Reduction in PAPR in OFDM System using Short Time Fourier Transform with variable window size

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ABSTRACT

Orthogonal frequency division multiplexing is the most popular modulation to overcome the effect of multipath and to obtain spectral efficient communication system. The main issue of OFDM is its high Peak to Average Power Ratio (PAPR) which results from sum of several sinusoids. The Short Time Fourier Transform (STFT) is used to reduce the PAPR of the OFDM System. The Different window sizes of STFT offer different PAPR reduction in OFDM System with variations in processing time.

Keywords: Short Time Fourier Transform, Orthogonal Frequency Division Multiplexing, Peak to Average Power Ratio, Modulation Techniques.

1. INTRODUCTION

Orthogonal frequency division multiplexing is one of the efficient communication techniques for next generation high speed wireless networks. It offers robustness against frequency selective fading channels, high bandwidth efficiency. Therefore it has been adopted as many standards of DAB/DVB (Digital Audio/Video Broadcasting) IEEE 802.11x, 3G LTE, and WiMAX systems. Inspite of many advantages, one of the major limitations of OFDM is its high Peak to Average Power Ratio (PAPR) because it consists of many subcarriers. High PAPR degrades the efficiency of linear power amplifier. The PAPR reduction is interesting area of research [1].

There are many methods on PAPR reduction such as Clipping [2], Coding [3], Selective Mapping (SLM) [5], Interleaving [6], Nonlinear Comanding Transform [7], Hadamard Transform [9], Partial Transmit Sequence(PTS) [4] Tone reservation and Tone Injection etc. All the existing systems use FFT as signal transformation and different modulation techniques. In this paper we propose system design by using STFT (Short Time Fourier Transform) in which time-frequency analysis of nonstationary signals is produced. There are two major approaches for STFT. One is based on the filter bank approach and another is the FFT-based approach [10]-[11]. In this paper we used second approach. In STFT, the signal is segmented by applying a window to it. The window size determines the temporal resolution of time-frequency analysis. A short window is required to analyze high chirped signals. The short time fourier transform is useful for different speech processing and speech communication applications, including time scaling, pitch shifting, noise reduction and echo cancellation [12]. The reduction of PAPR using STFT with increase in processing time is implemented in this paper.

2. SYSTEM DESCRIPTION

An OFDM System consists of \( N \) subcarriers. The OFDM symbol \( x(t), 0 \leq t \leq T \), consist of \( N \) complex baseband data \( X_0, X_1, \ldots, X_{N-1} \) carried on \( N \) subcarriers, chosen to be orthogonal with constant spacing \( \Delta f \). The OFDM symbol \( x(t) \) is

\[
x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi k t / T}, \quad 0 \leq t \leq T
\]  

(1)

The Bandwidth of OFDM symbols is \( B = \Delta f . N \) and symbol time \( T = 1/\Delta f \). \( X_k \) is the complex baseband data modulating the \( k \)-th subcarrier for \( x(t) \). The PAPR of OFDM symbol may be defined as [8]

\[
\xi = \max_{P_{av}} \mathbb{E}[|x(t)|^2],
\]  

(2)

where \( P_{av} \) is the average power of the transmitted symbol and maximum sought over the symbol duration defined as \( P_{av} \leq \mathbb{E}[|x(t)|^2] \). Where \( \mathbb{E}[\cdot] \) is the expectation operator. The value of \( \xi \) can be as large as \( N \) for Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude Modulation (QAM). However large PAPR occurs very less.
The PAPR can be best marked by its statistical parameter, Complementary Cumulative Distribution Function (CCDF). For proper values of PAPR oversampling is necessary. L is the oversampling factor. L=1 determines discrete-time signal sampled at Nyquist rate, whereas L=4 gives sufficient samples to capture continuous-domain signal peaks [2]. The oversampled signal can be obtained by (L-1)N zero-padding in the middle of the original input vector and converting frequency domain signal into time domain. The OFDM signal sampled at time instant $t = n\Delta t$ is then expressed as

$$x(n) = x(n\Delta t), \quad n = 0, ..., LN - 1$$  \hspace{1cm} (3)

3. SHORT TIME FOURIER TRANSFORM AS SLIDING WINDOW TRANSFORM

An input signal $x[n]$ of arbitrary duration, data signals are extracted at regular intervals using a time limited window $w[n]$. The signal segments or frames can be expressed as

$$x_i[n] = \omega[n]x[n + iL], \quad 0 \leq n \leq N - 1$$ \hspace{1cm} (4)

Where $N$ is the window length, $i$ is the frame index, and $L$ is the hop size giving spacing in sample consecutive applications of the sliding extraction window; $n$ is the time index. A discrete fourier transform is carried out for single frame [12] is

$$X[k, i] = \sum_{n=0}^{N-1} x_i[n]e^{-j2\pi kn/N}$$ \hspace{1cm} (5)

$$X[k, i] = \sum_{n=0}^{N-1} \omega[n]x[n + iL]e^{-j2\pi kn/N}$$ \hspace{1cm} (6)

Where $K$ is the DFT size and $k$ is a frequency index. The STFT $X[k, i]$ then characterizes the local time-frequency behavior of signal around time $iL$ and bin $k$. For a sampling rate $F_s$, these discrete indices correspond to continuous time $iL/F_s$ and frequency $kF_s/K$. A radial frequency $\omega = \frac{2\pi kn}{K}$ and hop size of $L = 1$. The STFT can written as

$$X[k, i] = \sum_{N=0}^{N-1} \omega[n]x[n + iL]e^{-j2\pi kn}$$ \hspace{1cm} (7)

In Sliding window, STFT gives the time slice of the input signal, interpreting $X[k, i]$ as a function of the frequency $k$ for each value of the time index $i$. The STFT represents a series of time localized spectra. It is opposite to that of analysis where firstly an Inverse Discrete Fourier Transform (IDFT) of each local spectrum is carried out and resulting signal frames are aggregated to synthesize the signal. The Inverse Short Time Fourier Transform are carried out with different window sizes replacing IFFT in OFDM system.

Fig 1 (a) Original OFDM transmitter with IFFT (b) OFDM transmitter with Inverse STFT
Fig 2. Comparison between different signal spaces

Fig 3. Comparison of Original OFDM PAPR and Varying STFT window with 4-QAM

Fig 4. Comparison of Original OFDM PAPR and Varying STFT window with QPSK
### Table 1. Comparison of Original OFDM PAPR and Processing time using different modulations

<table>
<thead>
<tr>
<th>OFDM Technique</th>
<th>Modulation</th>
<th>Time (sec.)</th>
<th>PAPR (dB)</th>
<th>Modulation</th>
<th>Time (sec.)</th>
<th>PAPR (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original with IFFT</td>
<td>QAM</td>
<td>2.266</td>
<td>11.270</td>
<td>QPSK</td>
<td>2.844</td>
<td>11.519</td>
</tr>
<tr>
<td>STFT (smaller window)</td>
<td></td>
<td>8.781</td>
<td>6.869</td>
<td></td>
<td>9.000</td>
<td>6.798</td>
</tr>
<tr>
<td>STFT (larger window)</td>
<td></td>
<td>5.187</td>
<td>8.113</td>
<td></td>
<td>5.438</td>
<td>8.274</td>
</tr>
</tbody>
</table>

### 4. Simulation Results

We use the computer simulations to evaluate the performance of the proposed PAPR reduction techniques over 64 subcarriers with 4-QAM and QPSK modulated data. As a performance measure for different techniques, we use the CCDF of the PAPR. Performances of the proposed system are first compared with Inverse STFT using larger and smaller window for a multicarrier system. Fig (3) shows the comparison of PAPR of IFFT with Inverse STFT with larger and smaller window with 4-QAM. Fig (4) shows the comparison of PAPR of IFFT with Inverse STFT with larger and smaller window with QPSK. Table 1 Shows the Processing time and PAPR of Inverse STFT with original OFDM using 64 subcarriers in QPSK and 4-QAM.

### 5. Conclusion

The STFT gives lesser PAPR as Compared to Original OFDM. STFT with smaller window provides a difference of PAPR 4.40 dB with difference of processing time of 6.51 seconds with QAM modulation. STFT with smaller window provides a difference of PAPR 4.72 dB with difference of processing time of 6.16 seconds with QPSK modulation. STFT with larger window provides a difference of PAPR 3.16dB with difference of processing time of 2.92 seconds with QAM modulation. STFT with larger window provides a difference of PAPR 3.24dB with difference of processing time of 2.59 seconds with QPSK modulation. PAPR of smaller window is 1.25dB less but processing time is 3.6 seconds more than larger window in QAM modulation. Similarly, PAPR of smaller window is 1.48dB less but processing time is 3.57 seconds more than larger window in QPSK modulation. By comparing the PAPR and Processing time of smaller and Larger window in STFT we conclude that, As we increase the size of window, it takes less time to process the signal and more PAPR is observed because more number of subcarriers are involved. The STFT shows the time-frequency synthesis and analysis. The STFT has some drawback such as bandwidth is arbitrarily small and increasing the resolution in time decreases the resolution in frequency and vice versa. Wavelet transform can overcome the fixed resolution of time-frequency of STFT by providing time scale resolution.

### References


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