

**WAVELET METHODS WITH DISCRETE COSINE
TRANSFORM FOR PEAK-TO-AVERAGE POWER RATIO AND
BIT ERROR RATE REDUCTION IN ORTHOGONAL
FREQUENCY DIVISION MULTIPLEXING SYSTEMS**

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UNIVERSITI SAINS MALAYSIA

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ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SYSTEMS**

By

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LIST OF ABBREVIATIONS

ADCHWT	Analytic Discrete Cosine Harmonic Wavelet transform
AWGN	Additive White Gaussian Noise Channel
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CCDF	Complementary Cumulative Distribution Function
CDF	Cumulative Distribution Function
CR	Clipping Ratio
DAB	Digital Audio Broadcasting
DCT	Discrete Cosine Transform
DWT	Discrete Wavelet Transform
DPQPSK	Quadrature Phase Shift Keying
DVB	Digital Video Broadcasting
EC	Exponential Companding
E_b/N_0	Ratio of Bit Energy to Noise Power
FFT	Fast Fourier Transform
IDCT	Inverse Discrete Cosine Transform
IDWT	Inverse Discrete Wavelet Transform
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
ICI	Intercarrier Interference
ISI	Intersymbol Interference

LAN	Local Area Network
OFDM	Orthogonal Frequency Division Multiplexing
PAPR	Peak-to-Average Power Ratio
PLC	Power Line Communication
PTS	Partial Transmit Sequence
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
SLM	Selective Mapping Method
SNR	Signal-to-Noise Ratio
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WT	Wavelet Transform

LIST OF SYMBOLS

A	the threshold clipping level
C	output of the time domain signal
E	expectation
$E_b N_0$	Ratio of bit energy to noise power spectral density
$E_s N_0$	ratio of symbol energy to noise power spectral density
$f_{M_n}(m)$	probability density function
Im	Imaginary part
k	$\log_2(M)$
k	The number-th of subcarriers in an equation
\log_{10}	Logarithm of base 10
M	number of arrays
M_{max}	Maximum of magnitude of x_n^v
M_n	magnitude of x_n^v
N	number of subcarriers
$P_{average}$	Average power
P_{peak}	Peak power
P_{noise}	Power Noise
P_{signal}	Power of signal
Re	Real part
T	data symbol period

x_n^v	Data value
X_k	transmitted symbol on the Kth subcarrier
X_n	symbol signal on th number of subcarriers
X_m	The symbol signal on time domain
Δf	subcarriers spacing
π	Pi=3.142
Φ	The frequency domain
β	Rayleigh distribution
σ	Variance

**KAEDAH WAVELET DENGAN TRANSFORMASI KOSINUS DISKRET
UNTUK PENGURANGAN NISBAH KUASA PUNCAK KE PURATA DAN
KADAR RALAT BIT DALAM SISTEM PEMULTIPLEKSAN PEMBAHAGIAN
FREKUENSI ORTOGON**

ABSTRAK

OFDM telah digunakan dalam rangkaian tanpa wayar, talian pelanggan digital (DSL) pengaksesan Laman Sesawang, 4G komunikasi mudah alih, televisyen digital dan siaran audio. Kadar bit yang tinggi semasa penghantaran isyarat, kecekapan spektrum yang tinggi dan saluran frekuensi pemudaran yang teguh merupakan kelebihan untuk aplikasi OFDM. Kelemahan dalam sistem OFDM ialah PAPR yang tinggi. Ia menyebabkan kemerosotan penghantaran isyarat. Dua objektif telah dinyatakan dalam projek ini. Objektif yang pertama adalah untuk membuat kajian tentang konsep teknik Wavelet dan transformasi kosinus diskret pada OFDM dan kesannya. Objektif yang kedua ialah untuk melaksanakan kaedah penambahbaikan Wavelet dengan DCT. Projek ini dibahagikan kepada empat peringkat iaitu: memahami konsep OFDM dan PAPR, pelaksanaan algoritma serta mencapai keputusan simulasi dan menganalisis keputusan simulasi. Keputusan simulasi menunjukkan pelaksanaan kaedah penambahbaikan Wavelet dengan DCT dapat mengurangkan PAPR kepada kira-kira 5.111dB untuk 1024 sub-pembawa isyarat dengan skema modulasi QPS dengan 35%. Di samping itu, BER juga dikira bagi semua skema modulasi untuk mengkaji prestasi sistem dengan perbandingan antara nombor bit yang diterima dengan nombor bit yang dihantar. DCT-precoded Wavelet mencapai kemajuan BER 30% manakala DCT- Wavelet mencapai kemajuan BER 34%

WAVELET METHODS WITH DISCRETE COSINE TRANSFORM FOR PEAK-TO-AVERAGE POWER RATIO AND BIT ERROR RATE REDUCTION IN ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SYSTEMS

ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) is nowadays applied in wireless networks, Digital Subscriber Line Internet Access, 4G mobile communications, digital television and audio broadcasting. This system has been widely used in high data rate wireless communications systems. High transmission bit rate, high spectral efficiency and robustness to frequency fading channels are the benefit for the application of OFDM. However, there is a major drawback in OFDM systems which is high Peak-to-Average Power Ratio (PAPR). High PAPR will reduce the performance of OFDM. Several techniques has been proposed to reduce PAPR. In this study, two objectives are identified. The first objective is to implement the improved PAPR reduction technique based on DCT on wavelet method. Then, the second objective is to analyze the performance of the proposed method based on PAPR and BER. This study is divided into four stages, understand the concept of OFDM implementation of algorithm, obtaining results and analyzing the simulation results. The simulation results show that improved method of DCT wavelet can reduce PAPR to about 5.111dB (35% PAPR reduction improvement) for 1024 subcarriers by using 64-QAM modulation scheme. Besides that, the Bit Error Rate is calculated to investigate the performance of the system by comparing the number of bits received in errors and the number of bits transmitted. DCT-precoded Wavelet gives 30% of improvement of BER whereas DCT-Wavelet gives 34% of improvement of BER

CHAPTER ONE

INTRODUCTION

1.1 Background

Orthogonal Frequency Division Multiplexing (OFDM) is a parallel and multipath transmission scheme at high data rates over time dispersive channels. OFDM utilizes the orthogonality properties for increasing the transmission bandwidth. OFDM solve many issues that could occur with high bandwidth single carrier. The aim of most of the OFDM-based system is to increase transmission data bit rate and it is actually the main attraction feature for OFDM system.

Orthogonal Frequency Division Multiplexing (OFDM) is one of the famous techniques for large capacity radio waves transmission. The technique helps in separating frequency selective fading channel into a number of orthogonal channels in which the technique is acting as a distinctive form of multicarrier modulation scheme. In terms of parallel stream, transmission of high bit rate data undergoes over several lower data rate subcarriers. Instead of using single wide-band carrier, multiple narrow band subcarriers are applied to ensure that more data can be transmitted through more than one path. In this instance, ISI will occur due to long symbol duration [1]. Cyclic prefix is applied for eliminating the effect of ISI. In addition, OFDM will unintentionally cause unparallel bandwidth density, which brings to high spectral efficiency [2].

Gu et al. [3] stated that OFDM has larger system capacity than traditional single carriers system. The transmitted signal has high sudden surge of peak values because the

factor of subcarriers are involved in the Inverse Fast Fourier Transformation (IFFT) operation [4]. The major advantages of OFDM include high spectral efficiency and high power efficiency. Besides that, the immunity to the frequency selective fading and multipath delay can also be found in OFDM [2]. From the above mentioned advantages, OFDM is recognized as the pioneer to enhance the world of wireless communication by most of the wireless LAN standards like IEEE 802.11a/g and Wi-Max. Wireless Local Area Network (WLAN), Wireless Personal Area Network (WPAN) and Digital Audio Broadcasting (DAB) are the examples of network policy which applied OFDM modulation. OFDM has its own advantages and disadvantages same goes to OFDM system. High peak-to-average power ratio (PAPR) is the agenda which are usually investigated by most researchers who are major in field of digital signal processing. PAPR increases the complexity of design implementation and decreases the linearity of the system.

OFDM needs linear power amplifier to reduce the undistorted signal phenomena. Once the amplitude of the signal reaches the nonlinear region of the power amplifier, the distortion of the signal will happen. When this incident happens, intermodulation among the subcarriers and out of band radiation problems will be displayed. Therefore, power amplifier is needed for this occasion, but this will increase the complexity and decrease the efficiency of the system due to the increasing power consumption of the system. With the increasing power consumption especially in devices running on battery, mobile devices which utilize OFDM system will have decrease in power efficiency.

Thus, several PAPR reduction technique have been studied and examined and this study discusses the wavelet method with the aid of DCT.

1.2 Problem Statement

As stated in the background section, research on OFDM has never been halted and reduced in trend of data transmission field. As OFDM is actually an attractive research topic, much researches have been conducted to discover the best method to reduce the high peak power of OFDM system. OFDM has aided in solving a lot of communications issues. Though it is quite beneficial in our devices nowadays, PAPR is still the major issue to be looked into. If left unattended, it will cause some problems on the devices like effectiveness of signal transmission. PAPR reduction is still one of the most interesting research topics in multicarrier modulation field. A lot of techniques and combination of several methods have been proposed to solve the PAPR problem. However, some of the methods especially distortion methods requires a lot of energy due to the distortion produced during the implementation of the methods.

Among all the proposed methods for PAPR reduction, wavelet technique introduces the intriguing concept of decomposing the signal into real and imaginary part and reform the signal with much lower PAPR [3]. Wavelet transform is implemented rather than fast fourier transform due to the fact that DWT has the decomposition effect which can excel fast fourier transform in terms of signal bit extraction purpose [3].

However, compared to other technique, wavelet techniques requires a lot of energy and power consumption during the decomposition process. Even though cyclic prefixes is no longer required with the implementation of wavelet method, the decomposition process of the signal induces the usage of several amount of energy in breaking down the signal into real part and imaginary part. This is the part where discrete cosine transform

is implemented to decrease the consumption power by implementing autocorrelation to induce the improvement on wavelet technique. In this study, DCT is introduced to further enhance the wavelet technique in peak power reduction agenda. A hypothesis is made that further reducing the peak power signal after the decomposition process of wavelet technique by using DCT could give better result in term of PAPR and BER.

DCT has been applied in many applications and researches. Due to the autocorrelation properties in DCT which helps in solving the limitation of fast fourier transform, DCT only involves summation of cosine signals compared to Fourier transform (FT) which involves both Cosine signals and Sine Signals. Therefore, it has been shown that DCT requires less energy [5]. DCT has been used for PAPR studying and researching. This can be found in Chapter 2 that a lots of researchers have combined different techniques with DCT or by DCT replacing Fast Fourier transform, it can be found that the result is promising and improving. This is because DCT helps in further alleviating the Peak Power in the signal. Therefore, this study introduces two DCT based wavelets techniques to reduce PAPR. The proposed techniques are DCT precoded wavelet and DCT-wavelet.

Both proposed techniques were simulated in MATLAB to study the effects towards PAPR reduction and the effects towards BER. In addition, the comparison between the two proposed techniques were carried out and studied. Besides that, the proposed technique were compared with other combined technique which are Clipping Filtering with DCT. This study also discover on the effect of the proposed methods on behalf of the parameters such as number of subcarriers, QAM modulations, the types of wavelet

families used and also the different level of same wavelet families used on the result and effectiveness in terms of PAPR reduction and BER.

1.3 Objectives

The main objectives of this study are:

- To implement an improved PAPR reduction technique based on DCT on wavelet method.

A combination of two techniques which are DWT and DCT to reduce PAPR are developed through algorithm with mathematical formula

- To analyze the performance of the proposed method based on PAPR and BER.

The efficiency of the proposed combination of two methods in term of PAPR and BER is investigated with several parameters such as number of subcarriers

1.4 Project Scope

The two techniques which are of wavelet method and DCT for reducing peak power to average power ratio for the modulation are studied. This was done by replacing FFT and IFFT with DCT and IDCT at the implementation of wavelet method. Improved wavelet method with DCT was carried out by using MATLAB. Then, simulation results in terms of tables' value and graphs were observed and analyzed. The effect of DCT with wavelet technique towards PAPR and BER reduction were compared with those of the original OFDM technique. The advantages of the improved technique compared to other

techniques were looked into in terms of several parameters which are number of subcarriers and modulation scheme applied.

The performance of PAPR was analyzed based on simulation results using this technique. Then, only 4-QAM, 16-QAM and 64-QAM are used as modulation schemes in this study. This three modulation scheme were usually applied in OFDM modulation. This study is also limited with varies number of subcarriers which are 64, 128, 256, 512 and 1024 using same frequency for each subcarrier. This five number of subcarriers were the optimum value of number of subcarriers in OFDM signal transmission. The comparison of the proposed method with wavelet method with DCT was carried out as well. Besides, the idea proposed regarding improved wavelet method with DCT, the effect of reduction of PAPR was determined. The BER is also calculated to look into the performance in each of modulation scheme under the technique proposed which are improved technique of wavelet method with DCT.

In addition, the effectiveness of the proposed method was compared with other combined methods as well. The effect of individual technique (wavelet and DCT) and the effect without using any technique which are original PAPR in each modulation scheme was explored.

1.5 Outline of Report

There are five main chapters which describe the full details from introduction to conclusion of this study. Chapter 1 includes the introduction, which explain on the study background, problem statement, objectives and scopes.

Chapter 2 is about a literature review of the past works done related to this study. Summary of the past studies on different technique and effects of parameter such as subcarriers towards PAPR of OFDM system is presented in this chapter. All relevant fundamental backgrounds of previous researches are also explained in this chapter.

In Chapter 3, methodology of this study is described in detail. It includes detailed description on technique used for algorithm implementation. Chapter 4 explains the results and discussion for this study. The simulated results to prove the performance of PAPR reduction using improved wavelet method with DCT is working is also shown in Chapter 4.

Finally, Chapter 5 provides the conclusion of this study. Summary on the project implementation is explained. This chapter also includes the limitations of this simulation and future works to further modify and enhance this simulation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Nowadays, OFDM technology seems to have appeared in the sight of a lot of researchers. Most of the latest wired and wireless devices apply OFDM. Due to the fact that utilization of orthogonality properties by OFDM to further improve bandwidth, Intersymbol Interference could be overcome. Hence, to achieve higher data rate and to counter Intercarrier interference and Intersymbol Interference, Cyclic Prefix (CP) has to be applied and low rates of symbols should be created in parallel [4].

Due to nature of parallel applied in the OFDM scheme, the addition of several subcarriers signal will lead to high peaks amplitude of the signal produced. Those high amplitudes could not be exaggerated linearly by the transmission line which contains final power amplifier. Thus, this will bring to signal distortion and might bring along a lot of issues. To apprehend this issue, a power amplifier system which is specially designed and with high complexity might be also costly and is believed could maintain the linearity, might be needed as well.

The created high peak values contribute to restrictions of the development of OFDM. To reduce complexity of the design, cost and inefficiency of OFDM systems, several methods are suggested and carried out to reduce PAPR values. Several mathematical, statistical and engineering techniques or methods are studied and examined

to eliminate PAPR in OFDM. Until recently, no methods can perfectly reduce PAPR values. However, several techniques was studied to effectively reduce the PAPR values

Among the proposed schemes and combined techniques by researchers until recently, some can be categorized as the following:

- a) Distortion based techniques such as clipping and filtering [3] and μ -law companding [3]. The mentioned techniques do not requires much steps or considerations to implement however it creates signal distortion issues which might leads to more drawbacks.
- b) Non-distortion techniques such as partial transmit sequence (PTS), selective mapping (SLM) and multi-point square mapping combined with PTS [1].

This category gives less distortion and the most important is the techniques implemented will not create any disturbance on OFDM signal.

The proposed technique in this study which is the improved wavelet techniques with DCT, is considered non-distortion technique. Due to the unique features of both wavelet and DCT techniques, it is expected that the simulation results will fulfilled the hypothesis stated in Chapter 1. The combination of the two techniques which are of wavelet techniques and discrete cosine transform was implemented through algorithm implementation in MATLAB.

2.2 The concept of OFDM

In OFDM, a portion of the user information is transmitted in each band. Each carrier is orthogonal or independent to each other, differentiating OFDM from the commonly used frequency division multiplexing [4]. In a classical parallel data system, the total signal frequency band is divide into N non- overlapping frequency subchannels. Each subchannel is modulated using a separate symbol and then the N subchannels are frequency- multiplexed.

In the input section, data symbols are channeled into encoder so that the transmitted data could be attached onto QPSK or QAM constellation. A lot of advantages is being introduced by OFDM and the beneficial idea is being adopted in many standards. The bit stream signals are converted from serial to parallel and applying Inverse Fast Fourier transform to obtain the time domain signals [5]. The real idea for introducing OFDM is the orthogonality concept which states that the integral of two carrier multiplication result in zero whenever the two carriers are with different frequency. Due to the fast development and advancement of Digital Signal Processing technology, the implementation of OFDM has become much easier.

At the output section, the signal with N as the number of subcarriers can be expressed as:

$$X_n = \text{IFFT} \{X_k\} \quad (2.1)$$

$$X(t) = \frac{1}{\sqrt{N}} \sum_{k=1}^{N-1} X_k e^{j2\pi k \Delta f t} \quad (2.2)$$

X_k is the transmitted data signals on the respective (K-th) numbers of subcarriers, N refers to the amount of subcarriers, $T = 1/\Delta f$ is the data period and Δf is the difference of frequency between adjacent subcarriers.

Mathematically the continuous time representation of transmitted signal is represented as follows:

$$X_m(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{2\pi k m / N} \quad (2.3)$$

Where $X_m(t)$ is the transmitted modulated signal with the same parameters as equation 2.2.

2.3 Peak-to-Average Power Ratio (PAPR)

High peak value is due to the randomly sinusoidal amplitude values in the transmission of the signal. This leads to the Peak to average power ratio grows higher. The nature of PAPR and the proposed modulation schemes to eliminate PAPR were discussed here. Gu *et al.* [3] commented that for the constant number of bits per sample, high PAPR creates a serious quantization error. To minimize the quantization error (value difference in ADC), the involvement of the analog-to- digital and digital-to-analog converters will increase the accuracy of the system. High PAPR creates a large region of linear power amplifier, otherwise the probability of nonlinear distortion will increase [6].

The formula for PAPR can be shown as:

$$PAPR = \frac{P_{\text{peak}}}{P_{\text{average}}} \quad (2.4)$$

Where P_{peak} = Lead power of the OFDM system, P_{average} = Average power of the OFDM system

The PAPR of an oversampled version of $x(t)$ is calculated with the same equality.

The fundamental purpose in this study is to obtain the minimum values of the $\max [|x_n^v|^2]$.

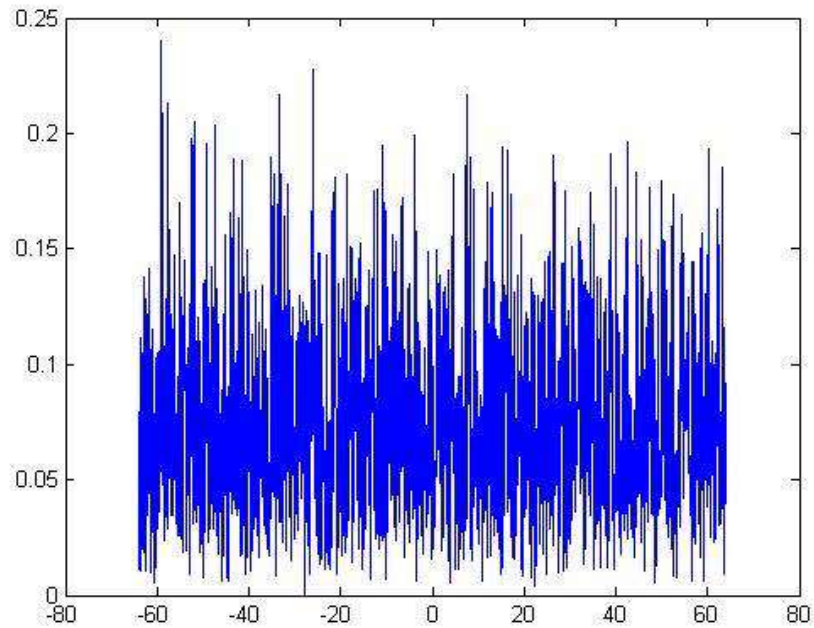


Figure 2.1: Sinusoidal amplitudes OFDM signal [4]

As shown in Figure 2.1 for observing the PAPR in OFDM system, the high sinusoidal amplitude power in OFDM signal can be seen. 64 data symbol per frame in term of the signal is transmitted to IFFT. For HPA, nonlinear distortion takes place along the analog domain although the majority of the operation related to PAPR reduction takes place in the digital. [7]

PAPR is known as the ratio between the peak power and the average power of OFDM signal x_n^v [8, 9, 10]. PAPR equation can be shown as:

$$PAPR = \frac{\max |x_n^v|^2}{E |x_n^v|^2} \quad (2.5)$$

Where E is expectation.

The OFDM signal x_n^v can also be expressed as in time domain:

$$x_n^v = \text{Re}\{x_n^v\} + \text{Im}\{x_n^v\} \quad (2.6)$$

Where $\text{Re}\{x_n^v\}$ is the real parts of the symbols and $\text{Im}\{x_n^v\}$ is the imaginary parts of the symbols

Whereas the Peak power and Average Power can separately expressed as [11]:

$$\text{Peak power} = \max |x_n^v|^2 = \max \left| \sqrt{\text{Re}\{x_n^v\}^2 + \text{Im}\{x_n^v\}^2} \right|^2 \quad (2.7)$$

$$\text{Average power} = E |x_n^v|^2 = \frac{1}{N} \sum_{n=0}^{N-1} \left| \sqrt{\text{Re}\{x_n^v\}^2 + \text{Im}\{x_n^v\}^2} \right|^2 \quad (2.8)$$

Where $n = 0, 1, 2, \dots, N-1$ and $v = 1, 2, \dots, V$.

If each IFFT input is independent and identically distributed, the real and imaginary parts of x_n^v have mutually independent Gaussian probability distribution function by central limit theorem. Eq. (3.9) shows the instantaneous power of x_n^v .

$$\beta = x(\text{Re}\{x_n^v\})^2 + x(\text{Im}\{x_n^v\})^2 \quad (2.9)$$

Where $\text{Re}\{x_n^v\}$ is the real parts of the symbols and $\text{Im}\{x_n^v\}$ is the imaginary parts of the symbols.

The instantaneous power is characterized as Rayleigh distribution. The probability density function is computed as:

$$f_{M_n}(m) = \frac{m}{\sigma^2} \exp\left(-\frac{m^2}{2\sigma^2}\right), n = 0, 1, 2, \dots, N-1 \quad (2.10)$$

Where M_n is the magnitude of x_n^v .

The maximum of M_n is equivalent to crest factor and the cumulative distribution function (CDF) of the maximum amplitude or crest factor of a signal is given by [12]:

$$F_{M_{max}}(m) = P(M_{max} < m) \quad (2.11)$$

Where,

$$M_{max} = \max\{M_n\}, n = 0, 1, 2 \dots N - 1$$

$$P(M_n < m) = \int_0^m f_{M_n}(x) dx, n = 0, 1, 2 \dots N - 1$$

From Eq. (3.8), $F_{M_{max}}$ is simplified as:

$$F_{M_{max}}(m) = (1 - e^{-m^2})^N \quad (2.12)$$

CCDF graph illustrates the period of signal applied within the designated power level. The CDF is not applied here, instead complimentary CDF was applied to counter the probability of PAPR of numerous data block exceeds threshold limit [13, 14].

Mathematically CCDF can be defined as:

$$CCDF = 1 - CDF \quad (2.13)$$

By using Eq. (3.8) and Eq. (3.9), the probability that crest factor exceed some threshold level, consider CCDF is given as [15, 16]:

$$\begin{aligned} \overline{F_{M_{max}}(m)} &= P(M_{max} > m) \\ &= 1 - P(M_{max} < m) \end{aligned} \quad (2.14)$$

$$\begin{aligned}
&= 1 - F_{M_{max}}(m) \\
&= 1 - (1 - e^{-m^2})^N
\end{aligned}$$

2.4 Bit Error rate

In the studies of efficiency of data transmission, BER is always the most important guideline parameters for the performance of the designated system. The higher the BER values, the system performance will degrade more [17, 18]. BER is the ratio between the numbers of bits received in error and the number of bits transmitted which produces the equation as follows:

$$BER = \frac{\text{number of bits in error}}{\text{total number of bits transmitted}} \quad (2.15)$$

By adding the noise channel to the transmitted signal, the performance of BER could be studied. In the cases of high signal-to-noise ratio (SNR), lesser the BER will it be. The greater the noise applied, the greater the BER. SNR is formulated as follow:

$$SNR = 10\log_{10} \frac{P_{signal}}{P_{noie}} \quad (2.16)$$

Where P is the mean power of the symbol.

Ratio of bit energy to noise power spectral density ($E_b N_0$) and ratio of symbol energy to noise power spectral density ($E_s N_0$) are another quantities used to describe relative power of noise in AWGN. The formula to be used in the calculation of BER in this study is as follow [19]:

$$SNR = \frac{E_b}{N_0} - 10\log_{10}(N) + 10\log_{10}(k) \quad (2.17)$$

Where $N = K \cdot 2$ (Product of 2 of number of subcarriers) and $k = \log_2(M)$; M =number of arrays.

Jamalludin *et al.* [20] investigated on BER performance in the influence of different wavelet level in Daubechies Families. At E_b/N_0 (signal-to-noise ratio) of 9.5 dB, all wavelet-based OFDM have BER performances of $5 \cdot 10^{-5}$. However, in order to achieve the same BER performance the conventional system has to use 12.5 dB where the difference is 3 dB.

2.5 Types of PAPR Reduction Techniques

2.5.1 Distortion based technique

For distortion methods, most of them do not need complicated steps and mathematical formula to be implemented without affecting the data rate of the signal & without any rise in power of the signal. However, signal distortion will be created during the implementation process which will lead to more drawbacks on the system such as low efficiency and high power consumption. One of the most well-known distortion methods is Clipping and Filtering method. To limit out-of-band radiation and PAPR, Jean Armstrong proposed iterative clipping and filtering scheme [3]. In the clipping technique hard limiting is applied to the amplitude of the complex values of the IFFT output. The filtering technique is designed to alleviate out-of-band distortion but cannot correct in-band distortion. The filtering operation will lead to peak power regrowth. By repeating

clipping several times, we can reduce the likelihood of peak power regrowth. The procedure is known as RCF (Recursive Clipping and filtering).

2.5.2 Non- distortion based technique

For non-distortion method, most of the methods give less distortion and no disturbance will be created during OFDM signal generation. The information undergoes scrambling process without any distortion in information. One of the non-distortion methods discussed here is Partial Transmit Sequence (PTS). Partial Transmit Sequence (PTS) algorithm [3] is a technique for improving the statistics of a multicarrier signal. The basic idea of Partial Transmit Sequence algorithm is to divide the original OFDM sequence into several subsequences and each sub-sequence is multiplied by different phase factors until an optimum value is chosen. Wavelet Technique and DCT are proposed in this study due to their less distortion and disturbance during OFDM signal generation.

2.5.3 Wavelet Technique

For the wavelet method application, several research on wavelet OFDM was carried out. Wavelet technique is applied not only in digital signal processing field but also applied in image processing and Artificial Intelligence application. The past research on wavelet method on PAPR reduction and BER calculation were discussed.

Wavelet technique was first introduced in the early 20th century by Alfred Haar. Wavelet transform coding were used in wavelet transforms in data compression algorithm. In 1975, continuous wavelet transform was introduced and is initially being applied in the study of reaction of the ear to sound. In the end of 20th century, discrete wavelet transform

is introduced to replace DCT algorithm for JPEG 2000 standard. This is why DWT is mostly used in image processing algorithm until recently DWT is being applied in OFDM transmission as well.

Chafii *et al.* [21] has investigated on the effect of level of scales L of wavelet on PAPR performance. Dmey and Daubechies(dB) are the families of wavelet. The performance of the Dmey is affected by the number of scales L in wavelet transform. L is referred as the decomposition level in wavelet transform. When L is high, the CCDF is shifted to the right and the PAPR performance is therefore degraded. In every decomposition level, the carriers system is being separated into single carrier system due to the similar bandwidth of the waveforms which has the same scale. The lesser the value of L , the single carrier system is less affected by the high peak values, the lesser the PAPR values. Moreover, the PAPR for the different variants of the Dmey wavelet-OFDM outperforms that of OFDM [21]. Given that $CCDF = 10^{-3}$, for 4-QAM (16-QAM respectively), the PAPR of the Dmey is less by 4.5 dB (3 dB respectively) than the original OFDM.

FFT based OFDM and WTOFDM (wavelet transform Orthogonal Frequency Division Multiplexing) were studied by Chandra *et al.* [22]. The performance of WTOFDM with several fundamental functions on Power Line Communication system was being investigated in the papers as well. WTOFDM system has better spectrum efficiency than the conventional OFDM since the subcarriers need no guard interval and no pilot tones are required. It is found that the wavelet OFDM has a larger gradient (difference by 20%) of graphs compared to FFT based OFDM. This shows that wavelet based OFDM shows lower 2 dB of bit error rates than FFT based OFDM [22].

Jamalludin *et al.* [20] investigated on BER performance in the influence of different wavelet level in Daubechies Families. The block diagram in Figure 2.2 used for the proposed technique is suggesting that Discrete Wavelet Transform (DWT) replaces the Fast Fourier transform (FFT) block. WFOFDM does not require cyclic prefix to enhance the bandwidth efficiency due to the overlapping nature of wavelet transform which maintains the orthogonality of the output signal [20].

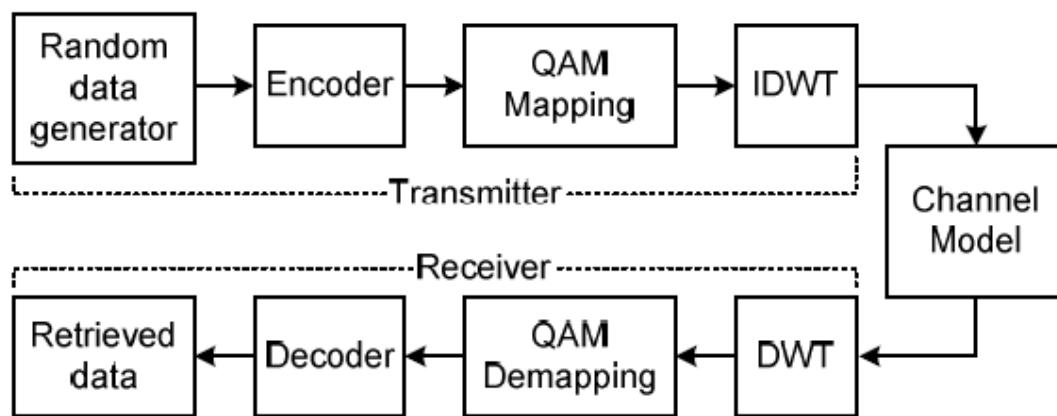


Figure 2.2: Block Diagram for wavelet-based OFDM system [20]

Wavelet OFDM also outperform the FFT OFDM by showing the lowest power of 8.5dB among the 6 variables which are Haar, dB3, dB5, dB10 and dB20. The difference between the Haar OFDM and FFT OFDM is 2 dB in terms of power.

2.5.4 Discrete Cosine Transform

The peak value of the auto correlation is the average of the power of the input data sequence. DCT conceptually extends the original N-point data sequence to 2N-point sequence by doing mirror – extension of the N-point data sequence. Since both ends of the data are always continuous in the DCT, the lower order of components were dominated

in the transformed domain signal after converted by DCT. The DCT is a Fourier-like transform, which was first proposed by Ahmed et al [8]. The idea to use the DCT transform is to reduce the autocorrelation of the input sequence to reduce the peak to average power problem and the transmitted signal does not require any side information at the receiver.

2.6 The hybrid methods

There are variety of mathematical and engineering methods proposed by researchers to counter the high Peak power issue. Initially, most of them are individual methods. As expected, they are still not sufficient enough to further improve PAPR performance. The room for improvement is still there. Therefore, combined techniques and several hybrids methods are introduced as well. Several hybrid methods with DCT were discussed here. DCT has been implemented in several ways. DCT could be applied before or after the implementation of main algorithm or main methods or DCT could be applied to replaced Fast Fourier transform (FFT) due to its simplified nature which focus only on Cosine Summation Signal.

Sroy Abouty *et al.* proposed a DCT with Clipping and Filtering for PAPR reduction method. There is comparison between both of the precoded combined techniques which are first, DCT is used before FFT and second, DCT is used after Clipping and Filtering. Based on simulation results, the second scheme, which is DCT is used after Clipping and Filtering gives better performance by 10% improvement of PAPR reduction than the first scheme, which is DCT is used after FFT/IFFT [12]. Besides that,

Sroy Abouty *et al.* also found that the larger the number of iteration for clipping and filtering method, the better PAPR performance [12]. At the CCDF of 10^{-3} , the PAPR reduction of the ICF with DCT/IDCT and 1 iteration is better than the original OFDM signal, by 0.3 dB, for 2 iterations ICF with FFT/IFFT and 3 iterations ICF with FFT/IFFT, PAPR reduction by 1.2 dB and 1.6 dB can be achieved respectively.

Kayalvizhi *et al.* [23] proposed the iterative addition and subtraction of OFDM symbols followed by DCT by adding a companding technique. A-Law companding technique is suggested to further reduce the PAPR. Using this method, in the receiver side, transmitted symbols can be decoded by taking simply the differentiation after IDCT. One more advantage of the proposed method is that side information is not required to receive the signal at the receiver side. This work was extended to implement receiver with better PAPR performance. The performance of iterative addition and subtraction with preprocessed DCT method is better for higher level modulation (16-QAM and 64-QAM) by 2.0dB. PAPR can be further reduced by adding compression coding in iterative addition and subtraction with preprocessed DCT.

A combination technique of a companding transform and DCT was initiated by Zhengpeng Wong [24]. DCT is applied for the processing of data bit stream. This transform magnifies the initial signal and suspend the period of high value data stream. This is why high PAPR value can be reduced by the combined technique [24]. Throughout the research by Wong, the combined scheme outperforms the companding method by 1 dB and it outperforms the DCT method by 2.5 dB [24].

Reny et al. [25] proposed PAPR reduction method by implementing discrete cosine transform with differential scaling technique. In this method different ranges of amplitudes of the signal are scaled in a different manner that is why it is called Differential Scaling. Three different types of scaling ranges which consist of up scaling, down scaling and up-and-down scaling are implemented with DCT. Up-and-down scaling shows the best results for PAPR reduction and the combined method excels the original method in terms of PAPR reduction by 15dB.

Jayashi *et al.* [26] once proposed the comparison between DCT before PTS and DCT after PTS technique. The purpose is to compare the precoded effect of discrete cosine transform on a specific method on the PAPR reduction. The comparison of DCT before PTS and DCT after PTS technique is being carried out in terms of PAPR reduction improvement. To further minimize the PAPR values, reduction of autocorrelation of input data sequences and signal energy compaction is essential in the process of reducing the signal distortion [26]. The comparison of original PTS, DCT before PTS and DCT after PTS were carried out through simulation. DCT before PTS techniques excels others three methods by having the lowest PAPR values. The PTS has a PAPR of 6.8 dB, DCT before PTS has PAPR of 4.8 dB and DCT after PTS has PAPR of 5.8 dB. There is a difference of nearly 1 dB between DCT before PTS and DCT after PTS.

Suma *et al.* [27] proposed Analytic Discrete Cosine harmonic wavelet transform (ADCHWT). The BER Performance comparison between ADCHWT-OFDM, Haar WT-OFDM and DFTOFDM was carried out. The Eb/No of ADCHWT is lesser than Haar and DFT at 15dB which shows that the BER of ADCHWT excels other two techniques. BER

value achieved for ADCHWT OFDM is 0.002 which is a considerable improvement compared to Haar and DFT OFDM, which have BER of 0.06 and 0.4, respectively.

2.7 Effect of modulations scheme towards the performance of PAPR and BER

Baranwal *et al.* [28] compared the effect of different modulation scheme on PAPR value of OFDM signals and its reduction using Selective mapping phase rotation method. Based on the simulation results, they found that QAM modulation has the least PAPR value among other modulation schemes without phase rotation. According to Dey and Islam [29], when lower order modulation scheme is moved to higher order modulation scheme, the performance of BER decrease as large number of bits is used to form a symbol.

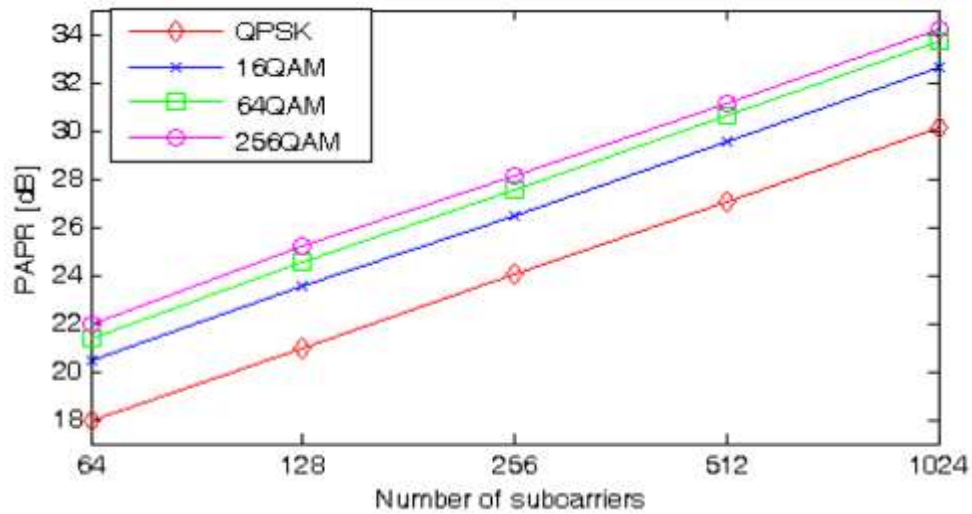


Figure 2.3: Modulation scheme affect PAPR [29]

2.8 Effect of number of subcarriers towards the performance of PAPR

According to the research done by Irena et al. [30], when number of subcarriers (N) is larger, the PAPR becomes larger as shown in Figure 2.4.

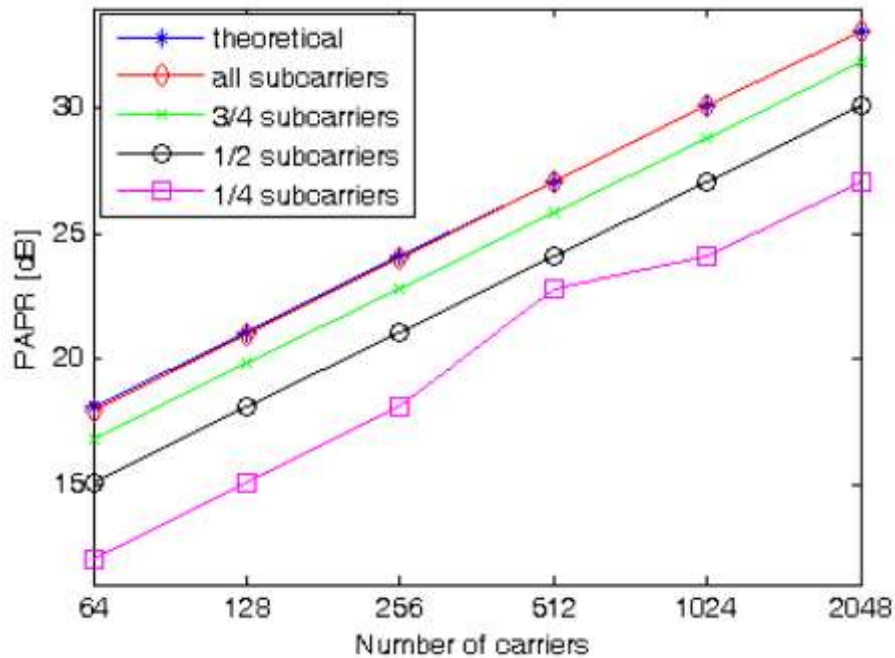


Figure 2.4: Number of subcarriers affect PAPR [30]

2.9 Summary

From this chapter, it can be concluded that high values of PAPR is the problem which is heavily investigated by a lot of researchers in the OFDM field. Many methods could be implemented to reduce peak power value. From past journal, wavelet method and DCT technique produce some significant results in which it reduces the PAPR value as summarized in Table 2.1. For this study, improved wavelet technique with DCT is implemented for further investigation on the effectiveness of PAPR reduction. The