REVIEW CARRIER FREQUENCY OFFSET ESTIMATION FOR CO-OFDM: THE MATCHED FILTER APPROACH

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Abstract: This paper proposes a novel carrier frequency offset (CFO) estimator for coherent optical orthogonal frequency division multiplexing (CO-OFDM) systems using the matched filter (MF) concept. The main objective is to implement the DA MF ML or the BL MF ML estimator. We treat the OFDM symbol as a pilot symbol in which we know the data in all the subcarriers, and this pilot symbol is used as the reference signal for the MF.The DA MF ML algorithm can achieve full-range (integral and fractional part) CFO estimation with high accuracy, while the BL MF ML algorithm has low computational complexity but focuses on fractional CFO estimation only.. Existing blind estimation schemes in the literature have been adapted, derived and implemented in the optical scenario. To study performances of these existing schemes are further compared with the proposed blind CFO estimator. The blind CFO estimation method has been proven through analysis and simulation to achieve a superior performance as compared to the prominent existing blind estimation schemes.

Keywords: —*Optical communication, orthogonal frequency division-multiplexing/offset quadrature amplitude modulation , laser phase noise*

I. INTRODUCTION

Coherent optical orthogonal frequency division multiplexing (CO-OFDM) has been intensively studied as a promising candidate for high-speed flexible optical networks due to its high spectrum efficiency and flexible spectrum assignments [1], [2]. One major drawback of the CO-OFDM system that hinders its application is the high sensitivity to the carrier phase variation because of its long symbol period. In applications with moderate transmission distances (e.g., metro [3] or long-reach access networks [4] with a few hundred kilometers of fiber), the carrier phase variation after coherentCFO originates from the incoherence between the signal laser at the transmitter and the LO at the receiver. The Schmidl&Cox algorithm [3] divides the frequency offset into the fractional part and the integral part according to the subcarrier spacing and then estimates the two kinds of frequency offset respectively by using two training symbols. The estimation accuracy of fractional part of frequency offset can be very high, but the range is limited. On the other hand, CFO estimation in the frequency domain is able to increase the estimation range to sampling frequency. However, the computational complexity and hardware latency are also increased accordingly since CFO compensation is usually performed in the time domain at the front end of the OFDM receiver [3, 4]. Moreover, this issue will be particularly severe in high speed OFDM systems. In this paper, a constant modulus algorithm-(CMA) based CFO estimation method for CO-OFDM is proposed. The algorithm can be used to estimate the full-range CFO without dividing the fractional and the integral frequency offset, with frequency offset range close to ±6 GHz. Particularly, according to our simulation, even under very low optical signal-to-noise ratio (OSNR), the frequency offset can be estimated by this method effectively. The proposed method is modeled and implemented in a practical optical system stressed by polarization mode dispersion (PMD), group velocity dispersion (GVD), and chromatic dispersion (CD) . . Although PMD may only have a moderate impact on a high-speed optical system, the combined impact of PMD, CD, and other polarization dependent loses cannot be ignored in the channel model of a practical optical system . Therefore, this work considers all these parameters during modeling before deriving and implementing the ML-based CFO estimator. For PDM CO-OFDM systems, several joint schemes have also been proposed for training-aided frame and frequency synchronization, see e.g., [8]. However, to the best of our knowledge, these schemes require extra overheads because they do not use the same training symbols (TS) to carry out both the joint synchronization and TA-CE. In addition, these schemes may be limited by one or more of the following: frame synchronization errors under poor optical signal-tonoise ratio (OSNR) conditions, limited carrier frequency offset (CFO) estimation range, and complex TS structures. We previously proposed a joint synchronization algorithm for a single-polarization RGI-CO-OFDM system [9], which used only one simple-structured TS for synchronization, and demonstrated better performance when compared with popular existing synchronization algorithms. Although the method in [9] can be readily extended for PDM transmission, it would still be disadvantaged by the need for additional TS for TACE. The rest of this paper is organized as follows. Section II presents the CO-OFDM system model. The CO-OFDM system employed is modeled in the presence of the CFO, and other pertinent fiber link distortions. Section III discusses the existing techniques in the literature. the proposed ML-based estimator as well as the closed-form approach is derived, analyzed and discussed. The performance of the proposed estimator in comparison with existing methods is also discussed. Finally, Section IV, gives the conclusion.

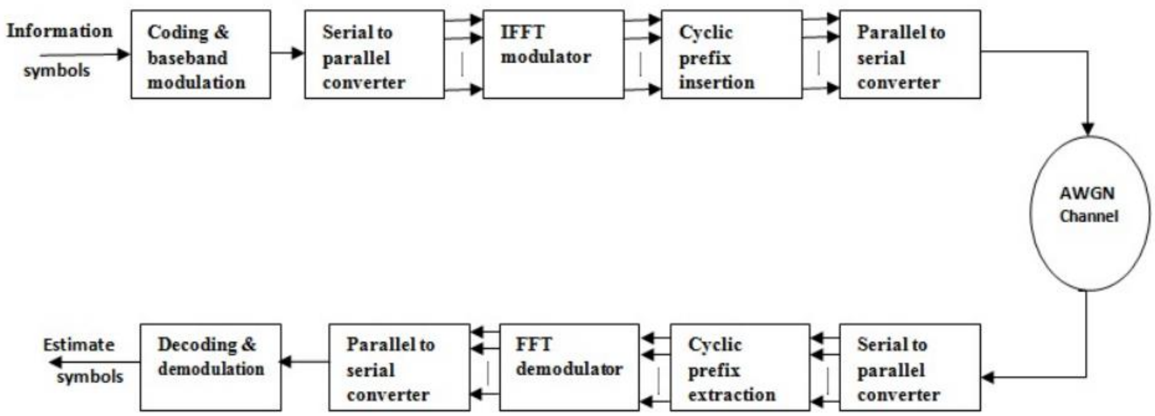

Figure 1: CO-OFDM: The Matched Filter Approach

II. RELATED WORK

Du, X., Song, T., et al[1]In this paper, a novel MF ML CFO estimator is proposed, which is conceptually easy to implement and understand, compared with the conventional ML estimators that solve the likelihood equation with more involved computations. By designing the pattern of the reference signal, both data-aided and blind MF ML CFO estimators can be achieved. The performance of the proposed MF ML algorithms is compared with two algorithms in the literature through simulations.

Huang, T., et al[2] n this paper, we proposed a CMA-based CFO estimation method for PMD-CO-OFDM. The proposed algorithm can be used to estimate the full-range CFO directly without separating the fractional and the integral frequency offset. This algorithm can successfully track [- 5.9, +5.9] GHz frequency offset even under OSNR as low as 2 dB. Particularly, the frequency estimation error is small and alters little with OSNR variation.

Yan, Q., et al[3] —In this paper, a low-complexity residual carrier frequency offset compensation (RCFOC) approach based on spectrum symmetry is proposed for coherent optical orthogonal frequency division multiplexing (CO-OFDM) systems. A closed-form expression of spectrum symmetry is derived, which shows the dependence of spectrum shape of carrier phase on the residual carrier frequency offset (RCFO). Compared with our previous proposal, the computational complexity of the new method is dramatically reduced by avoiding excessive times of discrete Fourier transform (DFT) operations in calculating the degree of symmetry.

Balogun, M. B et al[4] This work has derived, analyzed and implemented an MLbased method for CFO estimation in a CO-OFDM system, where only two long training symbols were utilized to achieve an efficient CFO estimation. The proposed method has been compared with existing ML-based CFO estimation methods and simulation results show that the proposed method achieves a superior performance.

Xian Zhou et al[5] The phase noise compensation algorithm of high linewidth tolerance, i.e., RAPR, is extremely sensitive to the impact of FO, and unfortunately its high power RF-pilot will cause a failure of FOE in the conventional FOE algorithm. In order to get rid of the dilemma, a new FOE algorithm, i.e. RAFOE, is proposed, with the high power characteristic of RF-pilot as a positive factor being further exploited to estimate FO.

Balogun, M. B. et al[6] Various schemes have been proposed and implemented in the literature to combat the degrading impact of CFO on the performance of CO-OFDM systems. However, most of the existing schemes are pilot-based or data-aided schemes, which results in an increased overhead in the optical system . Maximum likelihood based methods have been utilized but these also come with the associated computational burden. In contrast to the methods mentioned above, the blind estimation schemes offer a more efficient approach. Various blind estimation schemes have been proposed in the field of wireless communications.

Fang, X., et al[7]To our best knowledge, there have been no studies on the phase noise estimation and suppression methods for CO-OFDM/OQAM systems. In this paper, we systematically study and analyze phase noise induced interference for CO-OFDM/OQAM systems. Based on the theoretical analysis and the concept of orthogonal basis expansion, we develop a time-domain phase noise estimation and suppression method for polarization-division-multiplexed (PDM) CO-OFDM/OQAM systems. As shown in numerical Montel-Carlo simulations, the proposed method can improve the system robustness against phase noise effectively.

Omomukuyo, O., et al[8] proposed a novel joint frame and frequency synchronization scheme for a 238.1 Gb/s (197.6-Gb/s after coding) PDM RGI-CO-OFDM system based on 16-QAM GCS arranged using the Alamouti scheduling scheme. The proposed scheme realizes a bandwidth-efficient solution because it uses the same training symbols for both the joint synchronization and TA-CE, resulting in a total overhead of 9.2% (31.6% after coding). We have shown that the proposed scheme has a wide CFO estimation range, as large as half the sample rate, and is robust against linear fiber impairments

III. PROPOSED METHODOLOGY

WITH the rapid growth of bandwidth demand on optical transport network, many efforts have been made on developing high-speed optical transmission systems. Among various emerging techniques and applications, coherent optical orthogonal frequency-division multiplexing (CO-OFDM) is one of the most promising candidates due to its excellent spectral efficiency, flexible constellation modulation, and low demand for oversampling rate, etc [1]–[3]. However, the CO-OFDM signal is extremely sensitive to phase noise, and system performance penalty induced by the linewidth in CO-OFDM is more obvious with respect to the single carrier systems [4]. Therefore, the corresponding phase noise compensation algorithm as a hot issue has attracted much attention. Through investigation on the existing methods, two types of algorithms are commonly used for carrier phase estimation. 1) Multi-pilot subcarriers phase estimation algorithm (MSPE), which compensates for only the common phase impairments after OFDM demodulation (e.g., that proposed in [5]–[7]). However, the laser linewidth must be small enough and the OFDM symbol should be short as well in order to mitigate the impact of the inter-carrier interference (ICI) and obtain a satisfying performance of phase noise compensation. These requirements will consequently increase the device cost and the overhead ratio of cyclic prefix (CP). 2) RF-pilot aided phase recovery algorithm (RAPR), which compensates for the laser phase noise by extracting the phase of RF-pilot that is inserted beforehand at the transmitter in the center of OFDM spectra. The ICI-induced effects can thus be prevented effectively and spontaneously without such strict restrictions of MSPE, because the carrier phase compensation is performed prior to OFDM demodulation by using RAPR. In many studies [8]–[10], it has been demonstrated that a much better laser linewidth tolerance comparing to MSPE can be provided by a small overhead RAPR. However, an important influencing factor is generally neglected in those studies, which is that the commercially available tunable lasers may have a frequency accuracy of 2.5 GHz over the lifetime in practice [11], the frequency offset (FO) will thus be changed within the range of . Due to the impact of uncertain FO, the RF-pilot cannot be filtered out directly, regardless of using whether a low pass filter (LPF) or a band pass filter (BPF) in coherent receivers. Therefore, frequency offset estimation (FOE) is necessarily required and implemented before RAPR. However, for conventional FOE algorithms [12]–[14], two challenges arise in the integral part of frequency offset (IFO) calculation: 1) it causes high computational complexity by the use of a merit function, and 2) it cannot work coordinately with RAPR. Because in order to obtain a good phase compensation performance, RF-pilot is required with large power in RAPR so as to suppress the interferences from OFDM signal and ASE noise, but the correlation between training symbols of IFO estimation will be seriously disturbed by the high-power RF-pilot. In this paper, in order to get rid of the dilemma, we propose a new RF- pilot aided frequency offset estimation (RAFOE) algorithm, in which the high power characteristic of RF-pilot, regarded as a positive factor, is further exploited. FO can be easily estimated in RAFOE by searching the peak value of frequency domain samples without requiring any extra training overhead. Moreover, a large FOE range of (is the sampling rate of analog to digital converter (ADC)) can be obtained, with the estimation accuracy that is definitely determined by the number of samples participated in the operation of RAFOE. In order to obtain the optimum compensation performance with lower computing cost when combining RAFOE and RAPR, a joint compensation scheme is also developed, in which only IFO needs to be estimated by RAFOE based on the aid of the pre-estimation of the fractional part of frequency offset (FFO). After that, RAPR utilizes a BPF to filter and compensate all the phase impairments (including residual FFO, IFO and phase noise induced by linewidth) simultaneously, depending on a known centre frequency provided by RAFOE. Finally, the feasibility and effectiveness of the proposed joint scheme is numerically demonstrated in a 475 Gbit/s polarization multiplexed 16-ary quadrature amplitude modulation (PM-16QAM) CO-OFDM system the out-of-band elements of the covariance matrix decreases under severe channel conditions. Thus, a completely blind low-complexity CFO estimation approach for constant modulus constellations CO-OFDM systems is proposed, with a cost function similar to one utilized for blind channel equalization in . The performance of the proposed approach is analyzed and compared with prominent existing methods in a practical optical system with an uncompensated fiber link in terms of the mean square error (MSE), the bit-error-rate (BER) and the convergence speed. The main contributions in this paper therefore include: 1. The investigation of the performance of prominent constant modulus based blind estimation schemes, which have hitherto not been implemented and analyzed in the optical domain. This paper therefore investigates how these existing constant modulus schemes perform in the optical scenario, with fiber dispersion. 2. A blind low-complexity CFO estimator is proposed and compared with existing constant modulus schemes. In the existing methods, the cost functions are totally dependent on the channel characteristics, where it is usually assumed that the channel slowly varies over consecutive symbols. However, the proposed estimator is independent of this general assumption. This in fact makes the proposed method robust against channel impairments. 3. In order to achieve low-complexity, the proposed cost function is derived and approximated as a cosine function, so that the CFO estimate is obtained using the curve fitting method, where only three trial values are required. 4. The derived closed-form expression ensures a low complexity similar to the existing schemes while offering a superior overall performance.

IV. CONCLUSION

This paper proposes a blind carrier frequency offset (CFO) estimation method for coherent optical orthogonal frequency division multiplexing (CO-OFDM) systems, using constant modulus signaling. The proposed scheme is based on a robust cost-function, which deviates from the common assumption that the channel frequency response slowly varies either in time or frequency domain. The proposed method adopts a cost-function similar to the Godard's method for blind channel equalization. Using Monte Carlo simulations, the proposed method is shown to offer a superior performance compared to prominent existing methods, in a practical optical link scenario. Also, we show that the proposed cost-function can be approximated and expressed in a closed-form in such a way that the CFO estimate is obtained using only three trial values.

V. REFERENCE

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