Signaling Technique for Free Space Optics

Amrita Chakraborty, Avinash Gaur

Abstract— ***A new efficient method to implement orthogonal frequency division multiplexing (OFDM) on intensity modulated direct detection (IM/DD) channels is presented and termed auto-correlated optical OFDM. It is shown that a necessary and sufficient condition for a band limited periodic signal to be positive for all time is that the frequency coefficients form an autocorrelation sequence. Instead of sending data directly on the subcarriers, the autocorrelation of the complex data sequence is performed before transmission to guarantee non-negativity. In contrast to previous approaches, auto-correlated optical OFDM is able to use the entire bandwidth for data transmission and does not require reserved subcarriers. Using a sub-optimal design technique with 1024 subcarriers, auto-correlated optical OFDM has a better BER than the existing techniques.***

Index Terms—Auto-correlation, IM/DD,OFDM.

I. INTRODUCTION

The use of indoor illumination light-emitting diodes (LEDs) for visible light communications (VLC) is an active area of study. These systems have limited bandwidth but high SNRs, often in excess of 60 dB [1]. These optical systems employ intensity modulation and direct detection (IM/DD) where data are modulated on the instantaneous intensity of the LEDs. Furthermore, the average intensity of all emissions is limited and often user selected. Thus, all transmitted signals must be non-negative and constrained in the mean. Orthogonal frequency division multiplexing (OFDM) has emerged as a method of choice for bandwidth selective channels with sufficient SNR [2]. The amplitude non-negativity Constraint of VLC channels do not permit the direct application of OFDM. In DC-biased OFDM, a DC bias is added to a bipolar OFDM signal to ensure that it is non-negative [1, 3]. In general, DC-biased OFDM signals suffer from poor average optical power efficiency. Clipped multi-carrier systems, such as Asymmetrically Clipped Optical OFDM (ACO-OFDM) [4] and Pulse Amplitude Modulated Discrete Multitone (PAM-DMT) [5], have better average optical power efficiency than DC-biased OFDM. ACO-OFDM modulates odd subcarriers whereas PAM-DMT uses PAM modulation on only imaginary parts of the subcarriers. Therefore, in clipped multi-carrier systems only half of the degrees of freedom are available for data transmission. However, the resulting time domain sequences are asymmetric and the distortion introduced by clipping the negative amplitudes is orthogonal to the data. Notice that ACO-OFDM and PAM-DMT only guarantee non-negativity of the samples and not the time domain signal. Furthermore, clipped multi-carrier systems suffer from large peak-to-average power ratio. In this work, auto-correlated optical OFDM is introduced as a framework to design OFDM for IM/DD optical channels. In particular, the subcarrier amplitudes are chosen such that they form an autocorrelation sequence, which is shown to be necessary and sufficient to guarantee amplitude positivity. The autocorrelation sequences are generated by sub-optimally designing their z-plane zeros. The z-plane zeros are designed according to the criterion of maximizing the minimum distance between the corresponding autocorrelation sequences.

II. SYSTEM MODEL

It has been shown that line-of-sight indoor optical channels are well modeled by the IM/DD channel

$$y(t) = x(t) + w(t) \quad (1)$$

Where y(t) is the received current, $x(t) \geq 0$ is a non-negative, band-limited transmitted signal and w(t) is additive white Gaussian noise with zero mean and variance σ2 [3]. The optical signal to noise ratio, SNRo, and the peak-to-average power ratio, PAPR, in IM/DD optical systems are defined as

$$\mathrm{SNR}_0 = \frac{P_{ave}}{\sigma},$$

$$\mathrm{PAPR} = \frac{x(t)_{max}}{P_{ave}}$$

Where Pave = E{x(t)} is the average power of the transmitted signal.

III. DESIGN SCHEME

In Auto-Correlated Optical-OFDM, the autocorrelation of frequency coefficients in (4) is used to produce unipolar signals directly without constraining the modulation bandwidth. Figure 1 shows a simple block diagram of the Auto-Correlated Optical-OFDM transmitter. The input serial data is partitioned into parallel blocks which are mapped to the zeros of $S(z)$ which lie outside the unit circle, i.e., λ_i. The characteristic z-domain function $T(z) = S(z)\, S^*(1/z^*)$ is then formed with conjugate reciprocal pair zeros λ_i and $1/\lambda_i^*$ *I* to generate the autocorrelation coefficients *al*. Performing an $N = 2K + 1$ point IFFT on the coefficients of $T(z)$ produces a positive time sequence $r[n]$ which are samples of the continuous time signal $r(t)$.

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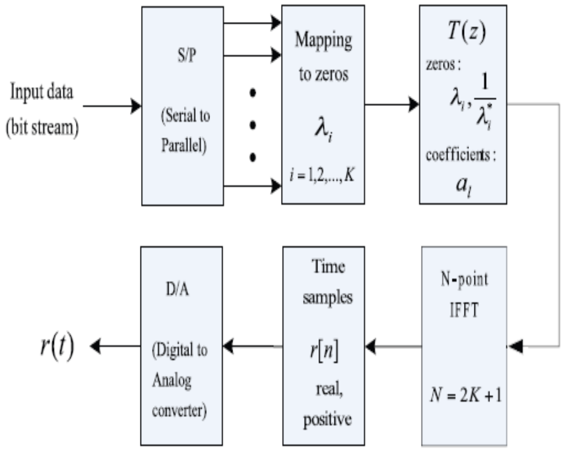


Figure (1)

IV. DESIGN CHARACTERIZATION

Since P_{norm} has a minimum when the λ_i are chosen on the unit circle, the K zeros of the proposed Auto-Correlated Optical -OFDM system are chosen on a ring $r = 1+\varepsilon$ for some small $\varepsilon > 0$. Notice that in DC-biased OFDM, placing λ_i near the unit circle also improves optical power efficiency. The ring $r = 1 + \varepsilon$ is partitioned into C uniformly distributed points. Define C as the set of all $\binom{C}{K}$ Possible zero configurations. To send M bits, an initial random set, B, of $2M$ possible polynomials are selected from C and the minimum distance, d_{min}, between any pair of autocorrelations are computed. Then, another configuration from $\alpha\ \varepsilon\ C$ is selected and if the minimum distance to all configurations in B is larger than d_{min}, it replaces an element in B.

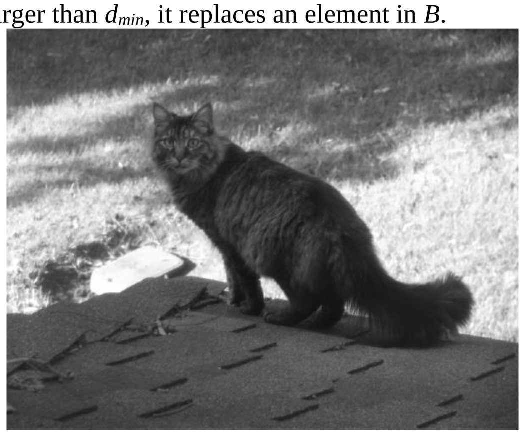


Figure (2) Original Image

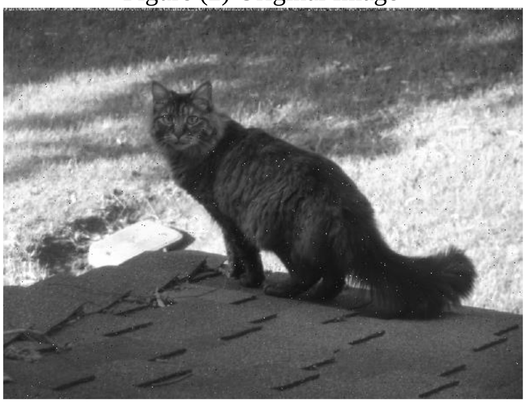
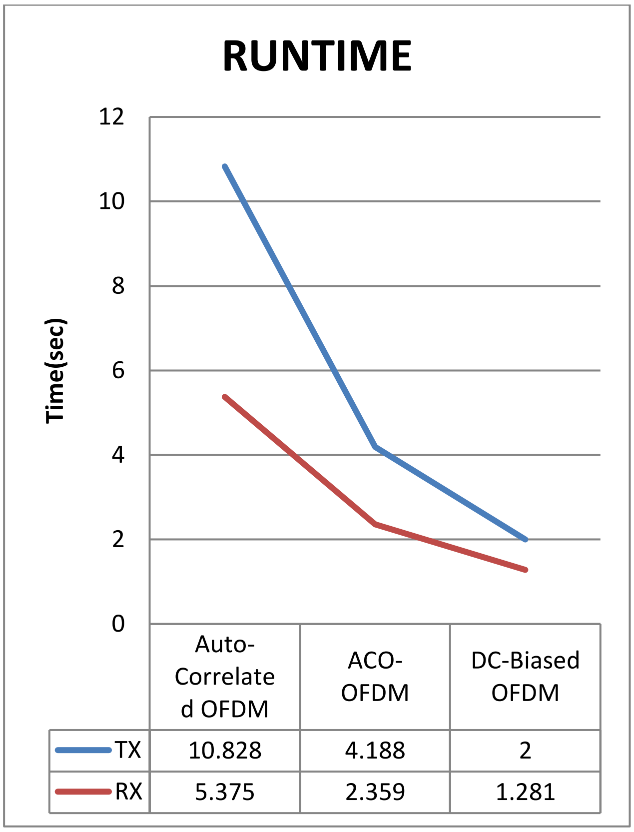


Figure (3) Transmitted Image

V. PERFORMANCE

Assume that M = 500 bits are transmitted with N = 1024 subcarriers. In DC-biased OFDM, the transmission time and reception time is the least with the highest BER. Also in ACO-OFDM the BER is high but lesser than that in DC-biased OFDM. Figure (4) shows the BER of Auto-Correlated Optical-OFDM, DC-biased OFDM and ACO OFDM versus SNRo. The performance of all the three methods are shown graphically.



	Auto-Correlated OFDM	ACO-OFDM	DC-Biased OFDM
TX	10.828	4.188	2
RX	5.375	2.359	1.281

Graph (1)

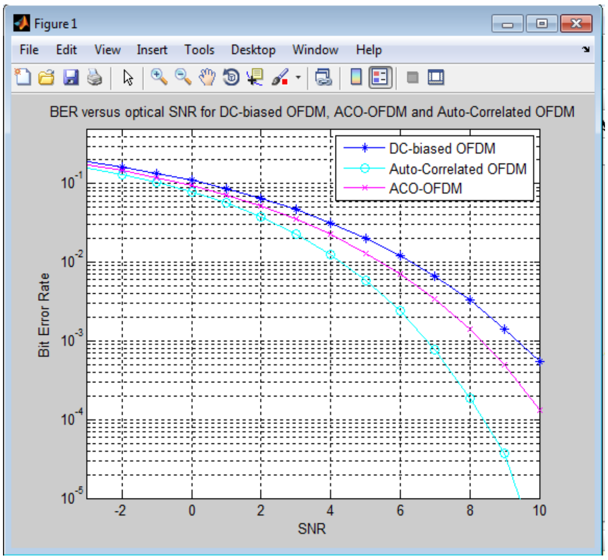


Figure (4)

VI. CONCLUSIONS

Spectral factorization provides formalism for non-negative multiple

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subcarrier modulation and can represent all band limited OFDM signals for IM/DD channels. Using spectral factorization, non-negative OFDM signals can be generated with no explicit bias. Moreover, the loss of half the carriers and high PAPR in ACO-OFDM and PAM-DMT are mitigated in Auto-Correlated Optical-OFDM. There is much room for improvement in the Auto-Correlated Optical-OFDM design presented in this paper. Instead of locating zeros on a fixed radius ring for simplicity, optimization techniques can be applied to guide the location of the zeros. Additionally, there is ongoing work to extend the Auto-Correlated Optical -OFDM model to incorporate a peak amplitude constraint.

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