UNIVERSITI PUTRA MALAYSIA

DETERMINISTIC PHASE SEQUENCE APPROACH FOR PEAK TO AVERAGE POWER RATIO REDUCTION IN ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SYSTEMS

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By

MOHSEN KAZEMIAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

June 2016

DEDICATIONS

This thesis is dedicated to **Dr. Pooria VARAHRAM** who was my previous supervisor, and the current external member of the supervisory committee. His supports are deeply appreciated.

Also, this thesis is dedicated to the only person that I have in the world,
To **my beloved Mother**
For all her encouragements and supports.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman : Assoc. Prof. Shaiful Jahari bin Hashim, PhD
Faculty : Engineering

Orthogonal Frequency Division Multiplexing (OFDM) is the current proposed approach in the several applicable wireless communication standards such as IEEE 802.15.3a, 802.11, and 802.16, and is utilized in the Digital Video Broadcasting (DVB) and European Digital Audio Broadcasting (DAB) systems. Stability against Inter Symbol Interference (ISI) and the high spectral efficiency are represented as the most important advantages of the OFDM system, however high Peak-to-Average Power Ratio (PAPR) is expressed as a major drawback of the mentioned system. When transmitted through a nonlinear power amplifier, this high PAPR signal creates spectral broadening and leads to low efficiency and low battery life; hence, the consumer electronics such as smart phones, tablet PCs and laptops in uplink communications usually are affected by these drawbacks.

Several PAPR reduction techniques have been proposed in the literature such as coding, companding, Tone Reservation (TR), and clipping and filtering. The existing schemes are different from each other in terms of requirements, and the enforced restrictions to the systems. This thesis has studied based on two distortion-less methods called Conventional Selected Mapping (CSLM), and Conventional Partial Transmit Sequence (CPTS) which are two of the most efficient techniques in this research area. In this thesis, a unique idea is proposed and applied in the time domain and frequency domain, separately. Therefore, it needs to be applied based on the CPTS and the CSLM structures, respectively. This approach uses the non-random phase sequences, instead of the random ones as in CPTS and CSLM techniques. The proposed idea reduces the computational complexity, processing time and the side information matrix content, basically and ensures the results. The first proposed method, called Gray Code-based Phase sequence (GCP) is a new low complexity PAPR reduction scheme based on a Gray code structure and a similarity measurement block; included on two steps: firstly, selecting the phase sequences based on Gray codes and finally, evaluating the similarity between the input and the output of the Power Amplifier (PA), among the selected phase sequences in the previous step. By this approach, a significant reduction is provided in terms of the addition and the multiplication operation numbers together with the side information. The last stage is useful to reduce the Bit Error Rate (BER)

performance degradation and out-of-band distortion. Simulations are based on IEEE 802.16e, Quadrature Phase Shift Keying (QPSK) modulation and performed with a power amplifier with memory effects. The proposed method provides a significant PAPR, BER performance degradation and out-of-band distortion reduction at almost the same total complexity compared with the CPTS and the Enhanced PTS (EPTS) techniques. More importantly, it is proved that at the same PAPR reduction value, this scheme provides a complexity reduction of at least 42.3% over that of the EPTS scheme, and leads to the out-of-band distortion reduction.

Additionally, for the second method, the idea is applied on the CSLM scheme. Simplicity of the search algorithm, and the requirement for large numbers of Inverse Fast Fourier Transform (IFFT) blocks are the most important advantage and disadvantage of the CSLM scheme, respectively. The second proposed technique called Low complexity Radix-II SLM (LR-SLM) uses the special structure of an N-point radix-II IFFT in the CSLM method to overcome on the CSLM drawbacks and reduce the redundant calculations which leads to a reduction in terms of computational complexity, processing time and the side information matrix content, while achieving the same PAPR reduction, BER performance, and power spectral density (PSD) results as the CSLM scheme. The simulation results show that the computational complexity is reduced by at least 46.8% compared with the CSLM scheme with approximately the same PAPR performance.

In order to evaluate the effect of these methods in the actual system, the PSD of the output signal when applying the predistortion block and the PA, is provided. The results show that the GCP method improves the PSD of the signal at least 4dB, compared with the CPTS method. Furthermore, it is shown that the PSD of the LR-SLM method does not differ with that of the CSLM.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Doktor Falsafah

PENGURANGAN NISBAH KUASA PUNCAK KEPADA PURATA PEMULTIPLEKSAN PEMBAHAGIAN FREKUENSI ORTOGON SECARA PENDEKATAN FASA JUJUKAN BERKETENTUAN

Oleh

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Jun 2016

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Pemultipleksan pembahagian frekuensi ortogonal (OFDM) adalah pendekatan semasa yang dicadangkan dalam piawaian komunikasi wayarles seperti IEEE 802.15.3a, 802.11 dan 802.16, dan digunakan dalam penyiaran video digital (DVB) dan penyiaran audio digital Eropah (DAB) sistem. Kestabilan terhadap gangguan antara simbol (ISI) dan kecekapan spektrum yang tinggi adalah penting dalam sistem OFDM, bagaimanapun sistem yang dinyatakan mempunyai kelemahan dalam nisbah kuasa puncak-ke-purata (PAPR) yang tinggi. Apabila dihantar melalui penguat-kuasa tidak linear, isyarat PAPR tinggi ini mewujudkan keluasan spektrum yang menyebabkan kecekapan yang rendah dan hayat bateri yang rendah; dengan itu, penggunaan elektronik seperti telefon pintar, komputer tablet dan komputer riba dalam komunikasi pautan naik biasanya dipengaruhi oleh kelemahan ini.

Beberapa teknik pengurangan PAPR telah dicadangkan dalam literatur seperti pengekodan, pengkompaunan, tempahan nada (TR), keratan dan penapisan. Skim-skim yang sedia ada adalah berbeza antara satu sama lain dari segi keperluan, dan sekatan kepada sistem dikuatkuasakan. Tesis ini telah mengkaji berdasarkan dua kaedah herotan-kurang dipanggil pemetaan konvensional dipilih (CSLM), dan konvensional urutan penghantar separa (CPTS) adalah dua teknik yang paling berkesan untuk kajian ini.

Dalam tesis ini, idea yang unik dicadangkan dan digunakan dalam domain masa dan domain frekuensi, secara berasingan. Oleh itu, ia perlu digunakan berdasarkan CPTS dan struktur CSLM. Pendekatan ini menggunakan urutan fasa bukan rawak, selain daripada urutan fasa rawak seperti dalam CPTS dan teknik CSLM. Idea yang dicadangkan mengurangkan kerumitan pengiraan, masa pemprosesan dan maklumat sampingan kandungan matriks, pada dasarnya dan memastikan keputusan. Cadangan pertama adalah urutan fasa kaedah dipanggil Gray Kod berasaskan (GCP) mempunyai kerumitan rendah dalam skim pengurangan PAPR baru berdasarkan struktur kod Gray dan blok merentas korelasi dan disertakan dalam dua langkah: Pertama, memilih urutan fasa berdasarkan Kod Gray dan kedua menilai persamaan antara input dan output penguat kuasa (PA), antara urutan fasa dipilih. Dengan pendekatan ini, nilai

pengurangan ketara disediakan dari segi penambahan dan nombor operasi pendaraban bersama-sama dengan maklumat sampingan. Peringkat terakhir adalah berguna untuk mengurangkan kadar ralat bit (BER) dan kemerosotan prestasi dari segi out-of-band distorsi. Simulasi adalah berdasarkan kepada IEEE 802.16e, anjakan fasa kuadratur menaip (QPSK) modulasi dan dilaksanakan dengan penguat kuasa dengan kesan ingatan. Kaedah yang dicadangkan mengurangkan PAPR secara ketara, kemerosotan prestasi BER, herotan out-of-band dan pengurangan gangguan. Kompleksiti yang sama berbanding dengan CPTS dan teknik-teknik PTS Dipertingkat (EPTS) telah direkodkan. Lebih penting lagi, ia membuktikan bahawa pada PAPR nilai pengurangan sama, skim ini menyediakan pengurangan kerumitan sekurang-kurangnya 42.3% berbanding skim EPTS, dan membawa kepada pengurangan out-of-band herotan.

Selain itu, untuk kaedah kedua, idea digunakan pada skim ini ialah CSLM. Kesederhanaan algoritma carian, dan keperluan untuk jumlah besar blok pengubah pantas Fourier songsang (IFFT) mempunyai kepentingan dan kelemahan, masing-masing dalam skim CSLM. Teknik yang kedua dicadangkan dipanggil kerumitan Rendah Radix-II SLM (LR-SLM) menggunakan struktur khas N-titik radiks-II IFFT dalam kaedah CSLM untuk mengatasi kelemahan CSLM dan mencadangkan satu kaedah baru untuk mengurangkan pengiraan berlebihan yang membawa kepada pengurangan dari segi kerumitan pengiraan, masa pemprosesan dan sampingan kandungan matriks maklumat, dan juga mencapai pengurangan dari segi PAPR, prestasi BER, dan ketumpatan kuasa spektrum (PSD). Keputusan simulasi menunjukkan bahawa kerumitan pengiraan dikurangkan sebanyak 46.8% berbanding dengan CSLM dengan prestasi PAPR yang sama.

Dalam usaha untuk menilai kesan kaedah ini dalam sistem sebenar, PSD isyarat luaran disediakan apabila blok pra-herotan dan PA digunakan. Hasil kajian menunjukkan bahawa kaedah GCP meningkatkan prestasi PSD sekurang-kurangnya 4dB, berbanding dengan kaedah CPTS itu. Tambahan pula, ia menunjukkan bahawa kaedah prestasi LR-SLM tidak berbeza dengan CSLM dari segi PSD.

ACKNOWLEDGEMENTS

I would like to acknowledge my supervisor **Assoc. Prof. Dr. Shaiful Jahari bin Hashim** for his guidance, assistance and encouragements. His kind help and supports are deeply appreciated and I wish the best of luck in his life.

I deeply thank my previous supervisor **Dr. Pooria Varahram**, who provided a perfect guidance and a calm situation during my education. Without his encouragement, I would not have finished this degree.

I would like to appreciate **Prof. Dr. Borhanuddin bin Mohd Ali** because of his kind guidance, helps, and supports. He has helped me in the critical situations, and I am indebted to him.

I am grateful to **Dr. Che Ahmad Bukhari Che Ujang** and the assistance of the Engineering faculty staffs, are also appreciated.

Finally, my gratitude is expressed to my mother, because of her understanding and supports during my life.

I certify that a Thesis Examination Committee has met on 30 June 2016 to conduct the final examination of Mohsen Kazemian on his thesis entitled "Deterministic Phase Sequence Approach For Peak To Average Power Ratio Reduction In Orthogonal Frequency Division Multiplexing Systems" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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Declaration by graduate student

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ACE	Active Constellation Extension
ACI	Adjacent Channel Interference
ACLR	Adjacent Channel Leakage Ration
ACPR	Adjacent Channel Power Ratio
ADC	Analogue to Digital Converter
A-LTE	Advanced Long-Term Evolution
AM-AM	Amplitude Modulation to Amplitude Modulation
AM-PM	Amplitude Modulation to Phase Modulation
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
CA	Complex Addition
CALLUM	Combined Analogue Locked Loop Universal Modulator
CCDF	Complementary Cumulative Distribution Function
CCRR	Computational Complexity Reduction Ratio
CDMA	Code Division Multiplexing Access
CGMP	Complex Gain Memory Predistortion
CM	Complex Multiplication
CPTS	Conventional Partial Transmit Sequence
CSLM	Conventional Selected Mapping
CT	Companding Transform
DIF	Decimation in Frequency
DMT	Discrete Multi-Tone
DPD	Digital Predistortion
DSI	Digital Signal Insertion
DSP	Digital Signal Processing
DVB	Digital Video Broadcasting
EGCP	Enhanced Gray Code-based Phase
EVM	Error Vector Magnitude
FDM	Frequency Division Multiplexing
FFT	Fast Fourier Transform
FPGA	Field Programmable Gate Array
GCP	Gray Code-based Phase sequence
HDTV	High-Definition Television
IBO	Input Back Off
IDFT	Inverse Discrete Fourier Transform
IFFT	Inverse Fast Fourier Transform
IO	Input Output
IP3	3rd Order Inter point
ISI	Inter Symbol Interference
LINC	Non-Linear Component
LNA	Low Noise Amplifier
LR-SLM	Low complexity Radix-II Selected Mapping
LTE	Long Term Evolution
LTE-A	LTE-Advanced
LUT	Look-Up Table
MCM	Multicarrier Modulation
MIMO	Multi Input-Multi Output

MISO	Multi Input-Single Output
OFDM	Orthogonal Frequency Division Multiplexing
PA	Power Amplifier
PAE	Power Added Efficiency
PAPR	Peak-to-Average Power Ratio
PDF	Probability Density Function
PSD	Power Spectral Density
PTS	Partial Transmit Sequence
QPSK	Quadrature Phase Shift Keying
RA	Real Addition
RAM	Random Access Memory
RF	Radio Frequency
RM	Real Multiplication
S/P	Serial to Parallel Conversion
SC-FDMA	Single Carrier Frequency Division Multiplexing Access
SISO	Single Input-Single Output
SIMO	Single Input-Multi Output
SLM	Selected Mapping
SNR	Signal to Noise Ratio
SSPA	Solid-State Power Amplifier
TE	Transmission Efficiency
TOI	Third Order Intercept point
TR	Tone Reservation
UWB	Ultra-Wide Band
VHDL	Very high speed integrated circuits Hardware Description Language
VLSI	Very-Large-Scale Integration
VSA	Vector Signal Analyzer
Wi-Fi	Wireless Fidelity
WCDMA	Wideband Code Division Multiple Access
WIMAX	Worldwide Interoperability for Microwave Access

CHAPTER 1

INTRODUCTION

1.1 Background

The world is now going mobile. Full communication of the people all over the world is the most important topic of the mind. Therefore, wireless communication is known as an important area of research that deserves superlative attention. In the primary technologies the communication was performed by frequency allocation for each subcarrier. Due to the limitation in the frequency bandwidth, few of the people were able to communicate. Multicarrier transmission provides use of the same frequency for many users. Orthogonal Frequency Division Multiplexing (OFDM) [1] which has been used in several wireless telecommunication systems such as IEEE 802.16, 802.11, 802.15.3a, 802.20, Broadcast Radio Access Network (BRAN) committees and European Telecommunications Standards Institute (ETSI) is the most useful technology in multicarrier transmission. It has been standardized as the European Digital Audio Broadcasting (DAB) and the Digital Video Broadcasting (DVB) [2] systems. It has also been proposed for the 3rd generation of the European mobile radio standard [3], [4].

The efficient spectral bandwidth in the OFDM signal comes from multiplexing a data stream into the wide number of orthogonal subcarriers. The recent advancement of the digital signal processing technology makes OFDM as an acceptable and interesting technique. An OFDM-based system can be the most attractive system for wireless applications, because of some reasons such as providing the efficient spectral bandwidth, robustness against interference, resistance against the multipath fading and no need to equalizers [5]. Supporting more subscribers because of a special condition named as orthogonality, and the efficient hardware implementation due to use of the Fast Fourier Transform (FFT) technique, are the other OFDM benefits [6] [7].

The Worldwide Interoperability for Microwave Access (WIMAX) technology based on IEEE 802.16e has been considered in this thesis [8]. OFDM is the main part of physical layer in the WIMAX technology and also is extended in LTE and LTE-Advanced (LTE-A) technologies, as well. Therefore, a deep research on the OFDM system to improve its technology is an important research area.

The OFDM technology and one of its most important drawbacks called Peak-to-Average Power Ratio (PAPR) are discussed in this chapter. PAPR reduction is the main target of this thesis.

1.1.1 OFDM History

The idea of parallel data transmission based on Frequency Division Multiplexing (FDM) was proposed in the 60s [9]. OFDM has been studied for high-speed modems in the 1980s, multi user mobile systems, high-density recording and digital mobile communications [10] [11]. In 1990s, OFDM has been applied for several wideband data communications over radio FM channels, High-bit-rate Digital Subscriber Lines (HDSL, 1.6 Mb/s), Asymmetric Digital Subscriber Lines (ADSL, 1,536 Mb/s), Very High-speed Digital Subscriber Lines (VHDSL, 100 Mb/s), Digital Audio Broadcasting (DAB) and High-Definition Television (HDTV) terrestrial broadcasting [12].

Discrete Multi-Tone (DMT), multichannel modulation and Multi-Carrier Modulation (MCM) are mostly used in telecommunication applications and replaceable with OFDM [13]. MCM and OFDM are a little different. In OFDM, each carrier should be orthogonal to all the other carriers when this property is not always required in MCM. Therefore, OFDM is an optimal multicarrier transmission scheme [14]. Weinstein and Ebert proposed a method to apply the Discrete Fourier Transform (DFT) into a parallel data transmission system as one part of the modulation and demodulation systems [15]. Therefore, a serious drawback of the OFDM approach, was the large size of DFT/FFT, which leads to the high complexity and high processing time. In the following, we describe an OFDM system and its components, briefly.

1.1.2 OFDM System

The OFDM transmitter and receiver is shown in Figure 1-1. An OFDM signal is a high data rate signal hence, it should be divided into low data rate signals. Pilot sequences are the unmodulated data which should be inserted in the data sequence [11]. Pilots are used for synchronization and channel estimation purposes to improve the channel capacity and use to track the residual phase error [16].

The most important part of the OFDM system is Inverse FFT (IFFT) block in the transmitter and FFT in the receiver side. IFFT causes the orthogonality phenomenon in the OFDM system. The orthogonality prevent from the overlapping and cross talking in the multicarrier multiplexing systems.

In order to decrease the Inter Symbol Interference (ISI), the last portion of the signal after the IFFT block, is copied to the head of the signal called Cyclic Prefix (CP). The error coding technique and equalization should be applied to neutralize the fading in the communication channel. The fading arises from either reflection or obstruction of the path between transmitter and receiver. By converting to the analogue signal and up-converting, the signal leads through the communication channel. The receiver procedures should be performed inversely of those performed for the transmitter. (see Figure 1-1). More descriptions are provided in section 2.2.

A good knowledge on the propagation study is required to design an applicable OFDM system. Because, the essential condition for designing the OFDM system is that the bandwidth occupied should be greater than the correlation bandwidth of the fading channel. OFDM has the ability to randomize the errors caused by Rayleigh fading, effectively. So, instead of several adjacent symbols being completely corrupted, many symbols are only distorted, slightly. OFDM divides a channel bandwidth into many narrow sub-channels.

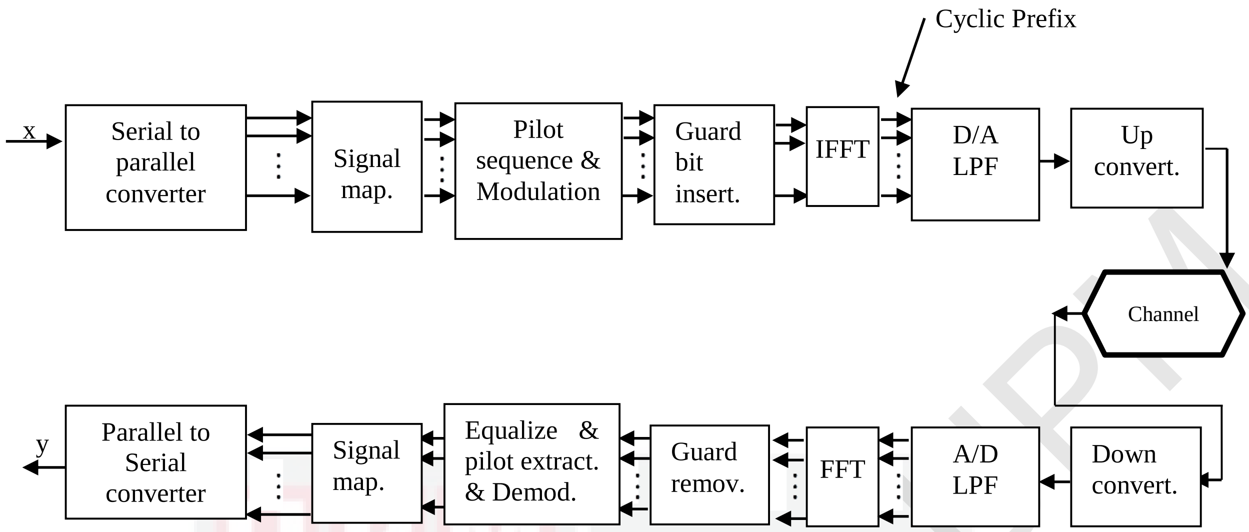

Figure 1.1: Block Diagram of an OFDM System in Terms of Transmitter and Receiver

Hence, the frequency response of each separate sub-band is relatively flat and each subchannel covers only a small fraction of the original bandwidth. A simple equalization algorithm can minimize mean-square distortion on each subchannel.

Receiving some bits in error and the majority of them correct, is because of the selective fading. Selective fading distributes the data over many carriers. Correcting many or all of the bits that were incorrectly received is possible, by using an error-correcting code, which adds additional bits at the transmitter named as channel coding. There are various coding techniques in the transmitter. One of the famous ones is Hamming coding. After the channel coding process, the missed data is corrected [17].

1.1.3 Orthogonality in OFDM

The "orthogonal" word in the OFDM, shows that there is an accurate mathematical correlation between the frequencies of the subcarriers in the OFDM system. In a normal FDM system which is the 1st mobile generation, the carriers are distanced in the frequency domain together with a guard band between each channel. In such receivers, guard bands have to be located between the different carriers, when setting the guard bands results into the reduction of the spectrum efficiency and the usage of the available bandwidth. Furthermore, because of the bandwidth limitation, a low number of subcarriers are able to be transmitted. While in the orthogonal FDM a high number of subcarriers can be transmitted by a shared frequency band and no overlapping happened as shown in Figure 1-2. Therefore, the number of subcarriers increased, without the cross talking phenomenon.

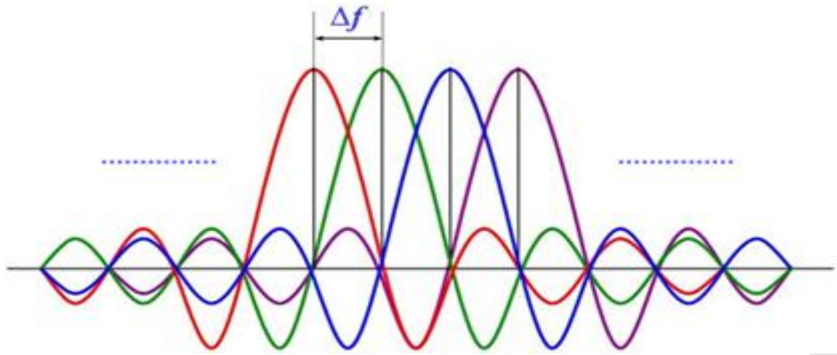

Figure 1.2: The Orthogonal Subcarriers of the OFDM Systems in the Frequency Domain without Overlapping

1.1.4 Fast Fourier Transform

The Fourier transform is a kind of transform operations in the mathematical science which changes the events in the time domain to the ones in the frequency domain. There are various versions of the Fourier transform. FFT is an algorithm to calculate the Discrete Fourier Transform (DFT) operation, quickly. Fourier analysis converts time (or space) to frequency and vice versa; hence the FFTs are developed and enhanced form of DFTs and widely used for many applications in engineering and mathematics. The most generally used FFT is the Cooley Tukey algorithm. This algorithm breaks down a DFT of size $N = N_1N_2$ into many smaller DFTs of sizes N_1 and N_2. The various types of FFT are radix-2, radix-4, mixed-radix and split-radix. [18].

1.1.5 Peak-to-Average Power Ratio Reduction (PAPR)

OFDM signal, is the superposition of a high number of sub channels. Therefore, it may produce a high signal peak with respect to the average signal level. This high peak is measured by a metric called crest factor which shows the ratio of peak values to the effective value. PAPR is the square of the crest factor. When expressed in decibels, crest factor and PAPR are equivalent. This high PAPR leads to the degradation of OFDM performance in the nonlinear power amplifier (PA) [19] and some undesirable effects on the consumer electronics such as; low battery life, low efficiency and the costly implementations. Therefore, in order to prevent spectral growing of the multicarrier signals, the power amplifier in the transmitter part of the telecommunication system have to be operated in its linear region. Since the linear amplifiers are expensive, the linearization techniques are inevitable. Although, the predistortion techniques aim to linearize the nonlinear amplifiers, the desired linear region cannot only be provided by them. Hence, the PAPR reduction block is necessary to reduce the envelope of the input signal and provide a wider linear region. In many low-cost applications, the drawback of high PAPR may void all the advantages of the multicarrier transmission systems. In the following, the most efficient PAPR reduction techniques are introduced.

1.2 Related Works

Various PAPR reduction techniques have been proposed in the literature. Some of them are based on the previous works [20] [21]. PAPR reduction methods can be categorized in two groups. Distortion-based and distortion-less methods. After applying distortion-based methods, out-of-band distortion will happen; whereas distortion-less methods do not create the out-of-band distortion in the output of OFDM signals. Clipping [22] and companding [23], are distortion-based techniques, and conventional partial transmit sequence (CPTS) [5], conventional selected mapping (CSLM) [24] [25], interleaving [26] and coding [27] [28] are some of the distortion-less techniques. A complete explanation of the relevant techniques is provided in chapter 2. Clipping as the simplest technique for PAPR reduction, limits the peak envelope of the input signal to a predefined value. The drawback of this method is in-band and out-of-band distortion due to generation of a noise in its procedure.

The coding method is based on the selection of the code words which minimize the PAPR for transmission [29] [30]. The most important distortion-less techniques are CPTS and CSLM which are the basis of this thesis. CSLM and CPTS multiplies the random phase sequences to the input signal in the frequency and time domain, respectively. Hence, a deep study and improvement on both of these methods, are necessary. The high computational complexity, high processing time, no confidence in the results, and need to send a large side information [31], are the shared drawbacks of the mentioned methods.

We have found that most of these problems can be solved by the arranged phase sequences idea which is described in chapter 3 and 4.

The PAPR reduction method have to consider the non-linearity property of the PA. There are some techniques to linearize the PA [32]. Some techniques like cross-correlation [33] and Input Back Off techniques (IBO) [34] try to keep the signal in the linear region of the PA but they are not the efficient techniques, because they reduce the output power of the amplifier. The other techniques such as feed forward, Cartesian feedback [35] and digital predistortion (DPD) [36] techniques allow the signal to work in the nonlinear region, when the nonlinearity drawback is solved by those techniques. In this thesis the proposed methods are tested with DPD, and a memory effect PA to evaluate the actual result in the OFDM system.

1.3 Problem Statement

This study discusses on the PAPR drawback in OFDM-based wireless systems which leads to the OFDM performance degradation in the nonlinear power amplifiers. High PAPR causes low efficiency communication, out-of-band distortion, in-band distortion, low battery life, and costly consumer electronics [37]. There are several methods to reduce the PAPR in literature such as; CPTS, CSLM and their modified versions. In order to solve the drawbacks of the recent methods, this thesis investigates the high PAPR problem in the OFDM systems. In particular the following problems have been addressed through this thesis.

1. The CPTS method uses the feedback procedure and generally 4 IFFT blocks to reduce the PAPR value of the OFDM system. Therefore, high computational complexity and processing time are the drawbacks of the CPTS scheme and its modified versions such as EPTS [38]. Additionally, due to the random phase sequences approach, CPTS method suffers from large side information and no confidence in the results

2. Although the CSLM method does not use the feedback procedure, high IFFT block numbers are needed to reduce the PAPR in this scheme. This concept leads to a high number of calculations, high computational complexity and high processing time. Same as above, large side information and no confidence in the results are the other drawbacks of the CSLM method.

3. Due to the non-linearity region of the PA, the output signal of the CPTS structure includes the out-of-band distortion. Spectral spreading phenomenon leads to efficiency degradation.

1.4 Thesis Objectives

In order to meet the requirements of a multicarrier transmission system such as low cost, long battery life, low BER degradation performance, and maximum PA linearity and efficiency, a comprehensive and efficient PAPR reduction technique is needed to be applied in recent wireless technologies. This study aims to provide these three objectives; which are listed below:

1. To design a new structure based on Gray codes and a similarity measurement block to reduce the computational complexity, processing time and the side information, improve the BER performance and suppress the out-of-band distortion in the CPTS method. Additionally, the proposed phase sequence is able to provide the confidence in the results.

2. To propose an approach to eliminate the redundant calculations of the IFFT block to reduce the computational complexity, processing time, the side information compared with the CSLM and the modified versions.

3. To integrate the proposed methods with the DPD and the PA block to evaluate the final PSD behavior.

1.5 Scope of Thesis

Having laid out the background and the main research problem, in this section we explain the scope of this study. Figure 1-3 illustrates some of the important blocks in the OFDM transmitter. This study is focused on the PAPR reduction block which is highlighted in Figure 1-3, however DPD and the PA are integrated to the proposed PAPR reduction techniques to evaluate the final PSD.

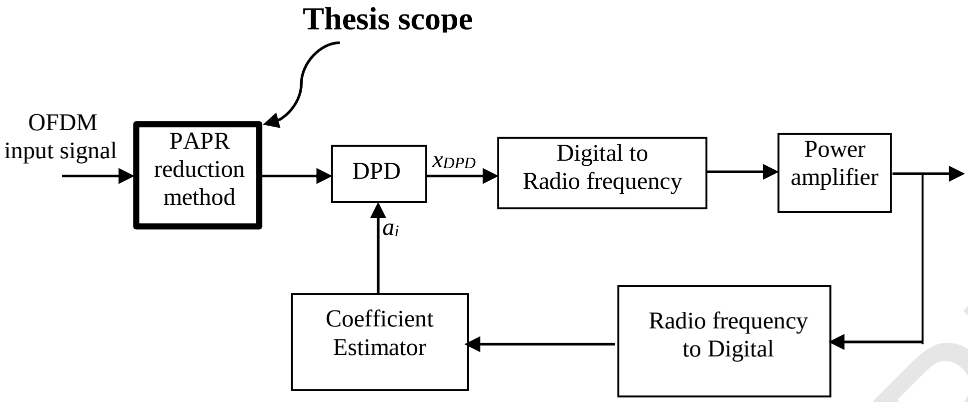

Figure 1.3: Block Diagram of an OFDM Transmitter

The proposed structures can be used in any multicarrier systems which are based on OFDM; such as WIMAX, LTE and LTE-A technologies. This study is applied in the WIMAX network. CPTS and CSLM are the most efficient methods in this area which have their own advantages, disadvantages and applications. CPTS works in the time domain and CSLM works in the frequency domain. Since, each of them has its related particular applications and enforces some restrictions to the system, enhancement of each of them is necessary in this research area. This study decides to solve the drawbacks of these two methods and their modified versions. We can provide this target with an enhancement in the phase sequences [39] [40].

1.6 Summary of Research Methodology

This study is based on replacing the random phased sequences of the mentioned methods with the non-random ones. By this approach the problems such as side information drawback and no assurance in the results can be solved. Additionally, by eliminating the repetitive calculations, the low computational complexity and the low processing time advantages can be achieved, significantly. Therefore, a *unique* idea is applied to CPTS and CSLM schemes and creates two novel techniques. Obviously, two different structures are needed. According to Figure 1.4, stages 1 and 2 are related to the 1st novel method called Gray Code Phase sequence (GCP)/Enhanced GCP (EGCP) which is based on CPTS method and the stages 1' and 2' are pertained to the 2nd method, based on CSLM scheme, called Low complexity Radix II SLM (LR-SLM). Stage 3 is the final stage which is used for both of them. Designing a new phase sequence using Gray codes [41] instead of the random phase sequences in the time domain is the 1st stage of the GCP method. Considering this idea, the CPTS drawbacks such as high complexity, high processing time [38], large side information as well as uncertainty of the results will be solved.

By using a similarity measurement block in the 2nd stage, the BER degradation performance and the out-of-band distortion of the output OFDM signal, are reduced. In the CSLM, the phase sequences are multiplied by the OFDM signal in the frequency domain, therefore we need to apply our idea inside the IFFT block. Therefore, a novel method using Radix-II structure of the IFFT block is proposed. Stage 1' points to a new location of the input samples X' and the stage 2' refers to the new proposed phase sequence.

This approach eliminates the redundant inner calculations of the IFFT block, and leads to solving the mentioned drawbacks.

Finally, at the 3rd stage, the signal is passed through a DPD block and the PA. The metrics such as Complementary Cumulative Distribution Function (CCDF), BER, Power Spectral Density (PSD) and Computational Complexity Reduction Ratio (CCRR) to evaluate the PAPR reduction value, BER degradation performance, out-of-band distortion and computational complexity are calculated, respectively. Figure 1-4 illustrates the study flow of this thesis

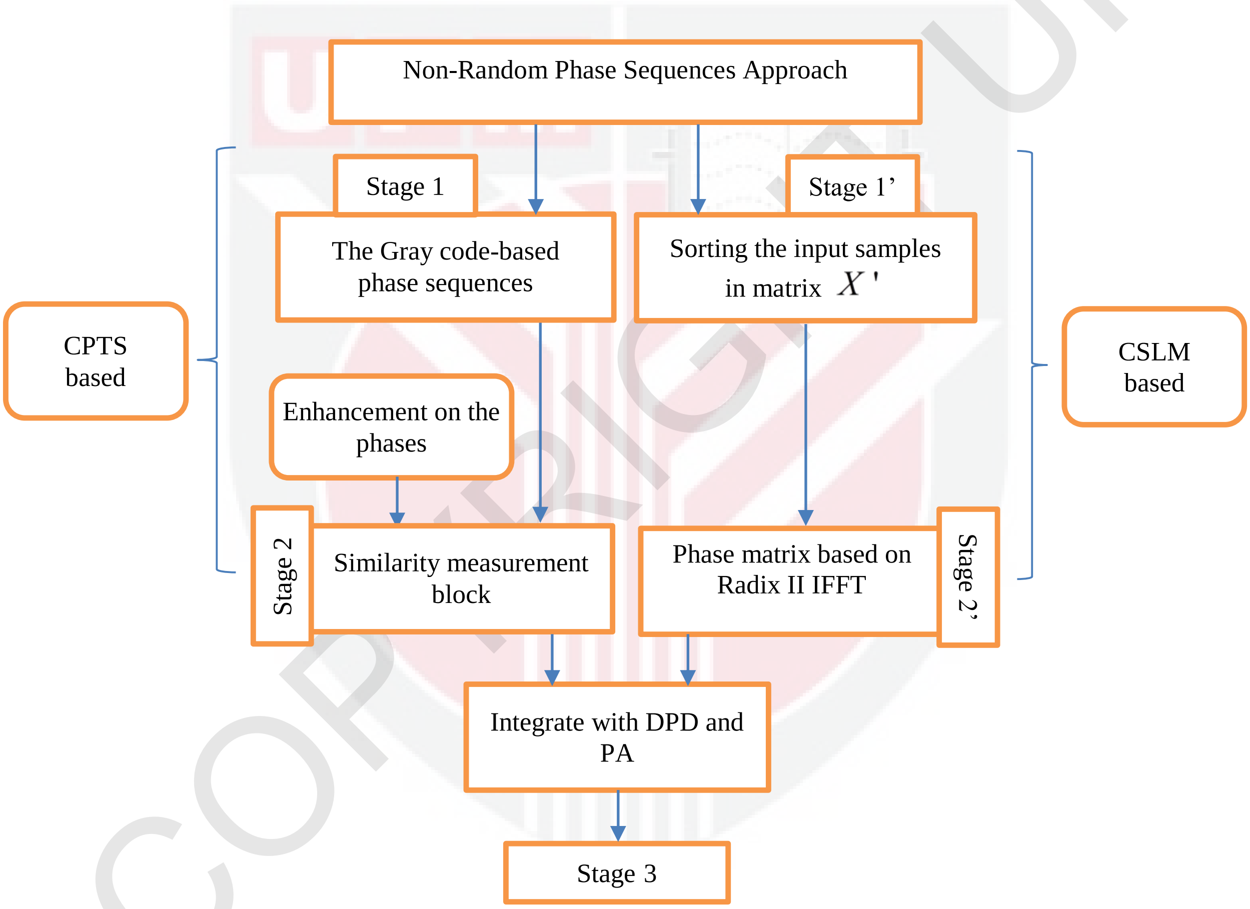

Figure 1.4: Methodology Stages

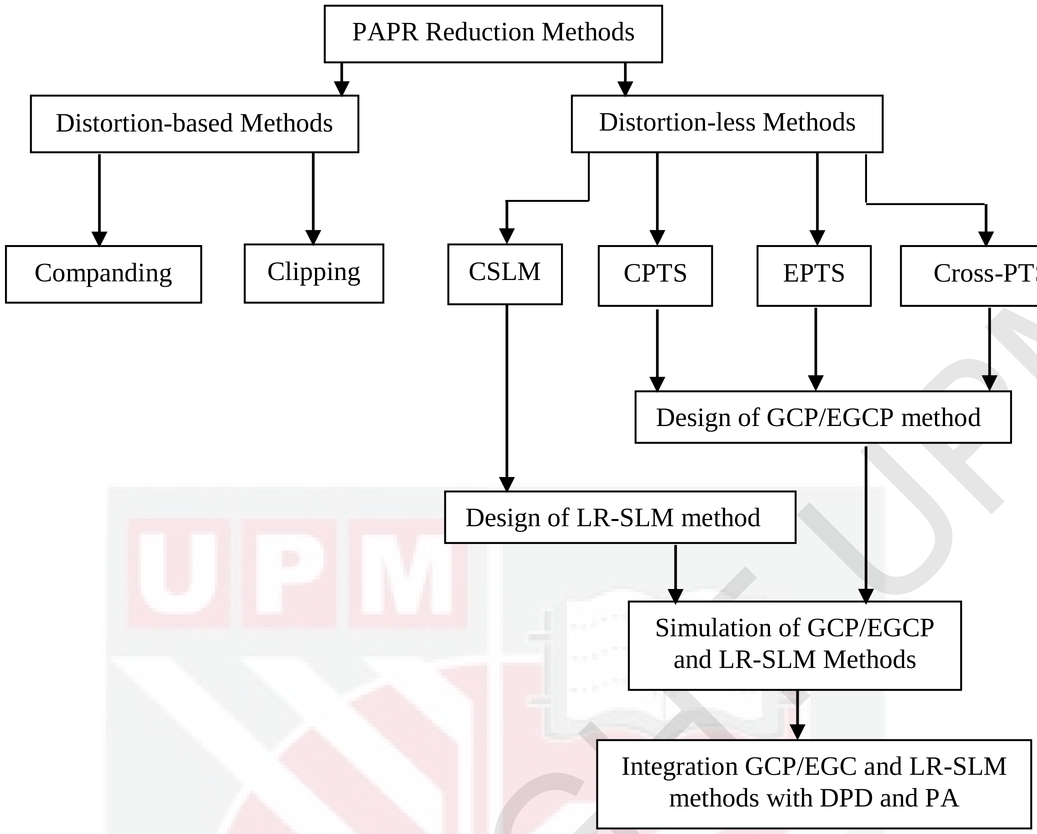

Figure 1.5: The Study Flow

1.7 Thesis Contributions

In this section we present the major contributions that resulted from our research. These contributions are discussed in chapters 3 and 4, in detail. Major contributions which totally includes; proof of the weakness in the recent methods, evaluation of the amplifier characteristics in order to simulate a full OFDM structure, and the novel and efficient techniques (in the time domain and the frequency domain) for PAPR reduction in the OFDM systems are listed as follows:

1) Designing a new phase sequence using Gray codes in the PTS method.

In order to reduce the computational complexity and processing time in the PTS method, a new phase sequence based on Gray code is proposed. Gray code is a pre-arranged phase sequence. Using this code, the calculations related to each stream can be achieved based on its previous one.

2) Reducing the BER degradation performance and the out-of-band distortion.

To improve the PTS method in terms of BER and PSD, a serial combination of the similarity measurement block is proposed. Through this approach, the optimized signal with the most similarity between the input and the output of the PA, is selected.

3) Significant reduction of the calculations in the CSLM scheme.

A new method called LR-SLM is proposed to improve the SLM method in terms of complexity, processing time and side information.

Table 1.1: Problem statements, objectives and the contributions

<table>
<tr><th rowspan="2">Problem statement</th><th colspan="2">Objectives</th><th colspan="2">Contributions</th></tr>
<tr><th>Time domain</th><th>Frequency domain</th><th>Time domain</th><th>Frequency domain</th></tr>
<tr><td>High complexity</td><td rowspan="7">To design a novel structure using Gray codes and similarity measurement block together with applying the predictability property in the proposed phase sequences.

To integrate the proposed method with the predistorted PA.</td><td rowspan="7">To propose an approach on the inner IFFT calculations to eliminate the redundant ones together with applying the predictability property in the proposed phase sequences.</td><td rowspan="2">Designing a new phase sequence using Gray codes. Each iteration is calculated by using the previous one, leads to reducing the complexity and the processing time, significantly (at least 42.3%)</td><td rowspan="2">Proposing the LR-SLM method which reduces the inner IFFT calculations, leads to reducing the complexity and the processing time, significantly (at least 46.8%)</td></tr>
<tr><td>High processing time</td></tr>
<tr><td>No assurance in the results</td><td colspan="2" rowspan="2">By proposing the non-random phase sequences, the results are ensured. Furthermore, the drawback of sending the large side information is solved.</td></tr>
<tr><td>Large side information</td></tr>
<tr><td rowspan="2">BER degradation</td><td colspan="2">Integrating with the PA and DPD</td></tr>
<tr><td rowspan="2">The new structure using similarity measurement, is able to improve the BER performance (about 1 dB) and suppress the out-of-band distortion (at least 4dB)</td><td rowspan="2">It is proved that the LR-SLM method does not affect the PSD and the BER performance of the SLM scheme</td></tr>
<tr><td>Spectral spreading</td></tr>
</table>

This method works on the inner IFFT calculations and prevents the repetitive ones by saving the required calculations.

4) Improving the side information transmission in the PTS and SLM methods.

By proposing the non-random phase sequences, the problem of transmitting the random phase sequences, which is known as side information is solved. By this approach, only the number of the proposed matrix row, is adequate to transmit to the receiver. Additionally, deterministic phase sequence approach provides the confidence in the results.

5) Integrate the GCP and LR-SLM methods with a nonlinear PA and DPD.

In order to evaluate the performances of the proposed methods on the out-of-band distortion problem and maximize the power efficiency, the proposed methods are integrated with the DPD and PA. It is found that, the GCP is able to suppress the out-of-band distortion, while LR-SLM does not affect the PSD of the OFDM signal.

Table 1-1 defines the problem statements, objectives and the contributions of this study.

1.8 Thesis Organization

Outline for the rest of the thesis is as follows:
We conduct a comprehensive survey on the earlier PAPR reduction methods in chapter 2 and this is followed by the investigation into their drawbacks, in detail. Additionally, a brief introduction of the PAPR problem, is provided at the beginning. This thesis is based on a unique idea to solve the mentioned drawbacks by the specified phase sequences. Chapters 3 and 4 are based on embedding the proposed idea in the time domain and the frequency domain, respectively. Therefore, the GCP scheme as the first proposed method and the related analysis are provided in chapter 3, and the second proposed method called LR-SLM is described in chapter 4. The results and discussions are based on the vital parameters in the OFDM systems such as; computational complexity, PAPR, BER, side information and, so on. Chapter 5 presents the integration of the proposed methods with the power amplifier and the DPD block and the output spectrums are evaluated.

Chapter 6 provides a summary of the overall thesis, summary of contributions and future works. We highlight the contributions of this research in detail and provide several future directions that could be taken.

1.9 Summary

This chapter provided the basic background, related works, problem statement, thesis objectives, the methodology, and the contributions of this thesis. With the foundation of the research laid out, next chapter will provide a thorough review of the previous PAPR reduction methods that are addressed.

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