Optical Carrier Phase Estimation Based on 8-PSK Partitioning and Modified Viterbi-Viterbi for 32-QAM

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***Abstract*— In this paper, a carrier phase estimation technique (CPE) based on 8-PSK partitioning and modified Viterbi-Viterbi for 32-QAM is proposed. The proposed algorithm shows 60% linewidth tolerance improvement compared to the already-existed CPE single stage techniques for 1-dB SNR penalty at BER of 1x10^{-2}.**

I. Introduction

Due to the continuous increase in data traffic, coherent optical communications combined with high-order spectrally-efficient modulation techniques are considered promising candidates to serve the forecasted future traffic rather than intensity modulation with direct detection (IM/DD) [1]. Consequently, the integration of digital signal processing (DSP) techniques into the optical receiver has received much attention in order to fully retrieve the amplitude and phase of the transmitted data.

Phase noise due to the finite laser linewidth is considered a challenging impairment that faces the coherent detection of the received optical signal. Unfortunately, it can distort the received constellation to a significant extend if not mitigated specially with high modulation orders. Phase noise can be mitigated using a carrier phase recovery (CPR) stage at the optical receiver DSP stack [1]. Many carrier phase recovery approaches were developed in literature [1],[3] to achieve high laser linewidth tolerance along with low computational complexity. Carrier phase estimation (CPE) has different structures and the estimation mode such as decision-directed (DD) versus non-data-aided (NDA) or blind estimation.

Viterbi-Viterbi (VV) algorithm is one of the common CPE techniques due to its simplicity. It is a feedforward blind CPE algorithm which is similar to the M^{th} power CPE technique. It is commonly used with *M*-ary phase shift keying (*M*-PSK) modulation and recently with *M*-ary quadrature amplitude modulation (*M*-QAM) when combined with PSK-partitioning techniques [2]. The problem with Viterbi-Viterbi algorithm with PSK partitioning is that at high-order QAM, only a few QPSK symbols can be used for the estimation, especially for the non-square QAM formats [4]. In most of carrier phase recovery scenarios, estimation is done using multistage CPE to enhance the performance of VV by adding fine estimation stages like maximum likelihood estimators (MLE) [6].

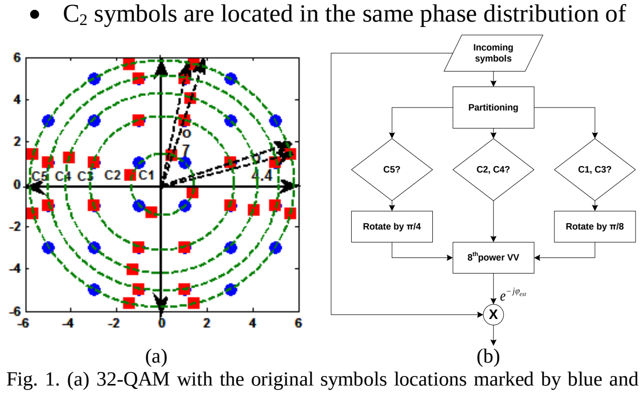
In this work, we propose a novel single stage CPE scheme for 32-QAM based on Viterbi-Viterbi algorithm with 8-PSK partitioning. The proposed algorithm class-transforms (CT) all the incoming data symbols to 8-PSK before Viterbi-Viterbi estimation stage using some phase rotations. It has the advantage of using all the incoming symbols in the estimation stage, which increases the ability to track the phase noise variations and the maximum tolerable linewidth if compared with QPSK and quasi-QPSK partitioning [4] techniques.

II. Proposed VV-CPE Algorithm

Using PSK partitioning of high order QAM schemes with VV CPE serves for the sake of using a large percentage of the incoming data symbols in the estimation stage. The 32-QAM is a non-square modulation scheme, where the constellation points can be classified into five rings from C_1 to C_5 representing the innermost to the outermost rings, respectively, according to the amplitude. Conventional QPSK partitioning uses the constellation points that belong to C_1 and C_3 rings which means that only 25% of the constellation points are used for the estimation ignoring some significant symbols like the points of C_4 and C_5 that have the highest SNR values between the constellation points. Accordingly, in [4] a quasi-QPSK partitioning scheme was proposed to use C_4 and C_5 symbols along with C_1 and C_3 symbols and hence the used symbols percentage is increased to be 75% of the constellation points.

In this paper, we propose an 8-PSK partitioning scheme that class-transforms (CT) all the incoming data symbols into 8-PSK (C_2) ring to use them in an 8^{th} power modified VV proposed in [5]. In Fig. 1 (a), by analyzing the phase values of the 32-QAM constellation points, it was noticed that:

- C_2 symbols are located in the same phase distribution of



(a) (b)

Fig. 1. (a) 32-QAM with the original symbols locations marked by blue and the transformed symbols are marked by red. (b) The proposed single stage 8-PSK partitioning VV CPE flow chart.

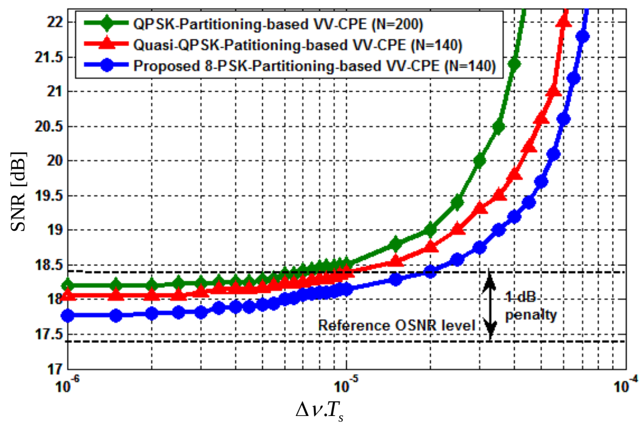


Fig.2: The maximum achievable linewidth tolerance for QPSK-, Quasi-QPSK and the proposed 8-PSK partitioning based VV CPE at BER of $1x10^{-2}$ and 1-dB power penalty.

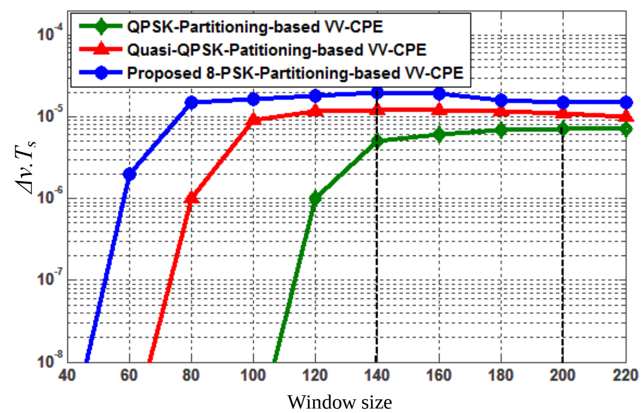


Fig. 3. The optimized size of VV estimation window for QPSK, Quasi-QPSK and the proposed 8-PSK partitioning techniques at $1x10^{-2}$ BER.

the conventional 8-PSK constellation points with a phase error of 4°. So, it can be assumed that C_2 symbols are 8-PSK [5].

- C_1 and C_3 are rotated by π/8 from C_2 symbols [5].
- C_4 and π/4-rotated C_5 symbols are aligned with C_2 symbols with phase errors of 7° and 4.4°, respectively.

So, the proposed CT technique transforms:

- C_1 and C_3 symbols to C_2 by rotating them by π/8 as proposed in [5].
- C_4 symbols are considered same as C_2 symbols.
- C_5 symbols are rotated by π/4 to align with C_2 symbols.

Notice that the phase error in both C_4 and π/4-rotated C_5 symbols when aligned with C_2 is negligible and amplitude normalization is done in all of the previous transformation steps.

For convenience, a flow chart of the proposed algorithm is illustrated in Fig. 1 (b). It is noticed that the proposed partitioning technique has just nearly a negligible increase in the computational complexity of quasi-QPSK-partitioning in [4] for C_1 and C_3 rotation.

II. Simulation Results and Discussion

The simulation results are obtained using 32-QAM data symbols and the received signal is assumed to be sampled with perfect timing recovery, and the optical channel impairments are equalized so that only the impact of the phase noise is studied. The phase noise is modeled as a Wiener process $\varphi_n = \sum_{i=-\infty}^{n} u_i$, $\varphi(n+1) = \varphi(n) + u_n$,

where u_i is a Gaussian random variable with zero mean and a variance of $2\pi\Delta\upsilon T_s$ such that Δυ is the optical source linewidth and T_s is the data symbol duration.

Fig. 2 shows the performance of the proposed scheme against the laser linewidth x symbol duration product. The performance of the proposed algorithm is compared to the conventional QPSK-partitioning and quasi-QPSK-partitioning single stage VV-CPE all with their optimized window sizes and at a bit error rate (BER) of 10^{-2}. Results show that the proposed scheme is more tolerant to the laser linewidth than the other two partitioning techniques. At a BER of 10^{-2}, the higher achievable values of the linewidth tolerance are of 7×10^{-6} and 1.3×10^{-5} for conventional QPSK partitioning and quasi-QPSK partitioning, respectively, while the proposed algorithm achieves 2×10^{-5}, all at their optimized window sizes (i.e N_{QPSK}=200, $N_{Quasi\text{-}QPSK}$=140 and $N_{8\text{-}PSK}$=140) and a 1-dB SNR penalty. This means that the proposed algorithm has a 60% performance improvement than quasi-QPSK partitioning. This linewidth tolerance can be further increased by adding other fine CPE stages as in [4-6]. The window size optimization of each algorithm is illustrated by fig. 3. The optimized window size corresponds to the highest tolerable linewidth at 1-dB power penalty.

III. Conclusion

We proposed a novel single-stage VV-CPE for 32-QAM based on 8-PSK partitioning. The proposed algorithm uses all the incoming symbols in the estimation stage which increases the ability to track the phase noise variations. It shows a high linewidth tolerance when compared to VV algorithm using conventional QPSK partitioning and quasi-QPSK partitioning with 60% improvement in performance with a negligible increase in the computational complexity.

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