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Tunable optoelectronic chromatic dispersion compensation based on machine learning for short-reach transmission

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1. Motivation

- An increase in information rate is especially a challenge for **inter-data center communication** due to **chromatic dispersion** and low power consumption requirements in the transceiver.

- State of the art:
  - Coherent systems using simplified digital signal processing (DSP) algorithms for low power consumption [1].
  - Direct detected (DD) systems:
    - Digital solutions (DSP): Volterra, maximum likelihood sequence estimation (MLSE), Kramers-Kronig receiver, neural networks and Tomlinson Harashima precoding.
    - Optical solutions: Dispersion compensation fibers, fiber Bragg grating and reservoir computing [2].

- Proposed solution:
  - **Share complexity between optical and electrical domain in a direct detection system [3].**

2. Optical processing

- The optical module spectral decomposition (SD) slices the signal into narrow frequency sub-bands, while the spectral composition (SC) recombine everything back again. Perfect reconstruction of the signal is obtained if the SD is applied followed directly by the SC [4].

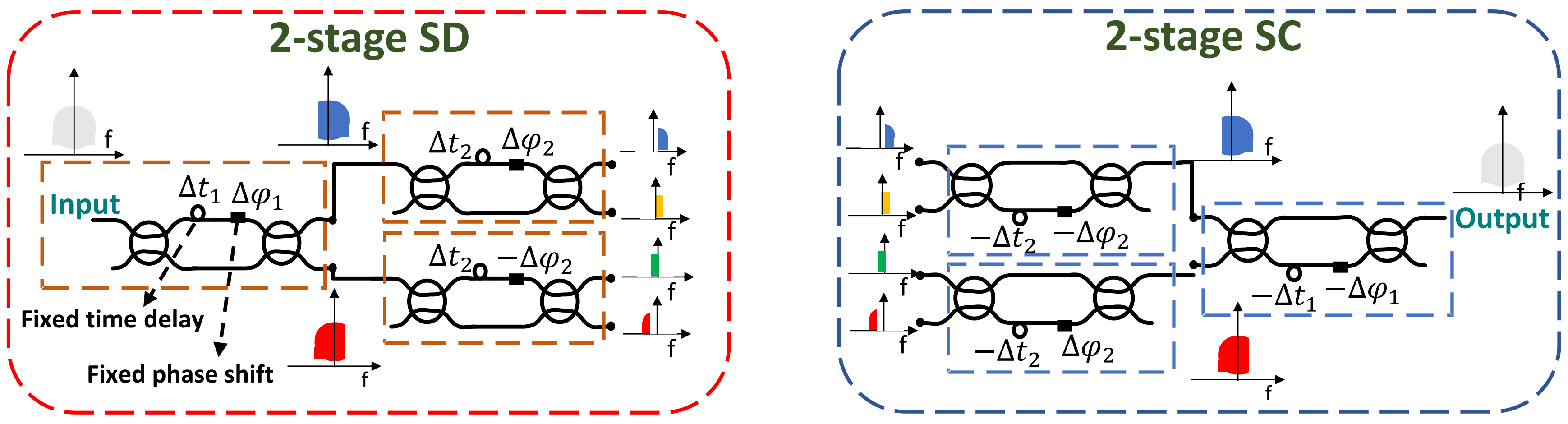
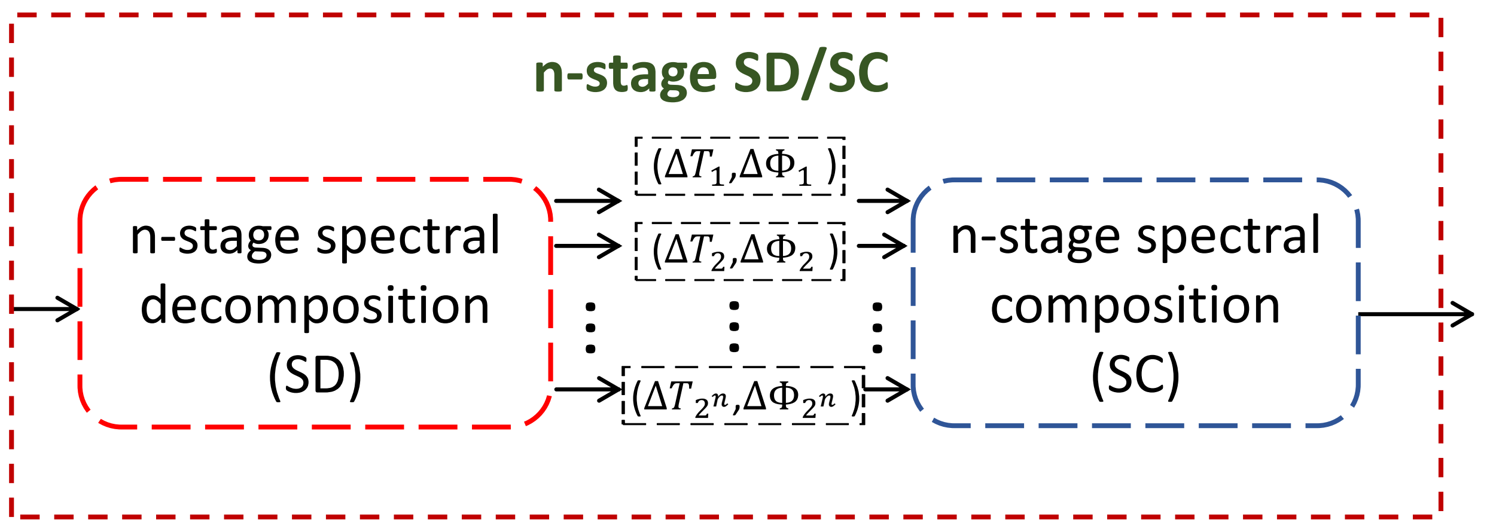


Fig.1 - Example with 2-stage SD and 2-stage SC.

- The Mach-Zehnder delay interferometer (MZDI) is the base block to build the SD/SC. The delay and phase in this component are calculated to have a specific transfer function (orthogonal narrow sub-bands) and are kept constant afterward.
  - Arrayed waveguide gratings (AWG) can also be considered.

- To mitigate CD a time delay and phase shift between SD and SC need to be applied. The optimal values are trained with backpropagation algorithm to optimize the cross-entropy of the system.


n-stage SD/SC

n-stage spectral decomposition (SD)

$(\Delta T_1, \Delta\Phi_1)$
$(\Delta T_2, \Delta\Phi_2)$
$\vdots$
$(\Delta T_{2^n}, \Delta\Phi_{2^n})$

n-stage spectral composition (SC)

Fig.2 – Optical processing to mitigate CD. Time delay (ΔT) and phase shift (ΔΦ) are adjusted to improve the bit error rate (BER) of the transmission. n is the number of stages used to perform the SD or SC function.

3. Neural network equalization

- Neural network (NN) equalizer used to mitigate the residual CD and to improve the signal-to-noise ratio in the receiver of a DD system.

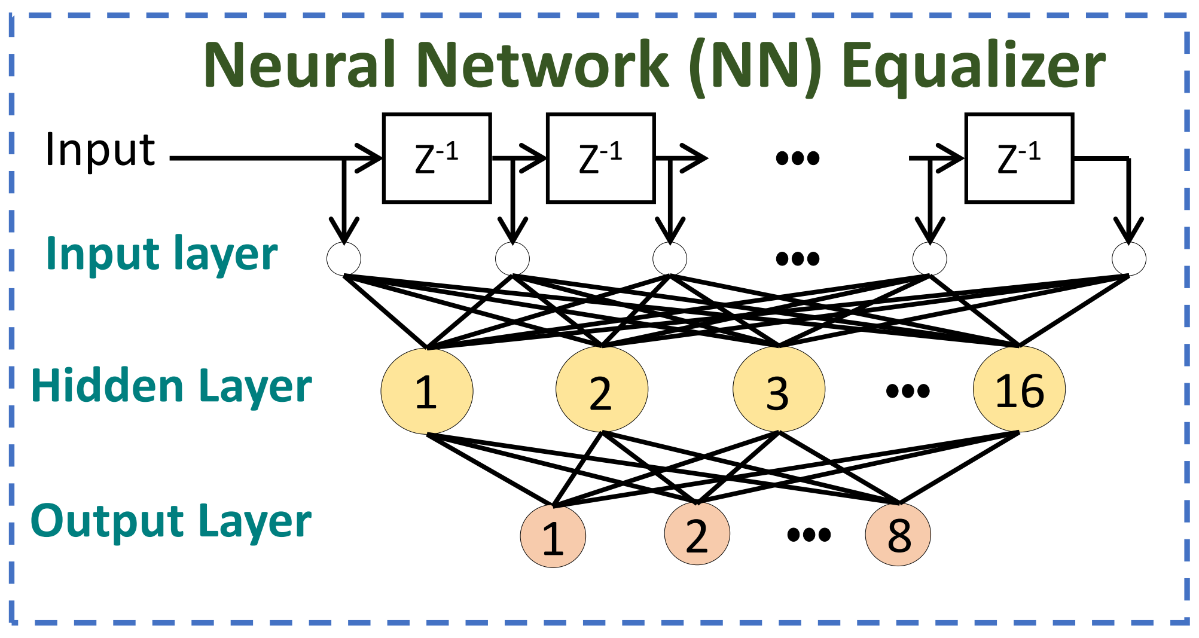

Neural Network (NN) Equalizer

Fig.3 – NN Equalizer performing regression with 16 neurons in the hidden layer and 8 neurons in the output layer (1 symbol). A hyperbolic tangent function is used as an activation function in the hidden layer, while a linear function is used in the output layer.

4. Simulation results

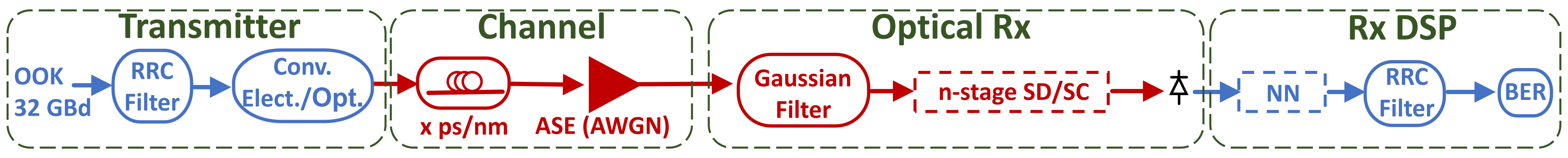


Fig.3 – Simulation setup. Reference system without the dashed blocks. RRC: root-raised cosine.

- All the results are shown in terms of SNR penalty at KP4 FEC, with a hard-decision BER threshold of 2.26×10^{-4}. The SNR varies from 13 to 20 dB. Each simulation is repeated 5 times to measure the statistical relevance of the results.

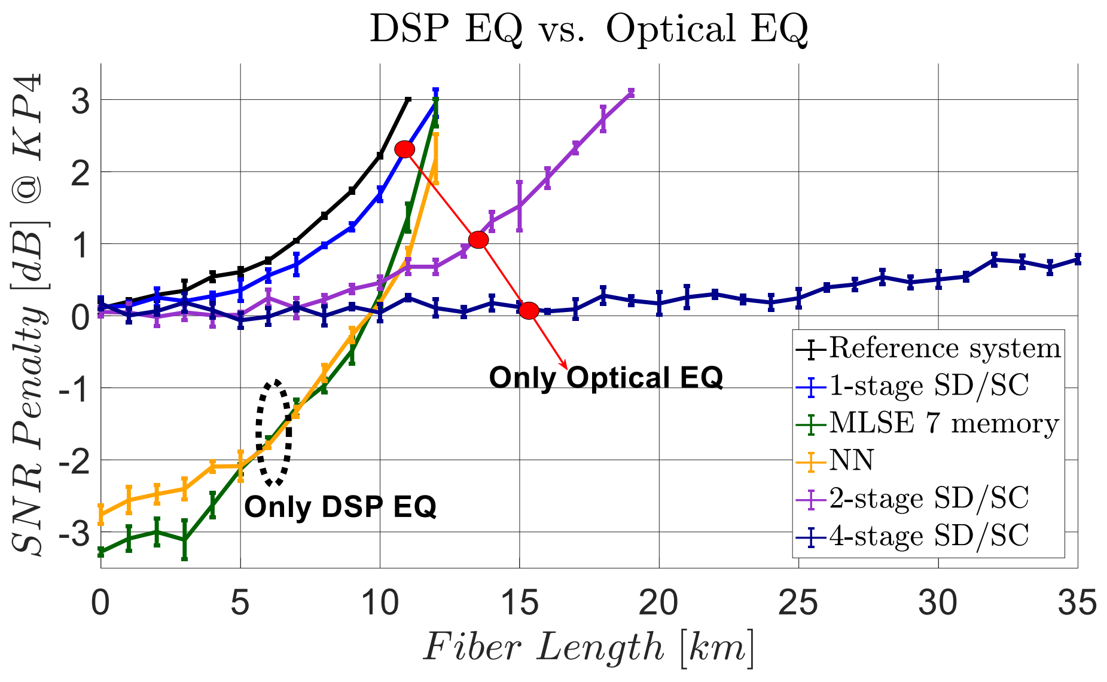


Fig.4 - Result comparing only DSP equalization (EQ) or optical EQ.

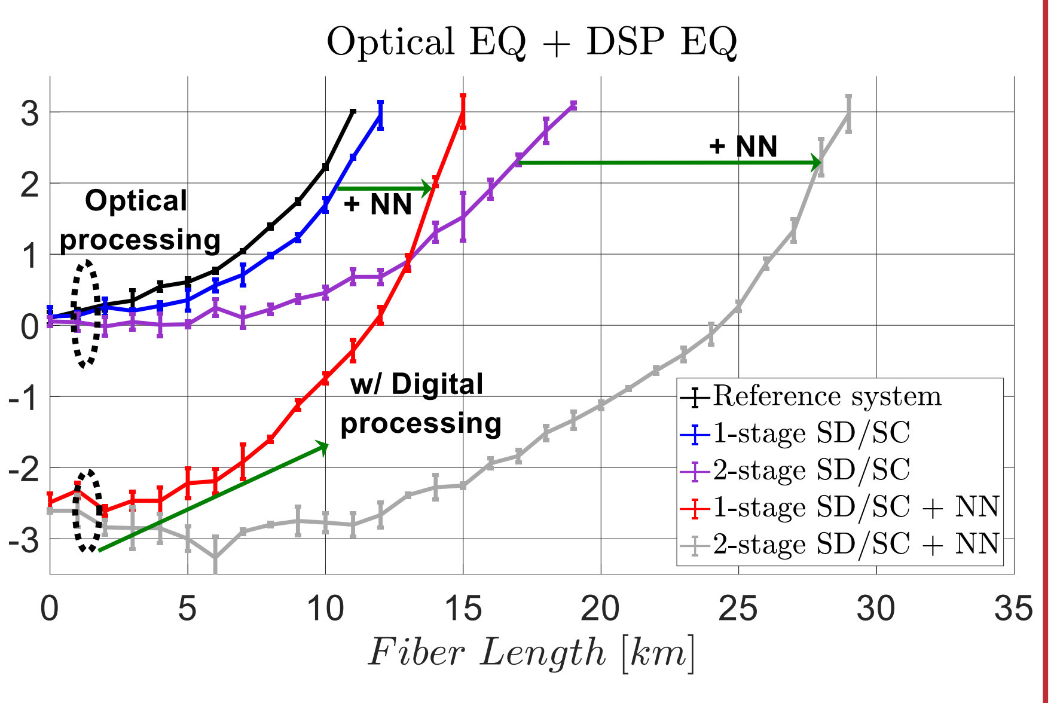


Fig.5 - Results comparing optical EQ with optoelectronic EQ.

5. Conclusions

- Using 4-stage SD/SC (only optical EQ) improves the transmission distance. However, increases the optical complexity.
- Applying only DSP EQ shows a limitation due to the phase information not being accessible in the digital domain.
- A hybrid optoelectronic solution increases the transmission distance with a less complex optical module.

References

[1] Chagnon, M. OFC 2019, pp. 1–41.
[2] Katumba, A.; Yin, X.; Dambre, J.; Bienstman. JLT 2019, 37, 2232–2239.
[3] Ranzini SM, Da Ros F, Bülow H, Zibar D. Applied Sciences. 2019 Jan 9 (20):4332.
[4] Hillerkuss, D.; Schmogrow, R.; Schellinger, T.; Jordan, M.; Winter, M.; Huber, G.; Vallaitis, T.; Bonk, R.; Kleinow, P.; Frey, F.; others. Nature photonics 2011, 5, 364.
[5] Chen, S.; Gibson, G.; Cowan, C.; Grant, P. Signal processing 1990, 20, 107–119.

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