drivers of innovation. In this context, parameter estimation and symbol detection are naturally

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regression and classification problems. Currently, most of these parameter estimation and decision rules are derived from probability theory and adequate understanding of the problem's underlying physics. As high-capacity optical transmission links are increasingly being limited by transmission impairments such as fiber nonlinearity, explicit statistical characterizations of inputs/outputs become difficult. The maximum likelihood decision boundaries in this case are curved and virtually impossible to derive analytically. Consequently, there has been an increasing amount of research on the application of ML techniques for fiber nonlinearity compensation (NLC). Another related area where ML flourishes is short reach direct detection systems that are affected by chromatic dispersion (CD), laser chirp, and other transceiver components imperfections, which render the overall communication system hard to analyze.

The other important application of ML is monitoring the performance of optical communication system. Many methodologies have been evaluated among which SVM [17], ANN [18] and Kernel based methods are most significant [19]. Recently, Parzen window method to mitigate the fiber nonlinearity in the context of dispersion managed and dispersion unmanaged systems has been proposed as well [20].

Finally, the other important application of ML method is smart decision in order to prevent any errors by fault detection. Reliable operation of an optical network requires incorporation of an early protection mechanism into the network. Recently, several ML-based techniques have been developed for cognitive fault detection/prevention in fiber-optic networks. A combination of Double Exponential Smoothing (DES) and SVM for network equipment failure prediction has been employed in [20]. In [17,21,22], an ANN is trained to learn historical fault patterns in networks and is subsequently used for detecting significant network faults with much better accuracies and proactive reaction times as compared to traditional threshold-based fault detection methods. The ML methodologies can be implemented in recent real time S-DRoF systems as explained in [23].

ML techniques offer the opportunity to optimize the design of individual physical components as well as complete end-to-end fiber-optic communication systems. Recently we have seen some noticeable research works in this regard with quite encouraging results. In [24], a complete optical communication system including transmitter, receiver and nonlinear channel is modeled as an end-to-end fully-connected DNN. This approach enables the optimization of transceivers in a single end-to-end process where the transmitter learns waveform representations that are robust to channel impairments while the receiver learns to equalize channel distortions. The results for 42 Gb/s intensity modulation/direct detection (IM/DD) systems show that the DL-based optimization outperforms the solutions based on two- and four-level pulse amplitude modulation (PAM2/PAM4) and conventional receiver equalization, for a range of transmission distances. Jones, et al. [25] proposed an ANN-based receiver for Nonlinear Frequency-Division Multiplexing (NFDM) optical communication systems. Unlike standard nonlinear Fourier transform (NFT) based receivers which are vulnerable to losses and noise in NFDM systems, the ANN-based receiver tackles these impairments by learning the distortion characteristics of previously transmitted pulses and applying them for inference for future decisions. The results demonstrate improved BER performance as compared to conventional NFT-based receivers for practical link configurations. In Ref. [26], an ANN is used in receiver DSP for mitigating linear and nonlinear impairments in IM/DD systems. The ANN infers linear and nonlinear channel responses simultaneously, which are then exploited for increasing the demodulation reliability beyond the capability of linear equalization techniques. Using an ANN along with standard feed-forward equalization (FFE), up to 10 times BER improvement over FFE-only configurations is demonstrated for 84 GBd/s PAM4 transmission over 1.5 km SSMF.

Figure 1 presents the summary of the applications of ML methods in optical communication systems.

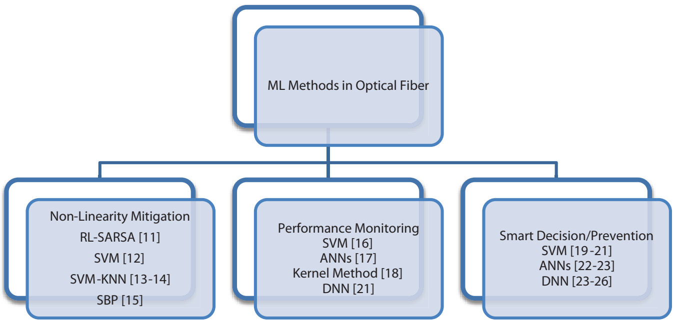

Figure 1: Key applications of ML methods in optical fiber systems.

Role of Machine Learning in Future

Looking to the future, we can foresee a vital role played by ML-based mechanisms across several diverse functional areas in optical networks, for example, network planning and performance prediction, network maintenance and fault prevention, network resources allocation and management, etc. ML can also aid cross-layer optimization in future optical networks requiring big data analytics, since it can inherently learn and uncover hidden patterns and unknown correlations in big data, which can be extremely beneficial in solving complex network optimization problems. The ultimate objective of ML-driven next-generation optical networks will be to provide infrastructures that can monitor themselves, diagnose and resolve their problems, and provide intelligent and efficient services to the end users [24].

Conclusion

The article provides a recent applications of ML methods in optical communication systems. The survey presents the categories of applications where ML has been successfully being employed. Indeed, the ML methods proposed are quite useful in mitigating the nonlinearities of optical communication systems.

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