Efficient embedded signaling through DCT precoding matrix for SLM method in OFDM system

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***Abstract*—Orthogonal frequency division multiplexing (OFDM) modulation technique is a promising transmission scheme for high performance broadband wireless communications. However, as a drawback, this scheme suffers from the high peak to average power ratio (PAPR) of the output signals. In order to overcome this issue, several methods requiring the transmission of side information SI bits have been proposed. The transmitted bits must be channel-encoded as they are particularly critical to the error performance of the OFDM system. This fact results in a high increase of the system complexity. Additionally, the wrong estimation of the SI leads to the damage on the total signal recovery and the loss of the entire OFDM sequence. For these reasons, we propose in this paper, a new robust technique based on selected mapping (SLM) scheme. The proposed method is based on a new form of embedded signaling such as the use of the discrete cosinus transform (DCT). Furthermore, we employ an optimized scheme during the estimation process, using the higher order statistics moments. Simulation results are given to illustrate the good performance of our proposed method and support our claim.**

***Index Terms*—Blind, BER, DCT, Embedded Signaling, Fourth Order Cumulant, OFDM, PAPR, SLM, Viterbi.**

I. Introduction and Discussion

Orthogonal frequency division multiplexing (OFDM) modulation technique is a multicarrier transmission scheme that has been widely adopted in various wireless communication standards (WLAN, DVB-T...), thanks to its high spectral efficiency and robustness especially for the frequency selective channels [1]. Recently, the OFDM technique has been employed in the 3rd generation partnership project (3GPP) of the advanced long term evolution (LTE-A) [3]. However, OFDM systems have the undesirable feature of a large peak to average power ratio (PAPR) of the transmitted signals. Consequently, the transmit amplifier must operate in its linear regions in order to prevent the spectral growth of the OFDM signal. Therefore, power amplifiers with a large linear range are required for OFDM systems, but such amplifiers are considered to be the most expensive component of OFDM systems. Thus, reducing the PAPR is pivotal to reducing the expense of OFDM systems [4], [5]. To overcome this problem, several techniques for the PAPR reduction have been proposed, including clipping and filtering (CF) [6] coding [7], selected mapping (SLM) [9], active constellation extension (ACE) [10], partial transmit sequence (PTS) [11] and tone reservation (TR) [12]. Among the cited techniques, SLM presents the most attractive technique since it can significantly reduce the PAPR by modifying the OFDM signal without any signal degradation. However, the SLM receiver should be aware about the used phase sequence at the transmitter side in order to recover the original OFDM data. Thus, it is necessary to transmit the index of the selected phase sequence as an explicit side information SI. Consequently, a wrong estimation of the SI leads to damage the total signal recovery and to a loss of the entire OFDM sequence which conducts obviously to a significant performance deterioration in terms of bit error probability (BEP).

For these reasons, several research works, known as semi-blind or blind SLM, suggest possible ways how to embed the SI index into the OFDM frame at the transmitter side. These methods can be mainly classified into two categories. The first category exploits some additional bits known as repeated repeated code, dummy sequence, pilot, which are added to the original transmitted sequence in order to embed the index used in SLM. Using this approach, the SI index is not transmitted explicitly, but is dispersed over the whole OFDM frame. In [13], a repetition code was investigated to embed the used index by exploiting a special form of signaling consisting on a rotated and un-rotated constellation. It is shown that this variant of SLM provides a perfect signal recovery but it requires high complexity at the receiver side. Moreover, [14] proposed a new technique knowing by dummy sequence insertion (DSI), where the dummy bits are inserted at the end of the data sequence. Moreover [17], [16] show that in order to guarantee a good performance in terms of the PAPR, the DSI technique must use an iterative version or exploits a high correlation sequence causing a loss time and energy. The second category proposes an implicit transmission of the SI, without any use of additional bits. In that case, the receiver exploits the received OFDM frame in order to estimate the used index. Nevertheless, as it has been shown in [18] , the proposed scheme performs a good bit error rate (BER) but seems to be impractical due to its prohibitive detection complexity, especially with high order modulations and large number of subcarriers. Additionally, some blind methods can only be applied for QAM modulation [20] or for specific matrix phase [21].

Therefore, this paper aims at investigating a new blind technique based on SLM with low-complexity transceiver and

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without any explicit SI. In order to embed the SI, the proposed method uses the discrete sinus transform (DCT) at the transmitter side. Furthermore, we exploit an optimized scheme which mainly uses the higher order statistics moments of the received signal, in order to recover the used SI index.
The remainder of the article is organized as follows: In Section III, we define the system model and we briefly review the conventional SLM technique. In Section V, we discuss our proposed blind technique. Subsequently, we describe in Section VI, the obtained simulation results to emphasize the performance of our proposed method. Finally, we conclude the paper in Section VII.

II. NOTATIONS

Throughout this paper, the boldface lower case and upper cases letters denote vectors and matrices respectively. The superscripts $.^T$ and $.^*$, denote the transpose and the element wise conjugation, respectively. Finally, $\mathbb{E}$ refers to the expectation operator and $|.|$ denotes the absolute value.

III. OFDM SYSTEM AND PAPR METRIC

This Section provides preliminary concepts related to the OFDM multicarrier scheme, the PAPR metric and the conventional SLM technique.

A. Typical OFDM system

In an OFDM system, a frequency bandwidth B is divided into N non-overlapping orthogonal subcarriers of bandwidth Δf where $B = N\Delta f$. For a given OFDM symbol, each subcarrier is modulated with a complex value taken from a known constellation. Let $\mathbf{y} = [y_0, \ldots, y_{N-1}]^T$ denotes a block of N frequency domain subcarriers. After performing an N length inverse fast fourier transform (IFFT), we obtain the following sequences $\mathbf{x} = [x_0, \ldots, x_{N-1}]^T$ where

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} y_k e^{j\frac{2\pi k\, n}{N}},\, n = 0, \ldots, N-1. \qquad (1)$$

B. PAPR expression

Due to the statistical independence of all subcarriers, the time-domain samples are approximated by complex Gaussian processes which results in high amplitude values and this is characterized by the PAPR of the signal $\mathbf{x}$. The conventional expression of the PAPR for the OFDM symbol in the time domain can be expressed as

$$PAPR(\mathbf{x}) = \frac{\max\limits_{n=0,\ldots,N-1} |x_n|^2}{\mathbb{E}(\|\mathbf{x}\|^2)}. \qquad (2)$$

C. Conventional Selected Mapping (SLM)

In general, to reduce the PAPR, the SLM technique is proposed as a reliable technique. It principal is simple: first it generates a special phase matrix denoted

$$\mathcal{PM}(D \times N) = [e^{-j\mathbf{\Phi}^{(0)}}, \ldots, e^{-j\mathbf{\Phi}^{(D-1)}}]^T, \qquad (3)$$

where, $\mathbf{\Phi}^{(d)} = [\phi_0^{(d)}, \phi_i^{(d)} \ldots, \phi_{N-1}^{(d)}]^T$, $\phi_i^{(d)} \in [0, 2\pi[$ and $i = 0, \ldots, N-1$.

Then, the input data ($\mathbf{y}$) is multiplied with D independent phase sequences to obtain a modified data block denoted as follows

$$\mathbf{y^{(d)}} = \mathbf{y}.\mathbf{e^{-j\,\Phi^{(d)}}},\ \mathbf{d = 0, \ldots, D-1}. \qquad (4)$$

Finally, an IFFT of the multiplied sequences is performed to produce the D sequences $\mathbf{x^{(d)}}$ among which the one with the lowest PAPR is selected for transmission as

$$\tilde{d} = \underset{d=0,\ldots,D-1}{\arg\min} \frac{\max\limits_{n=0,\ldots,N-1} |x_n^{(d)}|^2}{\mathbb{E}(\|\mathbf{x^{(d)}}\|^2)} \qquad (5)$$

The detailed steps of the proposed scheme are summarized in **Algorithm 1**

Algorithm 1 Pseudo code description of conventional PAPR reduction algorithm (Transmitter side)

Require: D, N, $\mathbf{y}$ and $\mathbf{\Phi}^{(d)} = [\phi_0^{(d)}, \ldots, \phi_{N-1}^{(d)}]^T$
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1: Define the used SLM phase matrix PM(D × N) = {e^{-j φ^(d)}}_{d=0}^{D-1}.
2: for d = 0 to D − 1 do
3:    Compute y^(d) = y.e^{-j φ^(d)}.
4:    Compute x^(d) = IFFT(y^(d)).
5:    Calculate PAPR(d) = max_{n=0,...,N-1} |x_n^(d)|^2 / E(||x^(d)||^2).
6: end for
7: d̃ = argmin_{d=0,...,D-1} PAPR(d).
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As discussed above, the conventional SLM receiver should know the used index $\tilde{d}$ of the actually transmitted signal candidate in order to reliably estimate the original OFDM sequence. This index must be protected against the transmission errors, because a wrong estimation of the SI can lead to damage the total signal recovery and leads to the lost of the loss the entire OFDM sequence. For these reasons, we investigate in this paper a new optimized and efficient blind technique that embed the used SI into the transmit signal and estimated it blindly at the receiver side.

IV. PROPOSED BLIND METHOD WITH IMPLICIT SIDE INFORMATION

In this section, we briefly review the main notions considered in this paper, in order to embed and detect properly the adequate index SI. In the second part, we detail the main steps of the proposed blind algorithm.

A. Discrete cosinus transform

The discrete cosine transform (DCT) is an orthogonal linear transform that can be implemented by a butterfly structure and which is similar to the IFFT. Moreover, the DCT presents a real transform in which the data are multiplied by a cosine function. We note that the main advantage of using the DCT as precoding matrix in our proposed system, is that it does not require any side information for the receiver.
The DCT precoding matrix denoted by $\mathcal{P}$, is defined as follows

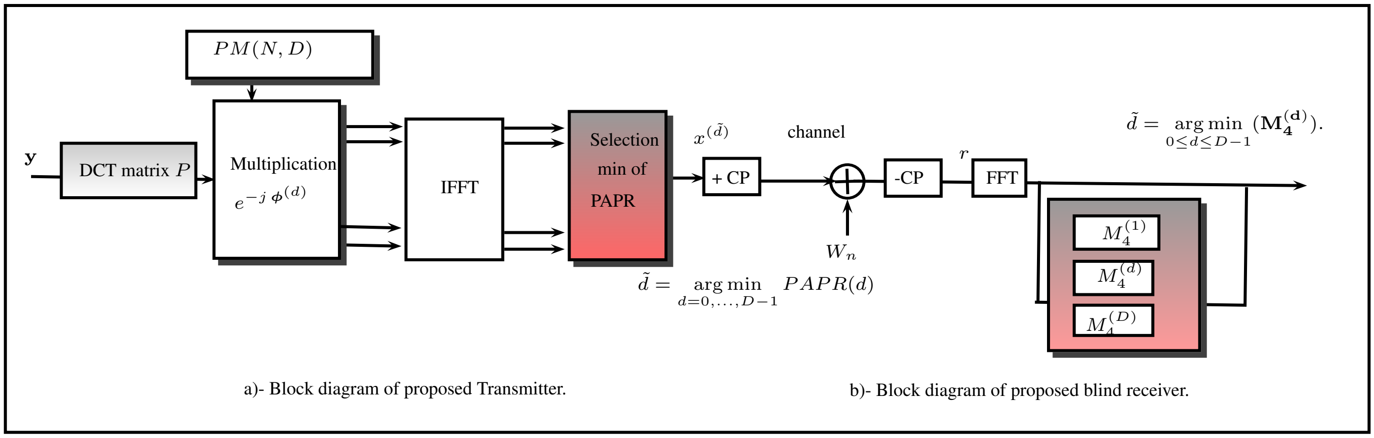

Fig. 1. Block diagram of the proposed blind SLM technique.

$$p_{(i,j)} = \begin{cases} \frac{1}{\sqrt{N}}, i = 0, j = 0 \dots, N-1. \\ (\frac{2}{\sqrt{N}}) \cos(\frac{(2j+1)i\pi}{\sqrt{2N}}), i, j = 0 \dots, N-1. \end{cases} \quad (6)$$

where i and j represent the row and column entries, respectively.

B. Fourth order cumulant

By definition [22] the fourth order cumulant, known as Kurtosis, is a statistical parameter based on the moment of a signal. In general, the Fourth order cumulant of a complex-Gaussian signal $\mathbf{y}$ denoted as $M_4(y)$ can be defined as

$$M_4(y) = \frac{M_{4,2}(\mathbf{y})}{M_{2,1}^2(\mathbf{y})} = \frac{\mathbb{E}(\|\mathbf{y}\|^4)}{\mathbb{E}(\|\mathbf{y}\|^2)^2} \quad (7)$$

where $M_{4,2}(\mathbf{y})$, $M_{2,1}(\mathbf{y})$ present respectively the fourth moment and the second moment of the signal $\mathbf{y}$. In the sequel, we will consider the Kurtosis as a metric to estimate the phase sequence.

C. Embedding and decoding the SI into the OFDM symbol

It is well known that the Fourth order cumulant of a white Gaussian noise is equal to 2 [23]. Consequently, this property is the main idea of the proposed decision metric. In fact, in order to embed the SI into the alternative symbol sequences, we perform an additional orthogonal transformation DCT. In other word, at the transmitter side, we multiply the original data ($\mathbf{y}$) by the orthogonal matrix $\mathcal{P}$, then we perform the conventional SLM block as showed in Fig.1. Regarding the receiver side, we can remark that if we don't compensate with the correct sequence used by SLM we will obtain a complex-Gaussian signal where the Fourth order cumulant is around 2 [24]. Otherwise we will obtain the used one. Thus, the used sequence will correspond to the one having the minimum of Fourth order cumulant.

To sum up, the main steps of the proposed method are detailed as follow

- Regarding the transmitter side, assumed that the original data $\mathbf{y} = [y_0, \dots, y_{N-1}]^T$ is transformed into a vector $\mathbf{v} = [v_0, \dots, v_{N-1}]^T$ via a multiplication matrix $\mathcal{P}(N \times N)$ and according to the following representation
$$v = \mathcal{P}.\mathbf{y}. \quad (8)$$
Secondly, the obtained sequence $\mathbf{v}$ is multiplied by the used SLM matrix $\mathcal{PM} = \{\boldsymbol{\phi}^{(d)}\}_{d=0}^{D-1}$. Then, the transmitter selects the vector having the minimum PAPR (as defined in Eq.5)
- Regarding the receiver side, we assumed that the response of the channel h_n is perfectly known and the received signal denoted r_n are expressed as follows
$$r_n = h_n v_n^{(\tilde{d})} + w_n, = h_n v_n e^{j\phi_n^{(\tilde{d})}} + w_n,\ n = 0, \dots, N-1, \quad (9)$$
where $\mathbf{w}$ is the zero mean AWGN, $\frac{N_0}{2}$ is the variance for both real and imaginary components.
Finally, the obtained decision is made by calculating the Fourth order cumulant of D combinations and select the index of the combination having the lowest of the fourth order cumulant
$$\tilde{d} = \arg\min_{0\le d\le D-1} (\mathbf{M_4^{(d)}}). \quad (10)$$
where,
$$\mathbf{M_4^{(d)}} = \frac{\frac{\sum_{\mathbf{n=0}}^{\mathbf{N-1}} \left|\mathbf{t_n^{(d)}}\right|^{\mathbf{4}}}{\mathbf{N}}}{\left(\frac{\sum_{\mathbf{n=0}}^{\mathbf{N-1}} \left|\mathbf{t_n^{(d)}}\right|^{\mathbf{2}}}{\mathbf{N}}\right)^{\mathbf{2}}}.$$

Moreover, it is important to stress that both transmitter and receiver must share the same SLM phase matrix $\mathcal{PM} = \{\boldsymbol{\phi}^{(d)}\}_{d=0}^{D-1}$.

Finally, the pseudo code of the proposed method can be summarized according to **Algorithm 2**.

Algorithm 2 Pseudo code description of the proposed Blind SLM

Require: $\mathbf{r}$, D, N and $\mathcal{PM} = \{\phi^{(d)}\}_{d=0}^{D-1}$

At the transmitter side

Calculate $v = \mathcal{P}.\mathbf{y}$.

Apply the conventional SLM as exlpained in (Algorithm 1)

At the receiver side

for $d = 0$ to $D - 1$ **do**

  Calculate: $\mathbf{s^{(d)}} = \mathbf{r.e^{j\,\phi^{(d)}}}$.

  Calculate: $\mathbf{t}^{(d)} = \mathcal{P}^{-1}.s^{(d)}$.

  Calculate: $\mathbf{M_4^{(d)}} = \dfrac{\dfrac{\sum_{n=0}^{N-1}\left|\mathbf{t_n^{(d)}}\right|^4}{\mathbf{N}}}{\left(\dfrac{\sum_{n=0}^{N-1}\left|\mathbf{t_n^{(d)}}\right|^2}{\mathbf{N}}\right)^2}$.

end for

$\tilde{d} = \underset{0 \le d \le D-1}{\arg\min}\left(\mathbf{M_4^{(d)}}\right)$.

V. Simulation results and discussions

The performance of the proposed blind SLM method in is evaluated through simulation results. These simulations are performed for both the transmitter and the receiver sides. At the transmitter side, the performances are evaluated in terms of the CCDF of the PAPR versus its threshold. At the receiver side, the performances are highlighted in terms of the Bit Error Rate (BER).

Fig.2 illustrates the CCDF of the PAPR for N=128 sub carriers in the case of 4-QAM modulation. As shown in this Fig.2, we have varied the number D of the used precoder sequences in the DCT SLM method. We deduce that when D increases the PAPR level decreases. Moreover, we can realize that the PAPR of the OFDM signal is reduced dramatically by over 4 dB compared with the original OFDM (blue curves) when the CCDF is 10^{-4} and $D = 16$.

Regarding the receiver side, in order to evaluate the performances of this method in terms of BER we compare the two cases: the first one is where we perform a blind decision process whereas the second one where the phase sequence is perfectly known SI at the receiver side (ordinary SLM). In addition, we consider a complex AWGN channel in Fig. 3. Then, we consider a Rayleigh channel with length $L = 4$ in Fig.4, where we perform a conventional Viterbi decoder with a rate equal to $\frac{1}{2}$ and a hard decoder at the receiver side.

These two figures show that the curves corresponding to the proposed blind SLM technique and those of the ordinary SLM, in the case of a perfect SI knowledge, are approximately subploted. This proves well that our proposed bind methods lead to a performance which is quasi-identical to the ordinary one with perfectly known SI.

VI. Conclusion

In this paper, we have investigated an efficient PAPR reduction technique in SISO-OFDM system that we denoted as blind SLM based on efficient form of embedded signaling ensuring no increase of the transmitted power. We have performed an optimized form of embedded signaling that consists on a specific DCT precoding matrix. Finally, we have demonstrated that when used the proposed scheme, it dramatically improves the system performances in terms of CCDF of the PAPR and BER.

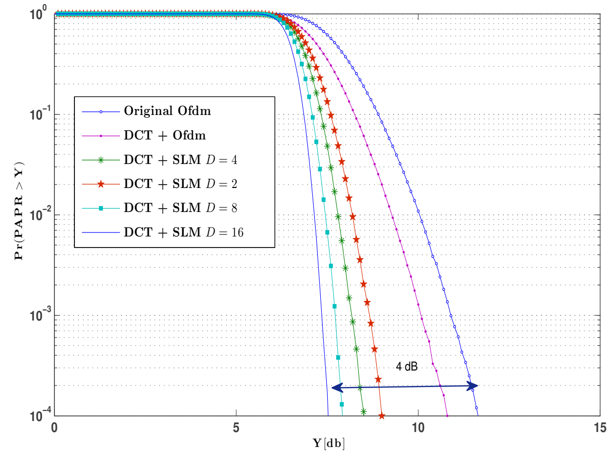

Fig. 2. CCDFs of the PAPR in the case of blind SLM DCT for different value of D and a 4-QAM modulation.

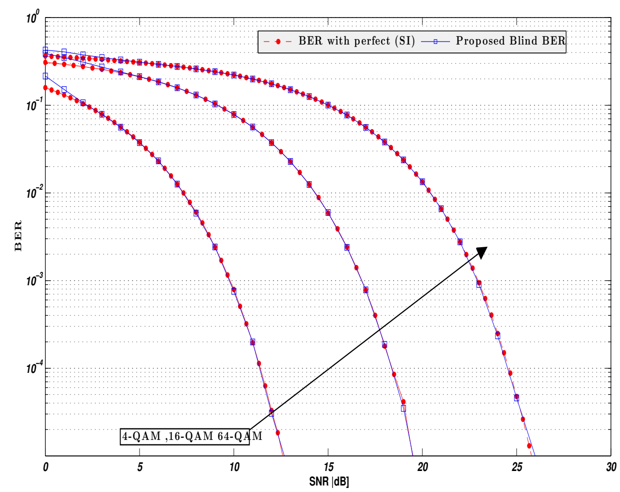

Fig. 3. BER comparison: Blind decision and perfect SI in the case of AWGN channel for $D = 8$ and $N = 256$.

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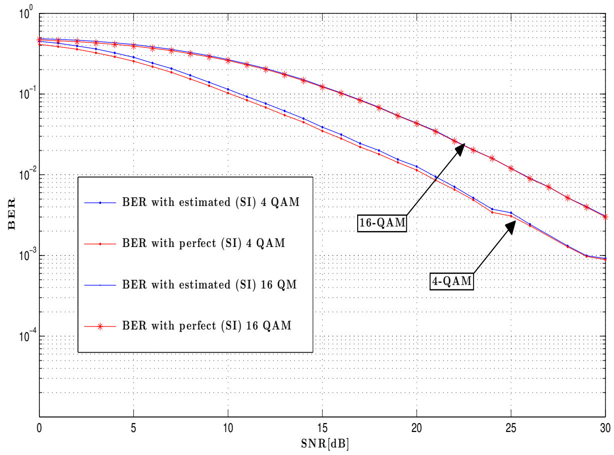

Fig. 4. BER performance comparison: encoded (Viterbi) Conventional and Blind BER in the case of Rayleigh fading channel where $D = 8$, $N = 256$ and $L = 4$.

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