HYBRID PEAK-TO-AVERAGE POWER RATIO REDUCTION IN ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SYSTEM

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To Allah (SWT)
To my beloved mother and my father's memorial
Whose taught me that, life is giving
To my beloved family, especially my wife and my children

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ABSTRACT

Multi-carrier systems based on Orthogonal Frequency Division Multiplexing (OFDM) is a widely-used modulation in wireless communication systems because it enables high throughput data transfer and is robust against frequency selective fading caused by the multipath wireless channel. Nevertheless, OFDM suffers from disadvantages such as high Peak-to-Average Power Ratio (PAPR) and high sensitivity to Carrier Frequency Offset (CFO) which leads to a loss of subcarrier orthogonality and severe system degradation. Thus, a suitable reduction technique should be used in OFDM system to mitigate these drawbacks. Mitigation of the impacts of PAPR and Inter-Carrier Interference (ICI) due to CFO at the OFDM transmitter is the main target of this work. In this work, PAPR and ICI reduction methods are proposed at the OFDM transmitter. Clipping Peaks Amplifying Bottoms (CPAB) method is developed to reduce PAPR, where the negative peaks of the clipped OFDM signal are amplified. However, to reduce further PAPR level, a combination of Partial Transmit Sequence (PTS) with Cascade CPAB (PTS-CCPAB) is proposed. To improve BER performance, a Carrier Frequency Offset (CFO) compensation method is added to the hybrid PTS-CCPAB. The proposed work was conducted in MATLAB simulator using the parameters of Wireless Access Vehicular Environment (WAVE) IEEE 802.11p standard. The hybrid PTS-CCPAB/CFO introduced a PAPR Reduction Gain (RG) of 39% compared to the conventional system. Also, system performance at BER $=10^{-4}$ improved by 12% and 5% over Additive White Gaussian Channel (AWGN) and Rayleigh channels respectively compared to the conventional system. Overall results show that the proposed work is a suitable solution to mitigate the loss of subcarrier orthogonality and system degradation by improving both PAPR and BER performances. The proposed work can be used in most multicarrier wireless communication system.

ABSTRAK

Sistem Pelbagai Pembawa berdasarkan Pemultipleksan Pembahagian Frekeuensi Ortogonan (OFDM) adalah pemodulatan yang digunakan secara meluas dalam sistem komunikasi tanpa wayar kerana ia membolehkan pemindahan data yang tinggi dan teguh terhadap kekerapan pudar terpilih disebabkan oleh saluran pelbagai arah tanpa wayar. Walau bagaimanapun, OFDM mengalami kelemahan seperti Nisbah Puncak-ke-Purata Kuasa (PAPR) dan kepekaan yang tinggi untuk Frekuensi Pembawa Ofset (CFO) yang membawa kepada kehilangan keortogonan subpembawa dan pemerosotan sistem yang teruk. Oleh itu, teknik pengurangan yang sesuai harus digunakan dalam sistem OFDM untuk mengurangkan kelemahan ini. Pengurangan impak PAPR dan Gangguan Antara Pembawa (ICI) disebabkan oleh CFO di pemancar OFDM adalah sasaran utama kerja ini. Dalam kajian ini, kaedah pengurangan PAPR dan ICI dicadangkan di pemancar OFDM. Kaedah keratan puncak dan penguat bawah (CPAB) dibangunkan untuk mengurangkan PAPR, di mana puncak negatif dikuatkan pada isyarat OFDM yang dipotong. Walau bagaimanapun, untuk mengurangkan lagi PAPR, gabungan Sekuen Penghantar Separa (PTS) dengan CPAB bertangga (PTS-CCPAB) dicadangkan. Untuk meningkatkan prestasi Kadar Bit Ralat (BER), kaedah pampasan CFO ditambah kepada hibrid PTS-CCPAB itu. Kerja yang dicadangkan ini telah dijalankan dalam simulator MATLAB dengan menggunakan parameter Capaian Tanpa Wayar dalam Persekitaran Kenderaan WAVE IEEE 802.11p standard. Hibrid PTS-CCPAB/CFO ini memperkenalkan PAPR Reduction Gain (RG) sebanyak 39% berbanding dengan sistem konvensional. Dan, prestasi sistem pada BER = 10^{-4} bertambah sebanyak 12% dan 5% masing-masing dalam saluran Additive White Gaussian Channel (AWGN) dan Rayleigh berbanding dengan sistem konvensional. Keputusan keseluruhan menunjukkan bahawa kerja yang dicadangkan adalah satu penyelesaian yang sesuai untuk mengurangkan kehilangan keortogonan subpembawa dan kemerosotan sistem dengan meningkatkan kedua-dua prestasi PAPR dan BER. Kerja yang dicadangkan ini boleh digunakan dalam kebanyakan sistem komunikasi tanpa wayar pelbagai pembawa.

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LIST OF ABBREVIATIONS

ADC	-	Analogue to Digital Converter
AWGN	-	Additive White Gaussian Noise
BER	-	Bit Error Rate
BPSK	-	Binary Phase Shift Keying
CAPPR		Cascade adaptive peak power reduction
CCDF	-	Complementary Cumulative Distribution Function
CDMA	-	Code division multiple access
CFO	-	Carrier Frequency Offset
CIR	-	Carriers Interference Ratio
CP	-	Cyclic Prefix
CPAB	-	Clipping Peaks Amplifying Bottoms
CCPAB		Cascade Clipping Peaks Amplifying Bottoms
CPRA	-	Constant Phase Rotation Aided
DAB	-	Digital Audio Broadcasting
DAC	-	Digital to Anlage Converter
dB	-	Decibel
DFT	-	Discrete Fourier Transform
DSI	-	Dummy Sequence Insertion
DSP	-	Digital Signal Presses
DSRC	-	Dedicated Short Range Communications
DVB	-	Digital Video Broadcasting
DWT	-	Discrete Wavelet Transform
EMI	-	Environmental Electromagnetic Interference
EVM	-	Error vector Magnitude
FD	-	Frequency Decimation
FDM	-	Frequency Division Multiplexing
FFT	-	Fast Fourier Transform

GI	-	Guard Interval
ICF	-	Iterative Clipping and Filtering
ICI	-	Inter-Carrier Interference
IDFT	-	Inverse Discrete Fourier Transform
IDWT	-	Inverse Discrete Wavelet Transform
IFFT	-	Inverse Fast Fourier Transform
ISI	-	Inter-Symbol Interference
ITS	-	Intelligent Transportation Systems
LTE	-	Long- Term Extension
LUT	-	Look-Up Table
MA	-	Memetic Algorithm
MAC	-	Media Access Control Layer
MBWA	-	Mobile Broadband Wireless Access
MC	-	Multi Carrier
MIMO	-	Multiple Input Multiple Output
ML	-	Maximum Likelihood
MMSE	-	Minimum Mean Square Error
NCI-OSDM		Non-Carrier Interference- Orthogonal Symbols Division Multiplexing
OFDM	-	Orthogonal Frequency Division Multiplexing
OPR	-	Optimal Phase Rotation
P/S	-	Parallel -to- Serial
PA	-	power amplifier
PAPR	-	Peak to Average Power Ratio
PBC	-	Pre-Coding Based Cancellation
PCC	-	Polynomial Cancelation Coded
PHY	-	Physical Layer
PI	-	Performance Improvement
PI /PIS		Pre-code Improvement Spectral
PICR	-	Peak Interference to Carrier Ratio
PN	-	Pseudo Noise
PRC	-	Partial Response Coding
PRCC		Phase Rotated Conjugate Cancellation

PSD	-	Power Spectral Density
PSK	-	Phase Shifting Keying
PTS	-	Partial Transmit Sequence
QAM	-	Quadrature Amplitude Modulation
QPSK	-	Quadrature Phase-Shift Keying
RF	-	Radio Frequency
RG	-	Reduction Gain
RMS	-	Root Mean Square
RS-GBSM	-	Regular-Shaped Geometry-Based Stochastic Model
RSU	-	roadside unit
Rx		Receiver Side
S/P	-	Serial-to-Parallel
SAL	-	the soft amplitude limiter
SC	-	Single Carrier
SD	-	System Degradation
SER	-	Symbol Error Ratio
SFO	-	Sampling Frequency Offsets
SIR	-	Signal to Interference Ratio
SLM	-	Selected Mapping
SNR	-	Signal to Noise Ratio
STO	-	Symbol Timing Offset
TDM	-	Time -Division Multiple
Tx	-	Transmitter Side
UWB	-	Ultra-Wide Band
V2I	-	Vehicle to Infrastructure Communication
V2V	-	Vehicle to Vehicle Communication
WAVE	-	Wireless Ad hoc Vehicular Environment
WLAN	-	Wireless Local Area Network

LIST OF SYMBOLS

$\hat{X}(t)$	-	Complex baseband signal
$b_p[p]$	-	Multipliers PTS subset
$x_n^p(\mathrm{t})$	-	Time domain signal of the pth partition by PTS
A	-	Clipping level
b_n	-	Phase vector
A_r	-	Clipping ratio
B_r	-	Amplifying ratio
B	-	Amplifying level
D_n	-	Data modulated symbols
E_b/N_0	-	SNR per bit
E_s	-	Energy of one symbol
$H(k)$	-	Channel in frequency domain
$h(l)$	-	Channel impulse response
$h(t)$	-	Rayleigh fading function
k	-	Sub-carriers index
L	-	Over-sampling
M	-	Modulation Index
N	-	Total number of sub-carriers
N_{cp}	-	Length of cyclic prefix
N_g	-	Length of Added Cyclic-Prefix
α	-	Roll-off Factor
P	-	Disjoint partitioned
R	-	Received signal
Rx	-	Receiver circuit
Tx	-	Transmitter circuit
Ts	-	Symbol period

σ^2	-	Variance
A_c	-	Sub-carrier amplitude
f_c	-	Carrier frequency
$X[n]$	-	Band-pass OFDM signal in the frequency domain
$x(n)$	-	the discrete-time baseband OFDM signal
$x(t)$	-	the continuous-time baseband OFDM signal
$y(t)$	-	the continuous-time baseband transmitted OFDM signal
$z(n)$	-	Symbol discrete time-domain received signal
$Z[n]$	-	Symbol frequency-domain received signal
$Max\ (x)$	-	Peak of OFDM signal
$E(x)$	-	Average of OFDM signal
λ	-	the time variance of the radio channel
c	-	the velocity of the light
k	-	k^{th} subcarriers
i	-	i^{th} symbols
E_b	-	Energy per Transmitted Bit
E_S	-	Energy per Transmitted Symbol
f_k	-	Subcarrier Frequency Associated with the *k*-th Subcarrier
$E\{.\}$	-	Expectation of a Random Variable
T_s	-	OFDM symbol duration = $T_u + T_g$
T_u	-	IFFT/FFT duration
T_g	-	Guard Interval duration
Δf	-	Sub-carriers spacing = $1/ T_u$
δf	-	Frequency Offset
T_s	-	OFDM symbol duration
W	-	Frequency Domain Gaussian Noise Vector
X	-	Frequency Domain Transmitted Signal Vector
Y	-	Frequency Domain Received Signal Vector
X_k	-	Data Symbol Transmitted on the k^{th} Subcarrier
Y_k	-	Data Symbol Received on the k^{th} Subcarrier
ε	-	Normalized Doppler Frequency
E_b	-	Energy per Transmitted Bit
E_S	-	Energy per Transmitted Symbol

f_k	-	Subcarrier Frequency Associated with the *k*-th Subcarrier
$E\{.\}$	-	Expectation of a Random Variable
$(.)^*$	-	Complex Conjugate
d_k	-	Input data of modulated symbols
α	-	Roll-off Factor
X	-	Input symbol vector
x_p	-	Sub-vector signal

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CHAPTER 1

INTRODUCTION

1.1 Motivation

The spectacular growth of wireless communications has created the demand for the high data rate, reliable communication systems, and spectrally-efficient communication environments. However, it has imposed significant challenges in wireless communications such as high data rate transmission and high mobility of transmitters and receivers which cause frequency and time offsets, and fading channels. Also, perfect Channel State Information (CSI) is not available at the receiver (Ma *et al.*, 2003). Many types of modulation techniques used wireless communication systems such as Orthogonal Frequency Division Multiplexing (OFDM) modem, Code Division Multiple Access CDMA (Munshi & Unnikrishna, 2015), Code Sense Multiple Access (CSMA) (Khairnar & Kotecha, 2013; Munshi and Unnikrishnan, 2015), and Time Division Multiple Access (TDMA) (Lin & Hung, 2014). Among them, OFDM is a multicarrier modulation system and widely-used in the wireless IEEE 802.11p standard communication system (Abdelgader & Lenan, 2014; Prasad, 2004). This popularity of the MC-OFDM technology is due to its robustness against the effect of frequency selective fading channel, simple receiver implementation, and high bandwidth efficiency. OFDM technique used in wireless communication systems such as WAVE IEEE 802.11p, WiFi 802.11a, WiMax IEEE Std 802.16 (2004) (Hiertz *et. al*, 2010), and 4G mobile cellular communication systems, such as Long- Term Extension (LTE) (Jeanette, 2012; Agarwal and Kabita, 2014).

One prominent example of wireless communication systems is the vehicular wireless communication. Recently, effective driver assistance is installed in vehicles, and people and goods are liable for the mobility and the enormous societal costs namely traffic congestion, fatalities, and injuries (Abdel Hafeez, 2012). The vehicular communication network is the main part of the Intelligent Transportation Systems (ITS). ITS allows nearby vehicles to communicate with each other without the dependency on any infrastructure or roadside equipment, and this enables the on-road vehicle to exchange the necessary information to minimise the collision as an example (Al-Khalil *et al*., 2013). For high-quality signals, parameters of IEEE 802.11p Dedicated Short Range Communications (DSRC) standard are adopted (Sur & Bera, 2012). As mentioned, OFDM is a real solution to overcome the impact of the multi-fading channel, appropriate for high data rate on frequency selective channels in a very efficient way, and easy design. However, some issues influence OFDM systems such as Peak to Average Power Ratio (PAPR), Inter-Symbol Interference (ISI), and Inter-Carrier Interference (ICI) problems (Cho *et al.*, 2010; Rohling, 2011). Furthermore, the data streams are modulated and mapped on orthogonal subcarriers. Therefore, many of signals with low bit rates are transmitted in parallel as symbols and frames, instead of one high bit rate signal. Thus, a single digital information stream is divided into multiple data streams and sent simultaneously in time which results in best usage of bandwidth. These systems used the Fast Fourier transform (IFFT / FFT) techniques efficiently for both the transmitter and receiver functions of OFDM modem (Pandy & Sharma, 2014). In short, the orthogonality among subcarriers should be kept by mitigating the effects of PAPR, ICI, and ISI. There are many reduction methods such as insertion pilots and cyclic prefix as an extension to the original OFDM symbol. Nevertheless, many researchers are still focusing in this area to offer solutions with considerations of low cost and easy implementation.

A design challenge of the OFDM transmitter is the comparatively high Peak to Average Power Ratio (PAPR). Because of the large number of sub-carriers, OFDM symbols may have high magnitudes instantaneously. This large magnitude may fall outside the linear dynamic region of a Power Amplifier (PA), resulting in system degradation (or high bit error rate) due to nonlinear distortion. Thus, a suitable PAPR reduction model is required to mitigate the degradation of OFDM transmitter (Uppal and Sharma, 2013). In additional, more improvements are necessary for the system performance by reducing the ICI due to the frequency error offset at the transmitter (Wu & Chung, 2016).

Therefore, to support future communications systems that require high-quality signals, thus focus on OFDM is the best candidate to achieve this goal.

1.2 Background of the Work

Accordingly, tremendous advances, cost limitation, low complexity system design, small size components and devices, large memory, high quality of signals, and accuracy of wireless technologies make the door wide open to develop these technologies in support of advanced vehicular safety applications. In particular, the standard wireless WAVE IEEE 802.11p physical layer system enables a new era of the high system performances which apply OFDM technology. Also, it provides the safety of vehicles applications that increase the overall safety, reliability, and efficiency of the current transport network (Abdel Hafeez, 2012; Zeadally *et al*., 2010).

The mobile nodes are used for broadcasting and multimedia services, and it provides high data rate transmissions because of employing efficient modulation techniques such as OFDM with different modulation types such as quadrature amplitude modulation (QAM) and phase shifting keying (PSK) (Ström, 2013). The chief motivations for using OFDM in modern communication systems are the power amplifier and spectral efficiencies (Al-khalil *et al*., 2013).

However, high PAPR is the biggest problems in OFDM wireless communication. If PAPR is still high, it leads to a low PA efficiency, loss of the orthogonality between sub-carries which is a speciality for OFDM system, degrades the BER performance, high-complexity DAC/DAC (Jiang and Wu, 2008). High PAPR problem occurs at the transmitter side caused by the peak power of the signals up to N times the average power (where N is the number of sub-carriers). Thus, the performance of PAPR reduction technique is directly proportional to the number of subcarriers. So, by the central limit theorem process, peaks of the OFDM signal baseband are randomly summed up statistically. If OFDM symbols are mutually uncorrelated, the peak-to-average power ratio (PAPR) will be high.

It led us to say; that OFDM system is recognised as one of the competent modulation and multiplexing methods for fast propagation of the data; it is suitable to use in all wireless communication systems. Therefore, it should also resolve high PAPR to get high-performance in OFDM system. However, there is always a trade-off between PAPR reduction and other factors (data rate, computational complexity, average power, BER performance, system components, and transmission bandwidth (Cho *et al*., 2010; Rahmatallah,2010; and Shiragapur *et al.*, 2013). The relationship between PA efficiency and PAPR reduction method should be considered because more reduction in PAPR lead to the high BER depends on the selection of the PAPR method (Al-Dalakta, 2012). For that, some PAPR reduction techniques are required optimisation approach to satisfy a balance between PAPR and BER. (Khairnar and Kotecha, 2013).

Lastly, a proposed work has suggested a hybrid method for reducing PAPR by combining a common simple technique such as clipping technique with other techniques. Probabilistic techniques such as PTS technique is the straightforward and capable method of PAPR reduction. Hybrid PAPR reduction schemes have are efficient with distortion-less PAPR reduction technique, but a bit complex than other techniques (Badran and El-Helw, 2011; Li and Qu, 2013; and Li *et al*., 2014).

On the other side, ICI issue is one obstacle in OFDM system discovered through calculating BER. ICI due to Carrier Frequency Offset (CFO) may occur at the transmitter (Yao, 2012), in the channel (Malipatil, 2014) and at the receiver (Chao Zhang, 2011). Thus, high inter-carrier interference (ICI) will destroy the subcarriers' orthogonality quickly (Cheng *et al*., 2013). Sources of ICI is an interference between the closer carriers in one OFDM symbol, interference between carrier with itself due to multipath propagations in the channels, and interference due to overlap between an individual carrier with a new component obtained by another inter-carrier interference at the same time.

Several techniques to mitigate ICI problem are presented by (Armstrong, 1999; Sharma and Joshi, 2007; Alexandru & Onofrei, 2010). For example, CFO estimation/compensation is the most common technique due to its simple application and acceptable performance. Also, performances of the OFDM system are determined by the particular orthogonal properties among OFDM subcarriers.

1.3 Statement of Problem

OFDM modulation technique has been adopted by many wireless communication systems such as WAVE IEEE 802.11p standard to overcome effects of multipath propagation that requires a high-complexity receiver to combat these effects. However, OFDM systems have diverse issues that can influence it such as high PAPR and ICI, if did not correctly handled, will lead to deterioration of system performance according to researchers in this field (Armstrong, 1999; Jaint and Wu, 2008; Rahmatalah, 2010; Mohseni, 2013). Two significant issues have been brought to attention, first; high Peak to Average Power Ratio (PAPR), second; high Intercarrier Interference (ICI) (Al-Dalakta, 2012). High PAPR and ICI problems should be mitigated to improve the quality of OFDM transmitted signal by using a suitable reduction technique.

High PAPR leads to making OFDM signal as complex because it drives power amplifier (PA) into the nonlinear region and causes a high range digital to analogue converter (DAC). When the orthogonal subcarriers are combined through the IFFT process, it is possible that some peaks of those subcarriers are aligned at some point in time and result in a high dynamic range in the output signal (Megha, 2008) to create high PAPR. High PAPR results in high complexity OFDM transmitter because DAC and PA will be a complex and expensive implementation (Wang and Li, 2009). Then, the nonlinearity of PA and frequency errors cause the loss of orthogonality among subcarriers, and hence the ICI appeares in the transmitted signal which results in a high BER. Existing PAPR reduction methods have the ability to minimise PAPR, but another problem of bit error rate (BER) will appear due to some data loss and some frequency error during the signal processing of PAPR reduction at the transmitter. These frequency errors are called CFO at the transmitter which causes ICI. Therefore, if the error still without reducing that it will cause to amplify these frequency errors via PA to transmit OFDM signal with ICI, and thus will lead to an additional problem in the received signal such as high complexity detection (Wu and Chung, 2016). Also, both high PAPR and ICI will influence the data rate, the mobile speed, and on the quality of transmitted signal exactly where the number of subcarriers is high (Ji *et al*., 2012; Al-Dalakta, 2012; Pradabpet, 2013). Therefore, considerations of selecting one method of PAPR reduction are to mitigate system degradation and maintain the complexity.

Many methods have been used to reduce the impacts of high PAPR. However, the simplest and the common PAPR reduction method is the clipping because it has low complexity and easy implementation (Rahmatalah, 2010). However, a nonlinear process which may cause momentary in-band distortion and the clipping threshold will be limited. Also, a further decrease in the clipping threshold leads to decreasing PAPR, but with side effects such as decreasing average power and some data loss which results in system degradation. For that, a new PAPR reduction method is required to get a good PAPR reduction while maintaining the average power and system performance. Although many researchers proposed different techniques to reduce PAPR in OFDM, the achievements which have been done, they did not significantly eliminate the ICI due to CFO and spectral spreading in the OFDM signals. The ICI due to CFO is the disadvantage of signals processing in the OFDM transmitter which may make a limitation on the data rate and on the mobility of transceiver, where the frequency offset errors are high (Park & Song, 2007; Wang & Huang, 2010; Al-Dakalta, 2012; Chitra & Kumaratharan, 2015; Wu & Chung, 2016). For that, a method should be required to mitigate ICI due to CFO in the OFDM transmitter for improving the system performance.

1.4 Objectives of Study

Mitigation of the impacts of PAPR and ICI at the transmitter of the OFDM systems based on the physical layer WAVE IEEE 802.11p standard is the main goal of this work. PAPR and ICI due to CFO should be reduced to ensure a high-performance broadband wireless communication systems. Thus, the specific objectives of the work can be listed as follows,

i. To develop the hybrid model for PAPR reduction in the transmitter of OFDM transmitter.
ii. To develop CFO compensation method to mitigate ICI due to CFO in OFDM transmitter.
iii. To validate the performances of PAPR and ICI mitigation methods in OFDM system.

1.5 Scope of the Study

This study adopted the Physical layer OFDM transmitters using the wireless access vehicular environment IEEE 802.11p standard. However, high PAPR and ICI caused by OFDM transmitters that degrade system performance severely.

PAPR/ICI reduction methods should be used to improve system the performances. Two metrics are used to evaluate the performance of the PAPR reduction methods; Complementary Cumulative Distribution Function (CCDF and Bit Error Rate (BER). On another hand, CCDF, BER and CIR are used to evaluate the ICI reduction method in this work.

In short, the scope of the study is to identify an appropriate technique in alleviating PAPR and ICI issues in the OFDM. It is used in the vehicular communication system by applying advanced algorithms models; the proposal focuses on hybrid technologies approach to reduce the PAPR and ICI due to CFO. The developed mechanism will be based on mathematical algorithm presented in this thesis and simulation work using Matrix Laboratory (MATLAB) software. IEEE 802.11p standard will be used as the best standard that reflects vehicular communication systems.

1.6 Significance of Work

WAVE IEEE 802.11p standard systems are found to be an attractive candidate to support wireless communication systems at high mobility and a high number of subcarriers frequency when using OFDM technique. Also, OFDM systems are robust against effects of wireless channels which is mostly suitable to satisfy these conditions of the time-variation mobile radio channels. However, high PAPR and ICI have an effect on the performances of OFDM system. Thus it is very important to mitigate these problems.

1.7 Contribution of Work

The research work in this thesis will efficiently utilise OFDM systems by proposing models for mitigating PAPR and ICI. The main contributions of this thesis can be stated as follows:

i. Propose a new Clipping Peak and Amplifying Bottom (CBAB) model based on OFDM transmitter for PAPR reduction by adding the amplifying bottom approach to the existing clipping technique. More PAPR reduction using clipping method leads to system degradation, System degradation can be mitigated by using amplifying approach. High PAPR is a challenge and will affect the quality of signals and subcarriers. CCDF is the usual performance metric utilised to evaluate PAPR reduction method.
ii. Propose a new hybrid PAPR reduction model by combining PTS technique with a cascaded CPAB. PTS-CCPAB is used for more PAPR reduction in OFDM symbols in time domain. Then these symbols will be applied to PTS block which consists of sub-blocks. After that, every sub- block will be passed to

CPAB block to clip undesired peaks and amplify the desired bottom. Finally, PAPR and BER performances are displayed and analysed.

iii. Develop CFO compensation model to mitigate frequency errors occurrence which affects the onset of ICI in the OFDM system. Hence, the CFO compensation model was proposed to mitigate ICI due to CFO while maintaining the PAPR reduction level.

The proposed OFDM transmitter equipped with PAPR and ICI reduction is a baseband signal processing approach that can be used in other future wireless communication systems.

1.8 Thesis Outline

The thesis consists of six chapters as follows;

Chapter 1 provides an overview of the research area which covers topics such as the problem statement, research objectives, scope of the work and contributions of work.

Chapter 2 presents a literature review of OFDM principles. Then, a brief review of PAPR and ICI reduction techniques together with its categorization and classification will be discussed. Lastly, research related to this work, its focus and their approaches for reducing PAPR and ICI are given.

Chapter 3 describes how the research will be carried out and the conceptual framework of this research will be presented. The work consists of PAPR reduction methods and followed by ICI mitigation techniques. Clipping Peaks Amplifying Bottoms (CPAB) approach for PAPR reduction is proposed and then followed by the hybrid Partial Transmit Sequence (PTS) Cascade CPAB (PTS-CCPAB) PAPR reduction method. Then, CFO compensation algorithm for reducing ICI is shown. Additionally, performance evaluation parameters to be used in the evaluation and analysis will also be given.

Chapter 4 describes the OFDM transmitter model, and then the simulation is done in MATLAB for the proposed PAPR reduction techniques. The most suitable threshold value will also be identified. Finally, PAPR/BER performances over different channels for both CPAB and PTS-CCPAB schemes will be presented.

Chapter 5 proposes CFO compensation approach to mitigate ICI problem. This chapter will describe and discuss the ICI problem, its effect on frequency offset error. CIR will be used to the determine the amount of offset and hence, can be easily mitigated. PAPR and BER performances will also be discussed.

Finally, Chapter 6 will summarise the work done and followed by recommendations of future works to be done.

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