PAPR Reduction Using Huffman Coding Combined with Clipping and Filtering for OFDM Transmitter

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Abstract—Orthogonal Frequency Division Multiplexing (OFDM) technique has some drawbacks. One of them is high peak-to-average power ratio (PAPR). This paper proposes a technique to reduce the PAPR using Huffman coding combined with clipping and filtering (CF). The simulation results show that using the combination of Huffman and CF methods is more effective than using each method separately. By using 52 subcarriers and QPSK modulation, about 7 dB PAPR reduction is achieved.

I. INTRODUCTION

The communication technology, nowadays, have moved into IP-centric platform based and the need of information grows exponentially. Thus, the need of broadband communications, including voice, data, and multimedia, increases rapidly through Internet and mobile devices [1]–[3].

OFDM technique can be used to transmit the broadband data over wireless channel. OFDM is a special case of multicarrier transmission where a single datastream is transmitted over a number of lower rate subcarriers [1]. The advantage of OFDM is that it can handle multipath interference by increasing the robustness against frequency selective fading or narrowband interference that may cause intersymbol interference (ISI). In addition, OFDM is more efficient in bandwidth than conventional multicarrier transmission.

OFDM is used in digital audio broadcasting (DAB), digital video broadcasting terrestrial–TV (DVB-T), asymmetric digital subscriber lines (ADSL), wireless local area networks (WLAN), broadband wireless access (BWA) networks, ultra wideband (UWB) systems, and expected to be standard for 4G cellular systems [4].

There are two drawbacks in OFDM system namely frequency offset and large peak-to-average power ratio (PAPR). Large PAPR may cause nonlinear distortion in the high power amplifier (HPA) because HPA limits the output with certain value (the output will be saturated) and reduces the power efficiency of the amplifier. Also, it increases complexity of the analog-to-digital and digital-to-analog converters [1], [4], [5]. The objective of this paper is to reduce the PAPR.

The methods of reducing PAPR are divided into three categories [4], [5], [6]: 1) Distortion method such as clipping and filtering (CF), active constellation extension, peak windowing, peak cancellation, and peak power suppression; 2) Distortionless or probabilistic method such as multiple signal representation (MSR), selective mapping (SLM), and partial transmit sequences (PTS); 3) Coding or signal scrambling method such as Golay complementary sequences, Shapiro-Rudin sequences, M-sequences, and Barker Codes.

Distortion method such as CF is very simple in practice. It has less complexity but at the expense of degraded BER performance. Coding method has good BER performance but it has less bandwidth efficiency [5].

This paper proposes PAPR reduction method by using combination of Huffman coding and CF. This paper is organized as follows. Section II discusses about OFDM, PAPR, and HPA theory. The proposed method is explained in section III and the simulation results in section IV. Finally, conclusion is presented in section V.

II. OFDM, PAPR AND HPA OVERVIEW

A. OFDM and PAPR

OFDM signal in baseband notation for interval

\[ mT_s \leq t \leq (m+1)T_s \]

can be expressed as [7]

\[ x(t) = \sum_{k=0}^{N_c-1} x_k(t) = \sum_{k=0}^{N_c-1} a_k^{\text{mod}} \exp\left(j2\pi k\Delta f t\right) \]  (1)

where \( x_k(t) \) is \( k \)-th modulated subcarrier with frequency \( f_k = k \cdot \Delta f \) and \( a_k^{\text{mod}} \) is modulation symbol in \( k \)-th subcarrier during \( m \)-th OFDM symbol interval.

Invers Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) are very helpful in OFDM implementation because they can replace complex subchannel modemcs. IFFT is used at the transmitter and FFT is used at the receiver. If the number of subchannel is denoted by \( N_s \) and \( N \)-point IFFT is used, then the ratio of \( N / N_s \) is called oversampling factor.

Cyclic prefix (CP) is required to avoid ISI. CP copies the last part of the OFDM symbol then place it in front of the symbol. CP length is usually about 25% [8].

The PAPR is defined by [8]

\[ \text{PAPR} = \frac{\max_{t} |x(t)|^2}{\mathbb{E}[|x(t)|^2]} \]

...
\[ PAPR = \frac{\max|x(t)|}{E[|x(t)|]} \]  

where \( E\{\cdot\} \) denotes expectation.

**B. HPA**

For the real implementation, high power amplifier (HPA) is used before transmission into bandpass channel. Memoryless Solid State Power Amplifier (SSPA) is commonly used for OFDM systems. This paper uses SSPA Rapp’s amplifier model. Suppose we have input signal as

\[ y_{in}(t) = A(t)\exp[j\phi(t)] \]  

and the amplifier’s output is given by

\[ y_{out}(t) = G[A(t)]\exp\{j(\Phi(t) + \Phi[A(t)]\} \]  

where \( G(\cdot) \) is AM/AM conversion and \( \Phi(\cdot) \) is AM/PM conversion. AM/AM and AM/PM for Rapp’s model is as follows:

\[ G(A) = \frac{g_s A}{\left[1 + \left(\frac{A}{A_{sat}}\right)^2\right]^{1/2p}} \]  

\[ \Phi(A) = 0 \]  

**III. PROPOSED SYSTEM**

The proposed system combines the use of Huffman coding as source coding and CF method as shown in Fig. 2. Huffman coding will reduce the PAPR because Huffman coding assigns fewer bits for frequently occurred symbols and more bits for seldom occurred symbols [6]. Therefore, the addition for the same phase multicarrier signals will be reduced.

The new peak signal is eliminated by using clipping method as proposed in [10]. Clipping will cause in-band distortion, out-of-band (OOB) spectrum, and BER degradation. To reduce the OOB, the signal should then be filtered; however, filtering causes peak regrowth. The filtering scheme is frequency domain filtering that is proposed in [11]. After modulated with QPSK, 16-QAM, or 64-QAM, the \( N \)-point IFFT is applied with oversampling factor \( I_n = \frac{N}{N_c} \) which results in time domain vectors, \( s(t) \). \( N_c \) denotes the number of subcarriers. The nonlinear clipping is applied with clipping ratio \( CR = \frac{A_{max}}{\sigma} \), where \( \sigma = \sqrt{\frac{N_c}{N}} \) for baseband signal [10]. The clipped signal is denoted as:

\[ s(t) = \begin{cases} 
    s(t), & \text{if } |s(t)| \leq A \\
    A e^{j \omega t}, & \text{if } |s(t)| > A 
\end{cases} \]  

Amplifier is a nonlinear device, so it is necessary to work in its linear region. The range of linear region of an amplifier is defined by input backoff (IBO). IBO is given by [8]

\[ IBO = 10 \log \left( \frac{A_{sat}^2}{E\{|x|^2\}} \right) \]  

where \( E\{|x|^2\} \) is the average of the input power.
After clipping, \( N \)-point FFT is applied in order to bring it back to frequency domain and filtering is applied. The filtering block diagram is shown in Fig. 3. The inband components \( c_{N/2-i} \) are passed to the second IFFT block while out-of-band components \( c_{N/2+1-i} \) are set to be zero. The middle values of the vector correspond to higher frequency due to DFT properties [11].

IV. SIMULATION RESULTS

The parameters used for simulation are as follows. The number of subcarriers is 52, QPSK modulation, IFFT length = 128, i.e. \( I_1 \) is about 2.5 and \( I_2 = 1 \). Clipping ratio used is 1.4 or about 3 dB. The HPA is Rapp’s SSPA with smoothness factor, \( p = 2 \).

The PAPR is shown by the use of complementary cumulative density function (CCDF) in Fig. 4 below. CCDF is a statistical parameter showing the probability the PAPR exceeds certain value. The proposed method reduces the PAPR significantly about 7 dB at probability < 10\(^{-2}\). When clipping is used the PAPR reduction is only about 6 dB and when use Huffman coding the PAPR reduction is about 3 dB.

The performance of Huffman coding depends on the compression ratio of Huffman coding itself. The higher the compression ratio the higher the PAPR reduction as shown in Fig. 5. When the compression ratio = 1, Huffman coding assigns same bits to all symbols; therefore, no PAPR reduction is performed by Huffman coding. In that case, CF will handle the PAPR reduction. Thus, it is helpful to add the CF to reduce PAPR when Huffman coding does not perform since the symbols sent are equiprobable.

Fig. 4. Comparison of CCDF

Fig. 5. Effect of compression ratio

Fig. 6. The power spectrum density

The effect of IBO of the proposed system is also shown in Fig. 7. When the IBO is low (= 0 dB), the OOB is larger than that for IBO = 2 and IBO = 5. When IBO is increased then the OOB is lower. It makes sense that IBO determines the linearity of an HPA. Thus, the bigger IBO means the more linear the HPA and the lower OOB.
V. CONCLUSION

In this paper, the proposed method reduces the PAPR significantly about 7 dB. However, the PAPR reduction depends on the parameters used. In addition, it reduces the OOB spectrum about 3 dB. The advantage of Huffman coding depends on the compression ratio. If the symbols sent have equal probability (or nearly equal) the Huffman coding will take no effect at all, but it will be compensated by the CF.

REFERENCES