Abstract: Orthogonal frequency-division multiplexing (OFDM) has received much attention for wireless broadband access in which single wideband channel is converted to many parallel narrowband channels, or orthogonal subcarrier. But the sum of $N$ orthogonal sinusoids results in a signal having large amplitude fluctuations called as high Peak to Average Power ratio. This undesirable feature of a large peak to average power ratio (PAPR) of the transmitted signals has a non-constant envelope and exhibits peaks whose power strongly exceeds the mean power. Such a signal is sensitive to nonlinearities found in the communications system. Iterative clipping and filtering (ICF) in combination with powerful Forward error correction (FEC) can provide significant performance improvement in OFDM. In this study, investigate through computer simulations, an effective coding schemes of convolution coding with iterative clipping and filtering method on the performance of OFDM including the bit error rate.

Keywords: OFDM, PAPR, ICF, Forward error correction (FEC)
1. Introduction:

The demand for fast and reliably transmitting multimedia information over wired or wireless channels is increasing rapidly. Orthogonal Frequency Division Multiplexing (OFDM) is a promising Multicarrier Modulation (MCM) technique for high-speed communications. It has been widely used in a number of communication systems such as IEEE 802.11a/g, IEEE 802.16e, HIPERLAN/2, and Digital Video Broadcasting (DVB). Its baseband version (Discrete Multitone (DMT)) has become the standard modulation technique for the Asymmetrical Digital Subscriber Line (ADSL) and the Very-high-speed Digital Subscriber Line (VDSL). In OFDM, the carrier spacing is carefully selected so that each subcarrier is orthogonal to the other subcarriers. Two signals are orthogonal if their dot product is zero i.e. if you take two signals multiply them together and if their integral over an interval is zero, then two signals are orthogonal in that interval. Orthogonality can be achieved by carefully selecting carrier spacing so that the spectrum of each carrier has a null at the center frequency of each of the other carriers in the system. This results in no interference between the carriers. OFDM transmits a large number of narrowband subchannels where the carriers are separated by an interval of $1/T$, where $T$ represents the duration of an OFDM symbol.

OFDM can be efficiently implemented by using the Inverse Fast Fourier Transform (IFFT) and the Fast Fourier Transform (FFT). OFDM eliminates the Inter-Symbol Interference (ISI) by using the cyclic prefix.

Consider an OFDM signal represented by

$$x(t) = \sum_{n=0}^{N-1} X_n e^{j2\pi f_n t}, \quad 0 \leq t \leq Nt$$  \hspace{1cm} (1)

where $X_n, n=0,1,2,...,N-1$

is a block of $N$ OFDM symbols with each symbol modulating one of a set of sub-carriers, $f_n, n=0,1,2,...,N-1, T$ is the original symbol period.

![Block Diagram of OFDM transmitter](image-url)
In the system used, serial to parallel converter converts serial input data having different frequency component which are base band modulated symbols and apply interpolation to these symbols by zero padding in the middle of input data. Then clipping operation is performed to cut high peak amplitudes and frequency domain filtering is used to reduce the out of band signal, but caused peak re-growth.

In OFDM systems, because the transmitted signal is the sum of a set of modulated signals, the peak power of the transmitted signal can be very high compared to its average power. Although occurring only with low probability, such large peaks have negative ramifications for the overall system. The PAPR of the transmitted signal can be defined as the ratio of the instantaneous power over the average power of the transmitted signal:

\[
\text{PAPR} = \frac{\max |x_c(t)|^2}{E[|x_c(t)|^2]}, 0 \leq t \leq T \tag{2}
\]

where \( E \{ \cdot \} \) represents the mean value of \( \{ \cdot \} \)

An OFDM signal is said to have a peak at\( \zeta \) with probability \( P_c \) if

\[
\Pr[\text{PAPR}(X) \leq \zeta] = P_c \tag{3}
\]

The PAPR Complementary Cumulative Distribution Function (CCDF), also called the clip probability, is defined as \( P(\zeta) = \Pr[\text{PAPR}(X) > \zeta] = 1 - P_c \); i.e., the probability that PAPR exceeds \( \zeta \) is \( 1 - P_c \).

2. Convolution Coding:

A system utilizing convolutional codes produces \( n \) coded bits from data bits, and the code word does not contain unaltered \( k \) data bits. Also due to the effects of noise and multipath fading in the channel, the transmitted signal arrives at the receiver with some errors. The errors in the demodulated data are characterized in terms of a BER, which is directly proportional to the symbol rate and inversely proportional to transmitter power and bitenergyto noise power spectral density ratio (Eb/No). The BER is an important performance parameter of digital communication systems. In forward error correction coding, a certain number of redundant bits are added to data bits in a particular pattern according to the type of the code. In other words, for every \( k \) data bits, \( n \) coded bits are transmitted, where \( n > k \). In the
receiver, the kdata bits can be recovered by performing a decoding operation on the n received coded bits.

3. Clipping And Filtering:

The clipping is the simplest model as it introduces no distortion in the phase of the input signal but cancels the signal components that exceed some unchanging amplitude called clip level. However, clipping yields distortion power, which is called clipping noise, and expands the transmitted signal spectrum, which causes interfering. Clipping is nonlinear process causing in-band noise distortion and degrade the performance of symbol error rate (SER) and out-of-band noise, which decreases the spectral efficiency.

\[ g(x(t)) = \begin{cases} A e^{j\theta t}, & |x(t)| > A \\ x(t), & otherwise \end{cases} \tag{4} \]

The output of the clipper can be written as

The filtering operation removes the out-of-band components. The basic idea of filtering is to multiply the envelop of clipped OFDM signal with a window function. Therefore

\[ x(t) = g(x(t)) \cdot f(t) \]

\[ f(t) = 1 - \sum \alpha \cdot w(t - t') \]

\[ w(t) = \text{window function} \]

\[ t' = \text{position of local maximum of envelope g(x(t))} \]

\[ \alpha = \text{attenuation constant} \]

Hanning windowing is an approach to reduce the PAPR of OFDM signals. The coded OFDM signal is multiplied by the window function when the signal exceeds the clipping level or
falls below the bottom level. While the clipping operation directly chops off the peaks, windowing results in a smooth signal. The peak window is given by,

\[ W_c(n) = \begin{cases} 1 - k_c \left(0.5 - 0.5 \cos \left(\frac{2\pi n}{M}\right)\right) & , 0 \leq n \leq M \\ 0 & , \text{otherwise} \end{cases} \]  \hspace{1cm} (5)

Where \(k_c\) is the attenuation factor of the window and \(M\) is the width of window.

Although filtering can decrease the spectrum growth, filtering after clipping can reduce the out-of-band radiation, but may also cause some peak re-growth where the peak signal exceeds the threshold clip level. The technique of iterative clipping and filtering reduces the PAPR without spectrum expansion. However, the iterative signal takes long time and it will increase the computational complexity of an OFDM transmitter. When the windows are multiplied with the COFDM signal, the resulting spectrum is the spectrum of the windowed signal.

4. Simulation Results:

Hanning windowing and peak clipping techniques were investigated for reducing the PAPR in OFDM systems. Figure 1 shows the Clipping and Filtering mechanism of OFDM transmitter which has been used in this research. In this setup, the input binary data stream is ensured against errors with Forward Error Correction codes (FECs) techniques that can detect with high probability the error location. The system model combines the use of convolution as source coding and CF (Clipping and Filtering) method as shown in Fig. 2.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulations</td>
<td>8-QAM</td>
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<tr>
<td>FFT Size</td>
<td>52</td>
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<tr>
<td>Error correcting code</td>
<td>Convolutional(1/2)</td>
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<tr>
<td>Number of iterations</td>
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<tr>
<td>Channel</td>
<td>AWGN</td>
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<tr>
<td>Filter</td>
<td>Hanning window</td>
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*Table 1: Simulation parameters*
Table 2: Simulation Results

<table>
<thead>
<tr>
<th>STATUS</th>
<th>PAPR</th>
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</thead>
<tbody>
<tr>
<td>Without Iteration</td>
<td>6.9473</td>
</tr>
<tr>
<td>With five iterations</td>
<td>6.3519</td>
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<tr>
<td>With clipping and Hanning Window</td>
<td>5.9379</td>
</tr>
</tbody>
</table>

Figure 3

Figure 4

PAPR reduction with FEC and ICF:

Component encoder: Convolution codes

Constraint length=3
Figure 5

Figure 6
5. Conclusion:

In this paper, PAPR reduction technique based on modified ICF with FEC in OFDM systems is considered. This approach, which combines the ICF technique with convolution code, divides the subcarriers of OFDM into several disjoint sub blocks resulting in significant performance gain in terms of PAPR reduction. Convolution coding provides good PAPR performance.
References:


