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Variable-step DD-FTN algorithm for PAM8-based short-reach optical interconnects

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Abstract: We experimentally demonstrate a variable-step DD-FTN algorithm for 129-Gbit/s PAM8-based short-reach optical interconnects. The fast and stable convergence of the proposed algorithm leads to better performance than conventional DD-FTN algorithm.
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1. Introduction

The past decades have witnessed an exponential explosive increase of network traffic, resulting from the emergence of cloud computing and all kinds of applications. To deal with the increasing network data, large-scale data centers is growing rapidly. Owing to high capacity and low-power consumption, optical interconnects have been employed to transmit mass data in the data centers [1,2].

Four-level pulse-amplitude modulation (PAM4) has been commercially applied in 4×100-Gbit/s optical interconnects. For higher capacity optical interconnects, eight-level PAM (PAM8) is a good alternative to achieve higher spectral efficiency [3]. However, feed-forward equalizer (FFE) with least mean square (LMS) adaptive algorithm for PAM4-based optical interconnects no longer performs well for 100+Gbit/s PAM8-based optical interconnects because PAM8 signal is more sensitive for inter-symbol interference (ISI) and noise, and LMS adaptive algorithm cannot converge rapidly and steadily [4].

In this paper, we propose a variable-step direct-detection faster-than-Nyquist (VS-DD-FTN) algorithm for 129-Gbit/s PAM8-based optical interconnects. The VS-DD-FTN algorithm includes FFE with variable-step LMS (VS-LMS) adaptive algorithm, post filter and maximum likelihood sequence detection (MLSD), which can effectively deal with the ISI and enhanced in-band noise using less training symbols.

2. Principle

In this section, the principle of VS-DD-FTN algorithm is given. Different to conventional DD-FTN algorithm (Conv. DD-FTN) [5], VS-DD-FTN algorithm uses the VS-LMS adaptive algorithm. Employing the gradient descent method, VS-LMS adaptive algorithm can get the optimal tap coefficient $\boldsymbol{w}$ of FFE [6],

$$\boldsymbol{w}(k+1) = \boldsymbol{w}(k) + 2\mu(k) \times \text{error}(k) \times \boldsymbol{x}(k) \tag{1}$$

where $\boldsymbol{x}(k)$ is the input vector of the FFE, error(k) is equal to $t(k) - \boldsymbol{w}^T(k)\boldsymbol{x}(k)$, $t(k)$ is the desired output, and $\mu(k)$ is the variable step, which is defined as

$$\mu'(k) = \varphi \times \mu(k-1) + \gamma \times \text{error}^2(k-1) \tag{2}$$

and

$$\mu(k) = \begin{cases} \mu_{max}, & \mu'(k) > \mu_{max}; \\ \mu_{min}, & \mu'(k) < \mu_{min}; \\ \mu'(k), & otherwise \end{cases} \tag{3}$$

where $0 < \varphi < 1$, $\gamma > 0$. Therefore, the VS-LMS adaptive algorithm can change the $\mu(k)$ depending on the $\mu(k-1)$ and error$(k-1)$ to ensure that $\boldsymbol{w}$ converges rapidly and steadily. The output $z(k)$ of FFE with VS-LMS adaptive algorithm is $\boldsymbol{w}^T(k)\boldsymbol{x}(k)$. FFE with VS-LMS adaptive algorithm can effectively eliminate the high-frequency distortions, but enhances the high-frequency in-band noise. Then a post filter is used to reduce the enhanced in-band noise,

$$y(k) = z(k) + \alpha \times z(k-1) \tag{4}$$

where α is the coefficient of the post filter. Finally, the MLSD is used to recover the signal from the known ISI introduced by post filter.

3. Experimental Setups and Results

The experimental setups of 129-Gbit/s optical PAM8 system using VS-DD-FTN algorithm is shown in Fig. 1. Digital PAM8 signal is re-sampled to 43-GSa/s and uploaded into a digital-to-analog converter (DAC) with 3-dB bandwidth of 16 GHz. Thus, the link rate of electrical PAM8 signal is 129 Gbit/s. After an electric amplifier (EA), the amplified electrical PAM8 signal is modulated on optical carrier by a 40-Gbit/s electro-absorption integrated laser-modulator (EAM). Then the optical PAM8 signal is transmitted over 2-km standard single-mode fiber (SSMF). At the receiver, after being adjusted the received optical power (ROP) by a variable optical attenuator (VOA), the optical signal is detected by a photodiode (PD) and fed into 80-GSa/s real-time oscilloscope (RTO) with 3-dB bandwidth of 36 GHz to implement analog-to-digital conversion (ADC). Finally, digital signal processing including VS-DD-FTN algorithm and PAM8 decoder is implemented.

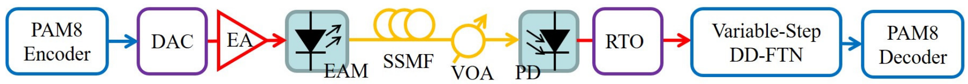

Fig. 1. Experimental setup of 129-Gbit/s optical PAM8 system with VS-DD-FTN algorithm.

Fig.2 (a) depicts that VS-DD-FTN nearly converges after training with 20000 samples, while Conv. DD-FTN requires about 50000 samples to converge. Generally, lots of training samples are needed, when μ is too small because $w(n)$ changes little every iteration. However, it may fail to converge, or even diverge, when μ is too large. VS-DD-FTN converges more rapidly and steadily than Conv. DD-FTN. As a result, as Fig.2 (b) reveals that both with 301 taps, VS-DD-FTN algorithm achieves the 7% FEC Limit at the ROP of -2dBm and -1dBm while Conv. DD-FTN with the same post filter cannot achieve even at the ROP of -1 dBm. As shown in Fig.2 (c), with the increase of α, BER decreases and then increases because the affect of introduced ISI is becoming more serous than that of enhanced in-band noise. By the way, BER minimizes when α is 0.7 and VS-FFE cannot achieve the 7% FEC Limit at the ROP of -1 dBm without post filter which means that α is 0.

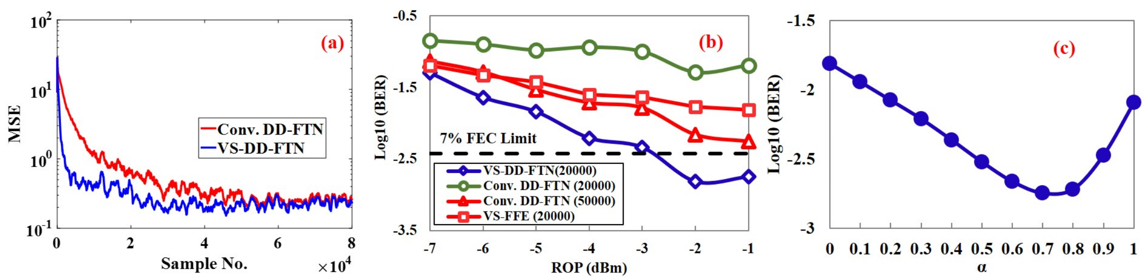

Fig. 2. (a) Comparison of MSE of Conv. DD-FTN and VS-DD-FTN algorithm. (b) Comparison of BER of Conv. DD-FTN, VS-FFE and VS-DD-FTN algorithm with different ROP and training samples. (c) BER of VS-DD-FTN algorithm with different α.

4. Conclusion

We propose and experimentally demonstrate 129-Gbit/s PAM8 system using the proposed VS-DD-FTN algorithm for short-reach optical interconnects. The experimental results show that even using less training samples, fast and stable convergence of the proposed algorithm leads to better performance than conventional DD-FTN algorithm.

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