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MINIMIZING HIGH PAPR IN OFDM SYSTEM USING CIRCULANT SHIFT CODEWORD

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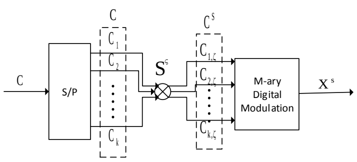
Graphical abstract



Abstract

Orthogonal Frequency Division Multiplexing (OFDM) has been widely used in various high data rate wireless communications standards. The high peak-to-average power ratio (PAPR) has however been known to be a constant problem in OFDM systems. The high PAPR in the OFDM system has led to many problems such as signal distortion, energy spilling to the adjacent channel and reducing system performance gradually. In this paper, a technique involving the manipulation of codeword using circulant shift will be introduced. The key idea of the proposed technique is to generate scramble data sequences like the conventional selective mapping (SLM) technique. The simulation results showed that the proposed technique overcame original OFDM signals and conventional SLM with a 19.5% improvement and 1.1 dB difference from conventional SLM. Besides that, the proposed technique offered a lower computationally complexity where the number of IFFT blocks can be reduced by about 57% as compared to conventional SLM.

Keywords: PAPR Reduction, OFDM system, SLM, circulant shift, codeword

Abstrak

Orthogonal Frequency Division Multiplexing (OFDM) telah banyak diaplikasikan di pelbagai standard badan komunikasi tanpa wayar sejak kebelakangan ini. Walau bagaimapun, masalah peak-to-average power ratio (PAPR) adalah seperti masalah yang tiada penghujungnya. Masalah ini boleh membawa kepada pelbagai masalah lain seperti tumpahan tenaga ke channel yang berdekatan dan secara beransur-ansur menyebabkan penurunan prestasi pada sistem. Di dalam usaha untuk menurunkan PAPR yang tinggi, kami memperkenalkan satu teknik yang memanipulasikan kedudukan bit di dalam codeword menggunakan circulant shift. Idea utamanya ialah untuk menghasilkan beberapa alternatif urutan data yang pelbagai seperti Selective Mapping konvensional. Keputusan simulasi menunjukkan teknik yang diperkenalkan mengatasi prestasi signal OFDM yang asal dan SLM konvensional sebanyak 19.5% penurunan PAPR dan 1.1dB perbezaan daripada SLM konvensional. Tambahan pula teknik ini menawarkan penurunan kerumitan pengiraan di dalam sistem di mana blok IFFT dapat dikurangkan sebanyak 57% dibandingkan dengan SLM konvensional.

Kata kunci: PAPR Reduction, OFDM system, SLM, circulant shift, codeword

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1.0 INTRODUCTION

The need for wireless communication system has contributed to the development of efficient, reliable and high-speed wireless communication in order to offer people with more sophisticated and ubiquity services. Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technique which is easier to carry out in a digital communications network. This technique yields significant growth in data rates, robustness in frequency selective fading, high spectral efficiency and low computational complexity[1]. These merits have driven OFDM to be widely applied in the most distinguished high data communication standards such as IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMAX), 3GPP Long Term Evolution (LTE) EUTRA in the downlink system and Digital Video Broadcasting (DVB) [2], [3], [4].

However, OFDM systems faced high PAPR problems caused by the nature of modulation to form a signal to be transmitted by mixing sinusoid signals [2], [5]. The high peaks of the signal caused other problems such as the probability of energy flow to the adjacent channel, signal contortion and error rate performance degradation as well as raising the amplifier cost significantly [6].

Several techniques have been discussed to overcome this problem such as clipping and filtering, coding, Selective Mapping (SLM) and Partial Transmit Sequence (PTS). Previous researches have showed the capability of reducing PAPR but several drawbacks like computational complexity, bit error rate (BER), data rate, bandwidth and others have since emerged [2], [7], [8], [9], [1]. The coding techniques discussed in [10], [11] proved that it do not lead to the signal distortion problem like the clipping and filtering technique [2]. Instead, the signal distortion could cause the bit error rate (BER) problem. This coding technique offers the benefits of PAPR reduction and also error correcting properties but requires high computational complexity[12]. Besides that, SLM and PTS schemes have been well-known as a techniques that reduce high PAPR without causing BER performance degradation. To obtain a good outcome, they have to deal with high computational complexity which required many inverse fast Fourier transforms (IFFT)[13], [14]. As reported by [15], the SLM computational complexity linearly increased as the number of phase sequences increased which corresponded to the number of IFFT blocks. There has been many modified SLM techniques that have been reported but they encountered drawbacks when dealing with computational complexity and high PAPR at the same time[1] such as BER degradation [16], [17], [18] and PAPR reduction performance degradation [19], [14].

In this paper, a technique to generate scramble data sequences using circulant shift is proposed. This technique has a lower computational complexity as compared to conventional SLM and other reported modified SLMs. This is because there was no multiplication of the phase factor involved in the process. Furthermore, it could also reduce the number of IFFT used.

2.0 PAPR in OFDM SYSTEM

OFDM signal is denoted by $X = [X(0, X(1), \ldots X(N-1))]^T$, where N is the number of subcarriers. The sums of subcarriers, N, produce NT period of OFDM signal. The complex time domain of transmitting OFDM signal is expressed as

$$s(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \cdot e^{j2\pi f_k t}, \quad 0 < t < NT \tag{1}$$

where $e^{j2\pi f_k t}$ is the orthogonal series of sinusoids performed by Inverse Fourier Transform (IFFT). Basically, PAPR of OFDM signals is determined by the ratio between the peak power and its average power,

$$PAPR = 10\log\left\{\frac{P_{peak}}{P_{avg}}\right\} \text{dB} \tag{2}$$

Mathematically, PAPR is given by

$$PAPR = 10\log\left\{\frac{\max|s(t)|^2}{E|s(t)|^2}\right\} dB \tag{3}$$

where $\max|s(t)|^2$ is maximum signal power and $E|s(t)|^2$ is the average signal power. Average signal power of OFDM system is thus calculated by

$$E = \frac{\text{Sum of the magnitude of all OFDM symbol}}{\text{No. of OFDM symbols}} \tag{4}$$

3.0 CONVENTIONAL SELECTIVE MAPPING

In the conventional SLM technique, alternative OFDM symbol sequences were implemented by multiplication of the symbol sequences, $X_k, 1 \le k \le K$ with phase sequences, $P^u = [P^0, P^1, \ldots, P^{U-1}], 0 \le u \le U-1$. Therefore, the alternative OFDM symbol sequences can be written as

$$X^u = \prod_{k=1}^{K} X_k \otimes P^u, \qquad 0 \le u \le U-1 \tag{5}$$

where $\otimes$ represents the component-wise multiplication of two vectors. The phase sequence, P^u was generated by using the complex number magnitude, $P^u = e^{j\varphi_u}$ where $\varphi_u \in [0, 2\pi]$. Thus, the new OFDM signal in the complex time domain can be written as

$$x^u(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} x^u \cdot e^{j2\pi f_k t} \tag{6}$$

The transmitted OFDM signals are obtained by

$$s^u(t) = \underset{0 \le u \le U-1}{\text{argmin}}\, PAPR(x^u(t)) \tag{7}$$

As U increases, the selection of OFDM signals became larger and improved PAPR reduction. However, for the large U, the number of IFFT blocks will be increased and the computational complexity becomes too high [15], [20].

4.0 PROPOSED CIRCULANT SHIFTS CODEWORD

Based on Eq. 1, it can be seen that OFDM signals were the form of data symbol X_k multiplied with orthogonal sinusoids IFFT, $e^{j2\pi f_k t}$. These two elements, X_k and $e^{j2\pi f_k t}$are important to determine PAPR.

Data symbol X_k is a sequence of sinusoidal waveform of duration T. It can be expressed as

$$X_k = \mathrm{C} \cdot \phi_j(t) \tag{8}$$

where C is the codeword and $\phi_j(t)$ is the M-ary digital modulation QAM.

In this paper, a technique to generate a scramble data sequences using circulant shift is proposed. This technique manipulates the codeword, C, in order to produce a new alternative OFDM symbol sequence (Figure 1).

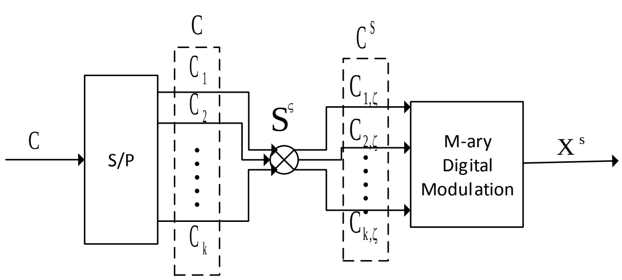


Figure 1 Circulant shift of codeword sub-blocks

Referring to the block diagram of the proposed technique in Figure 2, binary sequence codeword, C s indicated as C=[c_1,c_2,....,c_d]. The codeword was coded using Quasi-Cyclic Low Density Parity Check Codes (QC-LDPC) where d is the number of coded bits. For simplicity, the code rate was set at 0.5. Coded bits were then divided into sub-blocks. $\mathrm{C} = [C_1, C_2, \ldots. C_K]$, where $K = \frac{d}{m}$ is the number of sub-block and $m = \log_2$(M-ary QAM), is the number of bits per symbol. Codeword C in sub-block is written by

$$\mathrm{C} = \prod_{k=1}^{K} C_k\,, \qquad 1 \le k \le K \tag{9}$$

where $C_1 = (c_1, \ldots., c_m)$, $C_2 = (c_{m+1}, \ldots., c_{2m})$ and so on until C_K. To generate a number of the alternative codewords, C^S, circulant shift (one shift to the right) was applied to every sub-block of the codeword (Figure 1). S number of alternative codeword was produced by using the shift factor,$S^\zeta = [S_1^\zeta, S_2^\zeta, \ldots\ldots, S_K^\zeta]$, where $0 \le \zeta \le m-1$. The alternative codeword sequences are represented as

$$C^S = \prod_{k=1}^{K} C_k \otimes S^\zeta \tag{10}$$

Table 1 Circulant shift of codeword shift for one sub-block.

Sub-block Codeword bits, $C_{k,\zeta}$	64QAM $m = 6$ bits
Codeword, $C_{1,0}$,	$[c_1\ c_2\ c_3\ c_4\ c_5\ c_6]$
Codeword Shift 1, $C_{1,1}$	$[c_6\ c_1\ c_2\ c_3\ c_4\ c_5]$
Codeword Shift 2, $C_{1,2}$	$[c_5\ c_6\ c_1\ c_2\ c_3\ c_4]$
Codeword Shift 3, $C_{1,3}$	$[c_4\ c_5\ c_6\ c_1\ c_2\ c_3]$
Codeword Shift 4, $C_{1,4}$	$[c_3\ c_4\ c_5\ c_6\ c_1\ c_2]$
Codeword Shift 5, $C_{1,5}$	$[c_2\ c_3\ c_4\ c_5\ c_6\ c_1]$

Codeword shift sequences become $C^S = [C_1 \otimes S^\zeta, C_2 \otimes S^\zeta, \ldots., C_K \otimes S^\zeta] = [C_{1,\zeta}, C_{2,\zeta}, \ldots., C_{k,\zeta}]$, where $1 \le S \le m$. Circulant shift process for one sub-block is illustrated in Figure 1 and Table 1. Here, alternative OFDM symbol sequences are given by

$$\mathrm{X}^S = \prod_{k=1}^{K} C_{k,\zeta} \cdot \phi_j(t) \tag{11}$$

$$= [C_{1,\zeta} \cdot \phi_j(t), C_{2,\zeta} \cdot \phi_j(t), \ldots, C_{K,\zeta} \cdot \phi_j(t)] \tag{12}$$

$$= [X_{1,\zeta}, X_{2,\zeta}, \ldots., X_{K,\zeta}] \tag{13}$$

In this technique, there was no multiplication of phase factor, P^u involved. Thus, the S number of OFDM signals in the time domain can be represented directly as

$$x^S(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \mathrm{X}_k^S \cdot e^{j2\pi f_k t} \tag{14}$$

Lastly, the minimum PAPR among the S number of OFDM signal was selected. The transmitted OFDM signal is obtained by

$$s^S(t) = \underset{1 \le S \le m}{\text{argmin}}\, PAPR(x^S(t)) \tag{15}$$

It must be note that side information of the s^S index was included with the transmitted signals in order to properly retrieve the data at the receiver.

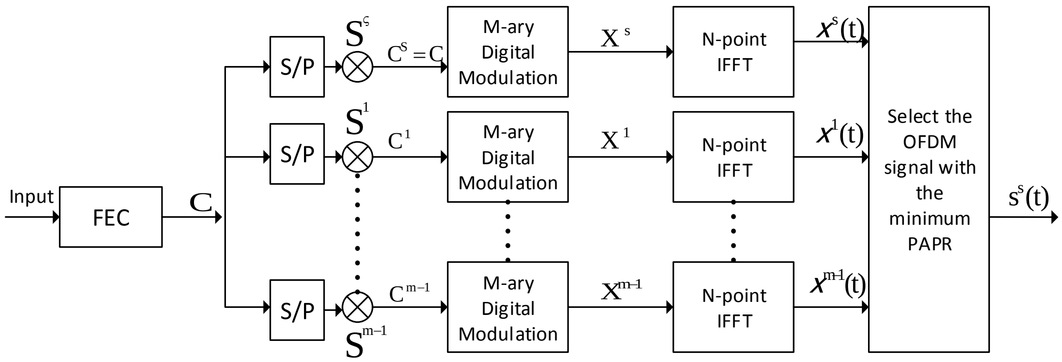


Figure 2 Block *Diagram of the proposed technique in OFDM System*

4.1 PAPR Reduction

Example 1 in Table 2 and Figure 3 explains the PAPR reduction based on the proposed technique applying 64 QAM and one sub-block of the codeword.

Table 2 Example 1 of codeword shift for 64 QAM

	Codeword, $C_{k,\zeta}$	OFDM symbol, X^S
$C_{1,0}$	1 0 0 0 1 0	1+5i
$C_{1,1}$	0 1 0 0 0 1	7+i
$C_{1,2}$	1 0 1 0 0 0	-7+5i
$C_{1,3}$	0 1 0 1 0 0	-5+i
$C_{1,4}$	0 0 1 0 1 0	-1-7i
$C_{1,5}$	0 0 0 1 0 1	5+7i

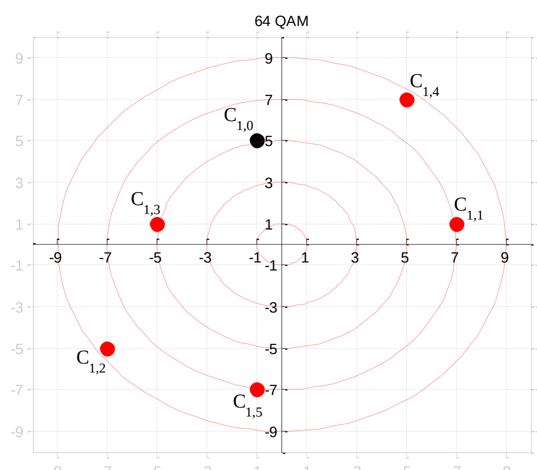


Figure 3 Example 1 of codeword shift for 64 QAM Constellation

In the example of 64 QAM, six different OFDM symbols were produced in the system. The original codeword, $C_{1,0} = [1\;0\;0\;0\;1\;0]$ is mapped onto $X^1 = (1 + 5i)$, then the codeword shifts $C_{1,1} = [0\;1\;0\;0\;0\;1]$, $C_{1,2} = [1\;0\;1\;0\;0\;0]$, $C_{1,3} = [0\;1\;0\;1\;0\;0]$, $C_{1,4} = [0\;0\;1\;0\;1\;0]$, and $C_{1,5} = [0\;0\;0\;1\;0\;1]$ are mapped onto $X^2 = (7 + i)$, $X^3 = (-7 + 5i)$, $X^4 = (-5 + i)$, $X^5 = (-1 - 7i)$, $X^6 = (5 + 7i)$ respectively. In Figure 3, the black dot is the original symbol, X^1 while the red ones are the shifted symbols X^2, X^3, X^4, X^5, X^6. The dotted circle red lines here represent the power of the symbol. It must also be noted that each symbol can hold a different power. Power symbols are calculated by

$$X^S_{pow} = \frac{|X^S|^2}{2} \tag{16}$$

In summary, referring to Figure 3, the farther the symbol is from origin, 0, the larger power value resulted.

PAPR was calculated as in Eq. 3 where IFFT applies to the OFDM symbol. Even though the symbol power has a small value here, it does not guarantee a low PAPR. The proposed technique did not interfere with the IFFT process but only concentrated on manipulating codeword, C which produced multiple alternative OFDM symbols, X^S. Unlike conventional OFDM systems which only had one output choice, the proposed technique increased the probabilities of obtaining the minimum PAPR like conventional SLM.

5.0 SIMULATION RESULTS AND DISCUSSIONS

Simulation of the proposed technique was carried out in order to verify the improvements of PAPR in the OFDM system. Firstly, random input data were generated to produce a ½ coding rate of the QC-LDPC Codes utilizing 128 IFFT. Then, to compute the PAPR complementary cumulative distribution functions (CCDF), 10^4 of OFDM signals were taken into account. Simulation used in this paper applied the 3rd Generation Partnership Project Long Term Evolution

(3GPP-LTE) standards. The parameter is shown in Table 3.

The result compared the proposed technique with the original signals and selective mapping (SLM). For SLM, phase factors, P^u, were chosen from $\{\pm 1, \pm j\}$ generated using a unit magnitude complex number. In order to make the computational complexity be equal, the number of *U* in SLM was set to be the same as the number of bits per symbol, *m*, used in the proposed technique.

Table 3 Simulation parameters for the 3rd Generation Partnership Project Long Term Evolution (3GPP-LTE) System [3]

Parameter	Value
Bandwidth (BW)	1.25 MHz
Sampling frequency	1.92 MHz
Sampling time	5.208×10^{-7} second
IFFT size	128
Used subcarrier	76
Modulation technique	64 QAM
Guard interval	1/4
Chanel model	AWGN

From Figure 4, it can be seen that the proposed technique overcame the original signals and conventional SLM. The improvement reached 19.5% which was 8.4 dB as compared to SLM which was only a 8.6% improvement at 9.5 dB.

Table 4 summarizes the numerical results of PAPR in Figure 4 at clip rate 10^{-3}.

The improvement differences between the proposed technique and SLM can be explained by the fact that the SLM phase factor value was limited to $\{\pm 1, \pm j\}$ in order to produce an alternative symbol sequence whereas the proposed technique's shifted range was as high as $\{\pm 9, \pm 9j\}$.

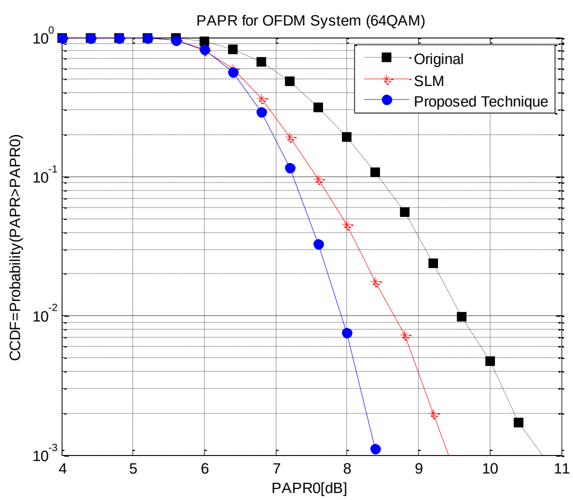


Figure 4 Comparison of the PAPR reduction in 64 QAM

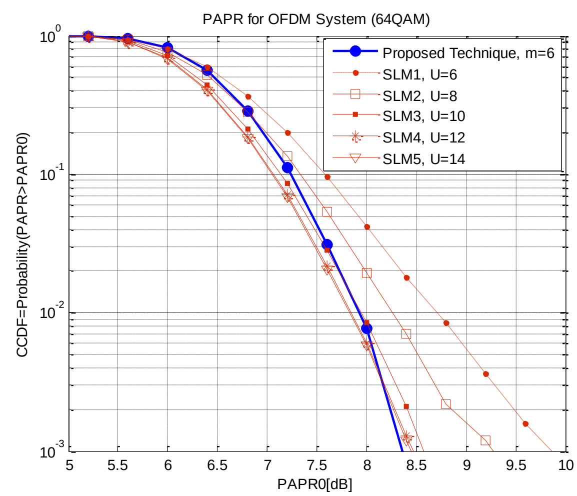
Table 4 PAPR Analysis at Clip rate of 10^{-3}

OFDM System (64QAM, 128IFFT)	PAPR in dB	Improvement (%)
Original OFDM	10.5	-
SLM	9.5	8.6
Proposed Technique	8.4	19.5

In

Figure **5**, the proposed technique with IFFT block=6 has almost the same performance with the conventional SLM with IFFT block=14. Meanwhile, there was a 1.5 dB difference when the number of IFFT block was the same for both the techniques (IFFT block=6). Table 5 summarizes the numerical results of PAPR in

Figure **5** at the clip rate 10^{-4}. The result concludes that the proposed technique reduced the used of IFFT



blocks by around 57% where this reduction of IFFT blocks will bring to the reduction of computational complexity in the system [15], [20].

Figure 5 PAPR performance comparison of the number of IFFT Blocks for SLM and proposed technique

Table 5 PAPR Analysis at Clip rate of 10^{-4}

OFDM System (64QAM, 128IFFT)	IFFT Blocks	PAPR in dB
Proposed Technique,	6	8.40
SLM 1, U=6	6	9.90
SLM 2, U=8	8	9.30
SLM 3, U=10	10	8.60
SLM 4, U=12	12	8.49
SLM 5, U=14	14	8.45

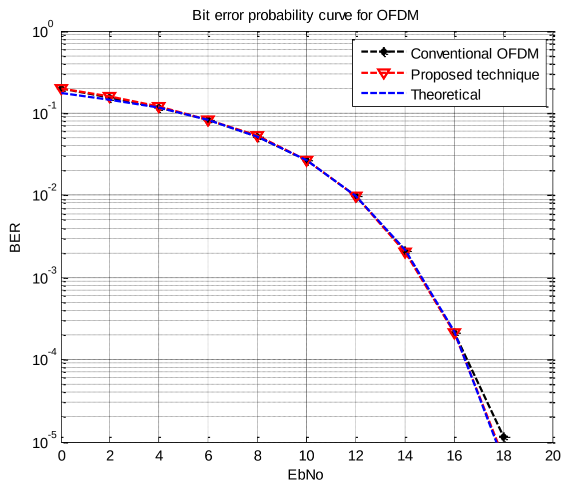


Figure 6 BER performance of the proposed technique

Figure 6 shows a BER performance of the proposed technique and conventional OFDM for additive white Gaussian noise (AWGN) channels. It is shown here that the proposed technique has a similar result as compared to conventional OFDM which illustrates the robustness of the system.

6.0 CONCLUSION

The purpose of the current study was to determine the PAPR reduction using this proposed technique. The result has shown a significant improvement in minimizing high PAPR while maintaining BER performance in OFDM systems. The PAPR improvement in 64 QAM OFDM system achieved by 19.5%. Besides that, the proposed technique offers a reduction of IFFT blocks used in the system about 57%.

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