

PAPR Reduction of OFDM Signal Using an Efficient SLM Technique

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Abstract— OFDM (Orthogonal Frequency Division Multiplexing) has been widely used in modern wireless communications because of its high data rate, immunity to delay spread and frequency selective fading, high frequency spectral efficiency and other advantages. Besides these benefits, one of the main disadvantages is the PAPR problem. High PAPR will increase the system complexity and restrict the system performance. Within the existing PAPR reduction methods, SLM (Selected Mapping) is one of the most popular. The PAPR performance of SLM-OFDM is improved by efficient phase rotation factors, which will increase the size of side information and reduce the information data rate. In this paper, we propose a method for SLM to choose the most efficient phase rotation factors, so that SLM-OFDM can get efficient PAPR performances with limited size of side information. Through simple analysis, we compare the PAPR performances of different phase rotation factors and make a conclusion of the regulation.

Keywords— OFDM, PAPR, SLM, Look Up Table, IFFT

I. INTRODUCTION

OFDM (Orthogonal Frequency Division Multiplexing) is one of the most popular techniques in broadband wireless communications [1]~[3]. OFDM has larger system capacity than traditional SC (single carrier) system, a strong ability to overcome the frequency selective fading and high frequency spectral efficiency [4]. So it meets the requirement of modern multimedia communication.

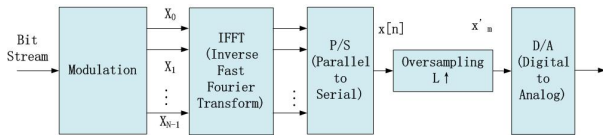


Figure 1. OFDM Transmitter

One main disadvantage of OFDM system is the high PAPR (peak-to-average power ratio) problem, which has been a restriction to the development of the OFDM technology. There are many PAPR reduction methods such as Peak Power Clipping, Block Coding, PTS (Partial

Transmitted Sequence), etc. Besides, SLM (Selected mapping) is one of the most popular PAPR reduction methods. The PAPR performances of SLM-OFDM can be well improved with different phase rotation factors. However, the number of available phase rotation factors in SLM determines the size of side information, which causes data rate loss [9]. So in a SLM-OFDM system with limited size of side information, it is necessary to pick out the most efficient phase rotation factors to achieve the best PAPR performance.

II. BACK GROUND

A. Overview on PAPR

PAPR (Peak-to-Average Power Ratio) is an important feature to evaluate the system performances. In an OFDM system with N subcarriers shown as Figure 1, the data bit stream are modulated and the modulated symbols $X = [X_0, X_1, \dots, X_{N-1}]^T$ are allocated onto N subcarriers, where X_i ($i = 0, 1, \dots, N-1$) are complex. These symbols on subcarriers are treated as frequency domain symbols. IFFT is applied to produce the time domain signal, which can be computed as:

$$x[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \times e^{j \frac{2\pi}{N} kn} \quad n = 0, 1, \dots, N-1 \quad (1)$$

Considering the features of digital signal and sampling theorem, an oversampling factor L is applied to simulate the continuous signal [5]. Research in [6] shows that $L=4$ is a sufficiently good approximation to continuous time.

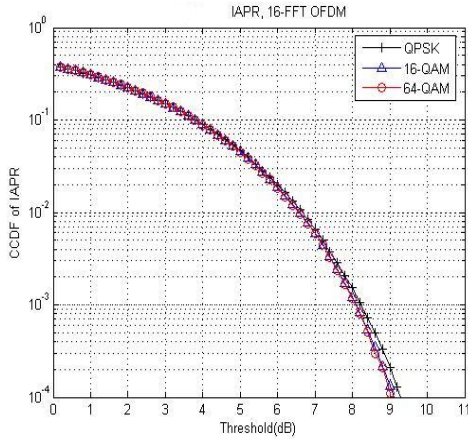
$$x'_m = \frac{1}{N} \sum_{k=0}^{N-1} X_k \times e^{j 2\pi k m / NL} \quad m = 0, 1, \dots, NL-1 \quad (2)$$

If the N symbols are of the same phase, the peak power of time domain output signal will be N times of the average power.

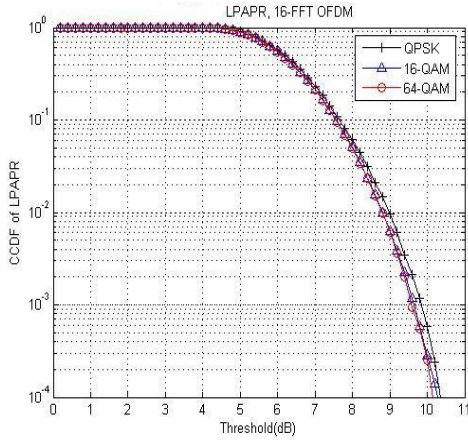
High PAPR restricts the application of OFDM system. First, high PAPR for the fixed number of bits per sample introduces the serious quantization error. To decrease the error, the

accuracy must be increased. So the complexity of DAC and ADC will increase. Second, high PAPR calls for a large region area of linear power amplifier, otherwise the probability of nonlinear distortion will increase. In order to overcome the problem, highly efficient but expensive linear amplifiers are needed. So an efficient PAPR reduction method is key to the system performance.

There're usually two functions used to represent PAPR performance: IAPR (Instantaneous-to-Average Power Ratio) and LPAPR (Local PAPR). IAPR is the ratio of instantaneous power and average power. LPAPR is the PAPR within one OFDM symbol.



(a) IAPR performance



(b) LPAPR performance

Figure 2. PAPR performance of 16-FFT OFDM with different modulation schemes

$$IAPR = \frac{P_{\text{instant}}}{P_{\text{average}}} = \frac{|x'_n|^2}{E[|x'_n|^2]} \quad (3)$$

$$LPAPR = \frac{P_{\text{peak}}}{P_{\text{average}}} = \frac{\max |x'_n|^2}{E[|x'_n|^2]} \quad (4)$$

CCDF (Complementary Cumulative Distribution Function) is an important criterion to PAPR reduction performance analysis [8]. It denotes the probability that the PAPR is larger than the given threshold z .

$$P(PAPR > z) \quad (5)$$

In this paper the CCDF of LPAPR and IAPR were both analyzed.

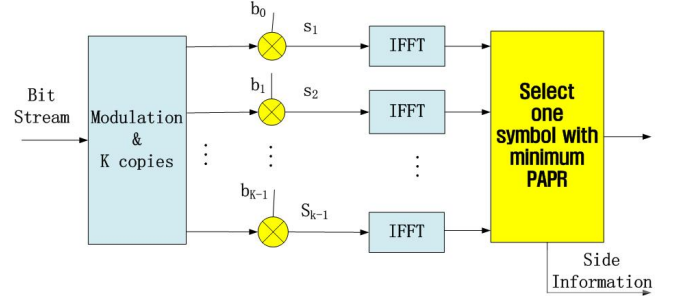


Figure 3. SLM-OFDM Transmitter

B. Selected Mapping (SLM)

The SLM technique is developed from the idea of symbol scrambling. Figure 3 shows the SLM-OFDM system. The N input modulated symbols are copied to K groups. Usually one group is not rotated and keeps the original PAPR performance, the symbols in each of the other groups are multiplied by a phase rotation factor (b_i = set of $b_{i,j}$, $i = 0, 1, \dots, K-1$ & $j = 0, 1, \dots, N-1$). The group of the minimum PAPR will be selected to transmit.

In a SLM-OFDM system with limited size of side information, the number of selected phase rotation factors is also limited. For example, besides the original symbol group not rotated, 1-bit side information means one additional phase rotation factor, while 2-bit side information means three additional phase rotation factors are used, etc. The PAPR performance improves with more rotated groups in SLM, but more bits of side information are required and the data rate is lower [9].

So it is necessary to find a way to pick out the most efficient phase rotation factors so that SLM-OFDM system with limited side information can get the most efficient PAPR performances.

III. LOOK-UP TABLE METHOD (LUT)

The Look-Up Table method is improved from the conventional ways based on table-searching, which tries every possible phase rotation factor to compare the PAPR performances. Some phase rotation factors may have the same PAPR performances. If the number of subcarriers is very large, the conventional ways take a long time for PAPR comparison and the system complexity is also high. So it is of a low efficiency and high system complex for conventional ways.

In this proposed method, we make use of the feature that the LPAPR performance of OFDM system is independent of modulation schemes. It provides a simple way to obtain the LPAPR value distribution. Then we can obtain those phase

rotations related to different LPAPR values. After trying different phase rotation factors and comparing the PAPR performances, some regulations about the phase rotation factors and their related LPAPR values can be concluded. And the most efficient PAPR performance can be obtained following these regulations.

A. Independency of PAPR distribution

First we compare the PAPR performances of one certain normal OFDM system with different modulation schemes. In this simulation, normal OFDM systems with 16-IFFT and 64-IFFT were tested, each with modulation schemes of QPSK, 16-QAM, 64-QAM.

The simulation results of LPAPR performances and IAPR performances were compared. The results show that in a certain normal OFDM system, the CCDFs of LPAPR and IAPR do not change with modulation schemes. So we may make a conclusion that the PAPR performance of a normal OFDM system is independent of the modulation schemes. With this conclusion, we may get the distribution of LPAPR performance with BPSK input symbols, which is much simpler than trying high-level complex symbols like QPSK or 16-QAM.

Then a table of possible LPAPR values can be and their input symbols can be built.

B. Loop-Up Table

Table 1. LPAPR value distribution for OFDM with 8 sub-carriers and BPSK input symbols

	Input Data	LPAPR(dB)
	[-1 -1 -1 -1 -1 -1 -1 -1]	9.03 (max)
0	[-1 +1 -1 +1 -1 +1 -1 +1]	9.03 (max)
1	[+1 -1 -1 -1 -1 -1 -1 -1]	6.53
2	[+1 +1 +1 +1 -1 -1 -1 -1]	6.36
3	[+1 +1 +1 -1 -1 -1 -1 -1]	5.99
4	[+1 +1 -1 -1 -1 -1 -1 -1]	5.16
5	[+1 -1 +1 -1 -1 +1 -1 -1]	4.65
6	[+1 +1 +1 -1 +1 -1 -1 -1]	4.45
7	[+1 +1 -1 -1 -1 +1 -1 -1]	4.23
8	[-1 -1 +1 +1 -1 -1 -1 -1]	4.10
9	[+1 +1 -1 +1 -1 -1 -1 -1]	4.07
10	[+1 +1 -1 -1 +1 -1 -1 -1]	3.98
11	[+1 -1 +1 -1 -1 -1 -1 -1]	3.73
12	[+1 -1 -1 -1 +1 -1 -1 -1]	3.71
13	[-1 +1 +1 -1 -1 -1 -1 -1]	3.01
14	[+1 -1 +1 +1 -1 -1 -1 -1]	2.78
15	[-1 +1 +1 -1 +1 -1 -1 -1]	2.18 (min)

Since the input N symbols of all 1 (or all -1) will have the largest LPAPR value, a series of phase rotation factors related to different possible LPAPR values can be obtained, which transforms the symbols of all 1 (or all -1) with the largest LPAPR into symbols with smaller LPAPR referred to the built table.

After the simulations trying different phase rotation factors, the regulations between the phase rotation factors selected for SLM-OFDM and the related LPAPR values of

their own can be concluded. The most efficient phase rotation factors are those related to the smallest LPAPR values. The SLM-OFDM can achieve the most efficient PAPR performances by choosing these phase rotation factors.

For example, in a SLM-OFDM with 1-bit side information, the most efficient phase rotation factor is the one related to the smallest LPAPR value. And in a SLM-OFDM with 2-bit side information, the three most efficient phase rotation factors are the ones related to the three smallest LPAPR values.

IV. SIMULATION

The simulations are made on the OFDM with 8 subcarriers. After inputting BPSK symbols, the LPAPR value distribution is as Table 1. There are 16 LPAPR values from the maximum 9.03 dB to the minimum 2.18 dB, and here we treat the symbol $\mathbf{m}=[-1, -1, -1, -1, -1, -1, -1, -1]$ as the benchmark.

$$s[i] = b[i] \times m[i] \quad i = 0, 1, \dots, 7 \quad (6)$$

Compared with the symbol $\mathbf{m}$ that has the maximum LPAPR value, 16 symbols related to the 16 possible LPAPR values were obtained as the candidate phase rotation factors. For example, the phase rotation factor $\mathbf{b}=[-1, -1, +1, +1, +1, +1, +1, +1]$ transforms the input symbol $\mathbf{m}$ with a LPAPR of 9.03dB into the symbol $\mathbf{s}=[+1, +1, -1, -1, -1, -1, -1, -1]$ with a LPAPR of 5.16dB because phase rotation factors related to four different LPAPR values from the maximum 9.03dB to the minimum 2.18dB, are picked out to compare the performances:

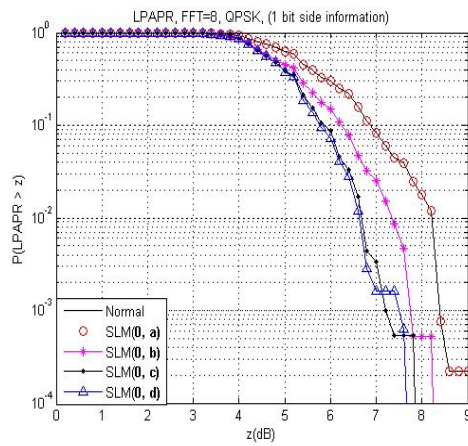
$$\begin{aligned} \mathbf{a} &= [1, -1, 1, -1, 1, -1, 1, -1] \quad (\text{max } 9.03\text{dB}) \\ \mathbf{b} &= [-1, -1, -1, -1, 1, 1, 1, 1] \quad (6.36\text{dB}) \\ \mathbf{c} &= [-1, 1, -1, 1, 1, 1, 1, 1] \quad (3.73\text{dB}) \\ \mathbf{d} &= [1, -1, -1, 1, -1, 1, 1, 1] \quad (\text{min } 2.18\text{dB}) \end{aligned}$$

Figure 4 shows the LPAPR performances for SLM-OFDM with 1-bit side information with QPSK and 16-QAM modulation schemes, and Figure 5 shows the IAPR performances.

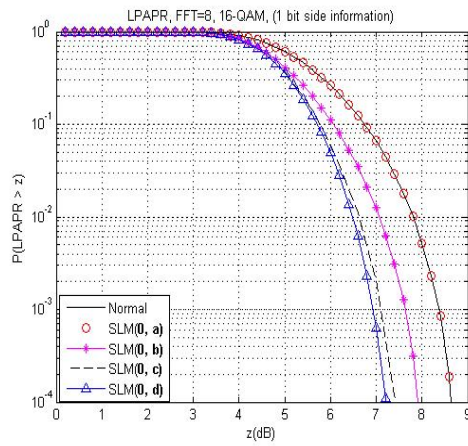
The simulation results show that the PAPR performances of LUT method are regular with the LPAPR values which the phase rotation factors are related to.

In SLM with 1-bit side information, the case with factor $\mathbf{a}$, which is related to maximum LPAPR value, has the same PAPR performance as normal OFDM. So it can be concluded that the groups with rotation factors that are related to the same LPAPR value will have the same PAPR performance. So it is necessary to choose rotation factors related to different LPAPR values.

The case with the rotation factor related to the smallest LPAPR values shows the best PAPR performances, while the case with the factor related to the largest LPAPR shows the worst performances. As shown by the simulation results, the case with rotation factor $\mathbf{d}$, which is related to the minimum LPAPR, shows the best PAPR performances. But the case with rotation factor $\mathbf{a}$, which is related to the maximum LPAPR, shows the worst PAPR performances. And the performances improve with smaller related LPAPR value.

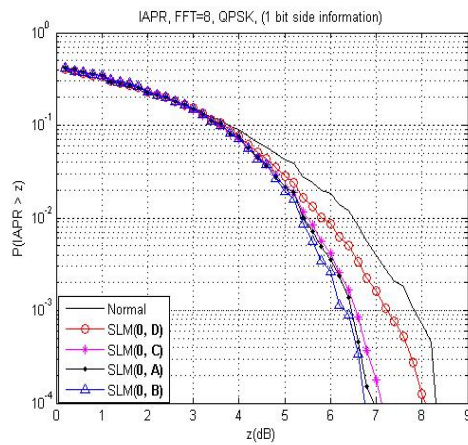


(a) QPSK

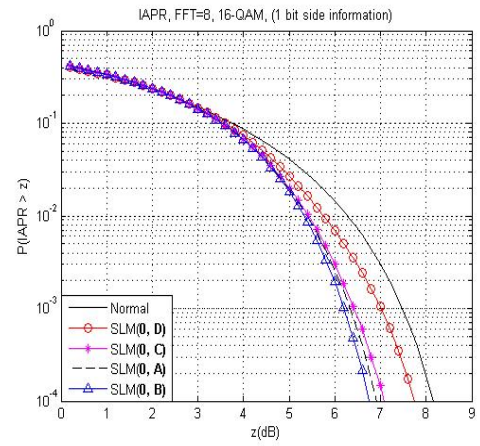


(b) 16-QAM

Figure 4. LPAPR performances for SLM-OFDM with 1-bit side information



(a) QPSK



(b) 16-QAM

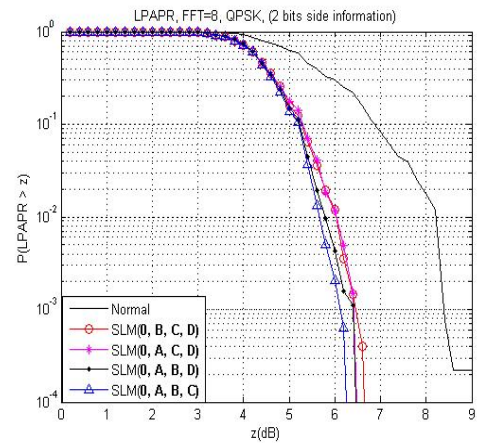
Figure 5. IAPR performances for SLM-OFDM with 1-bit side information

Figure 6 shows the LPAPR performances for SLM-OFDM with 2-bit side information with QPSK and 16-QAM modulation schemes, and Figure 7 shows the IAPR performances.

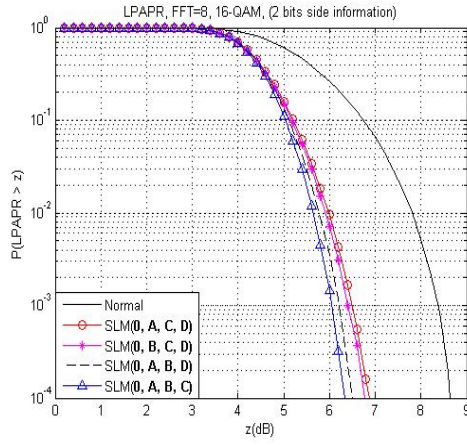
In SLM with 2-bit side information, the case without the rotation factor related to the smallest LPAPR values shows the worst PAPR performance, while the case without the rotation factor related to the largest LPAPR values shows the best PAPR performance. For example, the case without rotation factor **d**, which is related to the minimum LPAPR, shows the worst PAPR performances. But the case without rotation factor **a**, which is related to the maximum LPAPR, shows the best performances.

So from the simulation, we know that for SLM-OFDM with limited size of side information, we only have to choose those phase rotation factors related to the smallest LPAPR.

Within the tested four phase rotation factors, the most efficient phase rotation factor is **{0, d}** for SLM with 1-bit side information, and factors **{0, b, c, d}** for SLM with 2-bit side information.

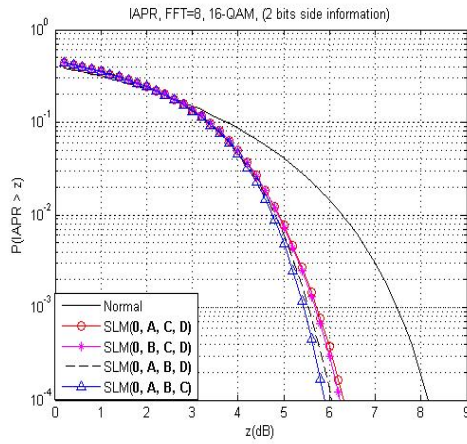


(a) QPSK

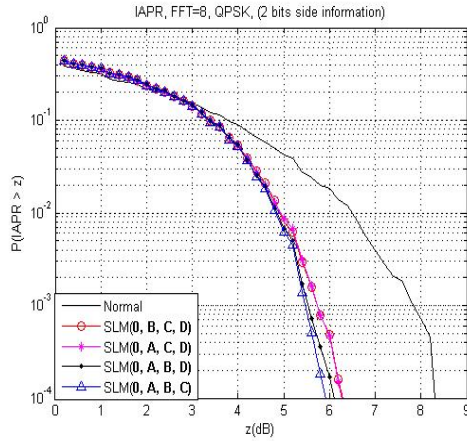


(b) 16-QAM

Figure 6. LPAPR performances for SLM-OFDM with 2-bit side information



(a) QPSK



(b) 16-QAM

Figure 7. IAPR performances for SLM-OFDM with 2-bit side information

V. CONCLUSION

In this paper, we propose a method to choose the most efficient phase rotation factors for SLM-OFDM with limited side information.

By making use of the feature that the PAPR performance is independent of modulation schemes in normal OFDM, LUT method shows the regulations of selecting efficient phase rotation factors. It provides a way to achieve the most efficient PAPR performance for SLM-OFDM.

But simulation environment is limited FFT size 8. Thus future works need simulation in common system environment. And, future works will consider overhead with FFT sizes.

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