Optical regeneration of a telecommunication signal with amplitude modulation

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Fiber lines with a high data rate (100 Gbps) over single-mode fiber over short distances are in wide demand in data centers for the implementation of the IEEE 802.3bs 400 Gbps protocol [1]. To achieve these data rates, it is necessary to compensate for optical signal distortions caused by chromatic dispersion, nonlinear effects, and their combination. However, not all existing solutions used in backbone communication lines can be implemented in data processing centers. The main requirements for fiber systems used in data centers are low cost, ease of implementation, and efficient energy performance. Therefore, it is desirable to avoid complex digital signal processing circuits to compensate for these effects, which can lead to additional power consumption and signal delay. In this work, we propose an optical regressor scheme that allows the restoration of an optical signal prior to direct detection. Such optic methods have the potential to be energy efficient and have a wide frequency bandwidth.

Figure 1 shows a diagram of a 27 km fiber link with an optical regressor. As the modulation format of the optical signal, a 4-level amplitude-pulse modulation with a transmission rate of 14 Giga-baud was used. After passing through the communication line and the optical regressor, the signal is detected by a photodetector. Average signal power ranged from 0 to 4 dBm.

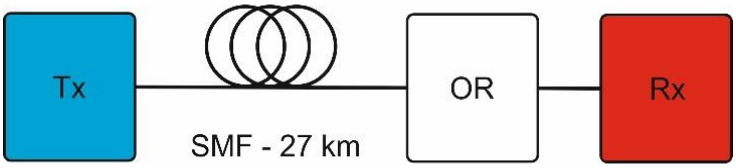

Fig. 1. Communication line diagram with optical regressor

Figure 2 shows a schematic of the proposed optical signal processing method, which consists of 3 fiber couplers and 3 fiber combiners.

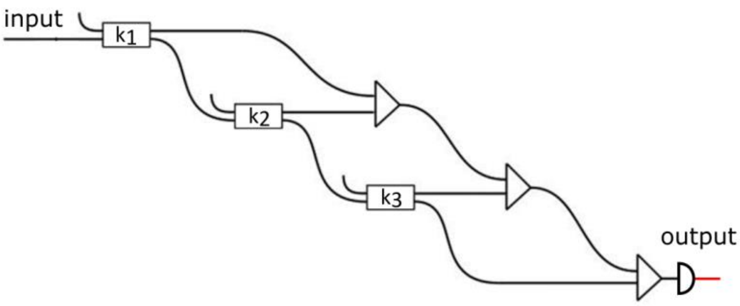

Fig. 2. Optical regressor circuit

The number of taps and the length of the fiber line between adjacent taps are hyperparameters of the proposed device and are selected for a given signal transmission rate and length of the fiber-optic communication line. For each set of hyperparameters, the split ratios α of the taps are determined by the backpropagation method. The backpropagation method finds a set of values of the division coefficients of the taps k, which provides the minimum root-mean-square error Err between the detected signal and the original signal without distortion.

$$Err = \frac{1}{N}\sum_{i=0}^{N}\left|D\big(F(u(i),k)\big) - D(\hat{Y}(i))\right|^2 \rightarrow min,$$

where u – is the signal at the output from the optical communication line, F – is the device transformation function, which depends on the set of dividing factors of the couplers k, D – is the detector function, Y – is the signal before transmission over the optical communication line, i – is the number of the transmitted symbol from 0 to N.

To demonstrate the operation of the optical regressor, we used numerical simulation of the propagation of an optical signal along an optical fiber by solving the nonlinear Schrödinger equation, which describes the evolution of the envelope of the optical signal A (z, t):

$$\frac{\partial A}{\partial z} = -\frac{\alpha}{2}A - i\frac{\beta_2}{2}\frac{\partial^2 A}{\partial t^2} + i\gamma|A|^2 A.$$

This equation was solved numerically using the symmetric Fourier splitting into physical processes with the following parameters: linear loss α = 0.2 dB / km, fiber nonlinearity γ = 1.4 1 / (W km), chromatic dispersion β2 = -25 ps2 / km, length wavelength λ = 1550 nm, number of counts per period q = 16. Figure 3 shows the eye-diagrams of the signal after detection for the case when the proposed scheme was used (a) and for the case of direct detection (b). The average signal power was 0 dBm. In the process of determining the circuit parameters, we received the following device architecture: 4 couplers with a distance of 0.9116 mm between them and coefficients of 0.99, 0.45, 0.08 and 0.25, respectively. The bit error rate (BER) without using the proposed method is 0.00415, and after applying 0.00026. For a power of 4 dBm, the BER without using the proposed method was 0.0042 and after applying 0.00038. The tap ratios are 0.95, 0.4, 0.09 and 0.66, respectively.

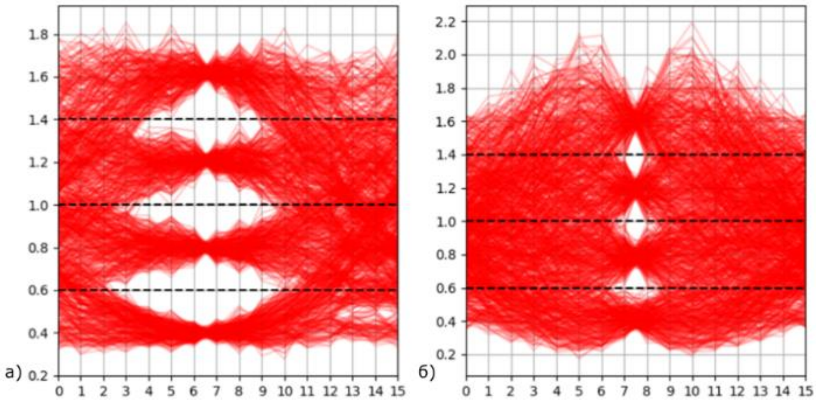

Fig. 3. Eye-diagrams of the recorded signal a) after passing through the device b) with direct detection after passing through the communication line.

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Reference

[1] "IEEE Standard for Ethernet, Standard 802.3bs", 2017.
[2] G.P. Agrawal, Nonlinear fiber optics, 4th ed. Academic press, 2007, 539 c.