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Recent Advances in Short Reach Systems

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Abstract: In this paper, we review recent advances in high speed optical short reach transmission systems. Recent progress on advanced modulation formats, DSP, transmission schemes and devices are discussed.

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1. Introduction

For the past 10 years, advanced modulation formats combined with digital signal processing (DSP) and coherent detection has dramatically increased the capacity of long-haul optical transmission systems. The capacity of long-haul transmission system can now reach up to 1Pbit/s. The emergence of cloud computing, 5G wire-less, Internet of Things (IoT) are driving the need for mass data centers. Because of this, high-speed optical interconnects, which play important roles in intra- and inter-data centers communications, have become the center stage of research and implementation in recent years. Different from long-haul transmission systems, factors such as system cost, power consumption and footprint will affect practical implementation of short reach transmission systems for data center inter-connects. In view of this, intensity modulation using low cost direct modulated laser based transmitter 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 short reach transmission systems.

Considering different applications, short reach transmission systems 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 up to 100km). There are several issues needed to be addressed in order to realize high capacity short reach transmission system while keeping cost low: 1) limited bandwidth due to low cost transmitter and receiver; 2) Chromatic dispersion induced channel fading when operating at C band; 3) generation of polarization multiplexing signal and polarization de-multiplexing in IM/DD systems that double the spectrum efficiency. In recent years, researchers have proposed and developed various advanced techniques to solving these problems and the capacity of short reach transmission systems has been increased significantly.

In this paper, we review recent advances in high speed optical short reach transmission systems. Recent progress on advanced modulation formats, DSP, transmission schemes and devices are summarized.

2. Recent Advances in High Speed Short Reach Systems

Advanced Modulation Formats

With the advances of high speed digital-to-analog convertor (DAC), digital signal processing can be implemented at the transmitter side, which enables the application of advanced modulation formats in high speed short reach transmission systems. Popular advanced modulation formats that have been studied include pulse amplitude modulation (PAM), carrier-less amplitude and phase modulation (CAP), discrete multi-tone signal (DMT) and sub-carrier modulation (SCM). With the help of these advanced modulation formats, high speed transmissions up to 100Gbit per lambda can be achieved within limited component bandwidth. Single wavelength 100Gbit/s transmission was demonstrated using PDM-PAM4 signal [1]. Considering implementation complexity and OSNR requirements, PAM-4 is regarded as a more promising format than PAM-8 or PAM-16. High speed PAM-4 transmission systems also have been demonstrated using DML or EML [2-3]. In our previous work, we have experimentally demonstrated single channel PAM4 signal with bit rate up to 140Gbit/s and 4-lane 500Gbit/s PAM-4 transmission system using commercially available 25G EML-TOSA and direct detection for short reach applications [4-5]. Carrier-less amplitude and phase (CAP) modulation is another option. CAP-16 and high-order CAP signals were demonstrated for short reach applications [6-7]. Employing multi-band techniques, single lane 102Gbit/s and four lanes with a bit rate of 400Gbit/s multi-band CAP transmission system were experimentally demonstrated [8-9]. Discrete multi-tone (DMT) modulation is another attractive scheme for low-cost short reach communications. Single channel 101Gbit/s DMT signal transmission over 10km was achieved with a 64GSa/s AWG and a directly

modulated laser [10]. More recently, 4x117Gbit/s DMT signals have been successfully transmitted over 40 km of SSMF [11]. A four-channel 560Gbit/s 128QAM-DD-OFDM short reach transmission system over 2km of SSMF was demonstrated in [12]. Another advanced modulation format named half-cycle M-QAM Nyquist subcarrier modulation (SCM) also attracts much interest in short reach applications [13]. In our previous work, four lanes with a capacity of 608Gbit/s using half-cycle 16QAM Nyquist-SCM signal was demonstrated for short reach application employing 25G EML and direct detection [14].

Advanced Digital Signal Processing

With the help of digital signal processing inside optical transceiver, strong filtering effect due to limited bandwidth of optical components and chromatic dispersion induced channel fading can be compensated or eliminated. Linear equalization based on different algorithms such as cascaded multi-modulus algorithm (CMMA). Modified CMMA, decision directed least mean square and their combinations were demonstrated for bandwidth limited short reach transmission systems [6-7]. Besides linear equalization, nonlinear equalization is also employed to compensate the nonlinearity of optical components and nonlinear channel response in order to improve system performance [15]. In our previous work, we proposed a direct detection-faster than Nyquist (DD-FTN) technique to overcome the bandwidth limitations of the transmission link. With this DD-FTN technique, 70Gbaud/s PAM-4 signal over 20km employing 25G device was experimentally demonstrated for short reach applications [4]. A total capacity of 500Gbit/s PAM-4 transmission system employed 25G EML TOSA and ROSA was demonstrated for 2km optical inter-connect applications [5]. If the system is operating at C band, chromatic dispersion induced channel fading would severally degrade system performance and limit the maximum capacity and transmission distance. One method is CD pre-compensation at transmitter side using complex IQ modulator [16]. Another approach is using single side band (SSB) signaling. SSB signal can be generated by either electrical or optical methods. Among these methods, SSB signal generation based on digital signal processing and a dual-section EAM [17] or a low cost dual-drive MZM modulator [18] are promising ways due to its low cost.

New Transmission Scheme

Polarization multiplexing is an attractive way to increase system capacity. However, polarization de-multiplexing was difficult to realize in IM/DD systems in the past. In 2014, Di Che et al proposed a stokes-vector direct detection (SV-DD) receiver based self-coherent transmission system [19]. With SV-DD and DSP based polarization de-multiplexing, M Morsy-Osman et al experimentally demonstrated a 224Gbit/s PDM-PAM4 transmission over 10km [20]. Zhou Xian et al proposed a simple SV-DD receiver based on SOP estimation and MPBI elimination [21]. Lower complexity SV-DD receiver with only 3 PD was recently proposed by Shieh [22]. In order to further increase system capacity, M Morsy-Osman et al proposed to encode signal in the differential phase between X and Y polarization with PAM-4 signals to achieve a bit rate of 350Gbit/s on single wavelength [23]. Furthermore, 4-dimensional SV-DD receivers which enable full coherent modulation are recently proposed with the help of an additional 90 degree hybrid. A total bit rate of 360Gbit/s is achieved employing 45GBaud PDM 2-ring/8PSK signal [24]. More and more research interest is focused on this type of transmission scheme in order to increase the system capacity with simple implementation and low cost components.

New Devices for High Speed Short Reach Systems

Besides the advances in modulation formats, DSP and transmission schemes, there are various research advances on optical device to support high-speed data center inter-connects. Single transverse mode VCSEL with a very small RMS-spectrum that reduces CD and enhances the effective link bandwidth is developed in [25]. Employing this SM-VCSEL, we have successfully demonstrated an 112Gbit/s DMT signal transmission over a record 300m OM4 fiber [26]. Normally, it is really difficult to generate polarization multiplexed signal using direct modulated lasers due to the center wavelength instability. A double side EML has been successfully developed recently for PDM signal generation and a 120Gbaud/s PM-NRZ signal transmission over 2km was successfully demonstrated with this new DS-EML [27]. Another application of this DS-EML is generation of PAM-4 signal by combining two optical NRZ signals, which significantly releases the requirement on high speed DAC and linear amplifier as only NRZ signal is needed. In order to further increase capacity and performance of short reach transmission system, new optical devices continue to be one of the key areas of research.

3. Conclusions

Advanced digital signal processing (DSP) techniques have dramatically changed the field of optical communications including short reach transmission systems. Recent advances in short reach transmission systems have been reviewed. It is expected that research in various aspects of short reach systems will continue to be the major drivers for optical communications in the next few years.

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