Inter-channel Interference in Non-linear Frequency-division Multiplexed Networks on Fibre Links with Lumped Amplification

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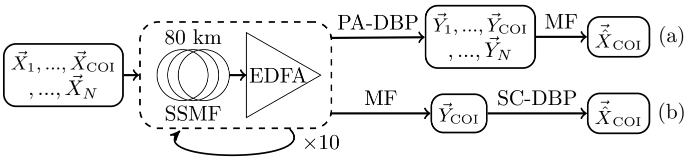
There has been some interest in the Non-linear Frequency-Division Multiplexing (NFDM) in optical fibre communication systems, because it promises interference-free or weak-interference between channels in an optical routed network [1]. NFDM scheme uses Non-linear Fourier Transform (NFT) to bring a time-domain signal into the non-linear frequency domain (NFD), where the spectra evolve in a linear manner during signal propagation in the fibre channel. The successful application of NFT relies heavily on the "channel's integrability" that is only fulfilled by an ideal distribution-Raman amplification. However, most of the optical fibre links are amplified by Erbium-doped fibre amplifiers (EDFAs). The impact of the non-integrability in NFDM networks is unclear. In such a network, one key device is the Non-linear Add-drop Multiplexer (NADM) that adds or drops channels in the NFD [2]. Simulating such device that processes many channels simultaneously is still difficult due to a high complexity and inaccuracy of the current INFT-NFT algorithm. To get around this difficulty, we adopt a different approach to estimate the inter-channel interference (ICI) in NFDM networks.

The optical fibre channel model of concern is a multi-span dual-polarisation (DP) dispersion unmanaged fibre link, which can be described by the Manakov equation as in (1)

$$\frac{\partial \vec{Q}}{\partial z}+\frac{\alpha}{2}\vec{Q}+\frac{j\beta_2}{2}\frac{\partial^2\vec{Q}}{\partial t^2}-j\frac{8}{9}\gamma\vec{Q}\left\|\vec{Q}\right\|^2=0, \quad (1) \qquad \frac{\partial \vec{Q}_{\text{pa}}}{\partial z}+\frac{j\beta_2}{2}\frac{\partial^2\vec{Q}_{\text{pa}}}{\partial t^2}-j\frac{8}{9}\gamma_a\vec{Q}_{\text{pa}}\left\|\vec{Q}_{\text{pa}}\right\|^2=0. \quad (2)$$

where $\vec{Q}(t,z)=[Q_1(t,z)\ Q_2(t,z)]$ is the complex envelope of the DP-signal as a function of time t and distance z along the fibre. Other parameters are listed in the table in Fig. 1. To apply NFT, we approximate (1) with the so-called path-averaged Manakov equation as written in (2), where $\gamma_a=\gamma(1-e^{-\alpha L_{\text{sp}}})/(\alpha L_{\text{sp}})$. After each EDFA at $z=ML_{\text{sp}}$, $M=1,2,...,N_{\text{sp}}$, $\vec{Q}_{\text{pa}}(t,z)$ *approximates* $\vec{Q}(t,z)$ with small error. We first clarify the concepts of different digital back-propagation (DBP) schemes, as DBP is the main tool in our estimation. The single-channel DBP (SC-DBP) refers to the process of filtering the channel of interest (COI) and solving (1) to recover $\vec{Q}(0,t)$ (input) from the filtered boundary condition $\vec{Q}(z,t)$ (output), using SSFM with fine step size (0.1 km). The EDFAs are replaced with attenuators of the opposite gain. The path-averaged DBP (PA-DBP) refers to the process of solving (2) to recover $\vec{Q}(0,t)$ from the boundary condition $\vec{Q}(z,t)$, using SSFM with fine step size (0.1 km). We compare two *noiseless* Wavelength-Division Multiplexed (WDM) systems illustrated in Fig. 1(a)(b) using DP 32-QAM Nyquist signal of 50 GHz bandwidth with equalisation: 1) full-band PA-DBP followed by matched filter, 2) matched filter followed by SC-DBP. In single-channel scenario, if viewed as a equalisation scheme, the combination of NFT, back-rotation in the NFD, and INFT is somewhat equivalent to the PA-DBP. Therefore, we consider the residual distortion in the system of Fig. 1(a) as a rough estimate of the ICI in NFDM networks.



β_2	$-21.5\times10^{-27}\ \text{s}^2/\text{m}$	group velocity dispersion
α	$0.2\ \text{dB km}^{-1}$	fibre loss
γ	$1.3\ (\text{W}\cdot\text{km})^{-1}$	non-linearity parameter
L_{sp}	80 km	span length
N_{ch}	$15, 25, 45$	number of channels

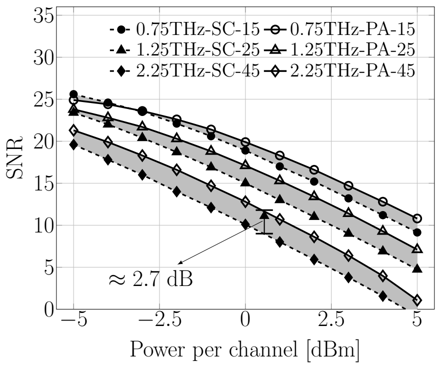


Fig. 1. (a)(b) Simulation diagram of noiseless non-integrable models. MF for matched filter. (c) Residual distortion of SC-DBP (In the legend preceded by total bandwidth and followed by number of channels) and PA-DBP systems.

The estimated ICI in NFDM is weaker than ICI in WDM with SC-DBP when N_{ch} is larger than 25.

References

1. M. I. Yousefi et al., "Linear and nonlinear frequency-division multiplexing," in *ECOC*, Sept 2016.
2. M. I. Yousefi et al., "Linear and nonlinear frequency-division multiplexing," arXiv:1603.04389v3, May 2016.