Signal Processing Algorithms in 100 Gb/s Optical Coherent and Non-Coherent Receivers with PSK Modulation

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ABSTRACT
The paper addresses multi-level PSK modulation formats with coherent and non-coherent detection and reviews signal processing algorithms like mitigation of phase noise, the clock and carrier recovery algorithms as well as the equalizer structures and their performance.
Keywords: optical communications, modulation, phase shift keying, phase noise, equalizer.

1. INTRODUCTION

Electronic signal processing is currently introduced in various subsystems of modern optical high speed transceivers. Traditionally electronic processing was basically limited to tasks like MUX/DEMUX, clock and data recovery and various synchronization loops as well as analog circuitry like modulator drivers or limiting amplifiers. In order to deal with advanced systems and with the need for increased performance at long reach and higher speed, additional signal processing requirements have appeared. Examples are FEC and electronic equalizers (EDC), electronic pre-compensation, differential encoders, clock and carrier recovery, and polarization control. Recent challenges employ pure digital processing, where ADCs and DACs are required, like OFDM (orthogonal frequency division multiplexing) modulation or MLSE (maximum likelihood sequence estimation) equalizers. In this paper some of these signal processing algorithms, which may be used in PSK modulated systems are considered in detail and their impact on performance and cost in terms of implementation effort is reviewed.

2. MITIGATION OF PHASE NOISE IN NON-COHERENT PSK-RECEIVERS

In a first part, phase noise is investigated. Phase noise is an important limiting effect in high-speed optical communication systems that make use of phase-shift keying modulation formats [1]. One method to mitigate nonlinear phase noise distortions is the compensation of the mean nonlinear phase shift (MEAN) [2]. Alternatively, multi-symbol phase estimation (MSPE) [3, 4] can be used to reduce the loss from direct detection compared to coherent detection by estimating a reference phase over several consecutive received symbols. Both phase noise compensation methods, MEAN (in a post detection version for DQPSK) and MSPE are requiring signal processing at the receiver side after optical-to-electrical conversion.

We investigates the performance of different phase noise compensation options for a high speed RZ-DQPSK transmission system with various dispersion maps and direct detection. The efficiency of MEAN, MSPE and the combination of both is examined by Monte-Carlo simulations for varying pre- and post-compensation. Furthermore the performance of these three strategies for different average fiber input powers is investigated. Not only the optimum phase noise compensation strategy is identified, also the sensitivity of all three compensation variants to the chosen dispersion map is compared to the conventional receiver. For the best noise tolerant receiver option a maximum Q-gain of approximately 2 dB can be achieved for a wide range of fiber input power values [13].

3. ELECTRONIC EQUALIZERS IN COHERENT PSK-RECEIVERS

In a second part we investigate electronic equalization in coherent receivers in combination with multi-level modulation and nonlinear fiber effects. The next bit rate in the Ethernet hierarchy is expected to be 100Gb/s. For this bit rate, multi-level modulation formats should be used to reduce the bandwidth requirements. In conjunction with a coherent receiver the multi-level formats can be demodulated in the electrical domain with digital signal processing (DSP), due to the availability of high-speed digital signal processors. Similarly carrier and phase recovery as well as the equalization can be achieved with DSP [5].

We propose a post detection equalizer design for complex multi-level modulation and coherent I/Q-detection. We investigate numerically the performance of electronic dispersion compensation (EDC) after coherent reception for RZ-QPSK, RZ-8PSK and Star-RZ-16QAM at 107 Gb/s for the linear and nonlinear (Kerr effect) channel. EDC is achieved by a zero-forcing (ZF) approach, using the minimum mean-square error (MMSE) criterion to derive the coefficients. We investigate the performance in terms of dispersion tolerance by Monte-Carlo simulations [14].

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4. DIGITAL CARRIER RECOVERY IN COHERENT PSK-RECEIVERS

In coherent receivers, a local laser (LO) at the receiver front end is required, which down-converts the optical signal into or close to the baseband. Here we assume an intradyne receiver, where the nominal frequencies of both, the received signal and the local laser are almost equal, however there is no phase- or frequency locking of the LO. Thus we have to compensate for (i) the carrier frequency offset, (ii) the carrier phase, and (iii) the phase noise of the lasers involved (transmitter and receiver). We review carrier recovery schemes based on M-th power approach in 100 Gb/s applications with QPSK-modulation and polarization multiplexing, where we can transmit with a baud rate of one quarter of the bit rate, making a hardware implementation feasible in the near future. The basic operation and fundamental limits of the recovery scheme, as well as some optimization with respect to the implementation of the filters involved, are shown in the paper.

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