الجمهورية الجزائرية الديمقراطية الشعبية
People’s Democratic Republic of Algeria
وزارة التعليم العالي والبحث العلمي
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DEPARTEMENT OF ELICTRONICS

Master Dissertation

DOMAINE: Science and Technology

FIELD: Telecommunication

OPTION: Telecommunications Networks

Presented By:

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THEME

PTS technique without number of searches to reduce the PAPR of CP-OFDM signal used in fifth generation wireless communication

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Publicly defended in front of the jury composed of:

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Academic Year 2021/2022

ACKNOWLEDGEMENT

All our praise and thanks to ALLAH for giving us the determination, strength and the courage to complete this work.

First of all, we would like to express our deep gratitude to our esteemed humble supervisor, **Dr.MERAH HOCINE**, who has always been available and who has enlightened us with his advice and guidance, and for the efforts he has made throughout this work.

We take this opportunity to express our gratitude to all the members of the jury for having been so kind as to examine this work.

Our thanks also extend to our dear parents whose courage gave us a chance for a better life, for their support, trust, generosity and their precious advices, which have enlightened us in the accomplishment of this work.

Finally, our gratitude and our heartfelt thanks to all those who have contributed from near and far and in particular the academic staff of department of Electronics University Amar Telidji Laghouat.

DEDICATION

This work is dedicated to our loving parents for always supporting and loving us, for giving all our needs during all our lives especially while doing this work.

To our friend "SAILAA AHMED CHAIB" who left us last year. To his pure soul, we are so grateful of everything you did for us, your memoires will always last in our hearts, May you rest in peace.

Abstract

Orthogonal frequency division multiplexing (OFDM) is well-known scheme and an emerging technology in wireless communication system, it’s a multi-carrier transmission for 5G networks, which has recently become a preferred choice for parallel-data-transmission which reduces the influence of multipath fading and avoids the use of complex equalized block. However, these modulations suffer from a large variation in time signal amplitudes, resulting in high Peak to Average Power Ratio (PAPR), which causes distortions in the time signal generated at the output of the High Power Amplifier (HPA).Several techniques has been studied of PAPR reduction such us, Clipping & Filtering, Selective Mapping (SLM), Partial Transmit Sequence (PTS), Tone reservation (TR) are some of the techniques which minimizes the PAPR. In this work we based on Partial Transmit Sequences (PTS) method using different number of sub-blocks, in this dissertation discusses a novel low complexity Partial Transmit Sequence (NEW-PTS) technique which has been proposed by the researchers for peak to average power ratio (PAPR) reduction in orthogonal frequency division multiplexing (OFDM) systems, in addition we propose a new PTS method to reduce the PAPR without number of searches. It’s based on new-pts to reduce the computational complexity by decreasing the number of Inverse Fast Fourier Transform (IFFT) operations required. Hence the main goal of the suggested scheme (WSN-PTS) is to reduce the PAPR without the number of search.

Keywords: BER, CP-OFDM, HPA, IFFT, NEW-PTS, OFDM, PAPR, PTS, SLM, TR, WSN-PTS.

Résumé

Multiplexage orthogonal de division de fréquence (OFDM) est bien connu et une technologie émergente dans le système de communication sans fil, c’est une transmission multi-porteuse pour les réseaux 5G, qui réduit l’influence de la décoloration par trajets multiples et évite l’utilisation de blocs égalisés complexes. Cependant, ces modulations souffrent d’une grande variation des amplitudes des signaux temporels, ce qui entraîne un rapport de puissance de crête à moyenne (PAPR) élevé, ce qui provoque des distorsions dans le signal temporel généré à la sortie de l’amplificateur de puissance élevée (HPA). Plusieurs techniques ont été étudiées de réduction de PAPR comme le Clipping & Filtering, Selective Mapping (SLM), Partial Transmit Sequence (PTS), Tone Reservation (TR) sont quelques-unes des techniques qui minimisent le PAPR. Dans ce travail, nous nous sommes basés sur la méthode des séquences de transmission partielle (PTS) en utilisant un nombre différent de sous-blocs, dans cette thèse, nous discutons une nouvelle technique de séquence de transmission partielle (New-PTS) de faible complexité qui a été proposée par les chercheurs pour le rapport de puissance de crête à moyen (PAPR) réduction des systèmes de multiplexage par division de fréquence orthogonale (OFDM), en outre, nous proposons une nouvelle méthode PTS pour réduire le PAPR sans nombre de recherches. Il est basé sur (NEW-PTS) pour réduire la complexité de calcul en diminuant le nombre d’opérations de Transformée de Fourier Rapide Inverse (IFFT) requises. D’où le but principal du schéma suggéré (WSN-PTS) est de éliminer WIDE BAle nombre de recherche.

Mots clés: Amplificateur de Puissance, BER, CP-OFDM, HPA, IFFT, NEW-PTS, OFDM, PAPR, PTS, SLM, TR, WSN-PTS.

ملخص

تعدد إرسال تقسيم التردد المتعامد (OFDM) هو مخطط معروف وتكنولوجيا ناشئة في نظام الاتصالات اللاسلكية، إنه ناقل متعدد الناقلات لشبكات الجيل الخامس G5، والذي أصبح مؤخرًا خيارًا مفضلًا لنقل البيانات الموازي الذي يقلل من تأثير تلاشي المسار المتعدد ويتجنب استخدام معادلات معقدة. تعاني هذه التعديلات من تباين كبير في سعات الإشارة الزمنية، مما يؤدي إلى ارتفاع نسبة الذروة إلى متوسط نسبة الطاقة (PAPR)، مما يسبب تشوهات في الإشارة الزمنية المتولدة عند إنتاج مكبر الصوت عالي الطاقة (HPA). تمت دراسة العديد من التقنيات لتقليل (PAPR) مثل: القطع التكراري القابل للقلب مدمج مع الترشيح الرقمي، ورسم الخرائط الانتقائية (SLM)، وتسلسل الإرسال الجزئي (PTS) و(TR), هي بعض التقنيات التي تقلل من (PAPR). في هذا العمل، اعتمدنا على تقنية تسلسلات الإرسال الجزئي (PTS) باستخدام عدد مختلف من الكتل الفرعية، وتم دراسة تقنية جديدة تسلسل نقل جزئي منخفض التعقيد (NEW-PTS) التي تم اقتراحها من قبل الباحثين للحد من نسبة الذروة إلى المتوسط (PAPR) لأنظمة الإرسال المتعدد لتقسيم التردد المتعامد (OFDM)، بالإضافة إلى ذلك، نقترح طريقة (PTS) جديدة لتقليل (PAPR) دون عدد من عمليات البحث.يعتمد على نقاط جديدة لتقليل التعقيد الحسابي عن طريق تقليل عدد عمليات تحويل الفورييه السريع العكسي (IFFT) المطلوبة. وبالتالي فإن الهدف الرئيسي للمخطط المقترح (WSN-PTS) هو القضاء على عدد البحث.

الكلمات المفتاحية: التضمينات متعددة الحوامل، مضخم الطاقة العالي، معدل الخطأ في البتات، التضمين الOFDM ,BER, CP-OFDM, HPA, IFFT, NEW-PTS, PAPR, PTS, SLM, TR, WSN-PTS، التسلل الجزئي لإرسال.

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List of Acronyms

AM/AM	Amplitude/Amplitude.
AM/PM	Amplitude/Phase.
BER	Bit Error Rate.
CCDF	Complementary Cumulative Distribution Function.
CCRR	Computational Complexity Reduction Ratio.
CP	Cyclic Prefix.
C-PTS	Conventional Partial Transmit Sequence.
CR	Clipping Ratio.
CR-New-PTS	Complexity Reduction of New Partial Transmit Sequence.
EVM	Error Vector Magnitude.
FFT	Fast Fourier Transform.
HPA	High Power Amplifier.
IBO	Input Back-Off.
IFFT	Inverse Fast Fourier Transform.
N-PTS	Novel of Partial Transmit Sequence.
OBO	Output Back-Off.
OFDM	Orthogonal Frequency Division Multiplexing.
OOB	Out-Off-Band.
PAPR	Peak to Average Power Ratio.
PTS	Partial Transmit Sequence.
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
SI	Side Information.
SLM	Selective Mapping.
SNR	Signal to Noise Ratio.
SSPA	Solid State Power Amplifier.
TR	Tone Reservation.
TWTA	Travelling Wave Tube Amplifier.
WSN-PTS	Without Number of Searches-PTS

General Introduction

General Introduction

The world of communications is currently at a very important crossroads in its evolution. This is particularly true for wireless communications, which are becoming increasingly important because of the many advances in the field and their accessibility to the general public. In addition, thanks to the miniaturization of technologies, their performance has increased, and will continue to increase at a breakneck pace **[1]**.

The wireless and mobile communication sectors are significant challenges in this regard. Over time, several generations have followed one another to increase throughput and capacity while maintaining an appreciable quality of service. The wireless world went through analog modulation before finally adopting digital modulation. Developments in this area are happening very quickly and are not about to stop or even slow down **[2]**.

In recent years, systems using the Orthogonal Frequency Division Multiplexing modulation (OFDM) it has contributed to the development of fourth generation (4G) and has been returned for 5G, currently in deployment in some countries. Thanks to the ease of implementation of the OFDM, it has been possible to reduce the complexity of the transmitter and receiver while increasing spectral efficiency. However, the basic disadvantage of the OFDM is represented by significant variations in instantaneous power. This problem called PAPR (Peak to Average Power Ratio) or large peak signals value on the transmitter side it is cause a serious degradation in performance when the signal passes through a nonlinear High-Power-Amplifier (HPA). This last causes In-band (IB) distortion and Out-of-band (OOB) distortion. Causes in-band distortion and out-band distortion. In band distortion can increases Bit Error Rate (BER) and out-of-band distortion radiation which cause adjacent channel interference **[1]**.

OFDM also cause time and frequency offsets and to overcome this it add Cyclic Prefix (CP) to message signal for synchronizing users but at the cost of spectral efficiency **[2]**. Therefore, a PAPR reduction technique is need to reduce the high PAPR value, and prevent the signals reach into saturated region of HPA, need to extend the nonlinear range by using the pre-distortion technique.

Some techniques for reducing the PAPR value have been suggested. There are various types of PAPR reduction techniques discussed in **[3],** as well as some remarks on the criteria for selecting PAPR reduction techniques. However, the core of this work will be the detailed study of the so-called Partial Transmit Sequence (PTS) approach as a possible solution to this high PAPR problem.

The purpose of our work is to study and implement appropriate techniques to solve this problem, we organize it as follows.

In the first chapter, we will first present firstly the OFDM modulation which is the multi-carrier modulation, and then we will discuss its concept, its characteristics, its advantages and disadvantages, the concept of the next generation expected in the field of 5G telecommunications. We will be interested in the theoretical study of the PAPR of signals with multiple carriers and the influence of the over-sampling factor on the relevant signal. This chapter also gives a reminder on the problems of mobile radio transmission.

The second chapter explains the characteristics of the power amplifier. To do this, we have defined the AM/AM and AM/PM characteristics of the power amplifiers. Thus, the problem study of the high PAPR of the OFDM signal and the various best-known techniques that reduce it, for example; coding and filtering, Selective Level Mapping (SLM), Partial Transmit Sequence (PTS), Tone reservation (TR).

Chapter three highlights on the PTS method used in OFDM system; a new partial transmission sequence scheme (New-PTS) in the OFDM system. The objective remains to reduce the PAPR level of the OFDM signal. Despite its competitive characteristics, the PTS technique is considered to be an expensive operation due to the multiplicity of Fourier Inverse Fast Transforms (IFFT) as well as the time allowed in the in-depth investigations in order to find the optimal phase factor.

Through this chapter, on a remarkable strategy was followed, consisting mainly of Analyze data available in RAM, calculate the smallest PAPR value and accurately determine the corresponding address. Such an address represents the side information (SI) to be sent in order to restore the original data of the users on the OFDM receiver. In addition, the effectiveness of the so-called new PTS complexity reduction method (CR-New-PTS) will be demonstrated in order to limit the amount of research number needed to achieve the best PAPR performance. Furthermore the CR-New-pts has not limit the search number as it was expected, hence in this work we proposed a new pts it’s called without Search Number of PTS (WSN-PTS).

The fourth chapter is the last chapter where we present a set of simulations and interpretations of the suggested solutions to investigate the computational complexity and performance of the OFDM system by used Complementary cumulative distribution function (CCDF) and BER analysis.

Finally, we conclude this work with a general conclusion.

The Orthogonal Frequency Division Multiplexing (OFDM) transmission

I.1. Introduction

OFDM for “Orthogonal Frequency Division Multiplexing” is a sophisticated multi-carrier modulation technology that has proven its worth in the field of wireless communication; allowing current technologies to attain high transmission rates, used on most communication standards **[4].**

The OFDM multiplexing technique involves dividing the transmission band into many sub-channels, resulting in longer symbol duration, to split the data stream into many parallel data streams that will be modulated and sent on various orthogonal sub-bands. Following that, the Fourier Rapid Inverse (IIFT) transform sends the signal through the various sub-channels and handles message decomposition on the receiver. The robustness of OFDM in the face of propagation time owing to many travels is increasing the duration symbol. The path-multiple, multi-delay, and Doppler Effect problems are all solved by this modulation **[5].**

For the high-speed wireless transmissions. It is easy to understand the enthusiasm for this technique since the 90s; well that historically, the concept has existed since 1960.

In this chapter, we discuss the principle of OFDM modulation, its concept description with its advantages and disadvantages.

I.2. Multi-carrier transmission techniques:

Interferences between symbols are frequently presented as an obstacle in single carrier modulation techniques (a single carrier frequency), because these techniques are subject to the channel's frequency or temporal selectivity, primarily in an environment conducive to multi-trips. In order to overcome these negative effects while increasing the transmission rate, multicarrier modulation techniques have been introduced and developed.

Multi-carrier modulation consist transmitting digital data by modulating them on a large number of carriers at the same time. On a multi-trip channel with attenuated frequencies, the system will still be able to recover the lost signal on other sub-carriers that have not been affected by the multi-trip phenomenon **[6].**

There are many forms of multicarrier modulation techniques like OFDM, Coded orthogonal frequency division multiplexing (COFDM**),** Generalised Frequency Division Multiplexing (GFDM), Filter Bank Multi Carrier (FBMC). In this thesis we are going to discuss the OFDM system.

I.3. Concept of orthogonality:

OFDM stands for orthogonal frequency division multiplexing. The attribute of orthogonality is fundamental since it allows combining a high spectral efficiency with an effective fight against interference between a frame's sub-carriers. In the frequency domain, the OFDM makes use of this concept by disseminating independent information on each of them. On the other hand the use of a very large number of carriers is a constraining perspective in the sense that:

- It necessitates a large number of modulators, demodulators, and filters.
- There is a demand for more bandwidth**.**

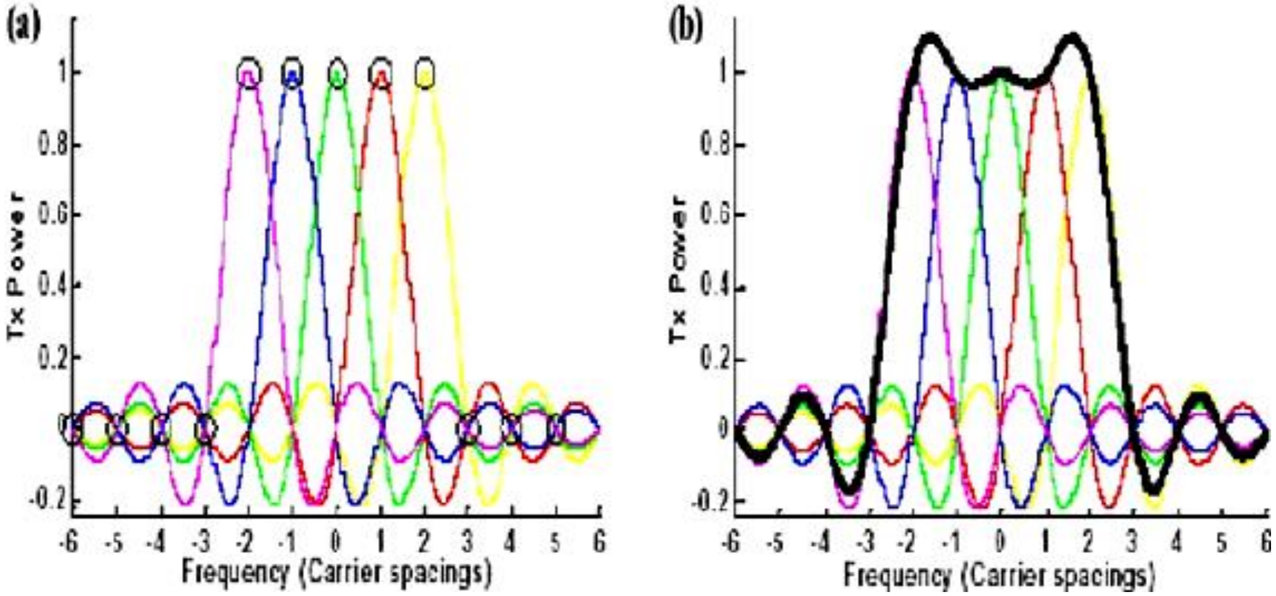


Figure I.1. Orthogonality of the OFDM carriers.

We specify a regular spacing of 1/T between the sub-carriers to solve these two problems as shown in figure II.1 which represents the OFDM spectrum composed of several sub-carriers, the spectrum of each sub-carrier corresponds to a cardinal sinus [sin(x)/(x)], which cancels all multiples 1/Ts (when a spectrum of a sub-carrier reaches its maximum, all the spectra of the other sub-carriers are zero), where the carriers form an orthogonal set **[7].**

Definition: Signals are considered orthogonal to each other if they are mutually independent. Mathematically, this condition is established for two signals a(t) and b(t) if:

$$\int_0^{Ts} a(t)b(t)dt = 0 \qquad \text{I.1}$$

The signals a (t) and b(t) are then orthogonal on the integration interval [0 T].

I.4. OFDM transmission chain:

The synopsis shown in the following figure shows the various components of an OFDM transmission chain. Binary b_i data of T_b duration are transformed into complex X_k symbols of T_k duration by the QAM modulator from where$T_k = \log_2 MT_b$, M is the size of the constellation of the QAM modulation used. Then a serial-parallel converter (S/P) is used to serialise the X_k symbols into N-frame symbols.

The duration of a frame T_u is N times greater than the duration of a symbol in series T_q thus reducing the effect of the channel. Subsequently a reverse Fourier transform is applied to obtain the OFDM frame (symbol). The IFFT stage transforms the spectrum of the OFDM signal to the time domain in order to transmit it through the channel. Come right after the step of adding a quantity of data named cyclic prefix or CP (Cyclic Prefix). The CP of T_g duration consists of copying the last Ng symbols of the OFDM frame, and then adding them at the beginning of the frame. After parallel/series conversion, we finally get the symbol OFDM, which contains N_a=N+N_g symbols of total duration T_s=T_u+T_g that we transmit through a channel.

On receipt, the reverse operations are performed, starting with the suppression of the cyclic prefix, then the use of FFT algorithm to perform the spectral decomposition of the samples (frequency domain) received calculated, and we finish with demodulation in order to find the binary data transmitted **[8].**

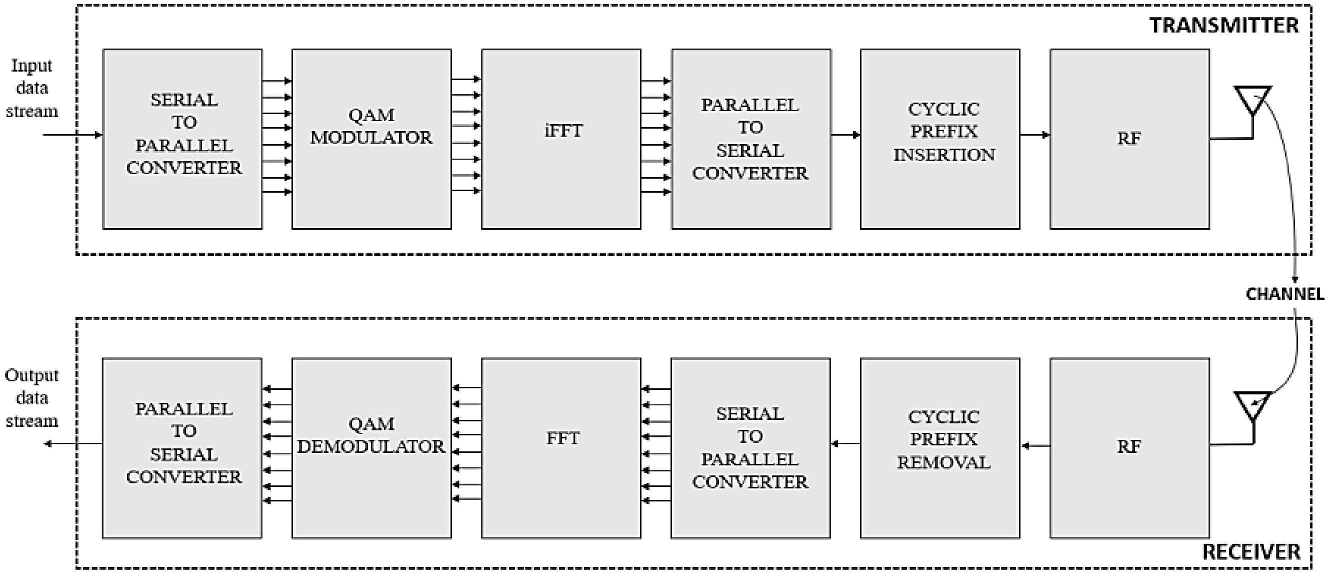


Figure I.2. Block diagram of an OFDM transmitter and receiver.

I.5. OFDM Modulation:

I.5.1. PSK and QAM

- **Quadrature Amplitude Modulation (QAM):** The most widely used modulation method in modern wireless communication systems is the Quadrature Amplitude Modulation (QAM), it is based on the modulation of two in quadrature signals called the in-phase carrier and the quadrature (90° shifted) carrier. In QAM, the baseband data stream is divided into two parallel data streams known as the **I** and Q streams. The **I** and **Q** streams modulate the in-phase carrier and the quadrature carrier respectively, and the sum of the modulated carriers is the output of the modulator **[9].** Figure I.3 shows the basic structure of a digital 16QAM modulator. The input bit stream is divided into the parallel I and **Q** streams. A local oscillator (LO) is used to generate the in-phase and quadrature signals. The **I** and **Q** data bits modulate the in-phase and quadrature LO signals respectively.

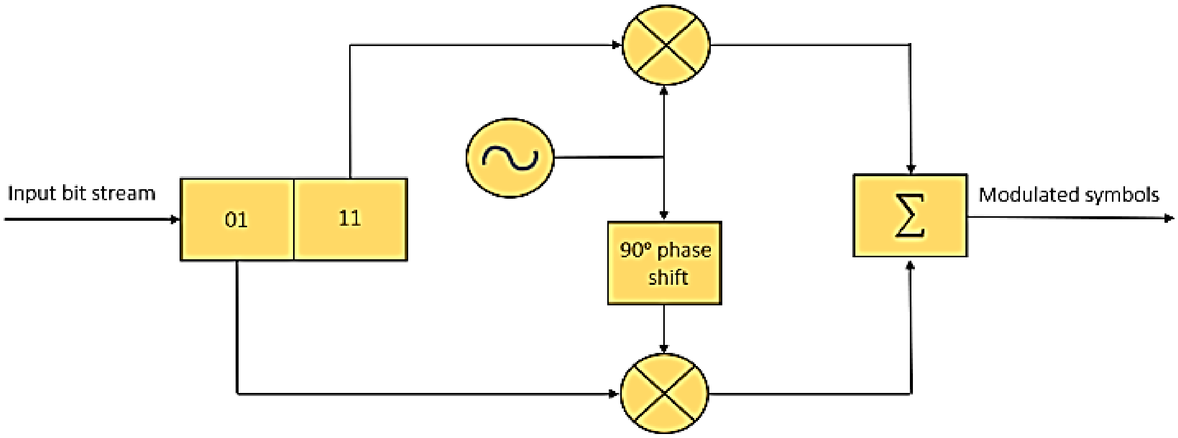


Figure I.3. Digital M-QAM modulator.

- **Phase shift keying [10]:** The lowest order modulation format in 5G technology is quadrature phase shift keying, or QPSK. Although this will provide the slowest data through put it will also provide the most robust link and as such it can be used when signal levels are low or when interference is high. The concept of multiplexing is to group N symbols to form an OFDM symbol; a different carrier frequency modulates each QAM (amplitude modulation quadrature) symbol of the OFDM symbol. Consider the N symbols emitted during a duration symbol T_u [X_0 , X_1 ,..., X_{N-1}].Consider the N symbols [X_0, X_1,..., X_{N-1}] emitted during a duration symbol T u Each complex symbol is modulated by a signal at the frequency f_k but of duration N times greater than Ts (T_u=NT_s). The x(t) signal resulting from the modulation of all modulated signals is the sum of the elementary signals.

$$\sum_{k=}^{N-1} x_k e^{2\pi j f_k t} \, for \; t \in [kT_u, \; (k+1)T_u] \qquad \text{I.2}$$

With x(t)correspond or OFDM symbol. Frequency multiplexing has the particularity of being orthogonal by setting the spacing between each frequency to $1/T_u$. Then the symbol OFDM can be written **[11]:**

$$x(t) = e^{2\pi j f_k t} \sum_{k=0}^{N-1} x_k e^{2\pi j \frac{kt}{T_u}} \qquad avec \quad f_k = f_0 + \frac{k}{T_u} \qquad \text{I.3}$$

Where f_0 represents the first carrier frequency of the signal band. Figure I.4 shows the block diagram of the OFDM modulation. The binary elements are grouped in packages of n bits to form QAM −2 thereafter, the X_K symbols series are paralleled (multiplexing) and are modulated by the corresponding carrier frequency. Finally, all signals are added together before being emitted. the OFDM modulation, by writing it in equation (I.3),is identical to a reverse discrete Fourier transform (IFFT Inverse Fast Fourier Transform) or the sampling is done at $F_e = \frac{N}{T_u}$ this algorithm is widely used in many applications In order to implement the IFFT, the number of symbol elements must be a power of 2.This does not really pose a problem for the OFDM because if the number of symbols is less than a power of 2, it is possible to add the symbol 0 to reach the desired number (0 padding). By this process the OFDM modulator using FFT and IFFT reduces the complexity of the OFDM system is detailed in Figure I.4 **[12].**

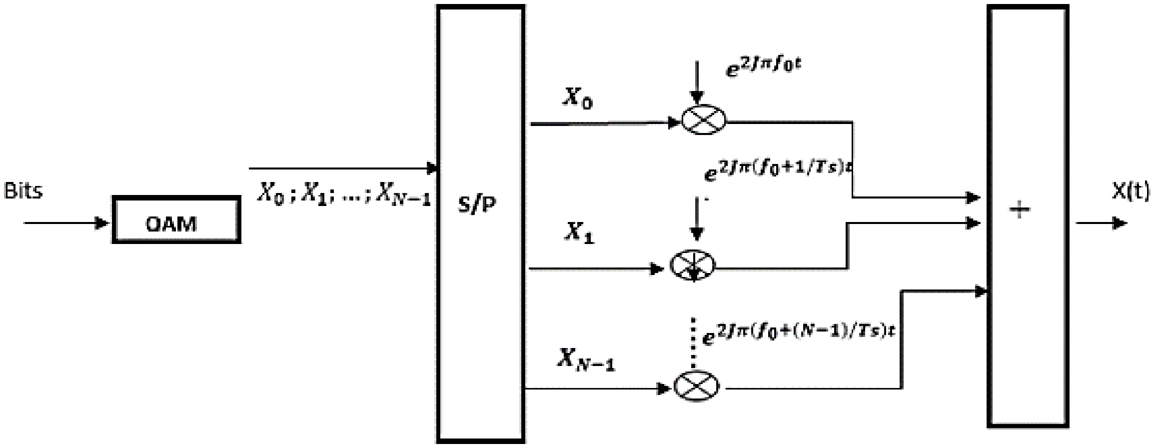


Figure I.4. OFDM modulation by IFFT

I.6. OFDM Demodulation:

The signal received at the receiver is written over a duration symbol T_s

$$y(t) = \sum_{k=0}^{N-1} X_k H_k(t) e^{2j\pi\left(f_0+\frac{k}{T_s}\right)t} \qquad \text{I.4}$$

Where $H_k(t)$ is the channel transfer function around f_k frequency and at time t. This function varies slowly and can be assumed to be constant over the period T_s **[12].** Conventional demodulation would consist of demodulating the signal according to the N sub-carriers (Figure I.5).

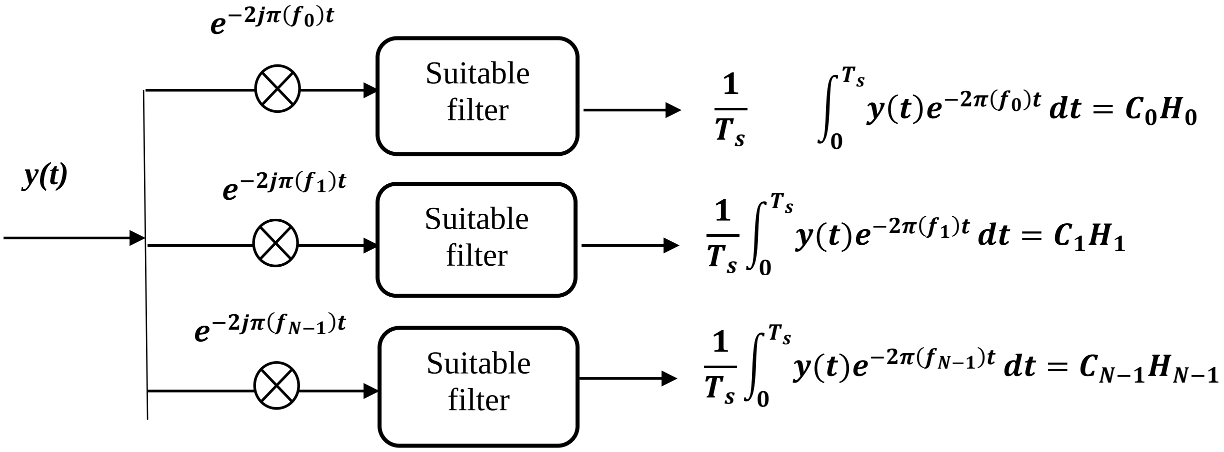


Figure I.5. OFDM demodulation by suitable filter.

I.7. Inter Symbol Interference:

OFDM signals are transmitted at equal intervals and must cross a certain distance to reach the receiver. In the multi-route channel, the transmitted symbol takes varying delays to reach the receiver due to different propagation paths, causing temporal spread, causing temporal spread. Increasing the duration of symbols causes them to cross, Extending the duration of symbols overlaps symbols, resulting in interference between symbols (IES) **[13].**

I.8. Inter Carrier Interference:

Loss of orthogonality results in the presence of sub-carrier data symbols on adjacent sub-carriers, known as carrier interference **[14].**

I.9. Interference between carriers and symbols:

Figure I.6 illustrates the interferences associated with multiple paths that cause echoes at reception. For example, two routes are considered one main and one delayed. The reception of frame i during integration time T is the sum of the different signals from the different routes, there are two observations that can be made here:

1. The overflow of the delayed i-*1* frame over the integration period of the signal from the main path is interference between symbols, which causes distortions on the first samples of the signal of

interest, resulting in the loss of orthogonality of the subcarriers. The direct consequence is a significant reduction in transmission performance.

2. In addition, the influence of frame *i*'s echo on itself causes interference between carriers. This results in either constructive or destructive additions to the signal conveyed by the main route, depending on the phase of the samples.

IES and IEP have a close relationship. Due to the time dispersion of communication channels, it is obvious that the orthogonality condition is largely threatened. In order to ensure its preservation, it is appropriate to use a time-keeping interval to ensure that adjacent frame advances or delays do not affect reception **[15].**

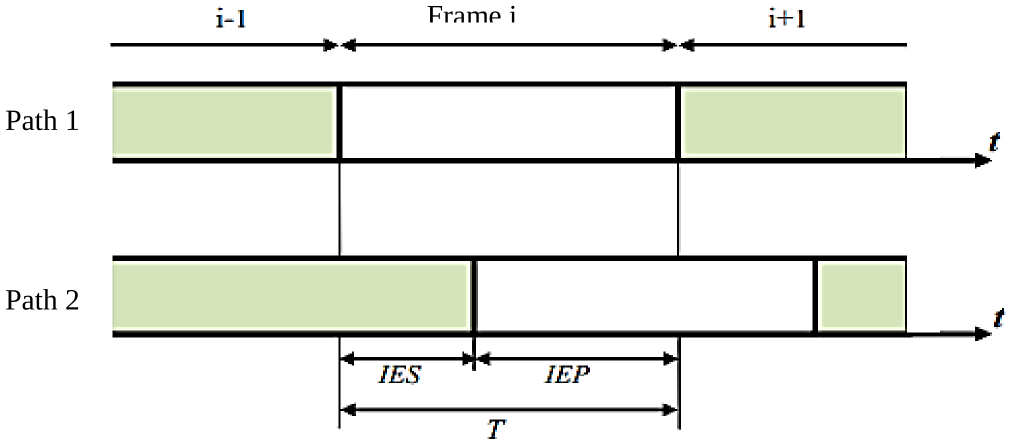


Figure I.6. OFDM frame spread without a guard interval: delays, multiple routes, and interference.

I.10.The Cyclic Prefix (CP):

The basic concept behind the OFDM cyclic prefix is quite straightforward. The cyclic prefix performs two main functions. The cyclic prefix provides a guard interval to eliminate inter symbol interference from the previous symbol.

It repeats the end of the symbol so the linear convolution of a frequency-selective multipath channel can be modelled as circular convolution, which in turn may transform to the frequency domain via a discrete Fourier transform. This approach accommodates simple frequency domain processing, such as channel estimation and equalization.

I.10.1. Cyclic prefix advantages and disadvantages

There are several advantages and disadvantages attached to the use for the cyclic prefix within OFDM.

- **Advantages :**

- **Provides robustness:** The addition of the cyclic prefix adds robustness to the OFDM signal. The data that is retransmitted can be used if required.

- **Reduces inter-symbol interference:** The guard interval introduced by the cyclic prefix enables the effects of inter-symbol interference to be reduced.

- **Disadvantages :**

- **Reduces data capacity:** As the cyclic prefix re-transmits data that is already being transmitted, it takes up system capacity and reduces the overall data rate.

The use of a cyclic prefix is standard within OFDM and it enables the performance to be maintain end even under conditions when levels of reflections and multipath propagation are high **[10].**

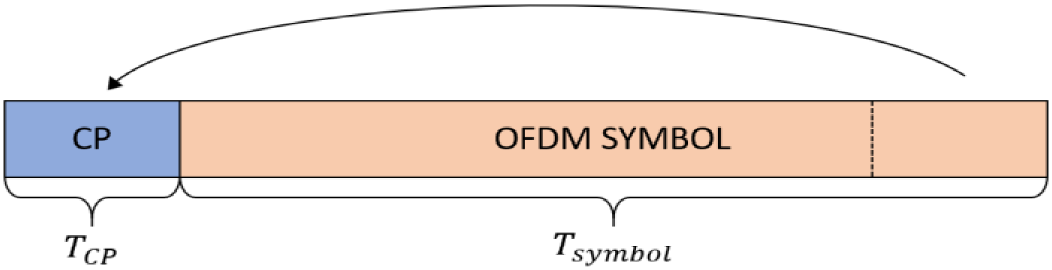


Figure I.7. The Concept of CP-OFDM

I.11.OFDM Signal Distribution:

The amplitude or power histogram is suggested as a tool of studying the large variation of the signal:

The IFFT entries come from a finite alphabet. The real part and the imaginary part of a constellation M-QAM have$\sqrt{M}$different states. Thus their amplitudes take different values. In the case of OFDM, several factors influence the variation of signal amplitudes, namely the number of sub-carriers, the over-sampling factor, the numerical modulation and the filtering [**16].**

An example of the power histogram of an OFDM signal for M=16 and N=64 is given in Figure I.8 showing the large dynamics of this signal. Generally, digital modulations assume that the elements of the vector X=[X_0,X_1,... ,X_N] are mutually independent and identically distributed random variables of zero mean and variance 1 such as $\frac{1}{2}\sigma^2$**[17].**

$$E\,[X_i] = 0 \tag{I.5}$$

$$E\,[X_i X_{q^*}] = \begin{cases} \frac{1}{2}\gamma^2 if = q \\ 0 \quad\quad if \neq q \end{cases} \tag{I.6}$$

Thus, the OFDM signal x(t) can be written as follows **[14]**:

$$x(t) = \sum_{k=0}^{N-1} Re(X_k)\cos(2\pi f_k t) + j\sum_{k=0}^{N-1} Im(X_k)\sin(2\pi f_k t) = I(t) + jQ(t) \tag{I.7}$$

Where Re(X_k) and Im(X_k) respectively represent the real and imaginary parts of the X_k symbol. Using Lyapunov's Central Limit Theorem **[14]**, we show that when N is sufficiently large, the real part I(t) and the imaginary part Q(t) are mutually independent and tend towards a Gaussian distribution of zero mean and consequent variance $\frac{1}{2}\gamma^2$, the amplitude of the OFDM signal defined By$p(t) = \sqrt{|I(t)|^2 + |Q(t)|^2}$follows asymptotically a Rayleigh distribution of parameter σ**[14] [17].**

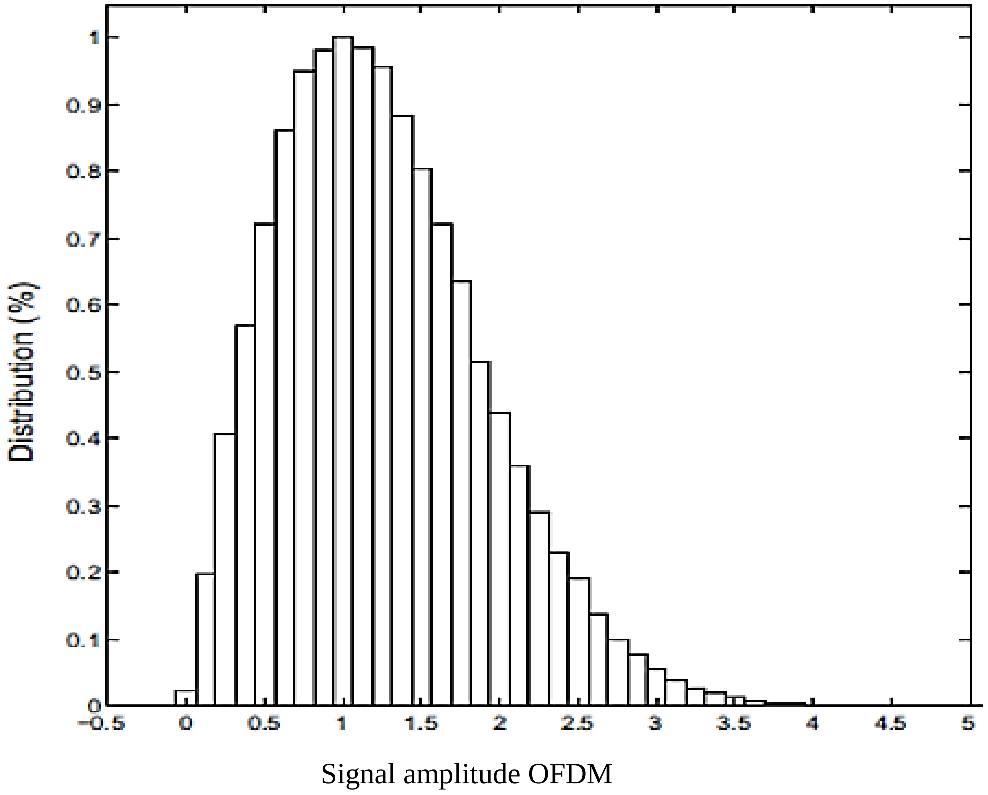


Figure I.8.OFDM Signal Amplitude Histogram.

I.12. Advantages and disadvantages of the OFDM:

Unlike single-carrier transmissions, one of the great advantages of OFDM modulation is the simplicity of distortion equalization. This makes it possible to have simple and inexpensive receivers. The main advantages and disadvantages of modulating the OFDM are numerous, we can mention:

✓ In comparison to traditional frequency multiplexing solutions, efficient utilisation of frequency resources. This is due to the fact that the channels in OFDM overlap while keeping perfect orthogonality.

✓ Multi-carrier techniques are robust to impulsive noise since each sub-carrier is affected by noise independent of the other carriers. Unlike mono-carrier modulations, where noise can affect a number of transmitted symbols, the loss of a symbol due to high noise does not affect the other symbols.

✓ In a multi-user context, OFDM techniques provide a lot of flexibility in the allocation of throughput. Each sub-carrier can be coded independently of the other carriers, depending on the amount of the channel's instantaneous gain.

✓ The more disturbances there are the more the technology loses its interest because it is then necessary to put in place filtering or coding methods that greatly reduce the speeds.

✓ OFDM is also susceptible to frequency shift (Frequency offset) and synchronisation issues **[18].**

I.13. Peak to Average Power Ratio:

In order to characterize the dynamics of an OFDM signal, the PAPR metric is commonly used in the literature. It is defined as the ratio of instantaneous power maximum or peak power and average power of the OFDM signal over a time interval of time T. The PAPR of an OFDM signal can be expressed in dB by the following relationship:

$$PAPR(dB) = 10\log_{10}\frac{max_0<t\leq|x(t)^2|}{E[|x(t)|^2]} \quad \text{I.8}$$

Where $max_0 < t \leq |x(t)^2|$it is the average signal power and $E[|x(t)|^2]$ is the average signal power. In the literature, some authors use the crest factor (CF) to characterize the dynamics of an OFDM signal such as:

$$CF = \sqrt{PAPR} \quad \text{I.9}$$

The PAPR of a signal transposed into RF the OFDM transmission is twice the PAPR of the same base band signal. Indeed, the frequency transposition of the OFDM signal corresponds to a modulation at the f_c frequency such as **[14]:**

$$x_r f(t) = Re\left[x(t)e^{j2\pi f_c t}\right] = I(t)cos2\pi f_c t - Q(t)sin2\pi f_c t \qquad \text{I.10}$$

For a MAQ type digital modulation:

$$E\left[\left|x_f r(t)^2\right|\right] = \frac{1}{2}E[|I(t)^2|] + \frac{1}{2}E[|Q(t)^2|] = \frac{1}{2}E[|x(t)^2|] \qquad \text{I.11}$$

Therefore,

$$\frac{\boldsymbol{max_0}<t\leq T\left|\boldsymbol{x(t)}^2\right|}{\boldsymbol{E}[|\boldsymbol{x_r(t)}^2|]} \approx \frac{\boldsymbol{max_0}<t\leq T\left|\boldsymbol{x(t)}^2\right|}{\boldsymbol{E}[|\boldsymbol{x(t)}^2|]} \approx 2\,\frac{\boldsymbol{max_0}<t\leq T\left|\boldsymbol{x(t)}^2\right|}{\boldsymbol{E}[|\boldsymbol{x(t)}^2|]} \qquad \text{I.12}$$

Thus, the basic band PAPR is linked to the PAPR in RF (PAPRRF) by the following relationship:

$$PAPR_{RF} \approx PAPR + 3dB \qquad \text{I.13}$$

A high PAPR translates a signal with a very high peak power in front of the average power. It means that the signal has great dynamics with the presence of several amplitude peaks. Signals with high PAPR are vulnerable to the non-linear effects of electronic devices and especially the power amplifier **[12].**

The peak to average power ratio is one aspect of performance that needs to be considered for any 5G communications modulation scheme. The peak to average ratio has a major impact on the efficiency of the power amplifiers **[10].**

I.14. 5G New Radio:

Now-a-days in wireless communication the demand for high data rate and quality of services is growing rapidly. The 4G cellular networks & LTE, was been optimized to provide high data rate and Band width using Orthogonal Frequency Division Multiplexing (OFDM) technology. It also combats multi-path fading with low implementation complexity.

Although it has efficient implementation and robustness to channel delays, OFDM suffers from several drawbacks like high PAPR and high out of band side lobes.., OFDM also cause time and frequency offsets and to overcome this it add Cyclic Prefix(CP) to message signal for synchronizing users but at the cost of spectral efficiency. To overcome some of the above mentioned drawbacks in OFDM, 5G communication introduces new transmission schemes. Similar to 4G, these new transmission schemes support huge number of users with high data rates but with low latency. This communication is also spectrally efficient by avoiding frequency and time offsets **[3].**

I.15. Conclusion

In this chapter, we have introduced and discussed the main concept of the Multi-Carrier Frequency Modulation Orthogonal and that recommends the use of a group of sub-carriers for parallel data transmission in wireless communications and that is the most suited for the last generations. Since this technique represents only the distribution of sub-carriers within a given bandwidth, other aspects of a communication system must be considered. But because this system has a large dynamic characterized by a strong PAPR, it is very sensitive to the non-linearity of analog components, especially those of the power amplifier (PA). PAPR reduction in OFDM systems is widely discussed in the literature and will be a major focus of our work.

PAPR (Peak – To – Average Power Ratio)

II.1. Introduction:

Orthogonal frequency division multiplexing (OFDM) is one of the promising techniques that employ a set of subcarriers in order to transmit the information symbols in parallel over the communication channel. The signal passes through several stages of the transmission chain, in particular coding, modulation, and carrier frequency transposition, before being sent into the transmission channel.

This operation is ensured by a high power amplifier which is by definition an electronic device making it possible to considerably increase any signal presented at its entrance. The power of the transmitter output signal is proportional to the distance between the transmitter and the receiver of the communication system, the high power amplifier being an active component.

One of the most serious problems is the high Peak-to-Average Power Ratio (PAPR) of the transmitted OFDM signal **[19]**, since this large peak introduce a serious degradation in performance when the signal passes through a nonlinear High Power Amplifier (HPA). The non-linearity of HPA leads to in-band distortion which increases Bit Error Rate (BER), and out-of-band radiation, which causes adjacent channel interference **[1]**.

There are several techniques have been proposed in the literature and implemented to reduce PAPR problem into different categories **[20]**, **[21]**. Signal scrambling techniques and signal distortion techniques are the two basic categories of these techniques. Signal scrambling techniques vary in how the codes are scrambled to reduce the PAPR. Signal scrambling can be accomplished using coding and filtering techniques. Block coding **[22]**; Selective Level Mapping (SLM) **[23]**; and Partial Transmit Sequences (PTS) **[24]**.

Clipping method is the simple method to reduce the PAPR **[22]** the OFDM signal before amplification **[25]**, but the nonlinear distortion causes both in-band and out-of-band interference to signals. Therefore the HPA requires a back off which is approximately equal to the PAPR for distortion-less transmission. This decreases the efficiency for amplifiers. And there are other method coding techniques, which are discussed in **[26]**. The key of those techniques is to choose the code words that minimize the PAPR. And there are techniques that cause no distortion and create no out-of-band radiation, although they may be require the transmission of the side information to the receiver for example Tone Reservation technique (TR). The present Chapter describes the foundations of these techniques, and makes some remark on the selection criteria which include the PAPR reduction.

II.2. General about the high power amplifier:

II.2.1 Definition:

The High Power Amplifier (HPA) is an essential component in the wireless communications and to ensure the correct routing of information, transmitters need HPA to provide a certain amount of power to the signals (radio frequency) to prevent them from being strongly attenuated during their propagation in free space **[27]**. The amplifier then draws the necessary power useful for the signal from a continuous current source that it then injects into the signal. The linearity and energy efficiency of the HPA are two very important criteria to take into account in the design of a communication system, especially in the context of OFDM where the signals have a high envelope fluctuation (high PAPR value). There are two main classes of HPA for telecommunications:

- **Traveling-wave tube amplifier (TWTA):** used mainly in satellite transmissions, to generate strong Powers **[28]**.
- **The Solid State Power Amplifier (SSPA):** used in terrestrial transmissions as in the case of radio communication mobile, mobile phones and radio loop **[29]**.

II.2.2 The high Power amplifier characterization:

The amplifier's input-output relationships are represented by the amplifier's transfer characteristics, or functions. The AM/AM (Amplitude to Amplitude) characteristic expresses the connection between the output voltage's amplitude and the input voltage's amplitude. The AM/PM (Amplitude to Phase) characteristic represents the phase variation of the output voltage as a function of the input signal amplitude **[30]**.This characteristic AM/AM has a particular aspect for SSPAs. Figure II.1a and Figure II.1b illustrate the form of the two characteristics of a power amplifier (AP) **[31]**. The power amplifier's AM/AM characteristic is divided into three zones **[32]**:

a- Linear Area (Zone 1):

The amplifier has a linear behavior in this area, the ratio between the output power and the input power gives a constant value called the amplifier’s gain expressed in decibel. This area is also characterized by very low power levels and almost non-existent distortions. However, the efficiency of the amplifier is very low in this area.

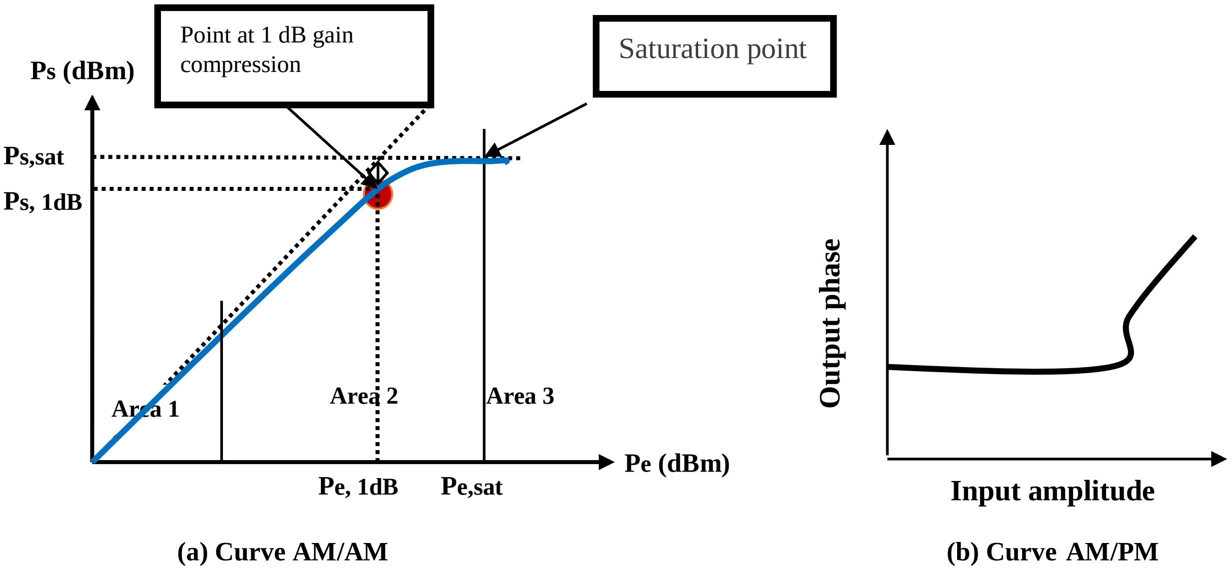
b- Compression Area (Zone 2):

The output power is no longer proportionate to the input power in this area, the curve begins to move away (relative to the linear line) and the signal distortions appear and are becoming more important. The gain of the amplifier decreases for high input powers, we speak of compression.

zone of the gain. The point at 1 dB of compression is located in this zone **[20]**,it is defined as the point where the difference between the linear and nonlinear operating curves in power is 1 dB. This is a characteristic of the power amplifier.

c- The saturation zone (Zone 3):

The output power in this area is almost constant regardless of the input power. This is referred to as "saturated power". This area is characterized by significant distortions, making it almost impossible to receive the signal.



(a) Curve AM/AM **(b) Curve AM/PM**

Figure II.1. The two characteristics form for the power amplifier SSPA.

II.3. Effect of the high power amplifier on communications systems:

II.3.1. Effect of the EVM (Error Vector Magnitude):

Current digital transmission systems use multicarrier modulations with a high number of phase states and amplitudes to make efficient use of the available spectrum. However, these modulations are very extremely vulnerable to distortions, particularly non-linear distortions caused by the amplifiers of the transmission chain. The amplifier has a direct incidence on the constellation which results in a deformation of this one involving errors on the transmitted bits, which are discussed in **[33]**.

The signal x (t) at the entrance of the power amplifier is a WLAN signal mono standard (OFDM signal of subcarriers, 16-QAM modulation). The EVM calculated from the signals x (t) and y (t) (fig II.3) **[33]**.It shows that the EVM decreases when the input back-off increases, i.e. when the amplification is done more and more in the linear zone, and also the EVM decreases with the signal to noise ratio (SNR). Indeed, a low IBO generates significant distortions in the amplified signal.

II.3.2. Effect on the spectrum ACPR (Adjacent Channel Power Ratio):

To quantify the interference generated in the adjacent bands of the useful band an ACPR parameter is defined by the power difference between the main lobe (useful band) and the secondary lobes as shown in Figure II.2 **[33]**. The ACPR is given by the following relation II.1 **[32]**:

$$ACPR = \frac{\int \mathrm{BUDSP(f)df}}{\int \mathrm{BA\ DSP(f)df}} \qquad \text{II.1}$$

Where BU it’s the adjacent band and BA it’s the useful band, respectively **[33]**.

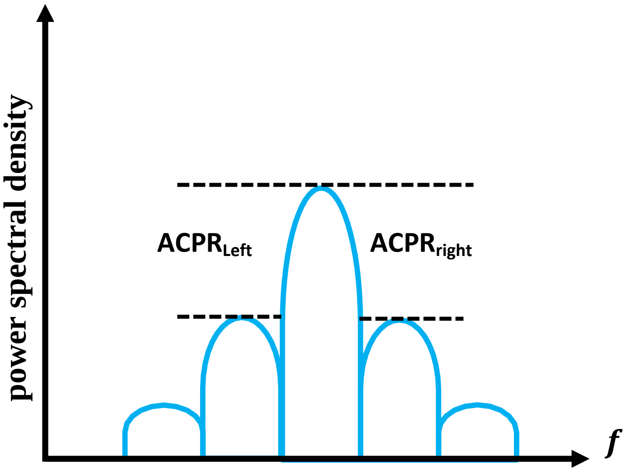


Figure II.2. ACPR Calculation.

The influence of the non-linear characteristic of the amplifier on the amplified signals is also expressed by spectral uplifts. This result in interference with other signals transmitted in neighboring channels. The merit factor that makes it possible to measure interference with adjacent channels is the ACPR equation (II.1).

Table II.1 **[33]** shows the measurements of the ACPR according to the values of IBO, where BU= BA=5MHz, it will be a question of showing the influence of a non-linear amplification on the spectrum of signals at strong dynamics (high PAPR). . The phenomenon of spectral uplift is shown in Fig II.4. It shows that the spectral uplift (interference with adjacent channels) increases when the recoil decreases. The low values of the IBO mean that the power amplifier is operating at the limit of its saturation zone. It is in this zone that the signals undergo the most distortions, which explains the increasingly important spectral rise when the IBO becomes weaker and weaker.

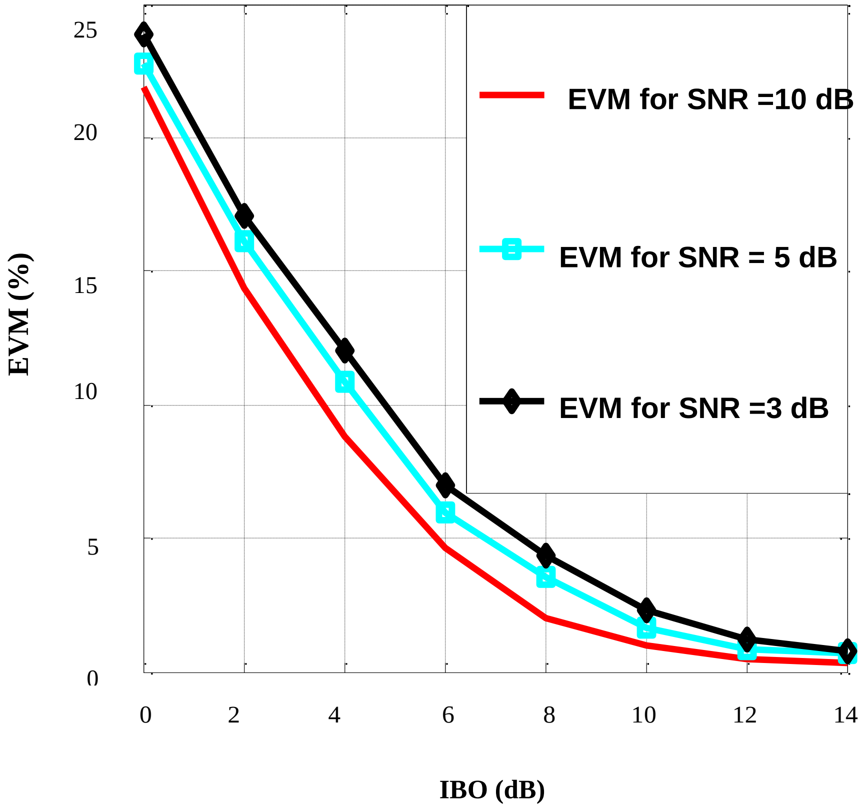


Figure.II.3. EVM in function of (IBO) for different values of SNR.

II.3.3. Effect of the BER (Bit Error Rate):

A modulation technique's performance can be measured in terms of the needed signal-to-noise ratio (SNR) to achieve a given bit error rate (BER).Although the primary goal of PAPR reduction techniques is to reduce the CCDF; this is sometimes accomplished at the expense of increasing the BER. The HPA clipping the high peaks of the OFDM signal causes a substantial in-band distortion that leads to higher BER. Other techniques may necessitate the transmission of side data as well. The entire OFDM symbol is recovered in error if the side information is received wrongly at the receiver, and the BER performance falls **[33]**.Figure II.5 gives the performance of the BER as a function of the SNR for different input recoil values (IBO).

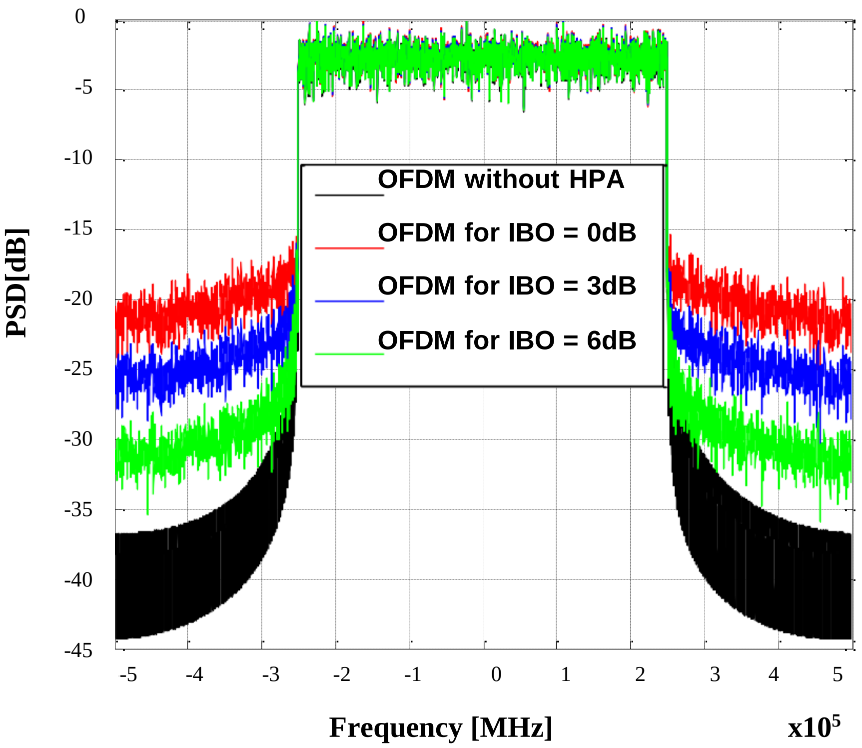


Figure II.4. Effect of the HPA on the spectrum for different values of the IBO

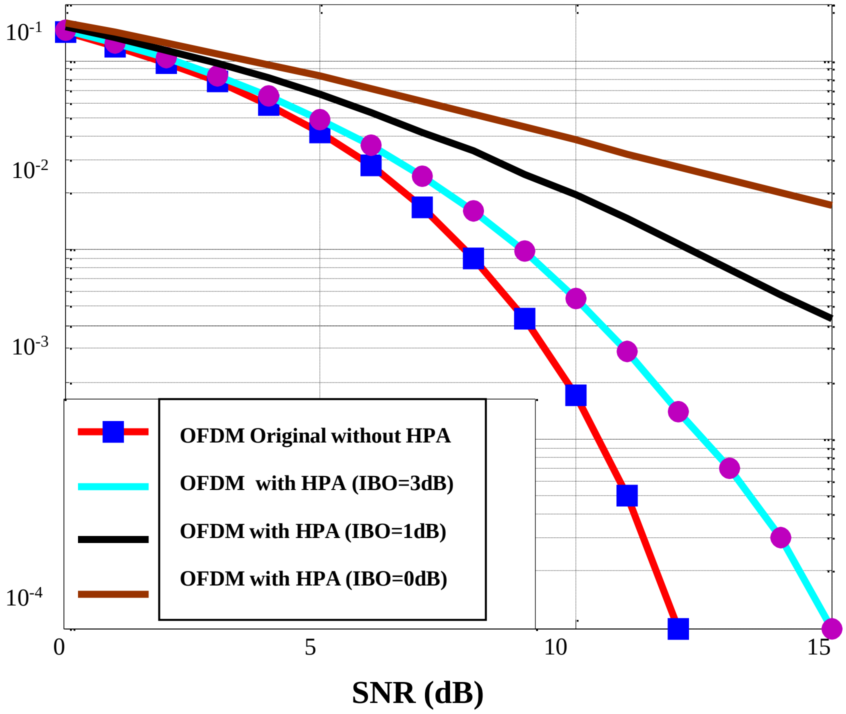


Figure II.5. Effect of the HPA on the BER for different values of the IBO.

Table II.1: Example of ACPR measurement according to IBO values.

IBO(db)	0	3	6	12	15
ACPR(db)	-34,1210	-34,0124	-33,8102	-33,4342	-33,2178

II.4. The Peak to Average Power Ratio (PAPR) of OFDM signal:

One of the challenging issues for Orthogonal Frequency Division Multiplexing (OFDM) system is its high Peak-to-Average Power Ratio (PAPR). The PAPR is a random variable that measures variations in the envelope of a multicarrier signal such as OFDM **[34]**. Simply put, PAPR is the ratio between peak power and average signal strength. It is expressed in dB.

In literature we find different PAPR definitions. The PAPR of the OFDM signal is expressed as the ratio of the utmost peak power $|x(t)|^2$ to the signal's average power $E\{|x(t)|^2\}$. The expression II.1 of the PAPR is given by **[8]**. It is defined as the ratio between the maximum power and the average power.

$$PAPR(x(t)) = \frac{\max\left|[x(t)]^2\right.}{\mathrm{E}\,[\mathrm{x(t)}]^2} \qquad \text{II.2}$$

Where: $E\{|x(t)|^2\}$ is the average signal power, x(t) is the original signal, and $[x(t)]^2$is the peak signal power.

PAPR occurs when in a multicarrier system; the different subcarriers are out of phase with each other. When all points simultaneously reach the maximum value, the output envelope suddenly rises, causing a "peak" in the exit envelope **[35]**. Each time we have a peak in the signal, the AP must consume more energy to transmit it.

However, it is necessary to optimize energy consumption especially in wireless transmissions. In Figure II.6, it is clear that there are very high peaks characterizing the OFDM signal which significantly increases the PAPR, this is the major disadvantage of OFDM signals.

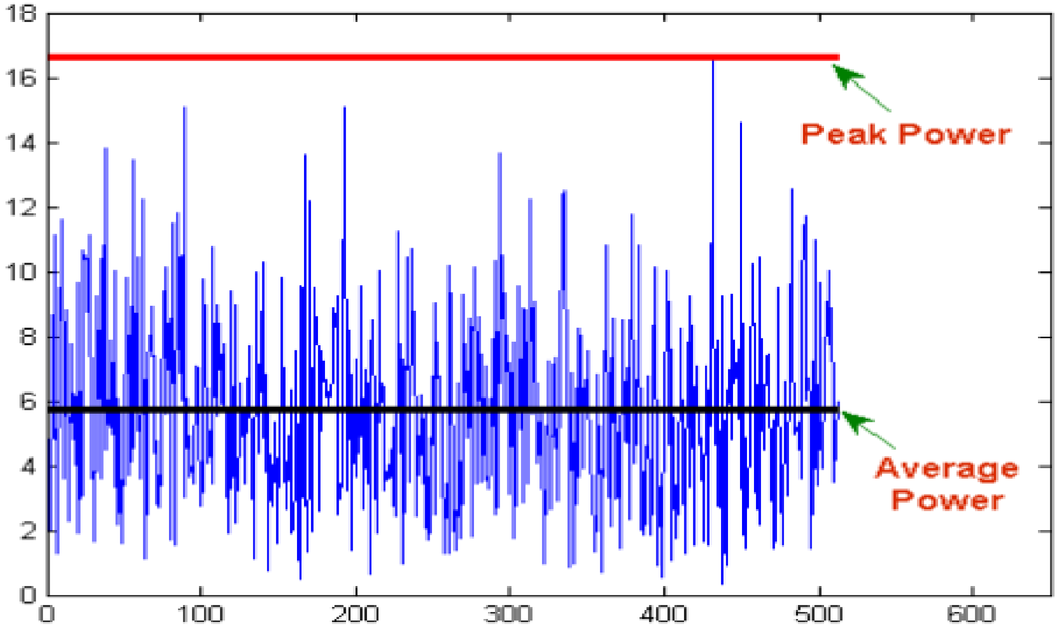


Figure II.6. Representation of the Peak-to-Average Power Ratio (PAPR).

II.4.1. The impact of a High PAPR value of OFDM system:

The linear of high power amplifiers are being used in the transmitter so the Q-point must be in the linear zone. Because the high PAPR the Q-point moves to the saturation region hence the clipping of signal peaks takes place which generates in-band (IB) and out-of-band (OOB) distortion. So to keep the Q-point in the linear zone the dynamic range of the power amplifier should be increased which again reduces its efficiency and enhances the cost.

As a result, there is a trade-off between nonlinearity and efficiency **[36]**. And also with the increasing of this dynamic range the cost of power amplifier increases.

The major disadvantages of a high PAPR are the increased complexity in the analog to digital and digital to analog converter and Reduction in efficiency of RF amplifiers.

In general, in multicarrier systems such as OFDM, the baseband signal is passed to the IFFT unit to modulate the subcarriers by the data symbol. Therefore, the OFDM signal is expressed as **[37]**:

$$s(n) = \frac{1}{\sqrt{NU}} \sum_{k=0}^{NU-1} S_k e^{j2\pi kn/NU} \qquad , 0 \leq n \leq NU-1 \qquad \text{II.3}$$

Where: n is the discrete sampling index, S_k(After constellation mapping) is the k_{th} subcarrier's complex block data, N represents the number of subcarriers, and U is the oversampling factor of the zero-padding operation, which is multiple times of the Nyquist rate to obtain highly accurate PAPR values.

The OFDM signal is generated within the time domain by applying the IFFT operation on the subcarriers simultaneously. The subcarriers are generally independent and have different phases. Occasionally, the phases of the subcarriers are in a similar direction. This might end in a high peak power compared with the signal's average power. Accordingly, the PAPR of the OFDM signal is expressed as the ratio of the maximum peak power $|s(n)|^2$ to the signal's average power $E\{|s(n)|^2\}$ II.4 **[36]**.

$$PAPR = \frac{\max|s(n)|^2}{E\{|s(n)|^2\}} \qquad \text{II.4}$$

Where E {.} symbolizes the signal's mean value.

PAPR reduction schemes do not give the same percentage of PAPR reduction for different inputs. Moreover, the complementary cumulative distribution function (CCDF) is generally utilized to evaluate the probability that the signal PAPR exceeds a selected threshold value (PAPR0):

The CCDF is formulated II.5 and expressed as **[2]**:

$$\mathrm{CCDF} = \Pr(\mathrm{PAPR} \geq \mathrm{PAPR}_0) = 1 - (1 - e^{\mathrm{PAPR}_0})^{NU} \qquad \text{II.5}$$

II.5. Eliminating distortion caused by high PAPR value:

The effect of high PAPR value on the HPA can be handled in a multiple number of methods which are described along with their pros and cons as below:

1- Regulatory or application constraints may limit peak transmit power, lowering the average power allowed in multi-carrier transmission **[19]**. This technique, however, lowers the range of multi-carrier transmission and prevents one of OFDM's primary advantages from being employed.

2- To accommodate the maximum power to be communicated, the dynamic range of the power amplifier can be expanded **[19]**. However, this technique is costly, as HPAs with a higher dynamic range cost more. This, too, necessitates hard-coding of the maximum permitted power, limiting the range of OFDM.

3- The most feasible method yet improvised, is to use number of techniques that reduce the PAPR of the generated OFDM signal to an acceptable limit before being transmitted. These techniques require an extra set of computation but allow the OFDM range to expand as required and also do not add on to the overall cost of the transmitter as the processing can be done in baseband.

II.6. Methods of reducing the PAPR:

In the literature, the problem of reducing the PAPR of multi-carrier signals has been studied at length and many works on this subject are available using various techniques, are classified into two groups **[16]**.

- Signal scrambling techniques.
- Signal distortion techniques.

II.6.1. Signal distortion Technique:

These techniques reduce the peak amplitude simply by nonlinearly distorting the OFDM signal at or around the peaks. The most well-known signal distortion techniques are **[24]**:

- ✓ Clipping and filtering.
- ✓ Peak windowing.
- ✓ Peak cancellation.

Clipping the signal's amplitude to a fixed level is one of the easiest ways to reduce the PAPR **[38]**.

$$y = \begin{cases} -A....(if x < -A) \\ x......(if -A \le x \le A \\ A......(if x > A) \end{cases} \tag{II.6}$$

Where: X represents the signal prior to clipping, and Y represents the signal after clipping

a- Clipping: The pseudo-maximum amplitude in this approach is referred to as the clipping level and denoted by A. In other words, any signal with amplitude exceeds clipping level a will saturate its amplitude to the clipping level A. However it is undoubtedly the simplest solution, but two major problems arises, first is self-interference which degrades the BER and second is level of the out-of-band radiation increases.

b- Windowing: Large signal peaks are multiplied with a certain non-rectangular window. This is solved using Gaussian shaped window functions (cosine, Kaiser, and hamming windows). To minimize out-of-band interference, the window should ideally be as narrowband as possible and not too lengthy in the time domain, as this suggests that many signal samples are affected, increasing the BER **[39]**.

c- Cancellation: Another method is linear peak-cancellation, a time-shifted and scaled-reference function is subtracted from the OFDM signal, and with each subtracted reference function reduces the peak power of at least one signal sample. A raised cosine window is one example of an appropriate reference signal **[40]**.

II.6.2. Signal scrambling technique:

The basic idea of the scrambling technique is to scramble an input data block of the OFDM symbols and transmit one of them with the minimum PAPR so that the probability of incurring high PAPR can be reduced.

While it does not suffer from the out-of-band power, the spectral efficiency decreases and the complexity increase as the number of subcarriers increases.

Furthermore, it cannot guarantee the PAPR below a specified level. There are techniques based on scrambling i.e. Selected Mapping (SLM), Partial Transmit Sequence (PTS) **[15]**, and Tone Reservation (TR).

II.6.2.1. Tone Reservation (TR):

The TR technique was proposed by Tellado **[41]**, based on the reservation of a small set of tones that are called carriers, in order to use them for PAPR reduction. The number and position of the reserved carriers are known by the receiver and the transmitter **[42]**. In addition the performance of TR in PAPR reduction depends on the number of reserved tones and their position.

The advantage of TR method is the side information is not there and also no additional operation is necessary at the receiver of the system and its complexity is less.

II.6.2.2.Selected Mapping (SLM):

The primary idea behind this technique is first generate a number of alternative OFDM signals from the original data block and then transmit the OFDM signal having minimum PAPR. However, this approach has two major drawbacks: data rate loss and transmitter complexity.

The peak to average transmit power of a multicarrier transmission system with selected mapping is minimized using this method. The good side of SLM method is doesn’t eliminate the peaks, and can handle any number of subcarriers. Figure II.7 shows the block diagram of selective mapping (SLM) technique for PAPR reduction **[43]**.

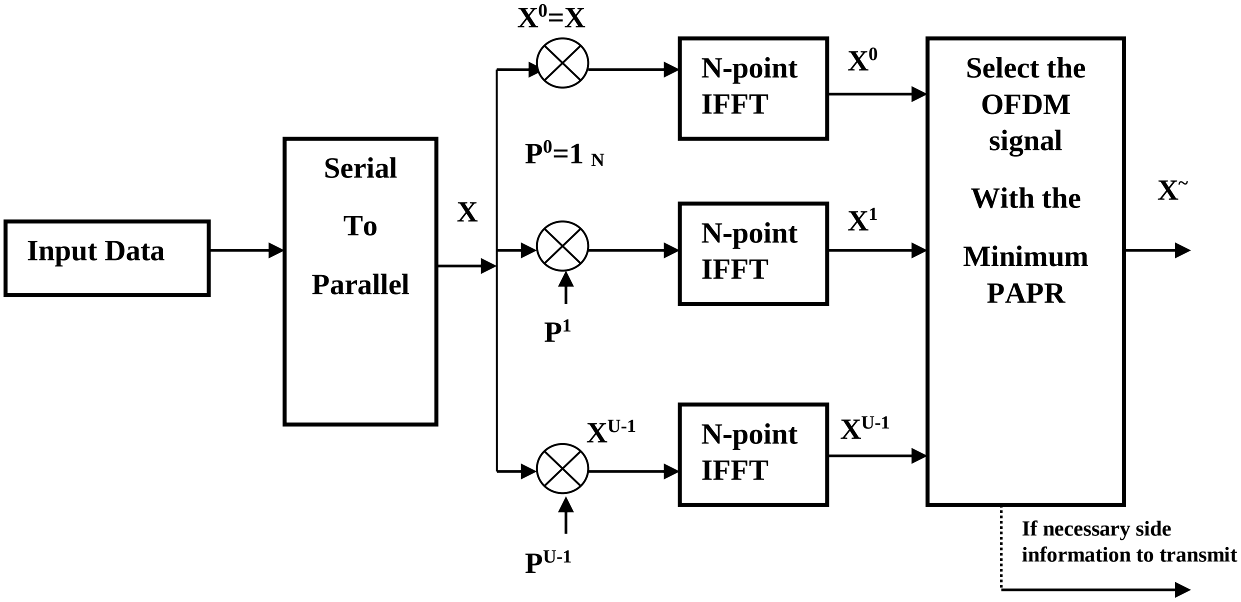


Figure II.7. Block diagram of selective mapping (SLM) technique for PAPR reduction.

II.6.2.3. Partial Transmit Sequence (PTS):

In 1997, Müller and Huber proposed the partial transmit sequence (PTS) approach **[44]**. This proposed method is based on the phase shifting of sub-blocks of data and multiplication of data structure by random vectors. This method is flexible and effective for OFDM system. The main purpose behind this method is that the input data frame is divided into non-overlapping sub-blocks and each sub block is phase shifted by a constant factor to reduce PAPR.PTS is a modified technique of Selective Mapping technique (SLM). In the next chapter we will describe more about this technique.

II.7. Criteria for the choice of PAPR reduction methods:

There are many factors that must be considered before a specific of OFDM-PAPR reduction technique is chosen **[45]**. In this section, we'll describe the several merit criteria that will allow us to assess a PAPR reduction technique's performance in its operational context.

- **High Capability to Reduce PAPR:** This is the most important factor in choosing a PAPR reduction technique. If a technique reduces PAPR largely, it is considered a good technique in this regard. It also has some harmful factors including in bond radiations and out of band radiation in selection of a technique **[46]**

- **Transmitted Signal Power:** If a technique reduces PAPR, it should also reduce average power of signal and maintain it in an acceptable region. If average power is increased and crosses an acceptable level, a large linear region is required in HPA due to which BER degradation takes place **[46].**

- **Degradation of BER:** The basic idea of using techniques that reduce PAPR is to increase performance of the OFDM System. It also includes BER, and be minimum BER in system than original OFDM system. Side information is sent to the receiver for synchronization with transmitting data. If errors occur in this information, it may cause increase in BER that may affect the whole data. So BER performance degraded **[32]**.

- **The variation of the average power:** Clipping is one of the PAPR reduction techniques that involve a variation in the average signal strength. This is actually the case for all signal addition techniques. The high power amplifier suffers as a result of this variation **[46]**.

- **Loss in Data Rate:** The issuer may be obliged to give information to the Side Information (SI) receiver on how it reduces the PAPR so that it can appropriately demodulate the signal. As with the PTS approach, this information decreases the system's usable throughput **[46]**.

- **Computational Complexity:** The technique used for PAPR reduction in an OFDM system, should have a low complexity in an OFDM system. In time and hardware implementation, complexity should be low **[32]**.

II.8. Conclusion:

This chapter has been devoted to the study of the PAPR; we have seen how the High power amplifier (HPA) becomes inefficient and causes a distortion of the signal.

As a consequence, this gives rise to distortion of the OFDM signal in the non-linear region of the high power amplifier (HPA), which is usually the Solid-state power amplifier (SSPA) model **[20]**. In fact, the operating point of the SSPA is determined by the input back-off (IBO) parameter, which expresses the ratio of the peak power of the output to the average power of the input. Another characteristic is the smoothness control coefficient that causes degradation of the bit error rate (BER). In effect, the HPA is not always operating in the linear region with large power back-offs, which makes it difficult and almost not possible to keep the outer band power below the required specific limits.

We noted that whenever the IBO be larger, the signal degradation be less and the lower the energy efficiency of the amplifier on return. These results show the value of making a compromise between energy efficiency and signal degradation. As a result, the larger PAPR, the more difficult it is to reconcile energy efficiency and signal degradation. This conclusion justifies the interest of reducing.

PAPR before amplification, and we provided that the solution is reduction of PAPR while operating the HPA in high-efficiency region, in the next chapter we provided the PTS method.

PAPR Reduction Technique : Partial Transmit Sequence (PTS).

III.1. Introduction:

Number of techniques has been proposed for reducing the PAPR in OFDM systems. But most of the techniques either increase the complexity of the system or deteriorates its bit error rate (BER) performance. Designing an algorithm to reduce PAPR without affecting the BER performance and increasing the complexity is a great challenge.

Among various techniques we will present in this chapter the PTS technique for reducing the PAPR. The partial transmit sequences (PTS) scheme does not deteriorate the BER performance, it achieves an excellent peak-to-average power ratio (PAPR) reduction performance of orthogonal frequency division multiplexing (OFDM) signals at the cost of exhaustively searching all possible rotation phase combinations, resulting in high computational complexity **[46]**.

In the same chapter we will discuss an improvement of the conventional PTS method (C-PTS) **[47]**. The objective is to reduce the PAPR in an OFDM system, despite its competitive characteristics, the C-PTS technique is considered expensive because of its multiple blocks of (IFFT) as well as the difficulty of finding the optimal phase factor through a thorough process. Furthermore, the effectiveness of the so-called complexity reduction of the New-PTS method (CR-New-PTS) is underlined in order to limit the number of research processes needed to obtain the best performance of the PAPR, which significantly reduces the complexity of the calculations **[33]**.

III.2. Partial Transmit Sequence (PTS):

PTS is a probabilistic method that has been used in numerous research papers **[48]**, **[49]**, **[50]** etc. Figure (III.1) presents the PTS method **[51]**.

- In the PTS technique, an input data block of N symbols is partitioned into disjoint sub blocks before transmitting the signal.
- There are three different types of sub block partitioning schemes: adjacent, Interleaved and pseudo random partitioning.

III.2.1. PTS Technique: Algorithm:

In the PTS technique, the input data block of N symbols is partitioned into disjoint sub-blocks. The subcarriers in each sub-block are weighted by a phase factor for each sub-block. The phase factors are selected in such a way that the PAPR of the combined signal is minimized. The transmitter must send the information to the receiver regarding the combination used to reduce

PAPR. The information transmitted about the treatment simply represents the combination of factors $b_m$that minimizes the PAPR. The complete algorithm as proposed by the authors is described below **[22]**; the Figure III.1 illustrates a single iteration in the form of a block diagram.

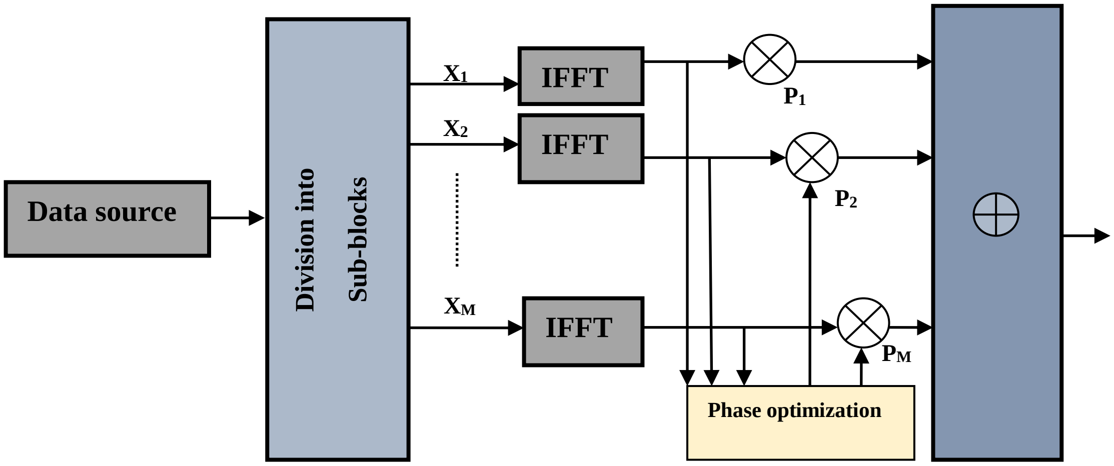


Figure III.1- the block diagram of Partial Transmit Sequence (PTS).

As in conventional OFDM transmission, the incoming bit stream is transformed to a parallel block of data, as detailed in Chapter I.

- After then, the parallel data block is broken into smaller sub-blocks. The length of each of these sub-blocks is the same as the length of the original parallel data block. If there are N sub-carriers, for example, the length of the parallel data block will be N. Similarly, each sub-block will be N in length. However, not all of a sub-N block's components will be non-zero. The division will be such that some sub-carriers in a sub-block will have non-zero values while others will have zero. It's also worth noting that non-zero values in more than one sub-block aren't allowed for a set of sub-carriers.

- The sub-blocks are then passed through IFFT blocks at the same time, which perform the inverse Fourier transform on each of them. The output of each of these IFFT blocks is referred to as partial transmit sequence.

- The PTSs are then rotated at the same time by a pre-determined phase factor. The phase factor is chosen from a list of permissible values that was previously defined. Once rotation is complete, the phase-rotated PTSs are added up to get a candidate signal.

The same procedure is then repeated, but with a different combination of phase factors being multiplied with the PTSs. This is continued until all possible combinations of phase-factor and PTS has been generated. As a result, a great number of potential signals are generated. The PAPR values of the candidate signals are compared, and the one with the lowest PAPR is chosen as the proper OFDM symbol to send.

III.2.2. PTS Technique: Mathematical analysis:

The frequency OFDM symbol X of N carriers is divided into M under disjoints blocks:

$$X_m = [X_{m,0}, X_{m,1}, ..., X_{m,N-1}]^T \;..m = 1,2,.., M \qquad \text{III.1}$$

So the sub-blocks can be expressed as X_m where:

$$\mathrm{X} = \sum_{(m=1)}^{M} X_m \qquad \text{III.2}$$

In the second step, to each disjoint sub-blockX_m, the phase rotation is applied and the new OFDM symbol is written:

$$\mathrm{X} = \sum_{(m=1)}^{M} b_m X_m, m = 1,..., M \qquad \text{III.3}$$

The same phase shift is then applied to all data symbols belonging to the same sub-block. In the third step, the temporal OFDM symbol after IFFT will be given by:

$$\mathrm{X} = IFFT\left(\sum_{(m=1)}^{M} b_m X_m\right) = X = \sum_{(m=1)}^{M} b_m IFFTX_m = X = \sum_{(m=1)}^{M} b_m x_m \qquad \text{III.4}$$

The way symbols are divided into sub-blocks affects the performance and complexity of the technique. The main disadvantage of PTS technology is the complexity of finding b_m weighting vectors to minimize PAPR. To reduce this complexity of the different schemes have been proposed, a particular example is a suboptimal combination algorithm that uses binary phase factors. Indeed, taking into account M sub-blocks and binary weighting factors (vectors b_m = 1, 2) are composed of only 1 or -1, the number of combinations possible is 2M. The idea proposed by ‘A.D.S.Jayalath’ and ‘C.Tellambura’ **[2]** will immediately stop the process of searching for a $b_m$vector to reach the expected PAPR. Another disadvantage of PTS technology is that it requires the transmission (SI) Side Information so that the receiver can recognize the sequence allowed to produce the lowest PAPR.

The standard system PTS requires in-depth research to find the optimal vector, resulting in high computational complexity, which may be the main disadvantage of this system. Many probabilistic solutions are proposed in the following literature to overcome the disadvantage of PTS **[34]**:

- **I-PTS (Iterative Flipping Algorithm) technique [52]:** the first step in the I-PTS is the calculation of the PAPR of the original signal, then the second step begins by multiplying the second sub-block by the factor $b_1=e^{j(2\pi/W)\gamma_1}$ following the calculation of the PAPR each time and finally the extraction (xx) of which corresponds to the lowest of the PAPR values. This value is saved in this sub-block, understanding that the first sub-block is multiplied by the factor $b_0=1$ and that the procedure will continue until the last step. If W is the number of search processes. As a result, the technique's research complexity is proportional to $W(V\text{-}1)$.

- **GD-PTS (Gradient Descent) technique [53]:** initially all phase factors consider that $b_v=1$, $v=0,\ldots,V\text{-}1$. Following that, GD-PTS optimizes the iteratively compared to their previous phase factors. Phase factors eligible for optimization are those for which the Hamming distance is equal to or substantially less than the radius ***r*** of their origin. This means that the computational complexity of GD-PTS is proportional to $C_r^{V\text{-}1}.I$. Where: I is the maximum number of iterations, and $C_r^{V\text{-}1}=\frac{(V-1)!}{r!(V-1-r)!}$ is the binomial coefficient.

- **ABC-PTS (Artificial Bee Colony**): this method proposed by Karaboga [**54**]. The task of the bees utilized in this algorithm, the observation bees and the scout bees, is to find the optimal food resources. First, the positions of food resources are produced randomly. In the problem of decreasing the value of the PAPR, the placement of a food source is identical to the phase vector $b_i=[b_{i0},b_{i1},\ldots,b_{i(V\text{-}1)}]$ where $i=1,\ldots,SN$ and SN indicates the population size, which includes the bees used or the observation bees. The bees used look for a fresh food source in a radius close to the previous resource, if the nectar quantity of the new resource is higher than the previous one. The new offer is stored as an optimal response. The steps of the ABC algorithm **[55]** are repeated within a cycle called the maximum cycle (MC). In a cycle, possible solutions of food numbers (FN) are identified and, possible solutions $MCN\times FN$ are given in the algorithm ABC-PTS to obtain the optimal phase vector.

- **The BFO-PTS (Bacteria Foraging Optimization) technique:** which models the feeding behavior of e-coli bacteria was proposed and developed by Passino**[55]**. BFO is a complicated algorithm with three steps that are grouped in nested loops: **(i)** the chemotaxis step: it models how bacteria move through the nutrient gradient. It consists of two parts: tumble and swim. A fall is simply a reorientation of bacteria in a random direction. A swim is a movement of the bacterium in the direction of dropping a specific step for each bacterium. **(ii)** The reproduction step: bacteria are sorted by health, the unhealthy half is eliminated and the remaining half is copied to create a population of original size. **(iii)** The elimination-dispersal step: with some probability, the bacteria are reset to a new position modeling the natural disturbances of E. coli in the environment. Chemotaxis occurs in the most internal loop, reproduction in the central loop and dispersion-elimination in the most external loop.

III.3. New-PTS technique for reducing the PAPR of the OFDM signal:

In this section, we will discuss the drawbacks of the PTS technique and among them **[33]:**

✓ The problem of IFFT sub-blocks: which corresponds to the number of IFFT blocks included in the design of the conventional PTS technique, is a primary parameter to decrease the high PAPR value. Therefore, increasing the number means an increase in the number of IFFT blocks, which complicates the PTS design. 'Hocine Merah, MokhtariaMesri, Larbi Talbi' **[47]**, in their Research they propose a new model to overcome the problems of this technique, is called "New-PTS".

✓ The second problem is the number of search processes in the determination of the minimum PAPR value, despite the existence of several techniques to deal with this issue, discussed earlier **[47]**.

III.3.1. New-PTS Technique:

III.3.1.1 Method Description:

- **Mathematical analysis:**

In this technique, the input data block (x) of length (N) is partitioned into (V) disjoint sub-blocks of length **[33]**:

$$X^0, X^1, \ldots, X^{V-1} \qquad \text{III.5}$$

As:

$$X = \sum_{V=0}^{V-1} X^V \qquad \text{III.6}$$

Where:

$$X_0, X_1, \ldots, X_{N-1} \qquad \text{III.7}$$

Its represents the complex symbols in the OFDM signal frequency domain:

$$\chi(X^i) \cap \chi(X^j) = \{\phi\} \qquad \text{III.8}$$

For i ≠ j, where {Ø}, and χ (**U**) = {i|u$_i$≠0} is the support of a vector **U = [**$u_0, u_1, \ldots, u_{N-1}$].

The idea of the New-PTS technique is to eliminate IFFT blocks by selecting interleaved partitions as follows:

$$X^V = [X_0^V, X_1^V, \ldots, X_{N-1}^V] \qquad / \qquad X_i^v = \begin{cases} X_i, \ldots i \in \Omega_v \\ 0, \ldots i \in \Omega_v^c \end{cases}, \tag{III.9}$$

Where: Ω_v={v+m.V|m∈{0,1...,N/V-1}}, v=0,1,...,V-1 and Ω_v^c is the complement set of Ω_v of in Λ_N={0,1,...,N-1}. The sub-sequence, **x**^{v}=[$x_0^v, x_1^v, \ldots x_{N.L-1}^v$], is generated by applying *N.L* point IFFT to each sub-block **X**^{v}, taking into consideration inserting $N \cdot (L-1)$ zeros in the middle of each X^v, based on the following equation:

$$\chi^v(n) = \frac{1}{V} \sum_{i=0}^{V-1} \chi\left(n - i\frac{N.L}{V}\right) e^{j\left(\frac{2\pi}{V}\right)iv}, \tag{III.10}$$

Where: $\chi(n - i\frac{N.L}{V})$ represents the leftward cyclically shifted version of the discrete-time OFDM symbol $x(n)$by some integer $i\frac{N.L}{V}$, x^v signifies the sub-sequences that are summed once multiplied by a rotating factor $b_v = e^{j(2\pi/W)\gamma v}$, like as:

$$\chi'(n) = \frac{1}{V} \sum_{v=0}^{V-1} b_v x^v(n), \tag{III.11}$$

We get the following by changing the expression $\chi^v(n)$ in equation III.11:

$$\chi'(n) = \sum_{v=0}^{V-1} \left(\frac{1}{V} \sum_{v=0}^{V-1} b_v e^{j\left(\frac{2\pi}{V}\right)iv} \right) x\left(n - i\frac{N.L}{V}\right), \tag{III.12}$$

With:

$$B_i = \text{IFFT}\{b_0, b_1, \ldots, b_{V-1}\} = \frac{1}{V} \sum_{v=0}^{v-1} b_v e^{j\left(\frac{2\pi}{V}\right)iv} \tag{III.13}$$

Then $\chi'(n)$ such as equation III.14:

$$\chi'(n) = x_B(n) = \sum_{v=0}^{V-1} B_i x\left(n - i\frac{N.L}{V}\right), \tag{III.14}$$

Given $b_v \in \left\{ e^{j\frac{2\pi}{W}\gamma v} | \gamma_v \in \{0,1,\ldots,W-1\} \right\}$, as a result W^{V-1} possibilities for phase vector **b**= [$b_0, b_1, ., b_{V-1}$] with b_0=1. In this way, all possible candidates for B= [$B_0, B_1, .., B_{V-1}$], can be stored as a matrix of size (*N*) in RAM memory $V \times W^{V-1}$.

Each candidate has an address (Ad) that is enclosed between 0 and $W^{V\text{-}1}$-1, and written in the W base number system as follows:

$$Ad = 0 \cdot W^{V-1} + \gamma_1 W^{V-2} + \cdots + \gamma_{V-1} = = \langle 0, \gamma_1, \ldots, \gamma_{V-1} \rangle_W, \qquad \text{III.15}$$

The possible B vectors are sorted by their corresponding address (Ad), equation III.16:

$$RAM(Ad) = B = IFFT\left\{1, e^{j(\frac{2\pi}{W})\gamma_1}, \ldots, e^{j(\frac{2\pi}{W})\gamma_{V-1}}\right\}, \qquad \text{III.16}$$

In order to choose the signal to be transmitted $x_{\hat{B}}(n)$ with the minimum PAPR corresponding to the address $\widehat{Ad}$ obtained by:

$$\hat{A}d = \underset{\substack{0 \le Ad \le W^{V-1}-1 \\ B = RAM(Ad)}}{\arg\min} = \left(\max_{0 \le n \le N.L-1} \left| x_B(n) \right| \right), \qquad \text{III.17}$$

Where **argmin** locates the minimum element of array max $_{0 \le n \le N.L-1}$ $|x'(n)|$ and returns the corresponding indices of this element in variable$\widehat{Ad}$. The optimum rotating vector $\hat{b}$ is again. Where: $\langle 0, \hat{\gamma}_1, \ldots, \hat{\gamma}_{v-1} \rangle_W = \widehat{Ad}$.

$$\hat{b} = [1, e^{j\left(\frac{2\pi}{W}\right)\widehat{\gamma_1}}, \ldots, e^{j\left(\frac{2\pi}{W}\right)\hat{\gamma}_{v-1}}] \qquad \text{III.18}$$

❖ Algorithm:

The OFDM transmitter utilizing the New-PTS scheme is shown in Figure III.2 **[48]**. The partitioning scheme of the IFFT sub-blocks is known that the PAPR reduction performance of the PTS depends on the partitioning scheme of the IFFT sub-blocks, in this case IFFT sub-blocks have been eliminated **[48]**.

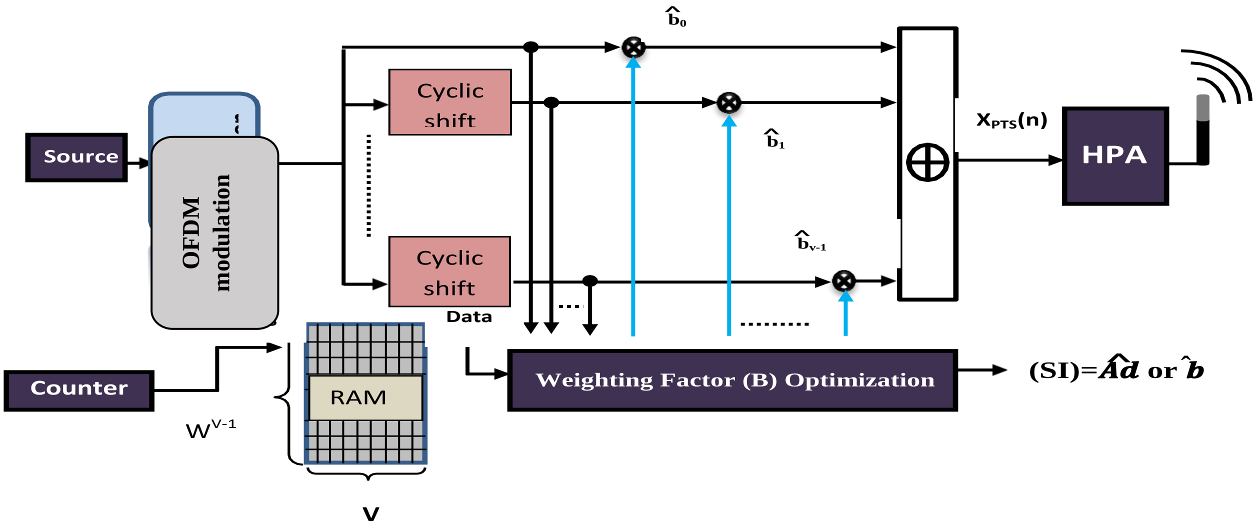


Figure.III.2. Block diagram of new-PTS.

III.3.2. Complexity reduction technique (CR-new-PTS):

The major goal of the CR-new-PTS technique is to solve problem of the number of search to obtain the optimal vector, which corresponds to the lowest PAPR. In fact, the new-PTS technique suggested by **[47]** in their research, do not take into account the reduction of the number of search W^{V-1} to get the optimal address.

Considering V sub-blocks, V_a groups are generated, each comprising V_b sub-blocks, i.e. $V = V_b \times V_a$; the sub-blocks V_b are added together and multiplied by the phase factor b_u, where: $u \in \{0, 1, \ldots, V_a - 1\}$ and $b_0 = 1$.

The stage of forming sub-groups χ'_u starting from the sub-blocks $X^0, X^1, \ldots, X^{V-1}$ will be such us:

$$\chi'_u = \left\lfloor X^{\text{index}(V_b \cdot u+0)} \ldots X^{\text{index}(V_b \cdot u + V_b - 1)} \right\rfloor, \qquad \text{III.19}$$

With $u \in \{0, 1, \ldots, V_a - 1\}$ and index(i) refer to the vector elements caused by the random inter-leaver of the vector π; then, to obtain the time signal, the IFFT method is applied as follows:

$$\chi'(n) = IFFT\left\{\sum_{u=0}^{V_a-1} b_u \sum_{m=0}^{V_b-1} X^{\text{index}(V_b \cdot u + m)}\right\} \qquad \text{III.20}$$

When the IFFT linear property is used, the following results are obtained:

$$\chi'(n) = \sum_{u=0}^{V_a-1} b_u \sum_{m=0}^{V_b-1} x^{\text{index}(V_b \cdot u + m)}(n) \qquad \text{III.21}$$

Where: $x^{\text{index}(V_b \cdot u + m)}(n) = \text{IFFT}\{X^{\text{index}(V_b \cdot u + m)}\}$,

When the new-PTS mathematical rules are used to eliminate partial IFFT blocks, the result is:

$$\chi'(n) = \chi_B'(n) = \sum_{i=0}^{V-1} B_i x\left(n - i\frac{N.l}{V}\right) \qquad \text{III.22}$$

Where:

$$B_i = \frac{1}{V}\sum_{u=0}^{V_a-1} b_u \sum_{m=0}^{V_b-1} e^{j(2\pi i/V).\ \text{index}(V_b \cdot u + m)} \qquad \text{III.23}$$

It is possible to calculate the addresses used to read the data B_i stored in RAM. Which counts from count = 0 to count = $W^{V_a - 1} - 1$; the decimal value, namely, count, is converted into a base W number system value so that $(\text{count})_{10} = \langle 0, \gamma_1, \ldots, \gamma_{V_a - 1}\rangle_W$ at each increment **[33]**, such as:

$$Ad = \sum_{u=0}^{V_a-1} \gamma_u \sum_{m=0}^{V_b-1} W^{\text{index}(V_b \cdot u + m)} \qquad \text{III.24}$$

To get The signal transmission $\chi_{\hat{B}}'(n)$ with the minimum PAPR is by the $\hat{Ad}$ that corresponds to the optimum vector of $\hat{\mathbf{B}} = [\hat{B}_0, \hat{B}_1, \dots, \hat{B}_{V-1}]$ is produced by:

$$\hat{Ad} = \underset{B = RAM(Ad)}{\operatorname{argmin}} \left(\max_{0 \le n \le N \cdot L - 1} \left| x'_B(n) \right| \right) \qquad \text{III.25}$$

The signal transmission such as:

$$\chi_{\hat{B}}'(n) = \sum_{i=0}^{V-1} \hat{B}_i x(n - i\frac{N.L}{V}) \qquad \text{III.26}$$

This technique is repeated multiple times; N_{iter} denotes the number of iterations, x(n) and $\chi_{\hat{B}}'(n)$ are replaced by x_j(n) and x_{j+1}(n) , respectively; then, the optimal address (Ad) can be

calculated for each iteration. Hence, to achieve this purpose, let us define the operation $\underset{W}{\oplus}$ between

the two integer numbers A and B contained between 0 and W^{V-1}), to calculate C, where:

$$C = A \underset{W}{\oplus} B \qquad \text{III.27}$$

And take the following steps **[48]**:

- The decimal numbers A and B are converted to the base W number system.

$$A = \langle 0, a_1, \dots, a_{V-1} \rangle_W \;\; / \quad B = \langle 0, b_1, \dots, b_{V-1} \rangle_W \qquad \text{III.28}$$

- $c_1, \dots, c_{V-1}$are calculated where :

$$c_i = (a_i + b_i)\bmod W, \;\; i = 1, \dots, V-1 \qquad \text{III.29}$$

- Calculate C′, where $\langle 0, c_1, \dots, c_{V-1} \rangle W$ is converted to the decimal value, such as:

$$C' = 0 \cdot W\,V-1 + c_1 W^{V-2} + \cdots + c_{V-1} \qquad \text{III.30}$$

- Finally:

$$C = A \underset{W}{\oplus} B = C' \qquad \text{III.31}$$

The following process III.32 can be used to select the optimum address for each iteration:

$$Ad_{j+1} = Ad_j \underset{W}{\oplus} \hat{Ad}_{j+1} \qquad \text{III.32}$$

Where: $\hat{Ad}_{j+1}$ is The optimal address to obtain the minimum PAPR of the time signal x_j(n).

The initial address is considered ($Ad_0 = 0$) and $x_0(n) = x(n)$. The number of search complexity for CR-New PTS is then $N_{iter}\, W^{Va-1}$.

III.3.3. Computational complexity analysis of C-PTS and N-PTS techniques:

It is generally known that $N{\cdot}L$ point IFFT necessitates $(N\cdot L/2)$ log2 $(N.\ L)$ numbers of complex multiplication and $(N{\cdot}L)$ log2 $(N{\cdot}L)$ numbers of complex addition. $(V.N.L/2)$ log2 $(N.L)$ complex multiplications and $(V.N.L)$ log2 $(N.L)$ complex additions are required in the C-PTS scheme involving V IFFT operations **[33]**.

Furthermore, $(V-1)\cdot L\cdot N\cdot W^{V-1}$complex multiplications and additions are necessary for combining the V sub-block signals to obtain the W^{V-1}candidates and searching for the minimal PAPR. Hence, the entire number of multiplications and additions for the C-PTS scheme namely, ($n_{\text{C-PTS,mul}}$) and ($n_{\text{C-PTS, add}}$), are as follows **[47]:**

$$\begin{aligned} n_{\text{C-PTS,mul}} &= (V.N\,.L/2)\log_2(N\cdot L) + (V-1).L\,.N\,.W^{v-1}, \\ n_{\text{C-PTS,add}} &= (V.N\,.L)\log_2(N\cdot L) + (V-1).L\,.N\,.W^{v-1}, \end{aligned} \qquad \text{III.33}$$

In the same way, the proposed PTS scheme (new-PTS) only has one (IFFT) block. As a result, in this situation, the total number of multiplications and additions, namely ($n_{\text{new-pts, mul}}$) and ($n_{\text{new-pts, add}}$), are $((N.L/2)\log2(N.\ L) + (V-1).\ L.\ N.\ W^{V-1})$ and $((N.L \log2\ N.\ L) + (V-1).L\ .N\ .W^{V-1}))$, respectively. Because one complex multiplication equals four complex additions **[56]**, the following equations are a description of complexity:

$$\begin{aligned} C_{\text{C-PTS}} &= n_{\text{C-PTS,mul}} + \frac{n_{\text{C-PTS,add}}}{4}, \\ C_{\text{New-PTS}} &= n_{\text{New-PTS,mul}} + \frac{n_{\text{New-PTS,add}}}{4}, \end{aligned} \qquad \text{III.34}$$

When analyzing the computational complexity of a conventional technique C-PTS compared to a recent technique new-PTS, the CCRR (Computational Complexity Reduction Ratio) is an important amount to consider. The following equation can be used to compute CCRR **[33]**:

$$\text{CCRR}_{\text{New-PTS/C-PTS}} = \left(1 - \frac{C_{\text{New-PTS}}}{C_{\text{C-PTS}}}\right) \times 100\% \qquad \text{III.35}$$

When the value of $\text{CCRR}_{\text{New-PTS/C-PTS}}$is negative, it signifies that C-PTS is better than New-PTS in terms of computational complexity. If the values are equal to zero, the computational complexity is the same. While the new technique is better when the values are positive, we can see the following by analyzing the results in Table III.1 **[34]**:

- Table III.1 indicates that CCRR values are positive regardless of V, W and N values **[47]**. The CCRR will increase as N is increased for a given value of V, W.

- CCRR increases rapidly regardless of the supplied values of N, whereas W is altered from (W=4) to (W= 2) when (V= 4), or (V= 8).

As a result, the new technique N-PTS is better than the conventional technique C-PTS.

Table.III.1. CCRR of new-PTS over C-PTS

	N		
(V,W)	64	256	1024
(16,2)	0.0146 %	0.0183 %	0.0220%
(8,4)	0.0293 %	0.0366 %	0.0439 %
(8,2)	3.5959 %	4.4492 %	5.2852 %
(4,4)	6.8182 %	8.3333 %	9.7826 %
(4,2)	33.3333 %	37.5000 %	40.9091 %

III.4. PTS technique without search number (WSN-PTS) to reducing the PAPR of the OFDM signal:

The major problem in PTS technique is the side information, the complexity and the problem of IFFT blocks and search number. Many probabilistic solutions are proposed bus not enough such as the BFO-PTS, ABC-PTS, GD-PTS, I-PTS to reduce those problems, the New-PTS method has limit the problem of IFFT block but there is another drawbacks in this technique which are:

✓ Problem of (SI).

✓ The second problem is the number of search which we focus on it processes in the determination of the minimum PAPR value, despite the existence of several techniques to deal with this issue, discussed earlier **[48]**, even the CR-NEW-PTS does not limit the number of research processes, a new technique proposed to limit search number, it is called "WSN-PTS".

III.4.1. WSN-PTS:

The diagram proposed PTS scheme (WSN-PTS) to limit the search number for reduces the PAPR value of the OFDM system is shown in figure III.3.

Basically, unlike all the pts techniques, this technique works on the digital and gives the same result in the continue signal. This operation is carried out on the transmitter.

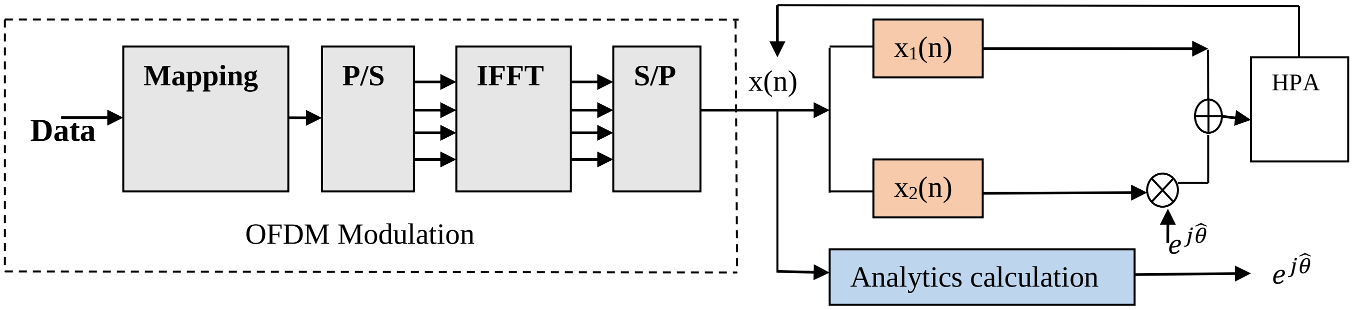


Figure III.3. Proposed scheme to limit search number (WSN-PTS).

WSN-PTS scheme composed of data after mapping, convert the data mapping to parallel to serial, after that applied the IFFT block and then convert the signal serial to parallel and we obtain the signal division to signals x_1,x_2 , be side the analytic calculation, for optimization and multiplexing the phase for PAPR reduction, we get signal with PAPR reduction, with five iteration.

- **Mathematical analysis:**

This method depends on the original signal x (n) from the equation in the new-pts, we are going to divides it to two different signals x_1 and x_2, where:

$$Q_k(n) = \sum_{i=0}^{V-1} q_i e^{jnpi/v} \qquad \text{III.36}$$

With:

$$\chi_1^{(0)}(n) = \sum_{i=0}^{V-1} Q_k x(n - i\frac{K.N}{V})$$

$$\chi_2^{(0)} = x(n) - x_1 \qquad \text{III.37}$$

Where the iteration is: $\chi^1 = x_1^{(0)} + x_2^{(0)} e^{j\theta_1}$

To calculate the signal x_1 from an index of information as a vector V= [0, 1, 1, 0, 1, 0 ...], then we calculate the FFT of the equation III.36 we got the elements q_i=[q_0, q_1, q_2, q_3, q_4,...,q_n] with q_i{0, 1}, hence, from **[48]** we calculate x_1, x_2, where the original signal OFDM is the sum of all the signals and x_2 it's the original signal minus x_1 as the equation III.37, consequently we can result the phase θ to reduce the PAPR value analytically as follows:

Sub-blocks $[x_0, x_1, \ldots, x_{v-1}]$, the groups are selected using an index that is created by changing the positions of the vector elements at random $\pi = [0\ 1 \ldots V\text{-}1]$. The random interleaving vector π is used to achieve this, x^1 with V=16, as following $x^1 = (x_1, x_2, x_4, x_5, x_7, x_8, x_{10}, x_{12})$.

As a result the sum of x^1 and x^2 such as:

$$\chi(n) = x_1(n) + x_2(n)e^{j\theta} \qquad \text{III.38}$$

the IFFT method is applied as follows, the equation will be such us:

$$x_1(n) + x_2(n)e^{j\theta} - P_x \qquad \text{III.39}$$

Where P_x is the power.

When the WSN-PTS mathematical rules are used to limit the search number, the result is:

$$\min_{0 \le \theta \le 2\pi} (\left| x_1(n) + x_2(n)e^{j\theta} \right|^2 - P_x)^2 = f(\theta) \qquad \text{III.40}$$

We get the following by changing the expression $x_1(n)$ and $x_2(n)$ in equation III.40:

$$(\left| x_1(n) \right|^2 + \left| x_2(n) \right|^2 + x_1^{*} x_2 e^{j\theta} + x_1 x_2^{*} e^{-j\theta} - P_x)^2 = f(\theta) \qquad \text{III.41}$$

We get:

$$\left| x_1(n) \right|^2 + \left| x_2(n) \right|^2 - P_x + x_1^{*} x_2 e^{j\theta} + x_1 x_2^{*} e^{-j\theta})^2 = f(\theta) \qquad \text{III.42}$$

We get the following by changing $f(n) = x_1(n)^2 + x_2(n)^2 - P_x$ and $\rho(n) = x_1^{*} x_2, \rho(n) = x_1 x_2^{*}$

$$E\left(f(n) + \rho(n)e^{j\theta} + \rho^{*}(n)e^{-j\theta} \right)^2 = f(\theta) \qquad \text{III.43}$$

After simplifying the equation from the form (a^2+b^2+2ab) we get:

$$E\left(f(n)^2 + 2f(n)[\rho(n)e^{j\theta} + \rho^{*}(n)e^{-j\theta}] + \rho^2(n)e^{j2\theta} + \rho^{*2}(n)e^{-j2\theta} + 2\left|\rho_r\right|^2 \right)^2 = f(\theta)$$

$$E\left(f(n)^2 + 2f(n)\rho(n)e^{j\theta} + 2\rho^{*}(n)f(n)e^{-j\theta} + \rho^2(n)e^{j2\theta} + \rho^{*}(n)e^{-j2\theta} + 2\left|\rho_r\right|^2 \right)^2 = f(\theta) \qquad \text{III.44}$$

With:

$$E\left(f(n)^2 + 2\left|\rho_r\right|^2 \right) = b_0$$

$$E\left(2f(n)\rho(n) \right) = a_0 = \left|a_0\right| e^{j\alpha}$$

$E(2f(n)\rho*(n)) = a_0^* = |a_0|e^{j\alpha}$

$E(f^2(n)) = c_0 = |c_0|e^{j\alpha}$

$E(f^{*2}(n)) = c_0^* = |c_0|e^{-2j\alpha}$

As a result we have:

$$b_0 + a_0 e^{j\theta} + a_0^* e^{-j\theta} + c_0 e^{j2\theta} + c_0^* e^{-j2\theta} = f(\theta) \qquad \text{III.45}$$

Where: $b_0=(x_1+x_2-P_x)*(2x_1x_2e^{j\theta})$, $e^{j\Theta}= \cos\theta + j\sin\theta$, $e^{j2\Theta}= \cos 2\theta + j\sin 2\theta$, we get the following by changing coefficients a_0, c_0:

$$b_0 + |a_0|e^{j\theta+\vartheta} + |a_0|e^{-j\theta+\vartheta} + |c_0|e^{j(2\theta+2\vartheta)} + |c_0|e^{-j(2\theta+2\vartheta)} = f(\theta)$$

$$b_0 + 2|a_0|\cos(\alpha+\theta) + 2|c_0|\cos(2\alpha+2\theta) = f(\alpha) \qquad \text{III.46}$$

We consider $\alpha = \theta + \vartheta$, hence the following equation:

$$b_0 + 2|a_0|\cos(\alpha) + 2|c_0|\cos(2\alpha) = f(\alpha) \qquad \text{III.47}$$

After deriving equation III.47 we get:

$\alpha = 0$

$\theta + \vartheta = 0$

$\theta = -\vartheta \Rightarrow -phase(a_0)$

This operation returned multi time for five times by mixing vector, the position of number 1 will change. So we created a new groups and get another phase to get the best PAPR value by this relation $x^1=x_1^{(0)}+x_2^{(0)}e^{j\Theta_1}$.

III.5. Conclusion:

In this chapter, we mentioned the importance of the PTS technique in reducing the PAPR of the OFDM system. Then we discussed the conventional technique C-PTS and the improved PTS (N-PTS) methods, the new technique has been developed by **[48]** to achieve better PAPR performances while the computational complexity is significantly reduced.

Due to the multiple (IFFT) blocks and the number of search procedures required to get the optimal phase factor, (PTS) has an inherent problem of computational complexity. In this section, a

(N-PTS) technique has been granted to eliminate the (IFFT) blocks in order to reduce the computational complexity in terms of the number of complex multiplications and additions involved, as confirmed by the (CCRR) analysis results. Furthermore, the proposed CR-new-PTS technique has brought enhancement regarding the number of search of such investigation. And because of the drawbacks of this technique (search number), WSN-PTS has proposed to reduce those problems analytically. In the next chapter we discussed about the best result of this technique.

Simulations and Discussion of Results

IV.1. Introduction:

In this chapter, we will study the parameters of the program and discuss the results obtained during our MATLAB (2013a) simulations. Generally the parameters used are found in most of the articles cited as references. The programs executed can be modified to test and compare different possibilities. Thus, programs have been developed to calculate the BER, and the PAPR of various parameters such as the number of carriers N, the size of QAM modulations (16) and can even choose the type of modulation (QAM). As a result, this chapter focuses on new (WSN-PTS) that can be used in OFDM modulation to reduce the number of searches.

IV.2. PAPR reduction methods performance in the OFDM system:

In this section, we analyze and verify the performance of the WSN-PTS method by simulations with the following parameters:

- The CCDF add-on distribution function is typically used to evaluate PAPR reduction performance. The simulation parameters that have served this study are provided in Table.IV.1, wherein convolution coded (CC) rate coding equals ½, constraint length is 7, first register g1 = 133, and second register g2 = 171 . The possible combinations of phase factors are 1, − 1 and 1, − 1, j, − j for W = 2 and W= 4, respectively. While, on the one hand, the authors are trying to fit requirements of data transmission in future wireless systems, on the other hand, they would like to indicate extension of reported results in this work; accordingly, all of the results are reported at measured CCDF = 10^{-4} and BER = 10^{-6}.

Figure.IV.1 shows the CCDF of PAPR for a 16-QAM/OFDM system using WSN-PTS technique as the number of sub-block varies. It is seen that the PAPR performance improves as the number of sub-blocks increases with V = 4, 8, 16, and 32 at CCDF = 10^{-4}. The CCDF performance of V=4 is 9.3 dB, Furthermore, the number of iterations in WSN-PTS technique is set to $N_{iter} = 2$. For V = 8 the PAPR value is 7.5 dB. In case when V = 16 and the PAPR value equals 7 dB, finally PAPR value is 6.4 dB for V=32.

Figure.IV.2 compares the PAPR reduction performance of WSN-PTS against C-PTS schemes, the sub-block number for the C-PTS schemes is V=4, V=8, V=32. 2; in C-PTS, when taking V= 4, a PAPR value of 11 dB is obtained, taking V=8 gives a PAPR value of 9dB, and with V=32 it's7dB comparing with WSN-PTS the PAPR value it is 6.5 dB, respectively. WSN-PTS scheme definitely exhibits the best performance.

Table IV.1. Simulation parameters.

Symbol	Quantity	Value
16-QAM	Modulation method	16 bits
N	Number of sub-carriers	1024
V	Number of sub-blocks	4, 8, 16, 32
W	Number of phase factor	2, 4
SSPA	Amplifier	—
IBO, dB	Input back-off	3
P	Smoothness factor	0.5
L	Oversampling factor	4

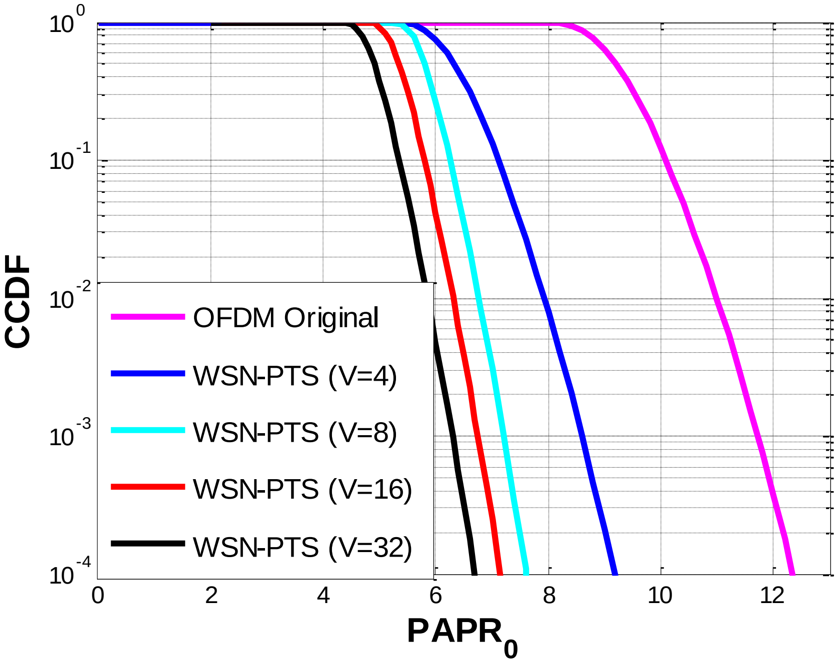


Figure.IV.1. PAPR performance of a 16-QAM/OFDM system with WSN-PTS technique when the number of sub-blocks varies.

Figs.IV.3 shows PAPR for different reduction techniques: clipping, SLM, TR, WSN-PTS, Compare to the new WSN-PTS for 16-QAM. The CCDF curve of PAPR of the original OFDM signal is also provided for comparison purposes. This figure reveals a PAPR value of 12.3 dB of the original OFDM signal. All traditional schemes use W=2. In clipping, SLM, TR the PAPR value of

10 dB, 9 dB and 8.2 dB is obtain, and the WSN-PTS case shows that the PAPR value is 6.5 dB, hence give us the best PAPR reduction performance.

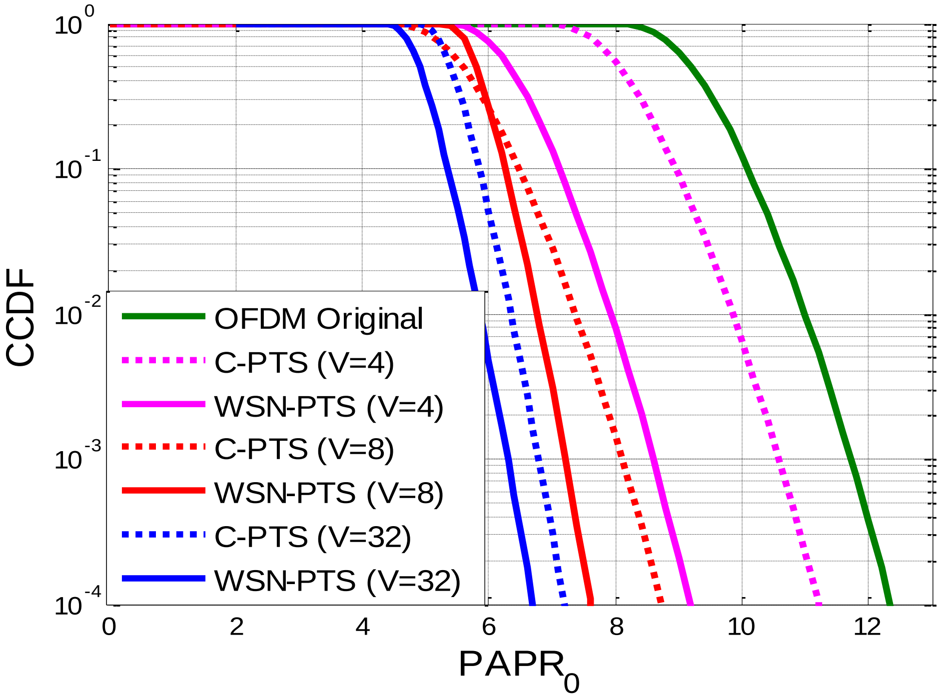


Figure.IV.2. PAPR reduction performance of a 16-QAM/OFDM system with WSN-PTS compared to C-PTS technique for V=4, V=8 and V=32.

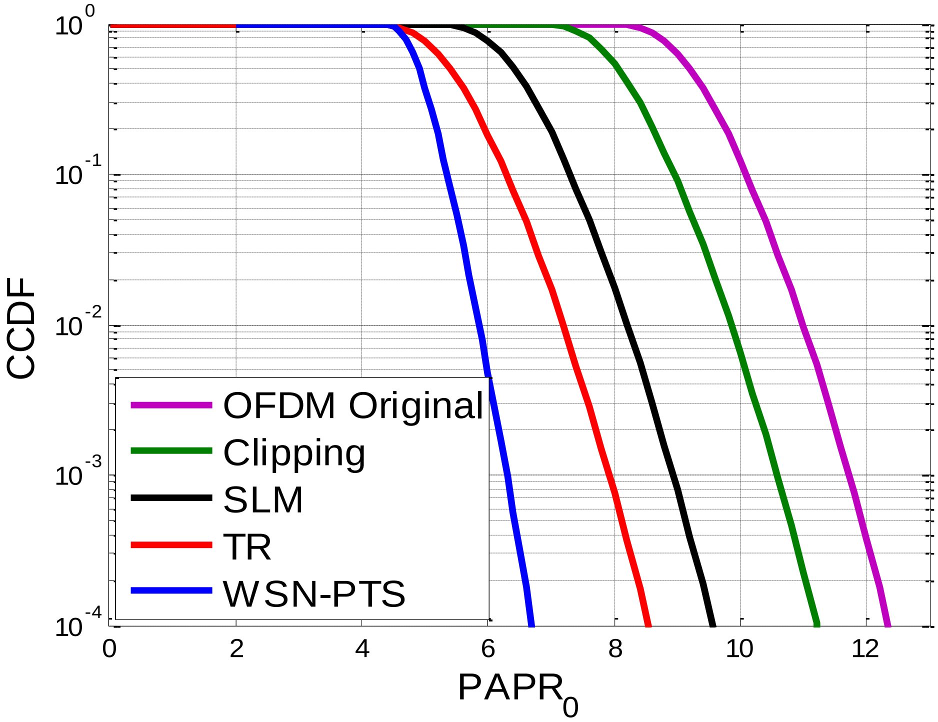


Figure.IV.3. PAPR for Different reduction techniques: clipping, SLM, TR, WSN-PTS, Compare to the original OFDM

IV.3. BER performance of OFDM system:

Measuring the BER of a digital transmission system is one of the most essential strategies to determine its quality. By comparing the transmitted and received bit sequences and calculating the amount of mistakes, the BER is determined.

The (BER) is the ratio of the total number of bits received to the number of bits received in error, with the total number of bits received calculated as follows: The received signal is first entered into the (FFT) to form the frequency-domain signal, and then it is rotated by the (SI), which is composed of the phase vector, to retrieve the original signal's phase. Finally, the original data is input into the demapping block to obtain the bits received **[48]**. Many factors affect BER performance, including the signal-to-noise ratio (SNR) and HPA-induced distortion. The SNR is given in terms of P_{avg}/N_0, where N_0 is the noise power spectral density and P_{avg} is the received signal's average power. ,Figs. IV.4 and IV.5 illustrate the BER curves that are obtained in the case of WSN-PTS with the number of searches of 1024, considering a non-linear amplifier, for 16-QAM modulations, respectively. The operating point of HPA is defined by the IBO parameter that corresponds to the ratio of saturated input power (P_{sat}) and average input power ($P_{ave,in}$), where the IBO value remains very important for the BER performance of the system. The stated value of IBO=3dB as reported in the related literature in this domain with different values of V=4, V=8, V=16 at BER = 10^{-6}.

Fig.IV.4 shows that when QAM modulation is used, the BER performance of WSN-PTS, the SNRs is 15 dB for IBO = 3 dB, V=4 with HPA. In case of IBO=3dB, V=8 it is 17 dB, finally, for IBO=3 dB, V=16 the BER performance is 18 dB, respectively, at BER = 10^{-6}.

Fig.IV.5 reveals that when using QAM modulation, the BER performance of WSN-PTS for IBO=3dB, V=4 is 28 dB, and for IBO=3 dB, V=8 it is 33 dB, respectively, at BER = 10^{-6}, and for IBO=3dB, V=16 of BER performance is about 40 dB. The ideal BER performance is achieved with the original signal without HPA (linear amplifier). The performance of BER is significantly impacted by the needed existence of HPA; the proposed N-PTS scheme leads to effective strong improvements in the BER performance compared to the original signal using HPA at BER = 10^{-6}.

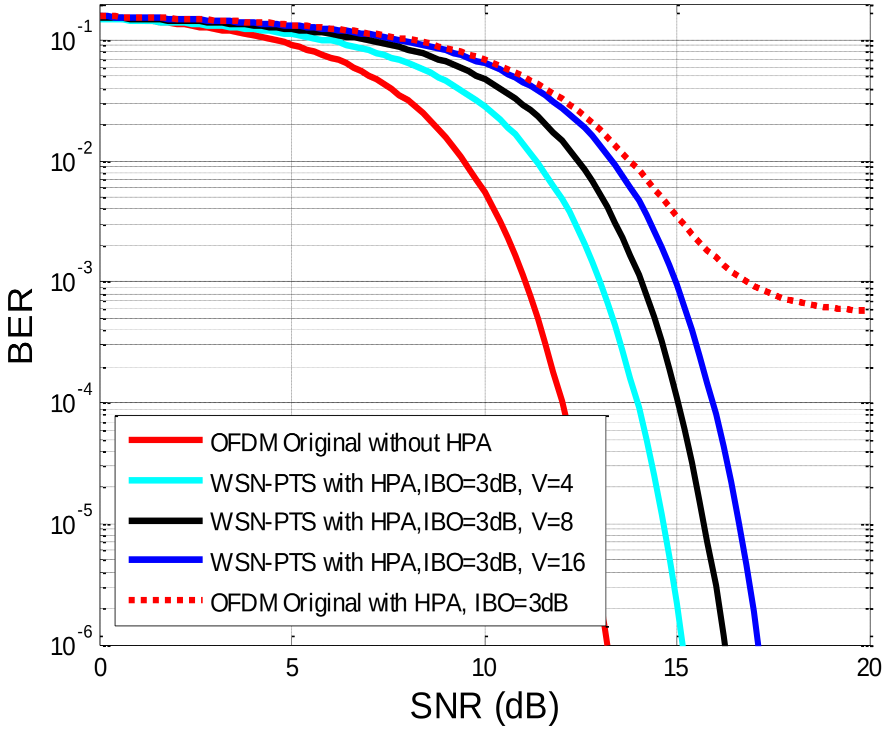


Figure.IV.4. BER performance of the OFDM system using WSN-PTS with HPA, for 16-QAM modulation. With different values of the parameters IBO=3dB with V=4, 8, 16

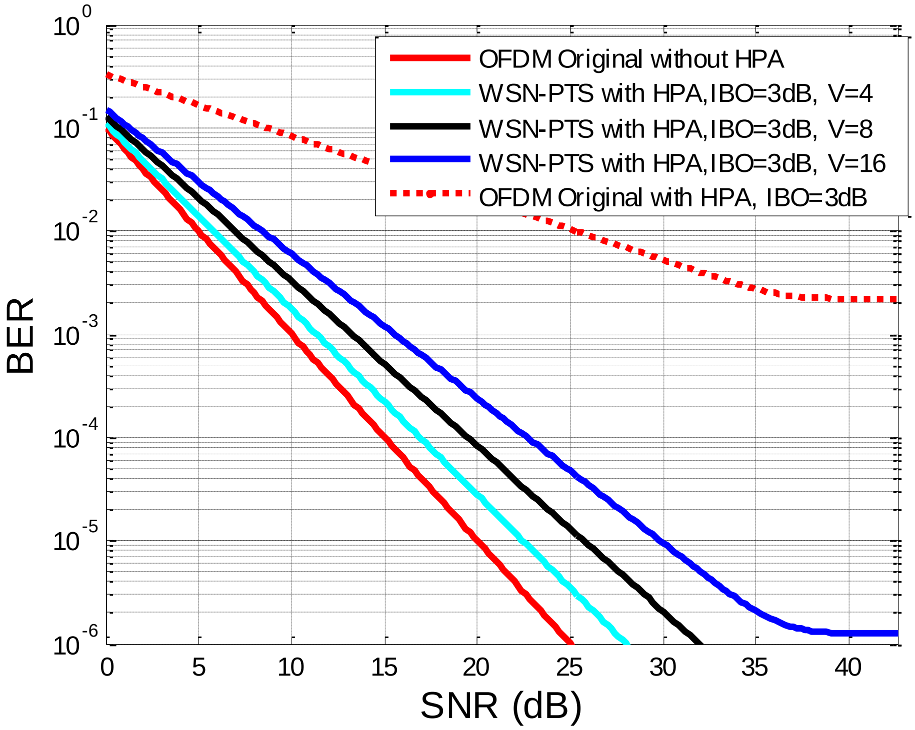


Figure.IV.5. The BER performance of WSN-PTS schemes for QAM with HPA (IBO = 3 dB).

IV.4.Conclusion:

In this chapter, the study of PAPR in an OFDM system was presented. In order to reduce the impact of PAPR, we studied a new PTS technique, which has been addressed to eliminate the number of search. As a result, it has led to a reduction in computational complexity, as confirmed by the meaningful results obtained through the CCRR analysis. In light of the results obtained for the OFDM system during our study. It can be concluded that the proposed method the WSN-PTS gives better results in terms of the arithmetic complexities. In addition, we managed to simulate its variants such as C-PTS, and Simulation results have been achieved by comparing the so-called the conventional PTS (C-PTS) in terms BER and CCDF. In general, the results show that the proposed method is better in terms of CCDF, BER, and the number of searches.

General Conclusion

General Conclusion

In this work, we have presented contributions for reducing the peak factor of multi-carrier (MC) signals in order to find the optimal balance between the power amplifier's energy efficiency and the signal's distortions.

Several techniques have been implemented to verify that the PAPR value does not exceed a certain limit considered acceptable, the work presented in this brief focused on the reduction of the PAPR in a transmission based on the OFDM by the PTS method which made it possible to obtain very good performances for the reduction of the PAPR at the cost of a significant calculation complexity **[33]**. The proposed application concerns 5G mobile networks.

We started with a detailed presentation of the OFDM multi-carrier modulation that is subject to a lot of attention in the field of high-speed wireless transmissions because of its ability to manage the frequency selectivity of channels, and thus its obstacles on the technologies and more precisely on the fifth generation, and then we discussed the concept of the new generation expected in the field of "5G" and its features that depend on the reduction of the PAPR by the PTS technique.

The multi-level of the modulated signal is advanced, and for that, the High power amplifier (HPA) high linearity is required even at low output power. The impact of PAPR is slightly less critical, since more advanced power amplifier linearization techniques such as coding and filtering, Selective Level Mapping SLM, Partial Transmit Sequence PTS, Tone reservation TR, are used to reduce the impact of a high PAPR waveform.

We were particularly interested in the PTS techniques, the one giving the lowest PAPR and the best performance in terms of BER and do not negatively affect the off-band signal (OOB). However, the multiplicity of blocks of Reverse Discrete Fourier Transform (IFFT) represents a major constraint for these techniques, which accentuates the complexity aspect of the calculations.

In chapter three, the solutions of these problems have been discussed; the PTS technique has been clearly outlined to reduce the OFDM PAPR. However, PTS suffers from the inherent problem of computational complexity, which is due to the multiple IFFT blocks and the number of search processes to obtain the optimal phase factor, there is a pressing need for innovative solutions.

A new PTS technique has been suggested at this stage to eliminate IFFT blocks. This has led to a reduction in numerical complexity in terms of the number of complex multiplications, confirmed by the significant results obtained through the CCRR analysis. In addition, the CR-new-PTS technique was proposed in order to reduce the number of searches to optimize the phase factor corresponding to the minimum of the PAPR. Because of its disadvantages (SI and Search number), the WSN-PTS was proposed to solve the problem of search number.

In the fourth chapter, the simulation results were carried out in particular by CCDF comparative studies of the CCDF for the reduction of the PAPR, the BER for the performance of the system and the complexity of arithmetic calculation. The substantial results obtained have shown that the proposed technique (WSN-PTS) provides is better in terms of CCDF, BER, and the number of searches.

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