A proposed combining technique for partially coherent optical signaling

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**Abstract**

In this paper, we propose a new least squares (LS) combining technique for coherent optical signals suffer from laser phase noise (partially coherent systems) and receiver shot noise. To assess the advantage of this method, we investigate the error rate performance of both homodyne and heterodyne partially coherent binary phase-shift keying (BPSK) systems. We also derive the gain penalties of the signal-to-noise ratio (SNR) due to the partial recovery of the incoming laser phase to verify the appropriateness of the new combining method in mitigating laser phase noise. For design purposes, we provide tabulated results for the number of required photoelectrons to achieve a certain error rate level for the systems under investigation. The evaluation results show that the proposed technique has the ability to improve the error rate performance, and hence, reduce the SNR gain penalties caused by the laser phase noise. Finally, we show that the error rate performance of ideal systems (no phase error) can be achieved through this method by increasing the number of bit segmentations up to a reasonable level.

**Keywords:** Optical systems, Partially coherent detection, Homodyne BPSK

1. Introduction

Coherent optical communication systems have emerged in the last several years as a compelling approach for enhanced data transmission performance. Moreover, advanced modulation formats that employ various forms of phase-shift-keying (PSK) represent some of the most popular approaches in coherent systems [1]. They exhibit highest sensitivity, allow to implement optical rather than fully optical wave-division multiplexing (WDM) demultiplex filters and allow to perform any required equalization of chromatic and polarization mode dispersion in the electrical domain. Also, optical PSK transmission systems feature a higher receiver sensitivity than intensity-modulated systems. They are attractive to increase transmission lengths while keeping the amplifier spacing fixed.

A critical limitation of phase-sensitive coherent PSK receivers is the phase noise that exists on the recovered data signal [2]. Important sources of phase noise at the coherent receiver is the laser linewidth of the transmitter laser as well as of the receiver local oscillator (LO); note that additional sources can include nonlinear phase noise created by amplified spontaneous emission interacting with the nonlinear Kerr effect [3]. A carrier recovery unit generates the required carrier at the receiver side even though the carrier is usually suppressed in the PSK signal. In a homodyne receiver the LO laser delivers the recovered carrier, and its frequency and phase are controlled by an optical phase-locked loop (PLL). The frequency difference between the transmit and the LO lasers, called intermediate frequency (IF), is equal to zero in homodyne receivers [4,5]. In receivers with nonzero IF, another down-conversion is needed in the electrical part of the optical receiver, using an electrical carrier that is usually delivered with the help of an electronic PLL. The PLL delay may be minimized by keeping optical fiber lengths short. Moreover, an electrical PLL in the IF domain may be employed instead of an optical one. Even though, a group delay of several symbol durations in the loop is unavoidable. In any case, external cavity lasers are required. These are costly, space-consuming, can be tuned only slowly, and could impair system reliability [6].

One possible approach for carrier recovery includes transmitting the carrier along with the data signal [7,8]. With this approach, the carrier occupies some part of the spectrum and polarization state suffers from fiber loss and can accumulate phase noise. Another approach is to have a local laser oscillator in the receiver, for which a PLL and signal processing algorithms ensure the locking of the local laser to the same frequency and phase [9]. However, this tends to be fairly complex and requires time to lock. Additionally, there have been optical methods to recover the carrier of an incoming data signal using nonlinear processing, but these techniques typically required an optical feedback loop for stabilization [10]. Recently, with the advent of high-capacity WDM transmission technologies, spectral efficiency has become one of the main concerns of researchers [11,12]. An ultimate goal therefore would be to enable optical homodyne/heterodyne detection for which the local laser oscillator is automatically locked in...