Advanced signal processing techniques for direct detected short reach systems

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Abstract

We review recent progress in signal processing techniques employed to address three key challenges in performance optimization of high-speed short reach interconnection systems using low-cost and simple direct detected transceivers.

I. Introduction

A recent CISCO report predicts that 86% of global internet traffic will be data center (DC) related [1]. The short-reach interconnections collectively refer to optical communication links in the hundreds of meters for intra-DC transmissions and in the tens of kilometers for inter-DC transmissions [2]. Taking system cost, form factor and power consumption into consideration, coherent detection is no longer a preferred choice at least in the near future. Direct detection (DD) is the dominant technology for short reach interconnections.

In order to realize high capacity short reach transmission with low-cost transceiver, several issues need to be addressed: 1) Non-ideal performance of low-cost component such as insufficient bandwidth and nonlinear characteristics; 2) Chromatic dispersion (CD) induced channel fading when operating in C band; 3) Exploiting polarization in DD systems to increase transmission capacity. In recent years, the research community has put in tremendous amount of efforts to develop signal processing strategies for short-reach systems to solve these problems.

In this talk, we will review recent advance in signal processing techniques for short reach optical communication systems.

II. Advanced Signal Processing Techniques

A. Non-ideal Low-cost Components:

Due to the cost and power concerns, low cost optical/electrical components are typically used in short reach systems. The common impairment is considerable low-pass filtering effects due to insufficient bandwidth of various components. Additional nonlinear distortions will also be produced by the components like electro-absorption modulators (EAM). To reduce the impact of these non-ideal characteristics of low-cost components, several advanced DSP algorithms have been proposed and investigated as follows.

Direct detection-faster than Nyquist (DD-FTN): It consists of a feed-forward equalizer (FFE), a digital post filter and maximum likelihood sequence estimation (MLSE) operation. For the IM-DD systems suffered from serious narrowband filtering effects, it can provide much better performance than traditional linear equalization, because the enhanced in-band noise induced by the linear equalization can be suppressed by the following post filter. Using DD-FTN algorithm, we have experimentally demonstrated 140Gb/s single-lane PAM-4 signal over 20 km SMF with 25G-class devices [3]. In [4], a single lane 152Gbit/s 16QAM Nyquist subcarrier modulation (Nyquist-SCM) signal using 25Gbps EML was demonstrated over 10 km SSMF with a BER below 3.8e-3 through the use of DD-FTN.

Spectrally efficient frequency division multiplexing (SEFDM): It is another effective way to mitigate the effect of narrowband filtering, which packs the sub-carriers closely together beyond Nyquist limit in frequency domain [4][5]. In IM-DD system, it was combined with discrete multi-tone (DMT) modulation. We have investigated the performance of spectral efficient digital multi-tone (SE-DMT) transmission through both simulation and experimental verification. Results show that 98.7Gb/s data rate can be realized using SE-DMT with 4-QAM under 25GHz bandwidth over 2-km SMF transmission [5].

Volterra series based nonlinear equalization (VNLE): The Volterra series expansion includes a linear term and nonlinear terms. VNLE can compensate for the linear and nonlinear impairments simultaneously. But considering the tradeoff between computation complexity and equalization performance, most VNLEs are only designed to equalize first linear and second-order nonlinear impairments. In [7], Zhang *et al*. employed VNLE in an SSB-DMT system and an average SNR improvement of 2 dB across subcarriers for a 100 Gb/s SSB-DMT signal is obtained by using VNLE.

Look-up table (LUT) pre-distortion: Another feasible approach to reduce nonlinear impairment from driver

This work was supported by National Natural Science Foundation of China (61671053, 61435006), Fundamental Research Funds for the Central Universities (Grant No. FRF-BD-17-015a), Foundation of Beijing Engineering and Technology Center for Convergence Networks and Ubiquitous Services, PolyU 1-ZVGB, PolyU152079/14E and PolyU152248/15E of RGC of Hong Kong SAR government.

amplifier, modulator and detector is LUT pre-distortion. It is a symbol pattern-dependent amplitude compensation at the transmitter and is mostly used for PAM modulated systems. Several high-speed PAM signal experiments have demonstrated the feasibility of using LUT for nonlinear impairment compensation and performance improvement [8]-[11]. Furthermore, LUT combined with pre-equalization can reduce the receiver DSP complexity effectively.

B. Enhancing Dispersion Tolerance

For inter-data center interconnection applications, the transmission distance can be as large as 80 km. Due to large signal attenuation in O-band (0.35 dB/km) and lack of good O-band amplifiers, C-band with low attenuation and mature erbium-doped fiber amplifier (EDFA) technology is preferred. However, the main challenge at C-band for IM/DD systems up to 80 km is the channel fading induced by CD after direct detection. A number of advanced DSP techniques have been investigated to enhance the CD tolerance of DD-based systems

CD pre-compensation (CDC): The direct approach for combating CD effect is to compensate it at the transmitter using complex IQ or dual-drive Mach-Zehnder modulator (DDMZM) with a prior knowledge CD of the transmission links [12]-[16]. For high-speed system, the accuracy requirement of the prior knowledge of CD is very high. Hence, the flexibility of CDC systems is poor.

Single-sideband (SSB) signaling: Another possible way to reduce the impact of CD is SSB modulation. After direct detection, the linear carrier-signal beating term is immune to CD effect inherently. However, an unwanted signal-to-signal beating interference (SSBI) is also produced during detection. To reduce its impact, guard band is required and spectral efficiency and as a result overall system capacity is compromised [17]. To overcome this, a number of iterative signal detection schemes have been proposed with much reduced requirement on guard band [18]-[24]. The main drawbacks are DSP complexity, latency and requirement on system memory.

Kramers-Kronig (KK) receiver: KK method can reconstruct optical phase information of the signal from the detected amplitude waveform, which allows one to easily compensate CD using receiver DSP. Here, two conditions need to be satisfied for a KK receiver: 1) optical SSB signal is required, 2) large CSPR is required to achieve minimum phase condition. Based on KK receivers, a number of high-speed transmission experiments were demonstrated [25]-[32]. Note that KK technologies require lower CSPR to satisfy minimum phase condition compared to that required for SSB systems to compensate SSBI effectively.

C. Increasing Transmission Capacity

Polarization-division multiplexing (PDM) is an effective way to increase transmission capacity. For short-reach systems limited by direct detection, PDM signal received in Stoke Vector Space is one of key research directions. Using Stoke Vector Direct Detection (SV-DD) scheme, 3 degrees of freedom can be used, i.e., two signal powers in orthogonal polarizations and the inter-polarization phase difference. Recently, a number of variations have been suggested with different level of trade off among performance, complexity and tolerance to transmission impairments [33]-[39].

III. Conclusions

Digital signal processing technology play a crucial role to realize high-speed short reach transmission with low-cost and simple transceiver. Recent advanced DSP technologies in short reach systems have been reviewed. It is expected that DSP innovations will continue to enable future development of short reach communications.

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