Robust Synchronization for IM/DD OFDM Optical Communication Systems

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Abstract: A linear frequency modulated chirp synchronization signal for IM/DD optical OFDM systems is proposed, evaluated and compared against the state-of-the-art through simulations and experimental validation. The proposed method improves detection performance and spectral efficiency.

OCIS codes: (060.4080) Modulation; (060.4510) Optical Communications.

1. Introduction

Optical orthogonal frequency division multiplexing (OFDM) is at the forefront of next generation optical communication research in both fiber and optical wireless communication systems (OWC) [1]. A viable method to using the optical channel, especially for OWC, is through intensity modulation and direct detection (IM/DD) of optical sources, such as laser diodes and light-emitting-diodes (LEDs). In conjunction with OFDM, IM/DD systems can provide high spectral efficiency, adaptive modulation, and low-complexity equalization. In optical OFDM, there is no carrier frequency offset or phase data and the signal is real and unipolar. Nevertheless, a robust synchronization method is needed that maintains effectiveness under time/frequency offsets, noise and interference.

There are typically two types of synchronization that uses a preamble: one that cross-correlates with a known local copy of the preamble and another that cross-correlates separate parts of the transmitted preamble, which structure is repetitive in nature. This paper focuses on using a known local copy based synchronization and optimizing it to provide the best accuracy and least latency. A recent state-of-art method that employs cross-correlation with known local copy is introduced in [2]. This method reconstructs an asymmetrically-clipped optical OFDM (ACO-OFDM) signal into an bipolar OFDM signal and cross-correlates with a known local copy of the bipolar OFDM signal.

In this paper, we propose a linear frequency modulated (LFM) chirp preamble for synchronization and evaluate and compare its performance in simulation and experimentally with the ACO-OFDM based synchronization method. We evaluate both synchronization methods under a visible light communications (VLC) or LiFi environment where dimmable lighting is an important parameter to the practicality of the system [3]. Reverse polarity optical OFDM (RPO-OFDM) transforms a typical optical OFDM signal, in this case an ACO-OFDM signal, into a pulse-width-modulation (PWM) shape that allows for dimming and data transmission [4]. Therefore, the synchronization preambles are evaluated attached to a RPO-OFDM modulation scheme.

2. Proposed LFM Chirp

We propose the use of a LFM chirp function for synchronization. This function has the form $s(t) = cos(2\pi f(t)t)$, $t \in [0,1]$, where $f(t) = f_0 + (f_1 - f_0)t$ is a linear function dependent on two user-defined frequencies, f_0 and f_1. The model parameters allows for maximization of the performance of an optical system by choosing optimal combinations of sample length and frequency range. Fig. 1 shows two example frames with our proposed chirp waveform as a preamble and either an RPO-OFDM period or an ACO-OFDM streaming sequence that serves as the useful data.

3. Monte Carlo Simulations

In this section, we analyze the performances of both our newly proposed LFM synchronization signal and the ACO-OFDM-based method through simulation. To quantify performance, we simulate the communication chain by formulating two frames consisting of a preamble and useful data, adding additive white Gaussian noise (AWGN), and correlating this signal with the initial chosen preamble to observe the correlation output for different lengths of preambles. A 15dB SNR is assumed in order to accurately model the amount of noise in a practical environment. Fig. 2 displays these results with that of the 16 sampled preambles zoomed in to showcase our chirps' minimal sidelobes

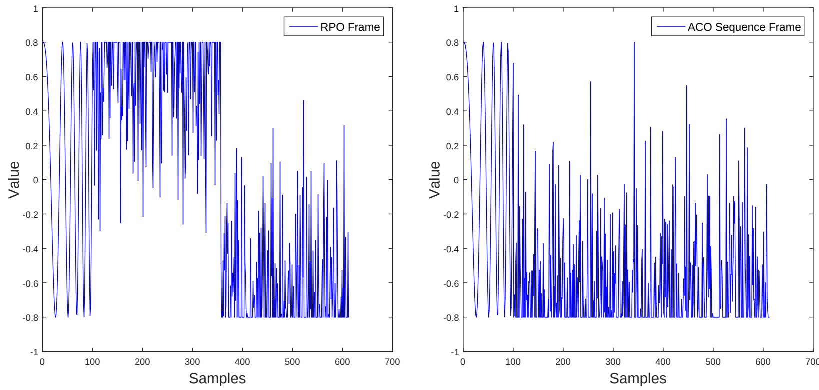


Fig. 1: Example frames showing the chirp preamble attached to an RPO-OFDM and ACO-OFDM data sequence, respectively.

versus those of the ACO-OFDM-based method. In this context, and related to the fact that the optical power is positive, it is also worth mentioning that negative auto-correlation samples are not considered in the decision making to determine the maximum peak. Also, since the ACO-OFDM-based method is based on ACO-OFDM sequences, its respective sidelobes can tend to be amplified due to the inherent randomness of the ACO-OFDM signal envelope. The chirp does not suffer from this because it is a deterministic waveform whose performance can reliably be modeled, *i.e.* to deal with Laser/LED nonlinearity and limited dynamic-range of operation.

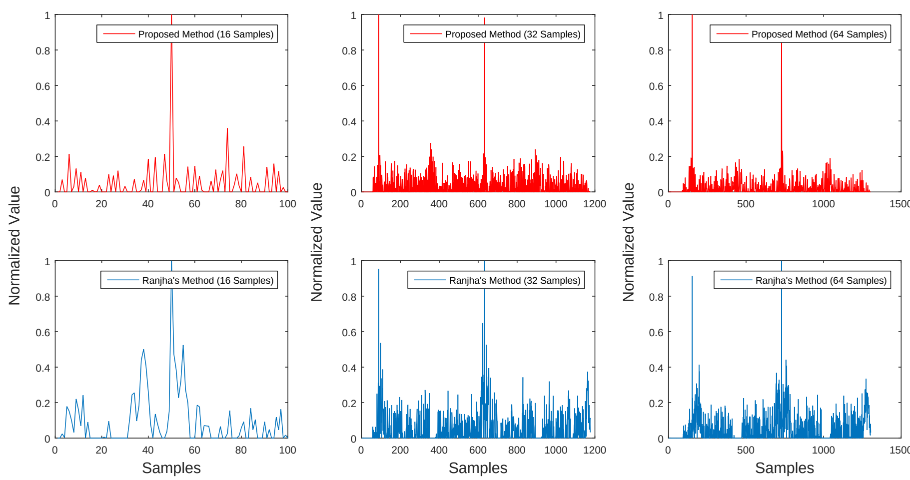


Fig. 2: Simulated correlation results for small sample length synchronization signals of ours and the ACO-OFDM-based methods.

We also quantify performance in terms of the probability of detecting a correct frame start and the variance of the maximum correlation peak for the studied methods in an AWGN channel. The variance is calculated based on the deviation of the maximum correlation peak from the ideal maximum peak at a correct frame start. Using Monte-Carlo simulations, and assuming a 40 dB SNR range, the plots are shown in Fig. 2. Looking at the probability curves of the 96, 64, 32, and 16 sampled preambles, we see that our method outperforms the ACO-OFDM-based method by 5, 5, 4, and 4 dB, respectively. In addition, the ACO-OFDM-based method cannot be used with 16 samples due to its inability to converge to a unity probability in a minimal noise environment. The variance plots again affirm our chirp's superiority since it attains the smallest variance.

4. Experimental Validation

According to simulation, our proposed chirp preamble has the potency to be effective with a small amount of samples; in this section, we test the ability of ours and the ACO-OFDM-based methods to be used in a practical VLC system.

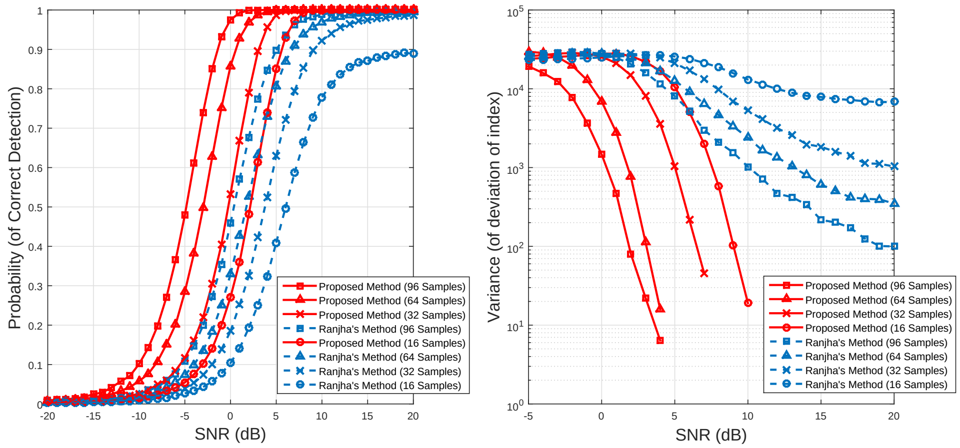
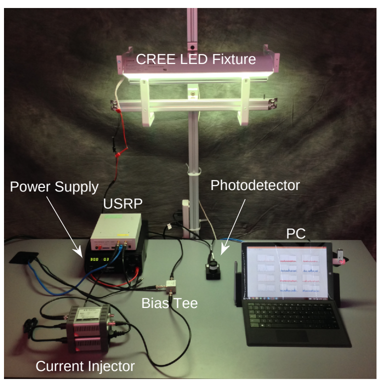
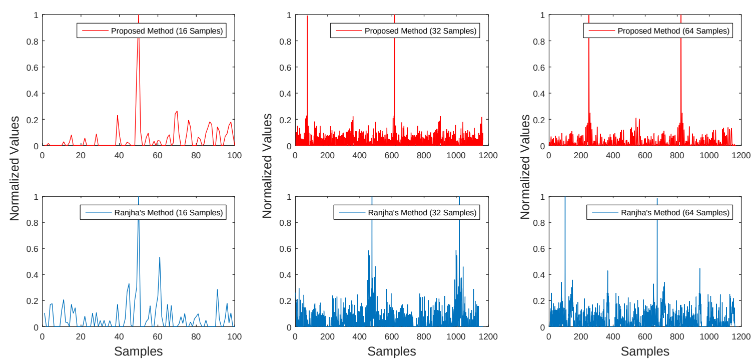


Fig. 3: Probability of correct peak detection and variance of maximum peak plots for small sample length preambles.



(a) Experimental setup.



(b) Experimental correlation output of small-sample preambles.

Fig. 4: Experimental setup and correlation outputs.

The experimental setup used is shown in Fig. 5a while the experimental correlation output is in Fig. 5b. From these results, we again see that the chirp performs very well since it attains the largest dominant peak relative to its sidelobes for any given amount of samples.

5. Conclusion

The application of a LFM chirp function as a means for synchronization is a viable and beneficial option due to its superior performance over current state-of-the-art methods and its ability to result in accurate data detection with a minimal amount of samples.

6. Acknowledgment

This work is supported by the National Science Foundation under Grant No. EEC-0812056.

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