International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:3, No:2, 2009

A Blind SLM Scheme for Reduction of PAPR in OFDM Systems

K. Kasiri and M. J. Dehghani[1]

***Abstract*—**In this paper we propose a blind algorithm for peak-to-average power ratio (PAPR) reduction in OFDM systems, based on selected mapping (SLM) algorithm as a distortionless method. The main drawback of the conventional SLM technique is the need for transmission of several side information bits, for each data block, which results in loss in data rate transmission. In the proposed method some special number of carriers in the OFDM frame is reserved to be rotated with one of the possible phases according to the number of phase sequence blocks in SLM algorithm. Reserving some limited number of carriers wont effect the reduction in PAPR of OFDM signal. Simulation results show using ML criteria at the receiver will lead to the same system-performance as the conventional SLM algorithm, while there is no need to send any side information to the receiver.

***Keywords*—** Orthogonal Frequency Division Multiplexing (OFDM), Peak-to-Average Power Ratio (PAPR), Selected Mapping (SLM), Blind SLM (BSLM).

I. INTRODUCTION

ORTHOGONAL Frequency Division Multiplexing (OFDM) signalling has been widely used for high data rate transmission applications, due to its high spectral efficiency and robustness to the frequency selective fading channels [1]. One major drawback of OFDM is the high peak-to-average power ratio (PAPR) of the output signal. Transmitting a signal with high PAPR requires highly linear power amplifiers with a large back-off to avoid adjacent channel interference due to nonlinear effects [2]. High values of PAPR result in low efficient usage of the ADC and DAC word length. With a limited number of ADC/DAC bits the designer has to decide about clipping the peaks, which results in burying the small variations of the signal in the quantization noise. Therefore, dynamic range reduction plays an important role for the application of OFDM signals in both power and band-limited communication systems.

Many PAPR reduction techniques have been proposed in the literature [3]-[9]. It should be noted that most of the methods are based on the same idea of selecting the time domain signal to be transmitted from a set of different representations with the constraint of minimization of PAPR which would degrade the performance of system. Nevertheless, PAPR reduction methods can be classified into distortionless and distortion techniques.

Distortion techniques are considered to introduce spectral regrowth. They do not require any side information to be sent and they have low complexity compared to the distortionless techniques with the drawback of increase in the error rate of the system.

On the other hand, distortionless techniques do not introduce spectral regrowth. But they require sending side information to the receiver and in some cases increase the error rate of the system. Two recently introduced Phase Optimization methods are the Partial Transmit Sequence (PTS) [8] and Selected Mapping (SLM) [9]. A drawback of these methods is high computational cost at the transmitter and extra information sent to the receiver.

In this paper, we propose a blind SLM method, in which the transmitted signal is modified in accordance with the opted phase sequence. The presented BSLM method tries to recover the OFDM signal using ML criteria at the receiver. This paper is organized as follows; In section II, the signal model and the PAPR problem are explained. Section III explains the conventional SLM method and then introduces the blind SLM scheme. The detailed simulation results and discussion are given in section IV and we make our concluding remarks in section V.

II. OFDM SYSTEM AND THE PAPR

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 (e.g. QAM, PSK, etc.). Let us denote a block of N frequency domain subcarriers as a vector $X = [X_0, X_1, \ldots, X_{N-1}]$. In the time domain, via an IFFT operation we obtain $x = [x_0, x_1, \ldots, x_{N-1}]$. Thus, the sampled sequence is:

$$x[n] = \frac{1}{N}\sum_{k=0}^{N-1} X[k]\, e^{j2\pi k n/N}, \quad 0 \le n < N \tag{1}$$

B. The PAPR Problem

The PAPR is a figure of merit that describes the dynamic

---

[1] Corresponding Author, IEEE Member, Electrical Engineering Department, Shiraz University of Technology, Modarres Boulevard, P.O. Box 313 Code 71555, Shiraz, Iran (phone: 0098-711-7353500; fax: 0098-711-7354514. Emails: dehghani@sutech.ac.ir and k.kasiri@sutech.ac.ir).

range of the OFDM time domain signal. The conventional definition of the PAPR for the OFDM symbol in the time domain x may be expressed as:

$$PAPR(x[n]) = \frac{\max|x[n]|^2}{E[|x[n]|^2]} \tag{2}$$

where E[.] denotes expected value of a random variable.

III. Blind SLM Scheme

A. Selected Mapping

Selected mapping (SLM) is a specific scheme for PAPR reduction that was introduced in [10]. SLM takes advantage of the fact that the PAPR of an OFDM signal is very sensitive to phase shifts in the frequency-domain data. PAPR reduction is achieved by multiplying independent phase sequences to the original data and determining the PAPR of each phase sequence/data combination. The combination with the lowest PAPR is transmitted. In other words, the data sequence X is element-wise phased by D N-length phase sequences, $\{\varphi[k]^{(d)}\}_{k=0}^{N-1} = \varphi^{(d)}$, where d is an integer such that $d \in [0, D-1]$. After phasing, the D possible frequency-domain sequences are given by

$$X^{(d)} = X \bullet e^{j\phi^{(d)}} \tag{3}$$

where $\bullet$ is element-wise multiplication. We assume that $\Phi^{(0)} = 0$ so that $X^{(0)} = X$.

Define the D candidate time-domain OFDM symbols $x^{(d)} = \mathrm{IFFT}\{X^{(d)}\}$. Note that all of the candidate symbols carry the same information. In order to achieve a PAPR reduction, the symbol with the lowest PAPR is transmitted. We define

$$\tilde{d} = \underset{1 \le d \le D_{\max}}{\arg\min}\ PAPR(x^{(d)}) \tag{4}$$

In SLM, we use $\log_2 D$ bits side information to indicate the phase weighting. As this side information is of highest importance to recover the data, it should be carefully protected by channel coding.

With $\tilde{d}$, the transmitted signal is $x^{(\tilde{d})}$. In the receiver, X can be recovered with

$$\begin{aligned} X &= FFT\{x^{(\tilde{d})}\} \bullet e^{-j\phi(\tilde{d})} \\ &= X \bullet e^{j\phi(\tilde{d})} \bullet e^{-j\phi(\tilde{d})} = X \end{aligned} \tag{5}$$

To recover X it is necessary for the receiver to have a table of all $\Phi(d)$.

B. Blind SLM Approach

As discussed in the previous section, the SLM approach suffers from sending side information in order to specify what phase sequence is utilized in the transmitter. However, using the side information the rate of data transmission will be decreased. This is mentioned as the important drawback of the SLM algorithm.

To avoid the information rate loss caused by the transmission of the optimum phase sequence index, a few blind SLM schemes have been proposed. Blind phase sequence detection was first mentioned in [11] and studied in [12]. In [11], a scrambling technique was described. A $\log_2 M$-bit binary label is inserted as a prefix to the frequency-domain OFDM signal and passed through a scrambler. Since the selected label is used in the receiver implicitly during descrambling, an erroneous reception of the label bits does not affect the error performance.

In [12], a blind SLM receiver was proposed by employing a maximum likelihood (ML) decoder, which avoids the transmission of any side information. For phase sequence detection in BSLM it is assumed that both the transmitter and receiver have the set of possible phase sequences. The basic idea is that the receiver takes DFT of the received baseband signal and then uses its set of phase sequences along with some sort of metric to determine which sequence the transmitter used. Traditionally [12], it is assumed that the receiver “derotates” the received symbols and compares each derotation to the symbol constellation. However, it is convenient in the derivation of the detection metric to use a different, but equivalent, method. Instead of derotating the received frequency-domain signal, assume that the received signal is compared to a rotated constellation. In [13] it is denoted a rotated constellation sequence by $C^{(d)} = \{C^{(d)}[k]\}_{k=0}^{N-1} = C \bullet e^{j\varphi^{(d)}}$. Notice that the constellation varies with because the phase sequence varies with k. In other words, the receiver has to determine which of the D constellation sequences was used for transmission. Once the constellation is known for each subcarrier (i.e. the constellation sequence is known), then classic decoding methods can be used to determine what data was sent.

Additionally, a novel method was proposed in [14] that integrates channel sounding and blind phase sequence detection in OFDM. In OFDM, the channel state information (CSI) can be acquired by modulating pilot tones onto predetermined sub-carriers; this is called pilot tone assisted modulation (PTAM). [14] combines the merits of PTAM and SLM, and proposes a novel joint channel estimation and PAR reduction algorithm. Instead of fixing the pilot tone locations as in conventional PTAM, it tries different pilot tone locations, and synchronizes the movement of the pilot tones with the choice of the phase rotation sequence. The pilot tone/phase sequence combination that results in the lowest PAR of the time-domain signal is used for transmission. However, the optimum index is not transmitted as side information in order to maintain the information rate. At the receiver, by taking advantage of the disparity between the pilot tone and information signal powers, they can blindly detect the optimum index by resorting to simple frequency domain averages. The concept of joint channel estimation and

PAR reduction was also explored in [15] – the "diversity" offered by the pilot phase (as opposed to the pilot location) was exploited and the transmission of side information was assumed in [15].

The method of [14] is very effective at blindly detecting BSLM phase sequences. However, when the channel is stationary (such as in DSL, immobile wireless links, etc.) and channel sounding is not necessary for every symbol period, it is desirable to leave out the pilot tones in order to increase data rate.

In [16] a combination of Hadamard matrix with SLM technique is used. In this algorithm the sequence of data bits are mapped to constellation points M-PSK or QAM to produce sequence symbols *X*[0], *X*[1], *X*[2] …. Then these symbol sequences are divided into blocks of length *N* and each block is multiplied by Hadamard matrix followed by M different phase sequence multiplication, $e^{j\varphi_i} b_i$, $i = 1,2, \ldots, M$, which depends on the constellation. Here b_i is each of the phase sequences in the conventional SLM algorithm. After IFFT of each branch is performed there will be M different OFDM frames with the same information. In this condition the receiver selects the branch that has minimum distance (based on Maximum likelihood (ML) criteria) to the transmitted symbols in the constellation used at the transmitter.

In this paper some modification is applied on the recent mentioned blind algorithm. The difference is that some of the carriers are reserved in order to inform the receiver which of the phase sequences are multiplied by the frequency domain carriers. Then the reserved subcarriers are modified using the following equation:

$$\begin{aligned} &X^{(d)}[k] = \rho^{(d)}[k] e^{j\varphi^{(d)}(k)} \\ &d = 0,1,2,\ldots,D-1 \ \ and \ \ k = 0,1,2,\ldots,N_r - 1 \end{aligned} \tag{6}$$

where *D* is the number of phase sequences opted to multiply the carrier sequences and N_r denotes the number of carriers to be reserved. $\varphi^{(d)}$ table is constructed as usual and $\rho^{(d)}[k]$ represents the sequence for specifying phase sequence multiplied by the overall frequency domain signal. In order to ensure that the average signal energy remains unchanged we require that

$$\sum_{k=0}^{N_r-1} \rho^{(d)}[k] = N_r \quad or \quad |\rho(d)|^2 = N_r \, . \tag{7}$$

For other carriers the process is done just like what is applied on the carriers in the usual SLM algorithm. Finally all of the different sequences, after serial to parallel conversion, pass through the IFFT block to produce *D* block of time domain signal. The block with the lowest PAPR is to be sent to the receiver through the channel.

In this condition receiver selects the branch that has minimum distance using sequences ρ (based on Maximum likelihood (ML) criteria [17]) in the constellation used in transmitter. Then receiver converts each data symbol block, to original data bits. In the proposed technique unlike the traditional SLM there is no need to transmit side information concerning the number of branches. So decreasing the rate of transmitted data as the drawback of the SLM technique will not occur.

IV. SIMULATION RESULTS

In this section the results obtain through the simulations are brought. The results are given here in terms of PAPR-CCDF and SNR-BER criteria for SLM and BSLM with U = 4 and U = 2 (U stands for the number of phase sequences in the SLM algorithm). In these cases, 5×10^4 random symbols are entered to the system and the results are obtained. Constellation is chosen to be 16-QAM with 64 subcarriers per symbol and the channel is assumed to be AWGN.

For the conventional SLM, the phase sequence is created using $\{-1, 1, -j, j\}$. For Blind SLM, it is assumed that 5 out of 64 subcarriers are reserved for determining the sequence number at the receiver. These reserved subcarriers are multiplied by a specified ρ sequences satisfying condition in Eq. (7) so that they can be determined through ML criterion at the receiver.

In the following the performance of the system for both conventional SLM and BSLM are examined.

A. CCDF-PAPR

Figure 1 shows the difference between the results of SLM and Blind SLM with U = 4 and U = 2 and Original OFDM signal in terms of CCDF-PAPR. As indicated in this figure, using limited number of reserved subcarriers for detection, will not affect the amount PAPR reduced.

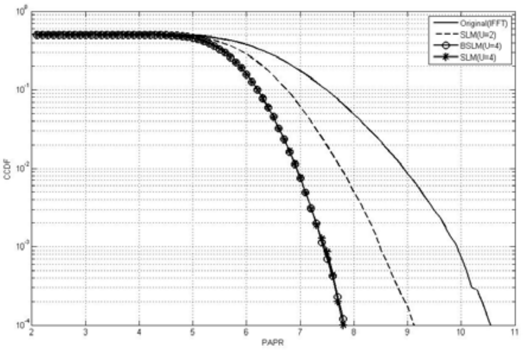

Fig. 1. PAPR-CCDF of SLM, BSLM and original OFDM signal.

B. BER-SNR

In this section, the performance of the system for each of the preprocessors in terms of BER (Bit Error Rate) for a given SNR (Signal to Noise Ratio) is discussed. In the following table BER for given SNRs is given for SLM and Blind SLM with U = 2 and U = 4 compared to the original OFDM signal with IFFT/FFT.

As indicated in the Table 1, all of the techniques utilized for reduction of PAPR are the same in system performance. Thus the parameter force the system to choose the algorithm for reducing the PAPR cannot be the system performance.

TABLE I
SYSTEM PERFORMANCE FOR EACH OF THE PREPROCESSING METHODS

	SNR			
	8	11	14	17
Original (IFFT/FFT)	0.099276	0.035613	0.004421	0.00000
SLM (U=2)	0.099136	0.035636	0.004407	0.00000
SLM (U=4)	0.099173	0.035623	0.004432	0.00000
BSLM (U=2)	0.099268	0.035607	0.004386	0.00000
BSLM (U=4)	0.099274	0.035664	0.004343	0.00000

V. CONCLUSION

A distortionless technique for reducing the PAPR of the OFDM system has presented. The method introduced here for Blind SLM is the same as conventional SLM algorithm, in terms of PAPR reduction and Bit Error Rate performance. In other words, 5 subcarriers among the total of 64 subcarriers do not affect the system performance. In return, these reserved subcarriers will help the receiver to detect the symbol transmitted through the channel. As a result the drawback of the SLM technique in sending extra information will be eliminated.

REFERENCES

[1] Y. Wu, and W.Y. Zou, “Orthogonal frequency division multiplexing: a multi-carrier modulation scheme,” *IEEE Trans. on Consumer Electronics*, vol. 41, no. 3, pp. 392-399, Aug. 1995.

[2] A. Conti, D. Dardari, and V. Tralli, “On the performance of CDMA systems with nonlinear amplifier and AWGN*”, Proc. of 6th IEEE International Symp. on Spread Spectrum Techniques and Applications*, vol. 1, New Jersey, USA, pp. 197-202., Sep. 2000.

[3] X. Li, L.J. Cimini, “Effects of clipping and filtering on the performance of OFDM,” *IEEE Com. Letters*, Vol. 2, No. 5, pp. 131-133, May 1998.

[4] X. Wang, T.T. Tjhung, and C.S. Ng, “Reduction of peak-to-average power ratio of OFDM system using a companding technique,” *IEEE Trans .on Broadcastaing*, Vol. 45, No. 3, pp. 303-307, Sep. 1999.

[5] A. E. Jones, T. A. Wilkinson, and S. Barton, “Block coding scheme for reduction of peak to mean envelope power ratio of multicarrier transmission schemes,” *IEE Electronics Letters*, vol. 30, pp. 2098–2099, Dec. 1994.

[6] N. Petersson, A. Johansson, P. Odling, and P. O. Borjesson, “Analysis of tone selection for PAR reduction,” *Proc. International Conference on Information, Communications & Signal Processing,* Oct. 2001.

[7] B. S. Krongold and D. L. Jones, “A study of active constellation extension for PAR reduction in OFDM,” *Proc. International OFDM Workshop*, Germany, pp. 107-111, Sept. 2002.

[8] L.J. Cimini, Jr., and N.R. Sollenberger, “Peak-to-average power ratio reduction of an OFDM signal using partial transmit sequences,” *IEEE Communication Letters*, Vol. 4, No. 3, pp. 86-88, Mar. 2000.

[9] R. W. Bami, R. F. H. Fischer, and J. B. Hber, “Reducing the peak-to-average power ratio of multicarrier modulation by selected mapping,” *IEE Electron. Lett.*, vol. 32, pp. 2056–2057, Oct. 1996.

[10] Bauml, R., Fischer, R., and Huber, J., “Reducing the peak-to-average power ratio of multicarrier modulation by selected mapping," *IEE Electronics Letters*, vol. 32, pp. 2056-2057, Oct. 1996.

[11] M. Breiling, S. H. M¨uller-Weinfurtner, and J. B. Huber, “SLM peakpower reduction without explicit side information,” *IEEE Commun. Lett.,* vol. 5, no. 6, June 2001, pp. 239-241.

[12] A. D. S. Jayalath and C. Tellambura, “A blind SLM receiver for PAR reduced OFDM,” in *Proc. IEEE Vehicular technology Conf.*, Sep. 2002, pp. 219–222.

[13] R. J. Baxely, G. T. Zhou, “ MAP Metric for Blind Phase Sequence Detection in Selected Mapping”, *IEEE Trans. on Broadcast.*, vol. 51, no.4, Dec. 2005, pp 565-570.

[14] N. Chen, G. T. Zhou, “Peak-to-Average Power Ratio Reduction in OFDM with Blind Selected Pilot Tone Modulation”, *IEEE Trans. on Wireless Comm.,* vol. 5, no. 8, Aug. 2006, pp.1536-1542.

[15] M. J. Fern´andez-Getino Garc´ıa, O. Edfors, and J. M. P´aez-Borrallo, “Joint channel estimation and peak-to-average power reduction in coherent OFDM: a novel approach,” in *Proc. IEEE Vehicular Technology Conference - Spring 2001*, vol. 2, pp. 815-819.

[16] D. L. Jones, “Peak power reduction in OFDM and DMT via active channel modification,” *Proc. Asilomar Conference on Signals, Systems, and Computers*, vol. 2, pp. 1076-1079, Oct. 1999.

[17] R.j Baxley, and T.Zhou, “Power Saving Analysis of Peak-to-Average Power Ratio Reduction in OFDM”. *IEEE Transactions on Consumer Electronics*, VOL.50, NO.3, , pp.792-798, August 2004