Analysis of Peak to Average Power Ratio Reduction in Optical Orthogonal Frequency Division Multiplexing

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ABSTRACT
Orthogonal Frequency Division Multiplexing (OFDM) has become the popular modulation technique in high speed wireless communications. It is very advantageous to modern digital wireless communication and finds application in fiber optics transmission technology called optical OFDM, being the core of this work. But despite its advantages it has some obstacles also. The high peak-to-average ratio is the main obstacle which causes non-linearity at the receiving end. The PAPR in any optical OFDM system can be reduced or treated using several PAPR reduction techniques. This work will analyze the effect of clipping and filtering as a PAPR reduction technique on optical OFDM systems.

Key words: Orthogonal, wireless, fiber, obstacles, clipping, filtering

1. INTRODUCTION
Wireless Local Area Networks (WLAN) and the exponential growth of the Internet have resulted in an increased demand for new methods of obtaining high capacity wireless networks to provide users with a high data rate, and to provide a wider range of services, such as voice communications, videophones, and high speed Internet access [1]. The higher data rate of future mobile networks will be achieved by increasing the amount of spectrum allocated to different services and by improvements in the spectral efficiency [2]. OFDM is a potential candidate sufficient to meet the need of high capacity fourth generation mobile systems [3]. Thus, OFDM will become a main multicarrier scheme for communication systems [4]. OFDM techniques are also known as Discrete Multi-Tone (DMT) transmissions (a method used to split the available bandwidth into a large number of sub-channels and maximize the throughput of individual sub-channels) and are employed in the American National Standards Institute’s (ANSI), ADSL (Asymmetric Digital Subscriber Line), HDSL (High-bit-rate Digital Subscriber Line) and VDSL (Very-high-bit-rate Digital Subscriber Line). However, any multicarrier signal with a large number of sub-channels is hampered by peak to average power ratio (PAPR) [5].

This PAPR is a main drawback of orthogonal frequency division multiplexing (OFDM) systems. This is because Large PAPR requires a linear high power amplifier (HPA) [6]. If the linear range of the power amplifier is not sufficient, large PAPR leads to in-band distortion and out-of-band radiation [3]. PAPR results in degraded system performance by reducing the efficiency of the high power amplifier and also limits the dynamic range of Analog-to-Digital (A/D) and Digital-to-Analog (D/A) converters [7]. These negative effects counteract almost all the potential benefits of OFDM transmission system. Even in individual sub channels, the amplitude of the transmitted OFDM signal still suffers from high peak-to-average power ratio (PAPR) [8]. This fact complicates implementation of the analog radio frequency (RF) frontend. When the PAPR is high, the digital-to-analog converter (DAC) [9]. And power amplifier (PA) of the transmitter requires high dynamic ranges to avoid amplitude clipping [10]. Such high dynamic range increases complexity, reduces efficiency, and increases cost of the components [11]. On the other hand, if the dynamic range is too low, there would be substantial amount of signal distortion which in turn will raise the amount of bit error rate (BER). Furthermore, the distortion would cause unwanted out-of-band radiation [12].
A handful of techniques to reduce the PAPR exist. Among these techniques, clipping and filtering (CF) are the simplest ways for PAPR reduction [4]. Compared to the in-band distortion, the out-of-band radiation is more critical since it severely interferes with communications in adjacent frequency bands [7]. CF techniques eliminate the out-of-band radiation by clipping the time-domain signal to a predefined level and subsequently filtering it. To suppress peak regrowth due to filtering, iterative clipping and filtering (ICF) techniques can be used [14]. An analytical advantage of OFDM system is that it can be implemented in fast Fourier transform (an algorithm that samples a signal over a period of time and divides it into its frequency components) which makes it faster and efficient [15]. The aim of this research is to successfully investigate the effect of clipping and filtering techniques on the performance of optical orthogonal frequency division multiplexing (Optical OFDM).

2. DESIGN AND METHODOLOGY

This chapter will present information on the simulation methodology for an optical OFDM setup. A stepwise algorithmic approach as to how the Optisystem environment and its component model library facilities have been used to model the effect of clipping and filtering in OFDM systems will be gradually presented in progressive subsections. The chapter will highlight parameters concerned with Optisystem simulation of an optical orthogonal frequency division system.

Optical OFDM System Description

Optical Orthogonal frequency division multiplexing systems employ orthogonal sub-carriers and thus will use available bandwidth very efficiently. However, as the number of carriers increase, the peak to average power ratio increases as well. This increase in PAPR will cause significant distortion when it is passed through a non-linear amplifier. The methodology to solve the problem of High PAPR is to employ PAPR reduction technique known as the clipping and filtering technique.

The complex exponential signal given by:

\[
e^{j2\pi f_k t} \quad k = 0, 1, \ldots, N-1.
\]

Represents the subcarriers in the OFDM signal \( f_k = \frac{k}{T_{sym}} \).

To verify the orthogonality of any two sub-carriers in the OFDM signal, the following conditions are applied.

\[
\frac{1}{T_{sym}} \int_{0}^{T_{sym}} e^{j2\pi f_k t} e^{-j2\pi f_i t} dt = \left\{ \begin{array}{ll} 1 & \text{when } k = i \\ 0 & \text{otherwise} \end{array} \right.
\]

If the dot product of the tested signals is not equal zero, the two signals did not fulfill the set of conditions shown above. Thus, the two signals are orthogonal to each other. However, there is still a challenge with using clipping technique to solve the problem of high PAPR. The clipping technique results in both in-band and out of band distortion. To reduce the problem of High PAPR using filtering will result in a problem of distortions within and outside the band. Therefore, a second technique which is usually employed in non-linear communication systems side by side with the clipping technique is used to solve the challenges of in-band and out-of-band distortions caused as a result of the employing of the clipping technique. The methodology presented in subsequent subsections of this chapter will discuss and analyze the effect of filtering and clipping technique on the overall performance of OFDM system. The methodology employed will also consider the Bit error Ratio as an analytical tool to ascertain the performance of the OFDM system.
The Optisystem Simulator Environment

OptiSystem is an optical communication system simulation package for the design, testing, and optimization of virtually any type of optical link in the physical layer of a broad spectrum of optical networks, from analog video broadcasting systems to intercontinental backbones. A system level simulator based on the realistic modeling of fiber-optic communication systems, OptiSystem possesses a powerful simulation environment and a truly hierarchical definition of components and systems. Its capabilities can be easily expanded with the addition of user components and seamless interfaces to a range of widely used tools. OptiSystem is compatible with Optiwave's OptiAmplifier and OptiBPM design tools.

OptiSystem serves a wide range of applications, from CATV/WDM network design and SONET/SDH ring design to map design and transmitter, channel, amplifier, and receiver design. OptiSystem contains a MATLAB component that enables the user to call MATLAB within its environment to incorporate new components or models into the software. OptiSystem uses the MATLAB .dll files to evaluate the MATLAB script in the component to perform the calculations.

Flow Diagram

The OFDM flow diagram reveals the system description process from the optisystem PRBS (pseudo random beat sequence) stage, the modulation and OFDM transmission system setup, the loop control and fibre optic link, the OFDM decoder and the reception of the intelligence bearing signal.

![Flow Diagram of OFDM Transmission and Reception Model](image)

Fig. 3.1 Flow Diagram of OFDM Transmission and Reception Model

Optisystem Model Description

The entire system simulation is comprised of six functional blocks in the optisystem work environment. Descriptive information on the functionality of each block is provided with regards to how they have been used in this work.

The input data is generated from the Pseudo Random Bit sequence generator at ten Giga bits per second in the Optisystem 7.0 laboratory. The component script function in optisystem helps us to create varying inputs in bit rate and also the bit sequence. The modulation technique used in the simulation is the QAM modulation scheme. The modulated signal is processed by a composition of M-ary pulse generators. Symbol extensions or zero values can be used in place of the cyclic prefixes. An assumption value of 512 subcarriers have been adopted for the purpose of the work simulation.
RF to optical up converter
The RF to optical up converter comprises a parallel structure of a cw- lazer and two machzender modulators. In design, a subsystem is usually created for the RF to optical uplink converter. An RF spectrum analyzer is used to visualize the behavior of the output signal at the electrical amplifier stage of the up converter.

Amplitude Clipping and Filtering
To limit the Peak envelope of the input signal, a threshold value of the amplitude is set in the simulation environment. So during the transmission of the signal, the values higher than the predefined or preset threshold value are clipped and the rest of the values lesser than the threshold value are passed through the channel undisturbed.

The equation is expressed as

\[ u(y) = \begin{cases} 
  y & |y| \leq A \\
  A \cdot \frac{y}{y} & |y| > A
\end{cases} \]

Where \( u(y) = \) Amplitude clipping value after clipping.
\( y = \) initial signal value.
\( A = \) threshold set by user for clipping.
The clipped form of the modulated signal is symbolized as $x_c^p[m]$. The expression of this signal is shown in following equation:

$$
\begin{align*}
-A & \; \; \; x_c^p[m] \leq -A \\
& \; \; \; |x_c^p[m]| < A \\
A & \; \; \; x_c^p[m] \geq A
\end{align*}
$$

Where the clipping level is denoted by $A$ and (CR) is the clipping ratio that can be represented as follow:

$$CR = \frac{A}{\sigma}$$

Where the RMS value of the OFDM signal is denoted by $\sigma$ and it is well known that $\sigma = \sqrt{N}$ for the baseband and $\sigma = \sqrt{N/2}$ for the passband OFDM signal.

**Optical link**

The number of loops is configurable if we want to increase the propagation of the optical fiber. This is done using the loop function in the optisystem component library. We can choose dispersion parameters we want to set along side any non-linear parameter.

**Optical to RF down converter**

The intelligence bearing signal is propagated to the RF down converter from the optical link using a technique referred to as coherent orthogonal frequency division multiplexing detection (CO-OFDM). CO-OFDM combines both the advantage of coherent detection and OFDM modulation. CO OFDM possesses many merits useful for future high speed OFDM applications.

**OFDM Receiver**

The QAM modulator is used in the transmitter functional block for modulation. The QAM decoder is also used in the receiver functional block. The BER Analyzer is interfaced with the NRZ pulse generator to give visual display of the decoded signal at the output of the QAM decoder.
PAPR reduction

The Mac zender modulator is used for modulating the data value. The length of the data block M is indicated by a vector \([ Y0, Y1, Y2, Y3, Y4,…,YM-1]^T\) Where M is the number of subcarriers.

The complex envelope of the transmitted signal is given by

\[
y(t) = \frac{1}{\sqrt{M}} \sum_{m=0}^{M-1} Y_m e^{j2\pi ft_m} , \quad 0 \leq t < MT
\]

The peak to average power ratio is calculated by the following formula:

\[
PAPR = \frac{\text{Peak}}{\text{Average}} = \frac{\max_{0 \leq t < NT} |x(t)|^2}{1/NT \int_0^{NT} |x(t)|^2 dt}
\]

![Fig. 3.8 Optisystem layout of OFDM receiver block](image)

![Fig. 3.9 Optisystem Algorithm of OFDM Clipping & Filtering](image)
SIMULATION TESTS AND RESULTS

Optisystem simulation results
Visualizers are used in this work to display run time results stored in data monitors during the simulation. Data monitors in Optisystem are represented by a small rectangle around the component output port. A data monitor is connected to a port thereby connecting it to a visualizer. The monitor will save the data after the simulation ends. If a monitor is inserted into the output port before the simulation starts, a visualizer can be connected to the monitor after the simulation ends to view data without having to run the simulation again.

Simulation
In order to find optimum values of IFFT length and QAM size, simulation of the model under variations of IFFT length and QAM size has been done in this experimentation. For each pair, certain parameters such as maximum PAPR, average PAPR, BER, computational Complexity (execution time) are calculated.
For this, some parameters are kept constant, while others varied to observe the outcome and effect of these varying parameters on the PAPR.
The tests and results done in this section will be analyzed regarding the following parameters:
- \( M \) = Number of constellation points
- \( N \) = Number of subcarrier signals = IFFT Length.
- \( N_s \) = Number of input symbols from optisystem PRBS.
- \( C \) = clipping level.

**optisystem analyzer**
Several analyzers integrated to the optisystem 7.0 work tool are used to display simulation outcomes and analyze results.
The BER analyzer in this work is used to provide bit error rate data, assess the full end to end performance of a system including the OFDM transmitter, receiver and the medium or wireless channel between the two. Simulation inputs for Number of constellation points, RF spectrum analyzer and BER ratio are presented.

4. INTERPRETATION OF RESULTS

**Effect of IFFT**
As IFFT length goes on increasing, since number of sub-carriers is equal to IFFT length, number of sub-carriers also increases. As number of sub-carrier increases, because of superposition effect, the number of peaks also increases resulting in increase in PAPR. As BER is not related to IFFT size theoretically, their negligible variation is observed in simulation process.

**Effect of QAM**
As QAM size increases, bits per symbol also increases, which reduces the number of symbols for a given input bit stream, effectively reducing the amplitudes of peaks resulting in reduced PAPR. As QAM size increases, number of constellation points increases, reducing the Hamming distance between adjacent constellation points. This results in an increase in number of errors and hence an increase in BER.
Fig. 4.1 Electrical constellation visualizer result after OFDM Modulation

Fig. 4.2 RF spectrum analyzer visualizer result after OFDM Modulation

Fig. 4.3 Q factor of QAM decoded OFDM signal
Fig. 4.4 Minimum BER of QAM decoded OFDM signal

Fig. 4.5 Eye diagram of QAM decoded OFDM signal

Results of OFDM with Clipping and Filtering

Table 4.1 Effect of number of constellation points on PAPR reduction and BER

<table>
<thead>
<tr>
<th>M</th>
<th>Number of input Symbols</th>
<th>IFFT size</th>
<th>Clip level</th>
<th>Clipping Ratio (CR)</th>
<th>PAPR before C &amp; F</th>
<th>PAPR after C &amp; F</th>
<th>PAPR Reduction</th>
<th>BER (* 10^-4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>100</td>
<td>128</td>
<td>4</td>
<td>0.7027</td>
<td>7.0291</td>
<td>6.1754</td>
<td>0.8537</td>
<td>0.4877</td>
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<td>4</td>
<td>0.7549</td>
<td>7.3441</td>
<td>6.7528</td>
<td>0.5913</td>
<td>0.5065</td>
</tr>
<tr>
<td>8</td>
<td>100</td>
<td>128</td>
<td>4</td>
<td>0.7384</td>
<td>7.3313</td>
<td>6.7502</td>
<td>0.5811</td>
<td>0.4976</td>
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<tr>
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<td>4</td>
<td>0.7516</td>
<td>7.3148</td>
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<tr>
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<td>6.7146</td>
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<tr>
<td>64</td>
<td>100</td>
<td>128</td>
<td>4</td>
<td>0.7441</td>
<td>7.3132</td>
<td>6.7924</td>
<td>0.5208</td>
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Table 4.2 Effect of Clipping Level on PAPR reduction and BER

<table>
<thead>
<tr>
<th>M</th>
<th>Number of input Symbols</th>
<th>IFFT size</th>
<th>Clip level</th>
<th>Clipping Ratio (CR)</th>
<th>PAPR before C &amp; F</th>
<th>PAPR after C &amp; F</th>
<th>PAPR Reduction</th>
<th>BER (* 10^-4)</th>
</tr>
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<tbody>
<tr>
<td>4</td>
<td>100</td>
<td>128</td>
<td>1</td>
<td>1.0545</td>
<td>7.3227</td>
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<td>0.4976</td>
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Table - 4.3 Effect of variation in number of input symbols and IFFT size on PAPR reduction and BER

<table>
<thead>
<tr>
<th>M</th>
<th>Number of Symbol</th>
<th>IFFT Points</th>
<th>Clip value</th>
<th>Clip Ratio (CR)</th>
<th>PAPR before C &amp; F</th>
<th>PAPR after C &amp; F</th>
<th>PAPR Reduction</th>
<th>BER (*10^6)</th>
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<td>64</td>
<td>4</td>
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<td>10</td>
<td>256</td>
<td>4</td>
<td>1.2500</td>
<td>7.5580</td>
<td>7.2082</td>
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<td>0.4923</td>
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<tr>
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</table>

5. DISCUSSION

i) As the number of constellation points increases, amount of PAPR reduction decreases. At the same time, there is no significant effect of number of constellation points on BER.

ii) As amount of clipping goes on increasing, amount of PAPR reduction increases. At the same time, there is no significant effect of amount of clipping on BER.

iii) As the IFFT size goes on increasing, amount of PAPR reduction goes on decreasing. At the same time, BER almost remains constant.

iv) As the number of input symbols goes on increasing, amount of PAPR reduction increases. At the same time, BER slightly decreases with increase in number of input symbols.

6. CONCLUSION

OFDM is a very attractive technique for multicarrier transmission and has become one of the standard choices for high speed data transmission over a communication channel. It has various advantages, but also has one major drawback: it has a very high PAPR. In this research, the different parameters of an OFDM system have been analyzed and the advantages and disadvantages of this system are understood. The optisystem simulator has provided multiple choice of visualizers to use for observing the stage by stage outputs of the system. The research work has also investigated some of the techniques which are in common use to reduce the high PAPR of the system. Among the existing techniques, Amplitude Clipping and Filtering has been analyzed as the core of the work, being the simplest PAPR reduction technique in use. However, no specific PAPR reduction technique is the best solution for the OFDM system. Various parameters like loss in data rate, transmit signal power increase, BER increase, computational complexity increase should be taken into consideration before choosing the appropriate PAPR technique.

REFERENCES


