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Recent Advances for High Speed Data Center Inter-connects

Kangping Zhong[1,*], Xian Zhou[1,2], Yiguang Wang[1], Changyuan Yu[1], Alan Pak Tao Lau[3], Chao Lu[1]

1 Department of Electronics and Information Eng., The Hong Kong Polytechnic University, Hung Hom, Hong Kong SAR, China
2University of Science and Technology Beijing, Beijing, China
3 Department of Electrical Eng., The Hong Kong Polytechnic University, Hung Hom, Hong Kong SAR, China
**zhongkangping1987@gmail.com*

Abstract: In this paper, we review recent advances on optical short reach transmission systems for data center inter-connects. Recent progress from our group on high-speed short reach transmission systems is summarized.

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1. Introduction

Coherent detection with advanced modulation formats combined with digital signal processing (DSP) has dramatically change long-haul optical transmission systems. The capacity of long-haul transmission system can reach to 100Tbit/s per fiber. However, factors such as system cost, power consumption and footprint will affect practical implementation of short reach transmission systems for data center inter-connects. In the view of this, low cost direct modulated laser based transmitters such as vertical cavity surface emitting laser (VCSEL), direct modulated DFB laser (DML) and DFB laser integrated with EAM (EML) combined with direct detection are promising for optical short reach applications.

According to different applications, short reach transmission system can be classified into four cases: chip to chip inter-connect, server to server inter-connect (<1km), inter-data center optical inter-connect (2km to 20km) and optical access and metro applications (>20km). Here, most of data center inter-connects are server to server inter-connection and inter-data center optical interconnection. Recently, four parallel streams of 25Gb/s transmission with OOK has been standardized as 100Gbps transmission of Ethernet frames. Research interest has now moved forward to 400Gb/s or higher, which means a high bit rate more than 100Gbit/s is desired. In this situation, high speed system has to be realized with low cost optics device with limited bandwidth which implies that high spectrum efficiency (SE) transmission system are required for future high capacity short reach applications. In order to meeting the high SE requirements, advanced modulation formats, polarization multiplexing and advanced DSP for channel impairments compensation are employed.

In this paper, we review recent advances on high speed optical short reach transmission systems for data center inter-connects. Our recent progress on high-speed short reach transmission systems is also summarized.

2. Recent Advances on High Speed Data Center Inter-Connects

In the past few years, intensity researches on high speed short reach transmission system employing advanced modulation formats (PAM-N, CAP, DMT et. al) and digital signal processing. A 100 Gb/s transmission link was demonstrated using polarization division multiplexed PAM-4 signal [1]. Comparing with PAM-8 and PAM-16, PAM-4 is regarded as a more attractive format for 100 Gb/s short reach applications in terms of system performance and implementation complexity.112 Gb/s short reach transmission using single polarization PAM-4 signal was demonstrated using SiP Mach-Zehnder modulator [2]. In our previous work, we have also successfully demonstrated a bit rate up to 128Gbit/s PAM-4 transmission system with commercial available EML-TOSA and PIN-ROSA [3,4]. Carrier-less amplitude and phase modulation (CAP) is another alternative scheme that may provide good system performance and high data rate using low-cost and bandwidth limited optical components. 10 Gb/s multi-level CAP for short reach communications was experimentally studied [5]. 40 Gb/s CAP-32 system was successfully demonstrated for low cost data communication links [6]. Higher order CAP signals were also experimentally demonstrated for short reach applications [7]. Using multi-band CAP, high-speed AWG and EML, 102 Gb/s signal transmission over 15km have been realized [8]. Subsequently, 400 Gb/s O band transmission over 20 km and 40 km of SSMF using multi-band CAP signal has been reported [9]. Discrete multi-tone (DMT) modulation also known as direct detection orthogonal frequency domain modulation (DD-OFDM), is another attractive scheme for low-cost and bandwidth limited short reach communication systems. DMT, as one kind of multi-carrier modulation techniques [10-14], shows high spectrum efficiency, flexible multi-level coding, and high tolerance to channel impairments. A 52.8Gb/s DMT signal transmission over 20km of SSMF has been achieved with a distributed feedback laser [12]. A single wavelength, single polarization 101 Gb/s DMT signal generated with a 64 GSa/s AWG

and a directly modulated laser has been transmitted over 10km of SSMF [13]. More recently, 4x117 Gb/s DMT signals have been successfully transmitted over 40 km of SSMF [14]. A four channel 560Gbit/s 128QAM-DD-OFDM short reach transmission system over 2km of SSMF was demonstrated in [15].

3. Advanced Techniques for High Speed Data Center Inter-connects

DD-FTN for Optical Channel Equalization

Limited bandwidth of optical/electrical components is one of the main impairments in low cost short reach transmission systems, which induce large attenuation of high frequency components of signal with large bandwidth. Different equalization methods were involved to compensate the bandwidth limitation. In [5], cascaded multi-modulus algorithm (CMMA) is involved for a 10Gbit/s CAP-16QAM system. Then, modified CMMA scheme is proposed in order to improve system performance [5]. Decision directed least mean squre (DD-LMS) is employed for a 40Gb/s CAP-32QAM short reach transmission system [6]. Different combination of these linear equalization methods are also demonstrated for higher-order modulation formats [7]. Besides linear equalization, nonlinear equalization is also employed to compensate the nonlinear of optical components and nonlinear channel response in order to improve performance of short reach systems [16]. However, the disadvantage of such equalization is that the noise in high-frequency components will be amplified which induce a decrease in SNR of signal. In short reach transmission system, the bandwidth of transmitter and receiver is relative low, which is even smaller than the Nyquist bandwidth of signal. In [3], we have proposed a direct detection faster than Nyqusit technology (DD-FTN) to recovery severely filtered signal. First, a post filter was placed after the equalizer for noise suppressing. The coefficient of post filter is optimized to obtain best performance. Then, the strong inter-symbol interference (ISI) induced by the post filter is eliminated by maximum likelihood sequence estimation (MLSE) algorithm. With this DD-FTN technique, 70Gbaud/s PAM-4 signal over 20km employing 25G device was experimentally demonstrated for short reach applications [17]. A total capacity of 500Gbit/s PAM-4 transmission system employed 25G EML TOSA and ROSA was demonstrated for 2km optical inter-connect applications [4]. Enabled by advanced equalization technique, we also demonstrated a 152Gbit/s SCM-Nyquist 16QAM transmission system, which is the highest bit-rate of such SCM system. More high bit-rate short reach transmission system employing higher order modulation formats and advanced digital signal processing technique are under investigating.

New Optical Device for High Speed Data Center Inter-connects

Besides the advanced digital signal processing for high-speed short reach transmission systems, there are lots of research on optical device to support high-speed data center inter-connects. Single transverse mode VCSEL with a very small RMS-spectrum that can reduce CD and enhance the effective bandwidth of transmission link is developed in [18]. Employing this SM-VCSEL, we have successfully demonstrated a 112Gbit/s DMT signal transmission over 300m OM4 fiber, which is the longest transmission distance at bit rate of 112Gbit/s at 850nm [19]. A double side EML has been successfully developed for low cost short reach transmission systems. We experimentally demonstrated a 120Gbaud/s PM-NRZ signal transmission over 2km with this new DS-EML [20].

4. Conclusions

Advanced digital signal processing (DSP) technique has dramatically changed the field of optical communications including optical short reach transmission systems. Recent advances in short reach transmission systems have been reviewed. Our recent progress on high-speed short reach transmission system has been summarized.

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