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Nonlinear Fourier Transform: Perpetual Research Topic or Future Game-Changer?

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Abstract: The topic of nonlinear Fourier transform (NFT) will be discussed focusing on the results achieved so far, on current open challenges and on an outlook on future prospects, especially focusing on machine-learning aided NFT systems. © 2020 The Author(s)

1. Introduction

Optical communication systems based on single-mode fibers are currently reaching a saturation in achievable transmission rate. Kerr nonlinearity is one of the fundamental challenges to overcome to try to increase the throughput of deployed transmission systems. Whereas the last decade has seen a plethora of digital [1,2] and optical [1,3-4] methods focused on compensating for the impact of nonlinear distortion, an older mathematical theory has also been re-discovered, i.e. the inverse scattering transform recently better known as nonlinear Fourier transform (NFT) [5]. The NFT theory provides analytical solutions of the integrable nonlinear Schrödinger equation (NLSE) by solving the Zakharov-Shabat spectral problem [6]. Through direct and inverse NFT, signaling schemes optimized for the dispersive and nonlinear fiber channel can be constructed, yielding to the concept of nonlinear frequency division multiplexing (NFDM) systems. Whereas this approach has been extensively explored in the past in terms of soliton and eigenvalue communications [7], current optical coherent transceivers allow overcoming a number of limitations of soliton transmission by enabling access to the full optical field. More complex signaling schemes can now be constructed, e.g. with complex modulation formats [8]. This key advance has fueled a renewed interest in the topic with several impressive demonstrations of NFDM transmission [9]. Single and dual-polarization transmission has been demonstrated for systems modulating not only the discrete (solitonic) part of the NFT spectrum [10-12] but also the continuous (dispersive) part [13,14]. Very recent demonstrations have shown novel methods to encode information on both spectral components for single [15] and dual-polarization [16] NFDM.

Whereas significant progress has been achieved by NFDM systems within very few years, a number of open challenges still limit their applications to practical scenarios. The NFT theory is defined for a lossless NLSE, therefore fiber loss and amplification strongly hinder the system performance limiting the transmission reach, especially for large amplifier spacing [11,17]. Furthermore, the impact of noise on NFDM systems is still not fully understood and researching optimal encoding (transmitter-side) and detection (receiver-side) strategies is an active research direction [18,19]. Finally, the vanishing boundary conditions, i.e. the need to transmit localized bursts, pose strong limitations on the achievable spectral efficiency. This limitation may be addressed by considering periodic boundary conditions with interesting preliminary results shown recently [20].

In this talk, we will review the fundamentals of NFT and NFDM systems, summarizing the state of the art, describing NFDM-specific digital signal processing techniques [21] and discussing future directions. In 2018, we reported on the use of a neural-network-based receiver for NFDM systems, showing a significant improvement in performance and/or achievable transmission reach [22]. More recently, we have shown how full end-to-end learning can be applied to NFDM systems yielding additional improvement [23]. The choice of applying end-to-end learning to NFDM is dictated by needing to restrict the vast parameter space for auto-encoders optimization in a standard coherent system. NFT provides a theoretically sound mapping between symbols and time-domain waveforms. We believe this is a valuable stepping stone towards applying full end-to-end learning to generic coherent communication systems transmitting over the nonlinear dispersive fiber channel. We will thus conclude the talk with brief prospects towards derivative-free end-to-end learning for optical communication systems.

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