Performance of Using RLE for PAPR Reduction in OFDM System

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Abstract—**Orthogonal Frequency Division Multiplexing (OFDM) in its position as the popular technique for future communication has several drawbacks. High peak-to-average power ratio (PAPR) is one of the concerns. We propose the use of run-length encoding (RLE) to reduce the PAPR and also to maintain the system's performance. The results show that the PAPR can be reduced significantly of about 3 dB and the performance is the same with the original system.**

***Index Terms*—OFDM, PAPR, RLE**

I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has been adopted by several 4G standards, such as IEEE 802.16 and LTE. Two of many reasons behind that are that the OFDM technique combats the frequency selective fading for the high-data rate transmission and offers the efficiency in bandwidth [1], [2].

However, OFDM also has two main drawbacks, namely sensitive to frequency offset and high peak-to-average power ratio (PAPR). High PAPR needs to reduce since it either affects the power amplifier or disobeys the regulation. Many methods have been proposed to reduce PAPR as overviewed in [3]. Some of them are clipping dan filtering (CF), tone reservation (TR), tone injection (TI), and selected mapping (SLM). Basically, the methods of reduction are divided into three categories, which are distortion method, distortionless or probabilistic method, and coding or signal scrambling method [4]. Distortion method, such as CF, is very simple in practice, but it degrades the performance of the system, i.e. degrades the BER. The coding or signal scrambling is more complex, but yields good BER.

The use of source coding, such as RLE, to reduce PAPR has been proposed in [5]. It can reduce the PAPR effectively, but the performance of the system has not been analyzed. RLE compresses the symbols, so the number of repeated symbols reduces and the PAPR is lower. This paper analyzed the performance, i.e. the error probability of the system in the AWGN and Rayleigh fading channel. This paper is organized as follows. Section II discusses about OFDM theory, PAPR, and also the RLE. Section III discusses about the proposed system, while the results of simulation and conclusion appear in section IV and V respectively.

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II. OFDM System, PAPR, and RLE

A. OFDM

The discrete OFDM symbol can be expressed as

$$s_n = \frac{1}{\sqrt{N_{sc}}} \sum_{k=0}^{N_{sc}-1} S_k \exp\left(j2\pi \frac{kn}{N_{sc}} \right) \tag{1}$$

where N_{sc} is the number of subcarriers and S_k is the modulated symbol. For instance, if QPSK modulation is used, then $S_k \in \{\pm 1 \pm j1\}$.

In implementation, the uses of Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) are very helpful since they can replace complex subchannel modems. IFFT is used at the transmitter while FFT is used at the receiver. By using *N*-point IFFT the OFDM symbol that appears in Eq.(1) can be formulated alternatively as

$$s_n = \alpha \cdot IFFT\left(S_k\right) \tag{2}$$

where $\alpha = L\sqrt{N_{sc}}$ and L is called the oversampling factor that is defined as

$$L = N/N_{sc} \tag{3}$$

In order to combat intersymbol interference (ISI), it is used cyclic prefix (CP). CP is a copy of the last part of the OFDM symbol placed in front of the symbol.

B. PAPR

PAPR is defined as the ratio between the maximum power and the average power of one OFDM symbol or

$$PAPR = \frac{\max\limits_{t\in[0,T_s)} \left|s(t)\right|^2}{E\left\{\left|s(t)\right|^2\right\}} \tag{4}$$

where $\left|s(t)\right|^2$ is the symbol's power and $E\left\{\left|s(t)\right|^2\right\}$ is average of power.

PAPR is usually analyzed by statistical parameter called complementary cumulative distribution function (CCDF). CCDF shows probability that PAPR exceeds a given threshold level. For a threshold level, z CCDF for OFDM system without oversampling can be formulated as [2]

$$P\left(PAPR \geq z\right) = 1 - \left(1 - \exp(-z)\right)^{N_{sc}} \tag{5}$$

C. RLE

RLE classifies as lossless compression method that is used as source coding. RLE codes are divided into two sections which are run length and the data themselves. A special character such as @ is usually used. The format of RLE is (Sc, X, C) where Sc is the special character, X is the run length, and C is the data [6], [7]. For the simulation we omit the special character because there is no need to use the special character. The function of the special character is just to separate between the "run" and the "data".

For example, a source emits the following data: aaaabbbbaaacccc. The RLE codes for the data is: @4a@4b@3a@4c. If a symbol is represented by one byte, the original message contains 15 bytes while the coded message just contains 12 bytes. Thus, the compression ratio is 15/12 = 1.25. The compression ratio is not too significant due to lossless compression.

III. Proposed System

The proposed system is shown in Fig. 1 below. After conducted RLE compression, the symbols sent are modulated. The RLE gives two kinds of information: the "run length", or simply the "run" and the "data" or "repeated characters". We transmit the "run" as information side. The 'run" is sent in line with the "data" so that they can be decompressed at the receiver. The side information should be sent very carefully in order not to influence by noise. IFFT makes the encoded symbols to be OFDM symbol. CP is then applied before transmitting to the channel. In this paper, we use two kinds of channels, which are AWGN and Rayleigh.

At the receiver, the reverse system is applied. First, we remove the CP and then we demodulate the symbols after taking the FFT process. The last step is to decompress signal by using the "run" data as reference.

IV. Simulation Results

The parameters used in this simulation are as follows. The number of subcarriers is 52, the IFFT points are 256. Thus, it has oversampling factor of 4.92. In addition, the modulation used is QPSK.

Fig. 2 shows CCDF of the original system (without RLE) and proposed system (with RLE). From the figure, we find out that the original system has the maximum PAPR of about 7.5 dB while the proposed system has maximum PAPR of about 5.5 dB.

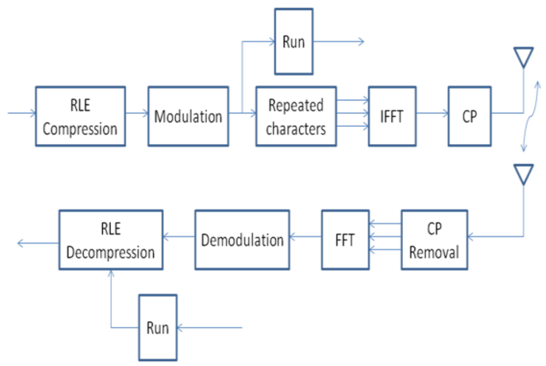

Fig. 1. Proposed system

At probability 10^{-2} the PAPR reduced at about 3 dB for compression ratio about 1.7. For a certain probability, the relationship below can be applied [8].

$$PAPR = PAPR' + \Delta PAPR \tag{6}$$

where $PAPR$ is the value of PAPR before encoded, $PAPR'$ is the value of PAPR after encoded, and $\Delta PAPR$ is the reduction of PAPR.

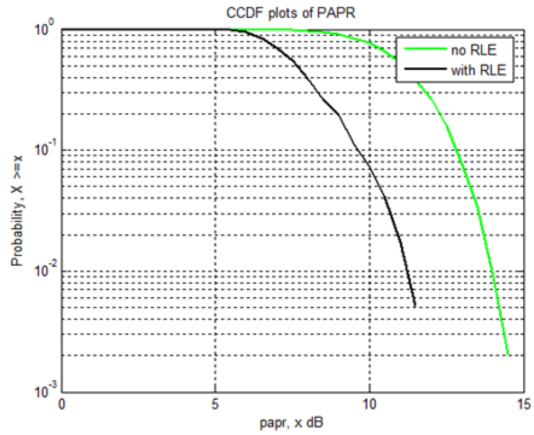

Fig. 2. CCDF with and without RLE

The performance of RLE is affected by the symbol's probability of occurrence. The probability occurrence of the symbols affects the compression ratio. Compression ratio is defined as

$$Compression\ Ratio = \frac{nS}{nS'} \tag{7}$$

where nS is the number of symbols before compression and nS' is the number of symbols after compression.

The power spectral density (psd) of the system is shown in Fig. 3. This psd is simulated before passing the HPA. Thus, it does not suffer out-of-band emission caused by the nonlinear HPA. We can observe that the proposed system yields lower out-of-band (OOB) of about 5 dB. When the signal is passed to the HPA, the nonlinear characteristics cause high OOB emission. However, in this paper we do not simulate the effect of HPA.

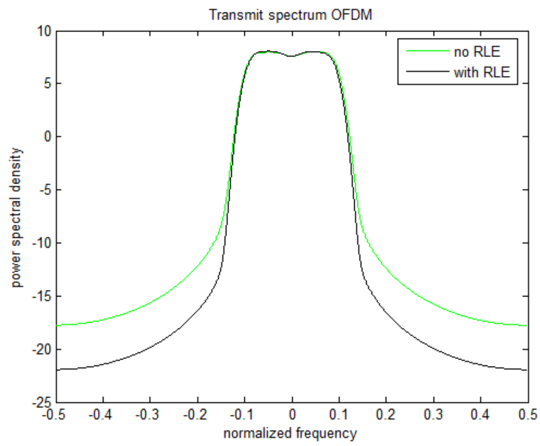

Fig. 3. Power spectral density

The symbol error probability (SEP) plots in AWGN and Rayleigh channel are shown in Fig. 4 and 5 respectively. Form the figures we find out that the use of RLE does not affect the performance of the system. From those results we conclude that the use of RLE as source coding reduces the PAPR but does not degrades the performance. In addition, the proposed system is simple enough to implement.

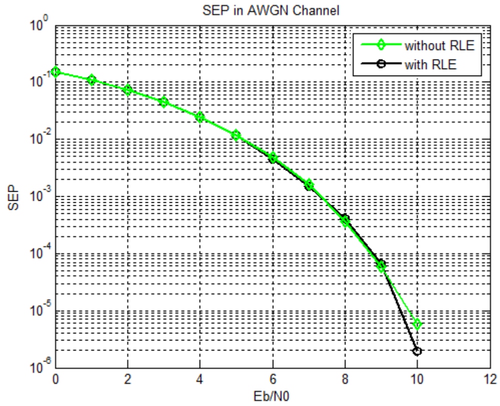

Fig. 4. SEP in AWGN channel

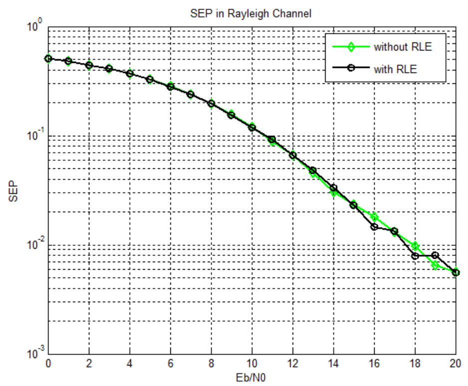

Fig. 5. SEP in rayleigh channel

V. Conclusions

The proposed system is effective to reduce PAPR and also maintain the performance. The PAPR is reduced about 3 dB at probability of 10^{-2} and compression ratio of 1.7. In addition, the psd is also lower of about 5 dB.

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