Hybrid Clipping-Companding Schemes for Peak-to-Average Power Reduction of OFDM Signal

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Abstract: Orthogonal frequency division multiplexing (OFDM) system is widely used wireless communication system in recent years. The major drawback of OFDM system is high Peak-to Average Power Ratio (PAPR). To reduce the PAPR of OFDM system different PAPR reduction techniques have been proposed. In this paper, we are evaluating the performance of different Hybrid Clipping-Companding techniques for PAPR Reduction.

Keywords: OFDM Signal, PAPR, PAPR Reduction, Clipping Technique, Companding Techniques.

I. INTRODUCTION

Orthogonal Frequency Division Multiplex or OFDM is a modulation format that is finding increasing levels of use in today's radio communications scene. OFDM has been adopted in the Wi-Fi arena where the 802.11a standard uses it to provide data rates up to 54 Mbps in the 5 GHz ISM band. In addition to this the recently ratified 802.11g standard has it in the 2.4 GHz ISM band. In addition to this, it is being used for WiMAX and is also the format of choice for the next generation cellular radio communications systems including 3G LTE and UMB.

Despite the great advantages OFDM offers, it has a few drawbacks, the most serious of which is the non-constant signal envelope with high peaks. These high peaks drive the power amplifier at the transmitter into nonlinear region of operation, thereby causing nonlinear distortion. To overcome this problem, power amplifiers with wider linear region are required. Otherwise, the power amplifier must be forced to work at a reduced efficiency. Since both solutions are not practical, many PAPR reduction techniques have been proposed in the literature. In this paper we are using different Hybrid Clipping-Companding techniques for PAPR Reduction and comparing their performances.

II. OFDM SYSTEM

An OFDM carrier signal is the sum of a number of orthogonal sub-carriers, with baseband data on each sub-carrier being independently modulated commonly using some type of QAM or PSK. This composite baseband signal is typically used to modulate a main RF carrier.

$S[n]$ is a serial stream of binary digits. By inverse multiplexing, these are first demultiplexed into $N$ parallel streams, and each one mapped to a (possibly complex) symbol stream using some modulation constellation (QAM, PSK, etc.). Note that the constellations may be different, so some streams may carry a higher bit-rate than others.

An inverse FFT is computed on each set of symbols, giving a set of complex time-domain samples. These samples are then quadrature-mixed to passband in the standard way. The real and imaginary components are first converted to the analogue domain using digital-to-analogue converters (DACs); the analogue signals are then used to modulate cosine and sine waves at the carrier frequency, $f_c$, respectively. These signals are then summed to give the transmission signal, $s(t)$. 
The receiver picks up the signal $r(t)$, which is then quadrature-mixed down to baseband using cosine and sine waves at the carrier frequency. This also creates signals centered on $2f_c$, so low-pass filters are used to reject these. The baseband signals are then sampled and digitized using analog-to-digital converters (ADCs), and a forward FFT is used to convert back to the frequency domain.

This returns $N$ parallel streams, each of which is converted to a binary stream using an appropriate symbol detector. These streams are then recombined into a serial stream, $\hat{s}(t)$, which is an estimate of the original binary stream at the transmitter.

### III. HYBRID PAPR REDUCTION SCHEME

Hybrid PAPR reduction techniques have been obtained by serialization of the clipping method and signal companding method. The performance of the Hybrid PAPR reduction techniques is analyzed with a MATLAB simulator as presented in Fig.3. Within this simulator, the samples from the generated signal are grouped in blocks. Each symbol is modulated using the QPSK method, forming the frequency domain OFDM frames. These OFDM frames are applied to the clipping block, where the signal is converted in time-domain, and then clipped and filtered. Next, the clipped signal is applied to a companding block which performs a nonlinear signal compression based on a given compression function. For the implementation of this block, many companding models have been used as discussed in next heading.
IV. DIFFERENT COMPANDING TECHNIQUES

A. Hyperbolic tangent (tanh) companding:
The hyperbolic tangent (tanh) companding function is defined by
\[ C(x) = k_1 \tanh(k_2 x) \]
where \( k_1 \) and \( k_2 \) are positive numbers controlling the companding level applied to the envelope \( x \).

B. Error Function (erf) Companding:
The error function (erf) is defined by
\[ C(x) = k_1 \text{erf}(k_2 x) \]
where \( k_1 \) and \( k_2 \) are positive numbers controlling the level of companding.

C. Logarithm Function (log) Companding:
The logarithm (log) companding function is defined by
\[ C(x) = k_1 \log_e(1 + k_2 x) \]
where \( k_1 \) and \( k_2 \) are two positive numbers controlling the amount of companding.

D. A-Law Companding:
The A-Law companding function is defined by
$$F(x) = \begin{cases} 
    \frac{A|x|}{1 + \ln(A)}, & 0 \leq |x| \leq \frac{1}{A} \\
    \frac{\text{sgn}(x)(1 + \ln(A|x|))}{1 + \ln|A|}, & \frac{1}{A} \leq x \leq 1
\end{cases}$$

Where $A = 87.7$

E. $\mu$-Law Companding:
The $\mu$-Law companding function is defined by

$$F(x) = \frac{\text{sgn}(x)\ln(1 + \mu|x|)}{\ln(1 + \mu)} \quad 0 \leq |x| \leq 1$$

Where $\mu = 255$.

V. RESULTS

The MATLAB simulations have been performed for original OFDM signals with $N=64$ subcarriers using QPSK modulation. We compared the performance of hybrid PAPR reduction schemes. Hybrid PAPR reduction schemes are composed by a clipping block followed by a signal companding block. We have used the hyperbolic tangent function (tanh), error function (erf), logarithm function (log), $\mu$-law and A-law for signal companding block.

Figure 4. Original OFDM Time-Domain Signal
Hybrid Clipping-Companding Schemes for Peak-to-Average Power Reduction of OFDM Signal

Figure 5. Clipped OFDM Time-Domain Signal

Figure 6. Signal Companding Functions

Figure 7. Comparison among CCDF Vs PAPR Plots of Different Hybrid Clipping-Companding Techniques
Fig. 4. and Fig. 5. represent the original OFDM signal and clipped OFDM signal respectively in time domain with clipping level equals to 0.4V. Signal companding functions for $k_1 = 0.7$, $k_2 = 1$, $\mu = 255$ and $A = 87.7$ are shown in Fig. 6. CCDF Vs PAPR plots of different hybrid clipping-companding PAPR reduction schemes are shown in Fig. 7.

Table 1. shows results obtained from various PAPR reduction techniques. From the table it is clear that PAPR of the OFDM signals after applying PAPR reduction techniques is 9.02, 8.82, 8.72, 4.75, 2.88 and 2.94 for Clipping, Clipping-Erf Companding, Clipping-Tanh Companding, Clipping-Log Companding, Clipping-Mu-Law Companding and Clipping-A-Law Companding respectively.

<table>
<thead>
<tr>
<th>S. N.</th>
<th>PAPR Reduction Technique</th>
<th>PAPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Clipping</td>
<td>9.02</td>
</tr>
<tr>
<td>2</td>
<td>Clipping-Erf Companding</td>
<td>8.82</td>
</tr>
<tr>
<td>3</td>
<td>Clipping-Tanh Companding</td>
<td>8.72</td>
</tr>
<tr>
<td>4</td>
<td>Clipping-Log Companding</td>
<td>4.75</td>
</tr>
<tr>
<td>5</td>
<td>Clipping-Mu-Law Companding</td>
<td>2.88</td>
</tr>
<tr>
<td>6</td>
<td>Clipping-A-Law Companding</td>
<td>2.94</td>
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</table>

VI. CONCLUSION

From Fig.7 and Table.1, we conclude that the performance of hybrid PAPR reduction scheme with either hyperbolic tangent (tanh) or error function (erf) as companding function is approximately same and it provides the 4dB reduction of PAPR with respect to original OFDM signal$(PAPR \approx 13dB)$. Hybrid PAPR reduction scheme with logarithmic (log) companding function is better than the last two and it reduces the PAPR by 8.25dB. Hybrid PAPR reduction scheme with either $\mu$-law or A-law companding gives the same performance and it reduces the PAPR by 10.1dB.

So the conclusion is that the Hybrid PAPR reduction scheme with either $\mu$-law or A-law companding is best.

REFERENCES