Time Domain Diversity Combining with Delay-and-Advanced Operation in Two Layered Asymmetrically Clipped Optical OFDM System

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Abstract

This paper discusses the implementation of time domain delay-and-advanced operation with diversity combining at the transmitter for a two-layered LACO-OFDM system. This technique utilizes all the subcarriers and improves the BER performance. The new improved 2-LACO-OFDM system achieves 2.7 dB, 3.3 dB and 3.7dB better optical signal to noise ratio (OSNR) than the ACO-TDDC, 2-LACO-TDDC, 3-LACO-TDDC respectively.

1. Introduction

Layered Asymmetrically Clipped Optical Orthogonal Frequency Division Multiplexing (LACO-OFDM) has been proposed in [1]], with similar approaches in [2–5], has gained lots of attention as the preferred modulated technique for intensity modulated/direct detection (IM/DD) OFDM system. LACO-OFDM increases the spectral efficiency of Asymmetrically Clipped Optical OFDM (ACO-OFDM) [6, 7] by transmitting multiple layers of ACO-OFDM on its subcarriers and iteratively removing the clipping noise at the receiver. Two layers LACO-OFDM or simply referred to as 2-LACO-OFDM uses 75% of total of subcarriers and 3-LACO-OFDM uses 87.5% of total of subcarriers. Hence, to utilize all the available subcarriers, LACO-OFDM implements more than 6-layers of ACO-OFDM, at the expense of a very large complexity [2].

Recently, Dual stream Asymmetrically Clipped Optical OFDM (DSACO-OFDM) was successfully demonstrated in [8], that uses delay and advance operations to combine two layers of ACO-OFDM signal without compromising the loss of information. DSACO-OFDM showed better BER than 2-LACO-OFDM and 3-LACO-OFDM while achieving high spectral efficiency [8] .

The clipping distortion occurring from conventional ACO- OFDM process, falls on even subcarriers that contains some valuable information of the transmitted ACO-OFDM signal. This information is utilized by the diversity combining (DC) technique [9] to improve the BER performance of ACO-OFDM signal. This technique is commonly applied to receiver known as Time-Domain Diversity Combining Receiver (TDDR) [10, 11]. This was applied at each layer of LACO-OFDM to further enhance its BER performance as demonstrated in [12]. In the above mentioned techniques, the application of DC to the receiver required the additional use of IFFTs which adds to the overhead complexity.

The additional use of IFFT is reduced when DC is applied to the ACO-OFDM transmitter in [13], referred to as Time-Domain Diversity Combining (TDDC). As the DC frees the subcarriers from clipping distortion, the advantage of reusing more number of freed subcarriers with more modulated information can be witnessed in TDDC.

In this work, a novel transmitter scheme is proposed for a 2-LACO-OFDM system through the application of TDDC with delay-and-advanced operation. The proposed system achieves improved BER performance, spectral efficiency and a lower computational complexity at the receiver.

2. Comparison Of Laco-ofdm With Tddr And Tddc

In general, the unipolar ACO-OFDM signal is generated by clipping the bipolar OFDM signal at zero, represented as in [14]

$$x_{ACO,n} = \begin{cases} x_n & x_n \geq 0 \\ 0 & x_n < 0 \end{cases} \qquad (1)$$

The clipping distortion that is resulted from clipping operation falls only on the even subcarriers, without affecting the data on the odd subcarriers. The ACO-OFDM signal in terms of data and clipping distortion is represented as

$$x_{ACO,\,n} = \frac{1}{2}\left(x_n + \left|x_n\right|\right)$$

2

$$x_{ACO,\,n} = x_{D,\,n} + x_{C,\,n}$$

3

where $x_{C,\,n} = \frac{1}{2}\left|x_n\right|$ (|. | denotes the absolute operator) is the clipping distortion falling on the even subcarriers, that does not affect the modulated data $x_{D,\,n} = \frac{1}{2}x_n$ present on the odd subcarriers as shown in [9, 14].

Multiple layers of ACO-OFDM represented by Equation (3), are then combined and expressed in [12] as

$$x_{LACO}(n) = \sum_{l=1}^{L} x^l_{ACO}(n)$$

4

$$x^l_{ACO} = x^l{}_{D,\,n} + x^l{}_{C,\,n}$$

5

where ‘l’ represents the layers, $x^l{}_{D,\,n}$ and $x^l{}_{C,\,n}$represents the data and the clipping distortion of ‘l’ layers.

2.1 LACO-OFDM with TDDR

The TDDR was applied to each layer of LACO-OFDM in [12], represented as

$x_{LACO-\,TDDR}(n)$ =$(1-\alpha)*x^l{}_D(n) + \alpha*(sign(x^l{}_D(n))*x^l{}_C$(n) (6) where '$\alpha$' is the combination factor that defines the relation between modulated data $x_{D,n}$ and the non-linear processing of $sign\left(x_{D,n}\right)*|x_{D,n}|$.

2.2 LACO-OFDM with TDDC

Similar to ACO-TDDR, the principle of operation remains the same in ACO-TDDC, represented as

$$x_{LACO-TDDC}(n) = (1-\alpha)*{x^l}_D(n) + \alpha*\left(sign({x^l}_D(n)\right)*{x^l}_D(n)\right) \quad (7)$$

3. Comparison Between Tddr And Tddc

This section analyzes the comparison between TDDR and TDDC in terms of BER and computational complexity. The BER comparison of TDDR and TDDC for ACO-OFDM is shown in Fig. 1.

It is seen that for a BER of 10^{-3}, the performance is the same for both TDDR and TDDC applied to each layer, and with both showing 3 dB improvement over ACO-OFDM for 64-QAM and 1024-QAM for a fixed $\alpha = 0.5$.

The computational complexity comparison of TDDR and TDDC is applied to one layer of ACO-OFDM as shown in Table 1. It can be observed that TDDC requires only one IFFT and only one FFT at the receiver. So, it requires only two IFFT/FFT for the entire system in comparison to TDDR technique which requires five IFFT/FFT's (one IFFT at the transmitter and four FFT's at the receiver). Therefore, TDDC is advantageous in comparison to TDDR in terms of BER and computational complexity.

Table1 Complexity comparison of TDDR and TDDC for ACO-OFDM

Techniques	Transmitter	Receiver
TDDR	$\Theta\left(Nlog_2N\right)$	$4\Theta\left(Nlog_2N\right)$
TDDC	$\Theta\left(Nlog_2N\right)$	$\Theta\left(Nlog_2N\right)$

3. Improved 2-laco-ofdm System

This section presents the transceiver design of the improved 2-LACO-OFDM system.

3.1 Transmitter

The block diagram of the 2-LACO-OFDM system with TDDC transmitter is shown in Fig. 2(a).

Figure 2(a) Block diagram of improved 2-LACO-OFDM Transmitter

The first layer carries the ACO-TDDC signal on the odd subcarriers given as

$x^{o}_{ACOTDDC} = (1 - \alpha) * x^{o} + \alpha * (sign(x^{o}\Big) * |x^{o}\Big|)$ (8)

As stated earlier, this signal resulting from this process has only the processed data on the odd subcarriers, and it contains no data on the even subcarriers. The second layer, carrying the real valued data on the even subcarriers X^{e} are shifted onto the empty odd subcarriers by delaying in time, represented asX^{ed}. This signal is then fed into the ACO-OFDM modulation block that generates the ACO-OFDM signal represented as x^{ed}_{ACO}. The TDDC block generates the resulting ACO-TDDC OFDM signal on the odd subcarriers $x^{ed}_{ACOTDDC}$ given as

$x^{ed}_{ACOTDDC} = (1 - \alpha) * x^{e} + \alpha * (sign(x^{e}\Big) * |x^{e}\Big|)$ (9)

This data signal present on the odd subcarriers, and is shifted to even subcarriers by advancing in time domain. This process generates the resulting signal represented as $x^{e}_{ACOTDDC}$. The two signals ACO-TDDC OFDM resulting from the two layers are now combined to yield the improved 2-LACO-OFDM signal given as

$x_{i2-LACO} = x^{o}_{ACOTDDC} + x^{e}_{ACOTDDC}$ (10)

This signal is appended with Cyclic Prefix (CP), converted from parallel to serial (P/S), converted into analog signal using a digital to analog converter (D/A) and then sent to the optical modulator.

3.2 Receiver

Figure 2(b) shows the block diagram of receiver. The received signal detected by a photodetector is expressed in time domain as

$$y_{i-2LACO,n} = x_{i-2LACO,n} * h_{n} + w_{n}$$

11

for $n = 0,1 \ldots\ldots . N - 1$, where h_{n}represents the channel state information and w_{n}represents the additive white guassian noise (AWGN). After the conversion of serial to parallel (S/P), analog to digital (A/D), removal of CP, the received signal is transformed into frequency domain by an N-point FFT. This signal is further equalized and represented as

$$Y_{i-2LACO,k} = X_{i-2LACO.k} H_{k} + W_{k}$$

12

for $k = 0,1 \ldots\ldots . N - 1$. Considering a flat channel, Eq. (12) can be re-written as

$$Y_{i-2LACO,k} = X_{i-2LACO.k} + W_k$$

13

The enhanced ACO-OFDM signal is detected from the odd subcarriers using the maximum likelihood (ML) detection, given as

$$X^o_{ACOTDDC,k} = \arg\min_{X \in Q_M} \left| H_k X - Y^o_{ACOTDDC,k} \right|$$

14

where$k = 1,3, \ldots\ldots. N/2 - 1$

Similarly, the enhanced ACO-OFDM signal is detected from the even subcarriers as

$$X^e_{ACOTDDC,k} = \arg\min_{X \in Q_M} \left| H_k X - Y^e_{ACOTDDC,k} \right|$$

15

where $k = 2,4, \ldots\ldots. N/2 - 1$

4. Results And Discussion

The BER curves for improved 2-LACO-OFDM shown in Fig. 3, are generated using Monte-Carlo simulations and are compared with the 2,3-LACO-OFDM as generated in [12]. The BER performance of proposed system is also compared with conventional ACO-OFDM and applied TDDC. The simulations were carried out for 64-QAM. As seen in Fig. 3 for a BER of 10^{-3}, improved 2-LACO-OFDM system has 2.7 dB, 3.3 dB and 3.7dB better optical signal to noise ratio (OSNR) than ACO-TDDC, 2-LACO-TDDC and 3-LACO-TDDC respectively.

5. Conclusion

In this letter, an improved 2-LACO-OFDM with lower complexity is presented that uses all the available subcarriers without losing any information. It was shown that the improved 2-LACO-OFDM with the implementation of time domain delay-and-advanced operation and time domain diversity combining has a better OSNR performance.

Declarations

Acknowledgments

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Figures

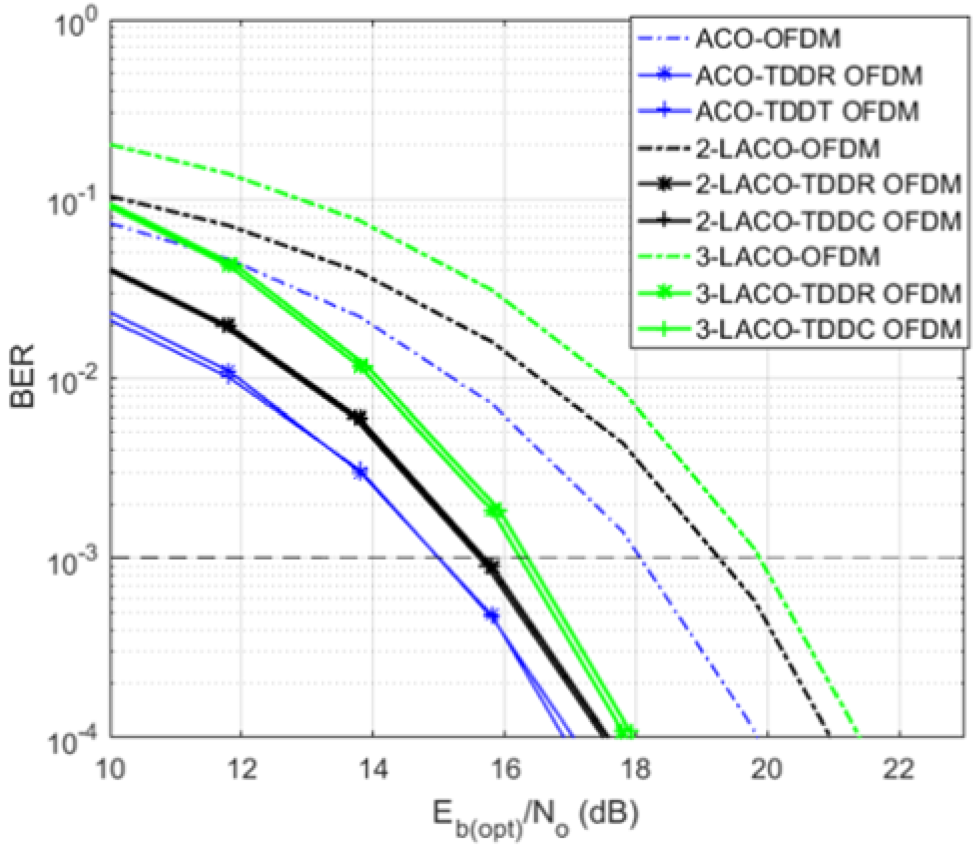
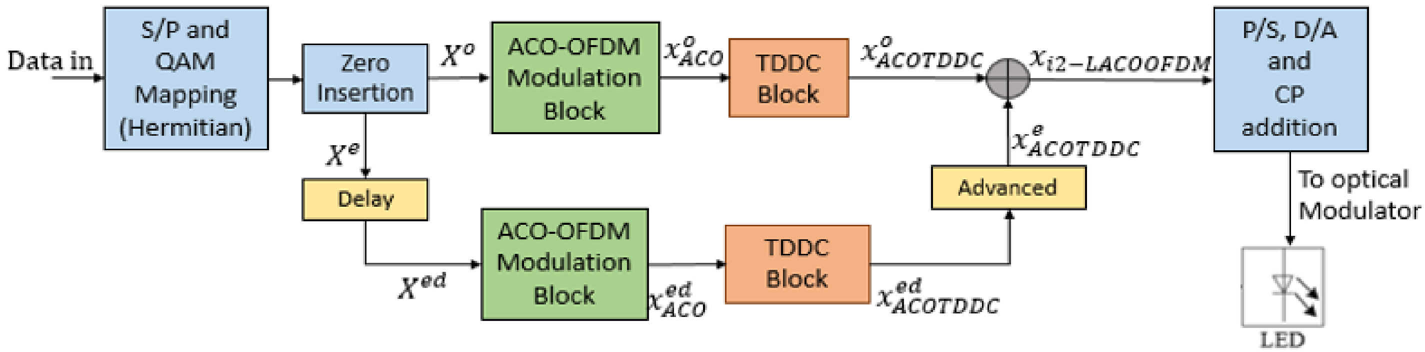


Figure 1

BER comparison curves for TDDR and TDDC applied to ACO-OFDM, 2-LACO-OFDM and 3-LACO-OFDM



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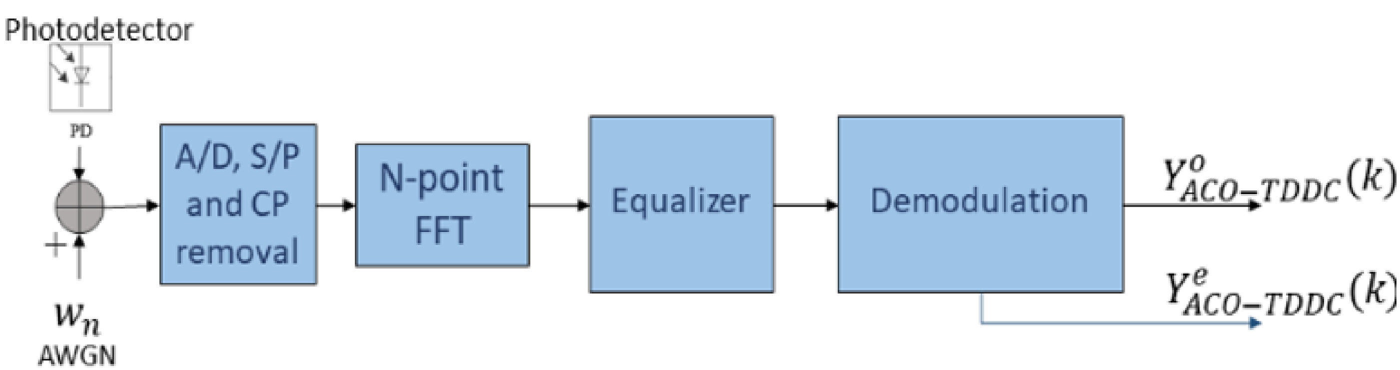

B

Figure 2

(a) Block diagram of improved 2-LACO-OFDM Transmitter (b) Block diagram of improved 2-LACO-OFDM Receiver

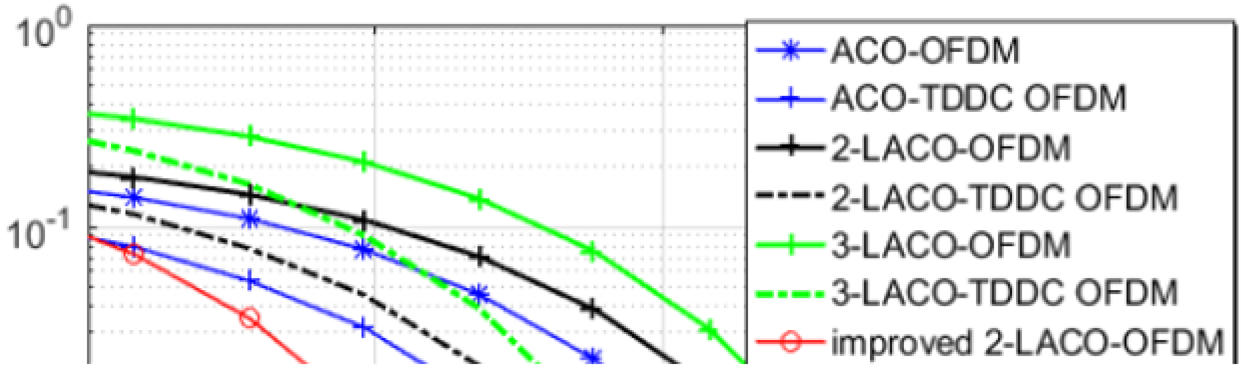

Figure 3

BER comparison curves for improved 2-LACO-OFDM, ACO-OFDM, ACO-TDDC OFDM, 2-LACO-OFDM, 2-LACO-TDDC OFDM, 3-LACO-OFDM, 3-LACO-TDDC OFDM