A Low Complexity BSLM Scheme for Reducing the PAPR of OFDM Systems

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Abstract— High Peak-to-Average Power Ratio (PAPR) is a well-known drawback in Orthogonal Frequency Division Multiplexing (OFDM). Selective Mapping (SLM) is an effective scheme for PAPR reduction of OFDM system. But SLM technique has a problem of the high computational complexity. The computational complexity of SLM technique is linearly increases as the number of phase sequences increase. The proposed BSLM technique is capable of partitioning the OFDM symbol sequence into several blocks to create more alternative OFDM signal sequences. This considerably reduces the computational complexity with the similar performance of PAPR reduction compared with the conventional SLM scheme. The simulation results show that proposed BSLM scheme achieves better performance of reduces the computational complexity than the conventional SLM scheme.

Key words: Orthogonal Frequency Division Multiplexing (OFDM), Peak-to-Average Power Ratio (PAPR), Selected Mapping (SLM), Block Selected Mapping (BSLM), Complementary Cumulative Distribution Function (CCDF), Side Information (SI)

I. INTRODUCTION

In wireless communication systems, Orthogonal Frequency Division Multiplexing (OFDM) has become the most widely adopted technique due to its high spectrum efficiency, easy implementation and channel robustness, but it also has some limitations such as the large deviation in envelope of OFDM signal, which causes high Peak-to-Average Power Ratio (PAPR) [2]. A large PAPR bring some disadvantages such as increase complexity and cost of the digital to analog and analog to digital converter, and power amplifier. This may damage system performance due to induced spectral regrowth and detection efficiency degradation [4].

In recent years, several techniques have been proposed to reduce PAPR. These techniques have been known as clipping and filtering, tone reservation, tone injection, partial transmit sequence (PTS), selected mapping (SLM) [5] [6]. One of these techniques called SLM has great PAPR reduction performance without destroy its own signal. But the problem with this technique is its high computational complexity [10]. The computational complexity of SLM technique is linearly increases as the number of phase sequences increase, which corresponds to the number of IFFTs required to generate the alternative OFDM signals. This paper is proposed a new modified Selected Mapping technique, called “Block Selected Mapping (BSLM) scheme,” which can reduce the computational complexity with keeping the similar PAPR reduction performance compared with the conventional SLM technique.

The paper is organized as follows: The PAPR problem of OFDM system is discussed in section II. Conventional SLM technique is introduced in section III. Proposed BSLM technique is developed and investigated in section IV. Section V shows all the simulation results of PAPR reduction performance, and the concluding remarks are drawn in section VI.

II. OFDM PAPR DESCRIPTION

The baseband model of an OFDM system is shown in fig. 1.. The number of orthogonal subcarriers used for parallel information transmission are denoted by N and X(k) (0 ≤ k ≤ N-1) denote the kth complex modulated symbol in a block of N information symbols. The outputs of N-point IFFT of X(k) are denoted by xn and can be expressed as [7]

\[ x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) \exp\left(\frac{j2\pi kn}{N}\right) \]  

(2.1)

The PAPR of discrete-time OFDM expressed as [8]

\[ \text{PAPR}(x_n) = 10 \log_{10} \frac{\max \{ |x_n|^2 \}} {\mathbb{E} \{ |x_n|^2 \}} \]  

(2.2)

The complementary cumulative distribution function (CCDF) is used when PAPR value exceeds the threshold. Thus the probability of PAPR of the discrete signal exceeds a threshold \( z_0 \) is given by

\[ \Pr (\text{PAPR} \geq z_0) = 1 - (1 - \exp(-z_0))^N \]

III. CONVENTIONAL SLM TECHNIQUE

SLM scheme is the most effective PAPR reduction scheme in OFDM system. First SLM scheme was introduced by Bauml, Fischer and Huber, in 1996 [2]. This technique is mainly based on the phase rotation sequences. In this scheme, several different candidate data blocks have been generated by multiplied with several different phase rotation sequences, each of length N [9]. All represents the same information as the original data signal, from a number of different data blocks, the lowest PAPR signal is selected for transmission. Block diagram of SLM scheme is shown by fig. 2. [2].

Original input data X \([X_0, X_1, \ldots, X_{N-1}]^T\) are multiplied with predetermined statically independent phase sequences \(P^{(u)} = [P^{(u)}_0, P^{(u)}_1, \ldots, P^{(u)}_{N-1}]^T\), where u = 0,1, U-
1, to generate \( U \) candidate sequences \( x^{(u)} = [x_0^{(u)} + x_1^{(u)}, \ldots, x_N^{(u)}] \) of length \( N \). The phase sequence \( P^{(u)} \) is generated by using the unit-magnitude complex number, that is \( P^{(u)}_n = e^{j\theta_n(u)} \), where \( \theta_n(u) \in [0, 2\pi] \). The alternative phase factor \( P^{(u)}_n = e^{j\lambda_n(u)} \) where \( \lambda_n(u) \in [0, 2\pi] \). Where \( W \) is number of alternative phase factor [10]. Then transform the signal from frequency domain to time domain by applying IFFT operation to each sequence. Finally the candidate sequence is calculated by

\[
x^{(u)} = \text{IFFT} \left\{ x \otimes P^{(u)} \right\}
\]

where \( \otimes \) indicate a component-wise multiplication. In the last step, compared the PAPR among the \( U \) candidate sequences \( x^{(u)} \) and the most favourable mapped one \( \hat{x} \) with the lowest PAPR is selected for transmission. That is given by,

\[
\hat{x} = \arg\min_{0 \leq u < U} \{ \text{PAPR}(x^{(u)}) \}
\] (3.2)

In the receiver end, in order to recover the transmitted signals, the receiver has to obtain the information with the actual phase rotation sequences \( P^{(u)} \). The straightforward method is to transmit the appropriate side information (SI) to the receiver for recovering the signal [10]. In general, the number of required SI bits is given by

\[
N_{SLM} = \log_2 U
\] (3.3)

Because this message of SI bit is of the highest importance, the actual SI should be protected by channel coding.

![Fig. 2: Block Diagram of Conventional SLM Technique](image)

### IV. PROPOSED BLOCK SELECTED MAPPING (BSLM) SCHEME

In order to improve the PAPR reduction performance and reduce computational complexity in an OFDM system, a proposed BSLM scheme is developed. In this scheme, the original OFDM signal sequence is partitioned into several blocks, whose number is denoted by \( B \). Then each block is multiplied by \( U \) phase rotation sequences for generating alternative signals as candidates, after that IFFT have been applied for generating time domain symbol sequences and then select the one sequence with the lowest PAPR for actual transmission. The block diagram of proposed BSLM scheme is shown in fig. 3.

![Fig. 3: The Block Diagram of Proposed BSLM Method](image)

In general, the original OFDM symbol sequence \( X \) of length \( N \) is expected to be partitioned into \( B \) blocks. Each block \( X_n \), where \( 1 \leq b \leq B \) is multiplied by different phase rotation sequences \( P^{(u)} \), where \( 1 \leq u \leq U \). The phase sequence \( P^{(u)} \) is generated by using the unit-magnitude complex number, that is \( P^{(u)}_n = e^{j\theta_n(u)} \), where \( \theta_n(u) \in [0, 2\pi] \). The alternative phase factor \( P^{(u)}_n = e^{j\lambda_n(u)} \) where \( \lambda_n(u) \in [0, 2\pi] \). Where \( W \) is number of alternative phase factor [10], \( W = 2 \) for BPSK and \( W = 2, 4 \) for QPSK. Furthermore, IFFT is applied to each sequence for transforming the signal from frequency domain to time domain. \( B \) groups of OFDM sequences \( x_n^{(u)}, \ldots, x_n^{(u)} \) are employed to generate more alternative OFDM sequences. Thus there are total \( B \times U \) alternative OFDM sequences generated as the candidate sequences. As a result, the candidate sequences are given by as follows:

\[
x_n^{(u)} = \text{IFFT} \left\{ x_n \otimes P^{(u)} \right\}
\]

In which \( \otimes \) denote a component-wise multiplication. The last step is comparing the PAPR among the total candidate sequences \( x_n^{(u)} \), the optimal mapped one \( \hat{x} \) with the lowest PAPR will be selected for transmission. That is,

\[
\hat{x} = \arg\min_{0 \leq n \leq B} \{ \text{PAPR}(x_n^{(u)}) \}
\] (3.4)

We have to select and transmit the resulting OFDM signal sequence \( \hat{x} \), which has the minimum PAPR among the whole OFDM signal sequences \( \hat{x}_{mn} \), where \( 1 \leq m \leq B \times U \), which are composed by \( \{ x_{b1}^{(u)}, x_{b2}^{(u)}, \ldots, x_{bU}^{(u)} \} \) after the IFFT process. The proposed block SLM scheme can obtain more differently alternative OFDM sequences by various phase rotation sequences compared with the conventional SLM scheme, so the PAPR reduction performance could be effectively improved. Noteworthy, the number of required SI bits for transmitter can be written as

\[
N_{SLM} = \log_2 B \times U
\] (3.6)

Considering \( B = 2 \) and \( U = 2 \), fig. 4 shows the block partitioning method. The partitioning method applied here is given below, block sequence \( X_{b1} \) and \( X_{b2} \) can be written as

\[
X_{b1} = [X_0, X_1, \ldots, X_N, 0, 0, \ldots, 0]^{T}
\]

\[
X_{b2} = [0, 0, \ldots, 0, X_N, X_{N+1}, \ldots, X_{N-1}]^{T}
\] (3.7)

The alternative OFDM sequence with lower PAPR can be obtained by
A Low Complexity BSLM Scheme for reducing the PAPR of OFDM Systems

\[
\hat{\mathbf{x}} = \min_{1 \leq m \leq 4} \{ \mathbf{x}_m \} 
\]

Where:
- \( \mathbf{x}_1 = x_0(1) + x_2(1) \)
- \( \mathbf{x}_2 = x_0(2) + x_2(2) \)
- \( \mathbf{x}_3 = x_0(2) + x_2(1) \)
- \( \mathbf{x}_4 = x_0(1) + x_2(2) \)

The Block Diagram of Proposed BSLM Method with \( B = 2 \) and \( U = 2 \).

Simulation Parameters

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<thead>
<tr>
<th>Specifications</th>
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<tr>
<td>Number of OFDM symbols</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of subcarriers ( (N) )</td>
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<td></td>
</tr>
<tr>
<td>Number of blocks ( (B) )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase rotation sequences ( (U) )</td>
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<tr>
<td>Modulation scheme</td>
<td>QPSK</td>
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Table 1: Parameters used in Simulation

V. Simulation results

MATLAB software has been used to verify the performance of conventional SLM and BSLM scheme. Table 1 shows the parameters used for simulation results. Comparative MATLAB simulation result of PAPR performance with conventional SLM scheme for various number of phase rotation sequences \( (U) \) are shown in Fig. 5. It shows that the PAPR reduction performance becomes better as the number of phase rotation sequences \( (U) \) increases. However, if \( U \) becomes larger, the computational complexity of IFFT would be very high [10]. Fig. 6 shows the PAPR performance with BSLM scheme for fixed blocks 2 and various number of phase rotation sequences \( (U) \) increased. Fig. 7 shows the PAPR reduction performance of BSLM scheme for various values of \( B \). It shows that as the number of blocks increases, PAPR reduction performance also increased. Fig. 8 shows that BSLM scheme with \( B = 2 \) & \( U = 2 \), \( B = 2 \) & \( U = 4 \) and \( B = 2 \) & \( U = 8 \) have almost the same performance compared with the conventional SLM with \( U = 4 \), \( U = 8 \) and \( U = 16 \), respectively. When the number of phase rotation sequence is fixed, it also shows that the PAPR reduction performance of BSLM scheme is better than that of conventional SLM scheme.

Fig. 5: PAPR Performance Of SLM Scheme With Various Number Of Phase Sequences \( (U=2,4,8, & 16) \)

Fig. 6: PAPR Performance Comparison of BSLM Scheme with \( B = 2 \) and Various Numbers of \( U \)

Fig. 7: PAPR Performance Of BSLM Scheme With \( B=2,4,8 \) & \( U=2 \)

Fig. 8: PAPR Performance Comparisons between Conventional SLM and BSLM Schemes with \( U=16 \) & \( B=2,4,8 \) & \( 16 \)
Schemes  | $\text{PAPR}_0 (10^{-1})$  | SI
---|---|---
$B_2U/2$  | 7.5 dB  | 2 bits
$B_2U/4$  | 6.8 dB  | 4 bits
$B_2U/8$  | 6.2 dB  | 8 bits

Table 2: Si Bits and PAPR Performance Comparison of BSLM Scheme with Various Number of $U$

Schemes  | $\text{PAPR}_0 (10^{-1})$  | SI
---|---|---
$B_2U/2$  | 7.5 dB  | 2 bits
$B_4U/4$  | 6.8 dB  | 4 bits
$B_8U/4$  | 6.2 dB  | 8 bits

Table 3: Si Bits and PAPR Performance Comparison of BSLM Scheme with Various Number of $B$

| $U$ | SLM | BSLM | $U=4$ | $U=2$ | $U=16$ | $U=4$
---|---|---|---|---|---|---
IFFT  | 4   | 4   | 16  | 8   | IFFT
SI    | 2   | 2   | 4   | 4   |

Table 4: Comparison of Computational Complexity between Conventional SLM and BSLM Schemes

From the simulation results, we can expect that those alternative OFDM signals generated from the original sequences of BSLM scheme should be almost different from the OFDM sequences in the conventional SLM scheme. Therefore, the BSLM scheme possesses excellent PAPR reduction performance with minor increase of SI complexity. The PAPR reduction performance and SI bits of BSLM scheme with various numbers of phase rotation sequences and blocks are given in Table 2 and Table 3, respectively. In Table 4, the system complexity with similar PAPR reduction performance is investigated with fixed $B = 2$. The complexity cost of IFFT in the BSLM scheme is less than that in the conventional SLM scheme.

VI. CONCLUSION

In conventional SLM scheme as the phase rotation sequences increases, PAPR reduction performance increases, but the computational complexity also increases. Therefore, a BSLM technique has been proposed to improve PAPR reduction performance without increasing the computational complexity of the system. After simulation results the BSLM scheme has shown that the best PAPR reduction performance can be achieved by increasing the partition blocks of the signal. PAPR reduction performance can be improved by increasing the number of alternative OFDM sequences. Simulation results show that if the number of phase rotation sequences is same, the BSLM scheme has better PAPR reduction performance compared with the conventional SLM scheme. As the simulation results, the proposed BSLM scheme have the potential to provide excellent PAPR reduction performance with lower computational complexity.

REFERENCES