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Peak to Average Power Ratio Reduction Techniques in Orthogonal Frequency Division Multiplexing Principle: A Comprehensive Review

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***Abstract*— Orthogonal frequency division multiplexing (OFDM), a major form of Multicarrier modulation has been employed as a technology to meet the increasing demand of high data rates in multimedia applications and wireless communication. This paper describes the importance of multi-carrier modulation, advantages, disadvantages, application, history, development, implementation, and conceptual model of OFDM. This technique is widely considered particularly in the field of wireless communication because of its robustness to the multipath fading, low inter-symbol interference (ISI), immunity to frequency selective fading, and high-power efficiency, and has been widely recognized as the standard transmission technique in the wireless local area network (LAN) systems. Despite the numerous advantages of OFDM, the problem of Peak to average power ratio has been a major drawback. From the literature, many methods have been proposed, presented, and developed to reduce this problem of OFDM. Some of these methods are precoding, partial transmit sequence, selective mapping, peak windowing, clipping, etc. This paper presents a review on various PAPR reduction techniques, comparison between various techniques, and conclude with the review of past works of researchers.**

Keywords—Orthogonal frequency division multiplexing(OFDM); Intersymbol interference(ISI); Peak to average power ratio(PAPR); Wireless local area network(LAN); Multipath fading.

I. INTRODUCTION

With the advent of technology which has resulted in the evolution of digital communication, there has been an enormous increase in multimedia data services which has grown immensely and brought about the growth of Long-Term Evolution (LTE) or 4th Generation (4G) wireless communication system [3]. It is stated in [1] that to accomplish the growing demands of higher data transfer rates for new multimedia applications, there have been numerous challenges on the physical wireless link of communication networks. Limited availability of bandwidth, mobility, and multipath fading are major problems associated with wireless communication links that need urgent solutions. Recently, there has been much progressive research to triumph over these limitations.

Different modulation techniques have been employed to solve and match for new solutions and future applications. This modulation is classified into single carrier and multi-carrier modulation. Multi-carrier modulation (MCM) is the most efficient modulation method when compared to single carrier modulation because it provides high digital transmission over channels that exhibit high frequency-selectivity and strong multipath characteristics [4]. The modern digital MCM wireless communication system provides high reliability as well as a high-speed data rate at the lowest cost for numerous users. Orthogonal frequency division multiplexing (OFDM) is a multi-carrier modulation technique that provides bandwidth-efficient signaling schemes for use in high data rate communication systems. This technique is widely considered particularly in the field of wireless communication because of its robustness to the multi-path fading, low inter-symbol interference (ISI), immunity to frequency selective fading, and high-power efficiency, and has been widely recognized as the standard transmission technique in the wireless local area network (LAN) systems and the terrestrial digital broadcasting systems [5]. In [6], OFDM is considered as the current and future technology for high data transfer in today's wireless communication systems. Some of the applications of OFDM and its usefulness in today's multimedia services are Long-Term Evolution (LTE), Worldwide Interoperability for Microwave Access (WiMAX), IEEE 802.11 a/g/n/ac/ax, and Digital Video Broadcast (DVB-T1/2). Despite all the advantages of OFDM, the problem of high peak to average power is associated with it. This problem has a major challenge in its performance. The high peak to average power ratio (PAPR) has nonlinear nature in the High-power transmitter which resulted in the degradation of the power efficiency of the system [3]. However, OFDM signal is formed as a result of subjecting input data symbols (arranged as a set of subcarriers) to an Inverse Fast Fourier Transform (IFFT), during this operation, there is a high possibility that some of these symbols add up coherently, resulting to the creation of some large peaks at the output. This process is usually measured in terms of PAPR, The High PAPR formed is directly proportional to the number of subcarriers available [33], [38]. Therefore, sending these high peak amplitude signals to the high-power amplifier without finding every possible solution to reduce the high peaks result in great havoc because the power amplifier used for the transmission in wireless communication is non-linear. Thus, inter-modulation and out-of-band radiation are caused as a result of the non-linearity of the power amplifier caused by high peaks [42].

Many methods have been developed and employed to reduce high PAPR but many factors are put into consideration before choosing the best method. These factors include; increase transmit signal power, bit error rate (BER), computational complexity and loss of data rate, etc. PAPR reduction techniques would favor one or two criteria at the cost of the others. These techniques include Amplitude Clipping and Filtering, Peak Cancellation, Peak Reduction Carrier, Tone Injection (TI), Envelope Scaling, Peak windowing, Coding, Partial Transmit Sequence (PTS), Selective Mapping (SLM), Tone Reservation (TR), Nonlinear Companding and precoding [62].

In this paper, we aim at reviewing the most acknowledged researches on precoding, partial transmit sequence, clipping, selective mapping and various algorithm that has been used to combat the problem of PAPR in OFDM. Section 2 gives a review of the History and Development of MCM. Principles of Multicarrier modulation, Implementation of OFDM, Principles of Orthogonality in OFDM are presented in sections 2,3,4,5 respectively. The Advantages, Disadvantages, Overview of Peak to Average power ratio in OFDM, Different PAPR reduction methods, and review of related researches are presented in other sections Finally, section 7 presents the conclusion and insight in probable future research and criteria to be taken when selecting a method to reduce PAPR

II. HISTORY AND DEVELOPMENT OF MULTI-CARRIER MODULATION

Multi-Carrier Modulation (MCM) is lately being identified as a superior alternative to single-carrier modulation, for high-capacity digital transmission over channels that shows strong multipath and high frequency-selectivity characteristics [4]. MCM networks for example Frequency Division Multiplexing (FDM) have been in existence since the late 1950s [28]. However, due to inefficient use of the frequency band, their difficulty in implementation was limited to military applications. At a corresponding data rate, a multicarrier system especially in wireless applications is less prone to channel-induced distortions when compared to single-carrier systems. In the 1960s, Saltzberg (1967) and Chang (1966) further developed FDM with the introduction of multiple carriers which utilize the frequency spectrum more efficiently and which overlap in the frequency without interfering with each other. However, the complexity issue remained. In the 1970s, the complexity of an OFDM system is significantly reduced by introducing Inverse Discrete Fourier Transform (IDFT) and Discrete Fourier transform (DFT) to perform the modulation and demodulation respectively by exploiting the sinusoidal nature of Fourier transform [27].

Until this time, all the proposals used raised cosine windowing in a time domain and guard spaces in the frequency domain to combat Inter-channel interference (ICI) and Inter-symbol interference (ISI). Another breakthrough achieved for OFDM history was the introduction of cyclic prefix (CP) and cyclic extension in 1980 by Peled and Ruiz. The problem of sustaining orthogonal characteristics of the transmitted signals at unadorned transmission conditions was unraveled. The general idea suggested was to introduce a cyclic extension of OFDM symbols instead of using empty guard spaces in the frequency domain. This successfully makes the channel into acting cyclic convolution, which offers orthogonality over diffusive channels when CP is longer than the channel impulse response [63].

Furthermore, more advances in practical OFDM systems where various prototypes and projects were initiated such as digital Terrestrial Television broadcasting (dTTb), DIgital VIdeo Narrowband Emission (HD-DIVINE), and System de Television En Radiodiffusion NumeriquE (STERNE) have been made in the last 10 years. This has progressively led to the approval of OFDM in many European standards. This success brings about the acceptance of OFDM in many European standards [25]. OFDM has developed to the extent that it is widely needed for many communication applications such as Digital Video Broadcasting (DVB) and Digital Audio Broadcasting in Europe. It has also been approved as the physical layer modulation technique for wireless networking standards such as Hiperlan2 in Europe and the Institute of Electrical and Electronics Engineers (IEEE) 802.11a, g standards in the United States. Despite OFDM advantages such as alleviating the problem of the diffusive channel, there are still some problems associated with it such as frequency and time synchronization, frequency selective fading, and peak to average power ratio (PAPR).

III. PRINCIPLE OF MULTI-CARRIER SYSTEM

In multicarrier modulation, the basic concept and principle of operation are to divide the input data stream into N parallel data streams. Each parallel data steams divided is modulated on a different narrowband subcarrier and add together before transmission takes place, therefore, the system provides the same data rate as a corresponding single carrier system. The wideband signal is separated by filter banks into the original narrowband subcarriers for demodulation at the receiver. The main advantage of this arrangement over single-carrier systems is that the extended symbol time (due to lower data rate) makes the signal less susceptible to effects of the channel such as multipath propagation which introduces Inter-symbol Interference (ISI). The multicarrier system is shown in fig. 4 and this picture shows that flat fading is likely to occur to each of the subchannels reducing the equalization complexity in the receiver intensely. The main shortcoming of the multicarrier technique is the computational and implementation complexity due to the bulky number of filter banks needed in the transmitter and receiver as well as the inefficient use of the available frequency band [35].

IV. OFDM IMPLEMENTATION

Orthogonal Frequency Division Multiplexing (OFDM) is the main example or technique that can best show the implementation of a multi-carrier system as depicted in fig. 5. In OFDM, the signals are produced in a mode that the frequency spectra of each subchannel overlap thereby exploiting the frequency spectrum resourcefully. Additionally, the output symbol of OFDM usually comes with a large dynamic envelope range due to the superposition process executed at the IFFT stage in the transmitter. Furthermore, the ability and characteristics of OFDM signals to efficiently spaced the subcarriers in the channel close together by the principle of orthogonality which prevents interference amongst the closely spaced subcarriers gave it the advantage to efficiently use the available spectrum. Fig. 6 shows the difference between the conventional non-overlapping multicarrier technique and the overlapping multicarrier modulation technique. It is observed in fig. 6 that almost half of the bandwidth is successfully saved by using the overlapping technique when compared to the conventional non-overlapping technique [48]

V. PRINCIPLE OF ORTHOGONALITY IN OFDM

In a multi-carrier system, the bandwidth occupied on the channel is minimized as possible. For minimization to be possible, the frequency space between carriers is reduced. The narrow space among the carriers is obtained when they are orthogonal to each other. To be orthogonal, the time-averaged integral product of two signals should be zero as expressed by [2] in equation (1)

$$\frac{1}{T}\int_{t_1}^{t_1+T} F_k(t) \times \frac{1}{T}\int_{t_1}^{t_1+T} F_l(t)\, dt = 0 \quad if\ k \neq l \qquad (1)$$

Where $F_k(t)$ and $F_l(t)$ are any two signals over a time interval $[t_1\ and\ t_1 + T]$. T is a signal time. With the further simplification of equation 1, the discrete-time domain of orthogonality of two signal is expressed as

$$\frac{1}{N}\sum_{n=0}^{N-1} e^{\frac{j2\pi k}{T}nT_s} \times e^{\frac{-j2\pi l}{T}nT_s} \qquad (2)$$

Further simplification gives:

$$\frac{1}{N}\sum_{n=0}^{N-1} e^{\frac{j2\pi(k-l)}{N}n} = \begin{cases} 0 & \forall \ \ k \neq l \\ 1 & \forall \ \ k = l \end{cases} \qquad (3)$$

Through the overlapping subcarriers, an OFDM-based communication system is capable of efficiently utilizing the frequency spectrum. In fig. 2, the five sub-carriers show that sub-carriers are moderately overlapping without interfering with adjacent sub-carriers because the maximum power of each subcarrier corresponds directly with the minimum power of each adjacent channel. In addition, different subcarriers are orthogonal to each other and they are different from one another.

VI. ADVANTAGES OF OFDM

From the literature, the importance of OFDM as a more spectrally efficient implementation of the Multicarrier system is analyzed and discussed. Some of the advantages of this system are Simple Implementation of Modulation and Demodulation, Protection Against ISI and ICI, Spectral efficiency, Susceptible to frequency selective fading, and Easy Equalization

VII. DISADVANTAGES OF OFDM

Despite the numerous advantages of OFDM, it is faced with some problems, some of them are: The high Peak to Average Power Ratio (PAPR) of the transmitted signal implies that the presence of a large number of subcarriers with varying amplitude results in a high peak to average power ratio (PAPR) of the system with a large dynamic range, which in turn affects the efficiency of the RF High power amplifier (HPA and secondly problem of synchronization (Timing and Frequency) at the Receiver.

VIII. CONCEPTUAL MODEL OF OFDM SYSTEM

According to [62], defined OFDM as a distinct form of multicarrier modulation (MCM) with closely spaced subcarriers, overlapping spectra, thus allowing multiple access. An OFDM transceiver model in fig. 1 by [34] described the complete OFDM transceiver system where forward error control/correction (FEC) coding and interleaving are included in the model to provide the strength required to guard against burst errors. An OFDM system incorporated with interleaving and channel coding is referred to as coded OFDM (COFDM). The basic principle of operation of OFDM involves dividing the input data symbol into several bits of streams. Each of the sub-streams has a much lower bit rate and is required to modulate several carriers. The input data is coded by FEC and then interleaved to obtain diversity gain.

The information sequence is mapped into the corresponding constellation point i.e. (BPSK, QPSK, QAM) symbols which are spread and sent over the N sub-channels (one symbol per channel). The output of the symbol mapping resulted in a complex data symbol and the pilot symbol is inserted. The complex data symbol is the input to serial to parallel converter (s/p), then IFFT operation is accomplished on the parallel complex data symbol. The transform data symbol is then gathered into different numbers of essential transmission subcarriers. Cyclic prefix, cyclic suffix, or zero paddings is inserted as a guard band to every block of data. Guard interval in the OFDM system is needed to remove ISI introduced between consecutive OFDM symbols. Therefore, the output OFDM signal is modulated and transmitted. Digital to analog converter functions as a system that converts the time domain complex digital data to time-domain analog data. Radiofrequency (RF) modulation is accomplished and the signal is up-converted by assigned transmission frequency.

Upon transmission of the OFDM signals by the Transmitter antenna, the signal goes through anomaly and hostility of wireless channel. The receiver received the transmitted signal and then converts it from time-domain analog to time-domain digital by the analog to digital converter (ADC). Carrier frequency synchronization is performed upon the down conversion by the receiver and symbol timing synchronization is achieved after ADC conversion. Demodulation of OFDM signal is achieved by FFT Symbol and channel estimation is accomplished by using the demodulated pilots. De-mapping is performed and complex receive data are obtained according to the transmission constellation diagram. At this moment, FEC decoding and de-interleaving are used to recover the originally transmitted bitstream.

A. Transmitter

In OFDM systems, modulation or mapping is firstly performed on the successive number of input data symbols by different M-ary modulators depending on the system requirement (e.g, BPSK, QPSK, or QAM). The N complex data symbol is then connected and transferred by serial to parallel converter. The parallel data is jointly connected using inverse fast Fourier transform (IFFT). The reason for using IFFT is to produce orthogonal data subcarriers. Let, data block of length *N* represent by vector $X = X(0)$, $X(1), \dots X(N-1)^T$. Duration of any symbol X_K in the set *X* is *T* and represents one of the sub-carriers set. Hence, the transmitted samples are $\{x(0), x(1), \dots x(N-1)\}$ which are IFFT of samples of information symbols of X. As the N sub-carriers chosen to transmit the signal are orthogonal, so we can have, $f_n = n\Delta f$, where $n\Delta f = \frac{1}{NT}$ and *NT* is the duration of the OFDM data block *X*. The complex data block for the OFDM signal to be transmitted is given by [49] as presented in equation (4)

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \, e^{j2\pi n\Delta f t} \quad 0 \leq t \leq NT \qquad (4)$$

Where N is the total number of subcarriers $X_k, k = (0,1 \dots, N-1)$ block of N input bits (symbol) is the mapped (QAM, PSK, QPSK) to be transmitted $e^{j2\pi n\Delta f t}$ is the k[th] subcarrier, $j = \sqrt{-1}$, Δf is the subcarrier spacing, and *NT* denotes the useful data block period, T is the total time of the transmit symbol.

In OFDM, the subcarriers are chosen to be orthogonal (i.e., $\Delta f = \frac{1}{NT}$). However, OFDM output symbols typically have a large dynamic envelope range due to the superposition process performed at the IFFT stage in the transmitter. The discrete form of OFDM signal $x(n)$ is presented in equation (5)

$$x(n) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_k \, e^{\frac{j2\pi kn}{N}} \quad for\ n = 0,1,2,3 \dots N-1 \qquad (5)$$

Equation (5) shows that transmitted signal $x(n)$ is obtained by taking the inverse discrete Fourier transform (IDFT) of modulated input data symbols. Practically IDFT can be comfortably and thoroughly obtained by using Inverse Fast Fourier transform (IFFT).

B. Guard band addition in OFDM

Delay spread or Time dispersion of multipath channel caused ISI in OFDM symbols. Guard interval in the OFDM system is used to remove ISI which is generally introduced between consecutive OFDM symbols. The guard interval can be used in two ways to protect OFDM from ISI. Cyclic extension and Zero padding. The cyclic extension can be extended in two ways which are cyclic prefix and cyclic suffix [2]

- **Cyclic prefix**

A cyclic prefix (CP) as a form of guard interval in the OFDM system is a technique of increasing the OFDM symbol duration to mitigate the ISI resulting from time dispersion caused by multipath propagation [52]. To protect successive OFDM symbols from multipath a CP of length T_p is used which is a copy of the last part of the samples of an OFDM transmit block appended to the front before transmission as depicted in fig. 3. The transmitted signal is therefore $T + T_P$ samples. Provided that the length of the CP chosen is longer than the longest expected delay path successive, OFDM symbols will be free of ISI. If the CP is less than the delay spread of the multipath channel then the head part of the next OFDM symbol will be altered by the tail part of the previous OFDM symbol, leading to ISI. The cyclic prefix larger than the delay spread of the multipath channel maintains the orthogonality among the subcarriers. If the CP is less than the delay spread of the multipath channel then the head part of the next OFDM symbol will be altered by the tail part of a previous OFDM symbol, leading to ISI. The cyclic prefix larger than the delay spread of the multipath channel maintains the orthogonality among the subcarriers [63]. The addition of cyclic prefix extends OFDM symbols to $T_{sym} = T + T_P$ and it is further expressed in equation (6)

$$x(t)_{ext} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \, e^{j2\pi n\Delta f t} \quad - T_P \leq t \leq NT \qquad (6)$$

Where $x(t)_{ext} = x(t+T,$ for $-T_P \leq t \leq 0$ and the discrete form of the prefixed OFDM symbols can be expressed as

$$x(t)_{ext} = \begin{cases} x(n+N) & for\ n = 0,1,\dots,P-1 \\ \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} X_k\, e^{\frac{j2\pi k(n-P}{N}} & for\ n = P, P+1,\dots,P+N-1 \end{cases} \quad (7)$$

Where N is the total number of sub-carriers and P is the total number of CP symbols added in the OFDM symbol.

After multipath fading channel $h(\tau, t)$ the received signal $y(t)$ is expressed as

$$y(t) = \sum_{l=0}^{L-1} h_l\,(t)\, x_{ext}\,(t-\tau) + w(t) \quad (11)$$

where $w(t)$ is the additive white gaussian noise (AWGN). Finally, the recovered data symbols are converted back into the serial stream and demodulated by using a scheme like (M-PSK, M-QAM) to baseband

Table 1: Application of OFDM

Standard	Meaning	Carrier Frequency	Applications	Data Rate (Mbps)
DVB-H	Digital video broadcasting	UHF	Digit al TV Broadcasting to handheld	13.7
DVB-T	Digital video broadcasting	UHF	Digital TV Broadcasting	3.7-32
DAB	Digital audio broadcasting	FM radio	Audio Broadcasting	0.008-0.384
IEEE 802.11g	Wireless LAN/Wi-Fi	2.4GHz	Wireless internet	6-54
IEEE 802.11a	Wireless LAN/Wi-Fi	5.2GHJz	Wireless internet	6-54
IEEE 802.11g	Wireless LAN/Wi-Fi (high speed)	2.4GHz	Wireless internet	6-100
HIPERLAN/2	High-Performance Radio LAN	5 GHz	Wireless LAN standard.	54

C. Receiver Model

At the receiver, the guard band is removed and the received OFDM data streams are then converted from serial to parallel and then subjected to FFT block. The FFT converts these parallel data streams into the corresponding frequency domain from the time domain. At the receiver, the inverse of the transmitter is done. Here, first, the guard interval of an OFDM symbol is removed. Then, these unguarded OFDM symbol is converted from serial to parallel which are passed through FFT block. The FFT converts these parallel OFDM data streams into a frequency domain. The output of FFT operation can be expressed as:

$$X_k = H_k\, x(k) + w(k), \quad for\ 0 \le k \le N-1 \quad (8)$$

Where H_k denotes the frequency response of the multipath fading channel at the k^{th}sub-channel and is defined as

$$H_k = \sum_{l=0}^{L-1} h_l(t)\, e^{\frac{-j2\pi k\tau_l}{N}} \quad (9)$$

where $w_k$is the AWGN component in the frequency domain. It is observable in Equation (8) that the complex data symbol X_k can be correctly recovered by a single complex multiplication of factor F_k, where F_k is the gain of a single tap frequency domain equalizer (FEQ). The gain F_k of the equalizer can be determined by using any channel estimation techniques which is given as:

$$F_k = \frac{1}{H_k} \quad (10)$$

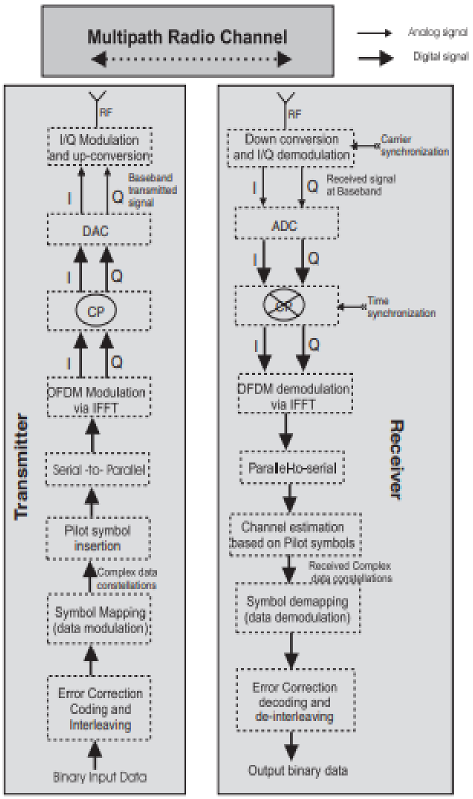

Fig. 1: OFDM transceiver model [34]

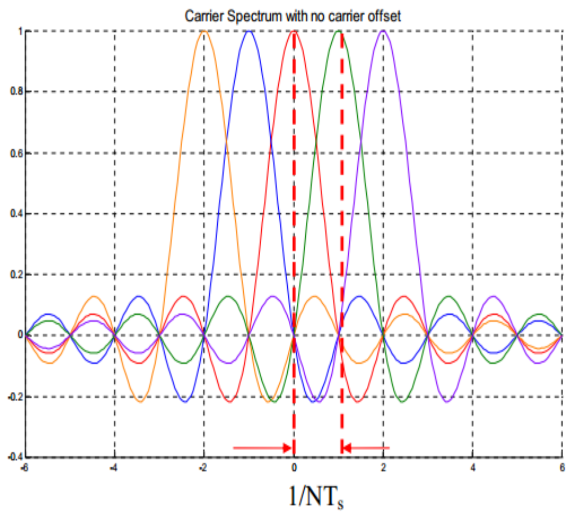

Fig. 2: Frequency response of 5-subcarriers of OFDM signal [25]

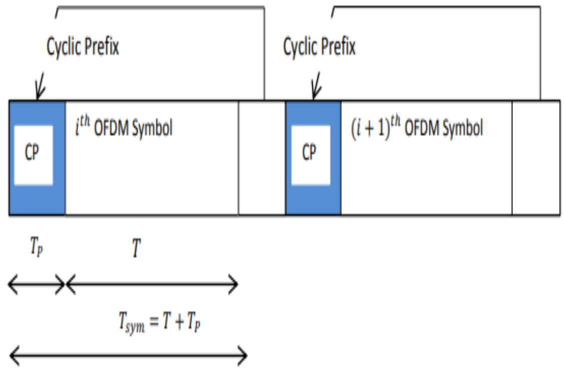

Fig. 3: OFDM symbols with the cyclic prefix [2]

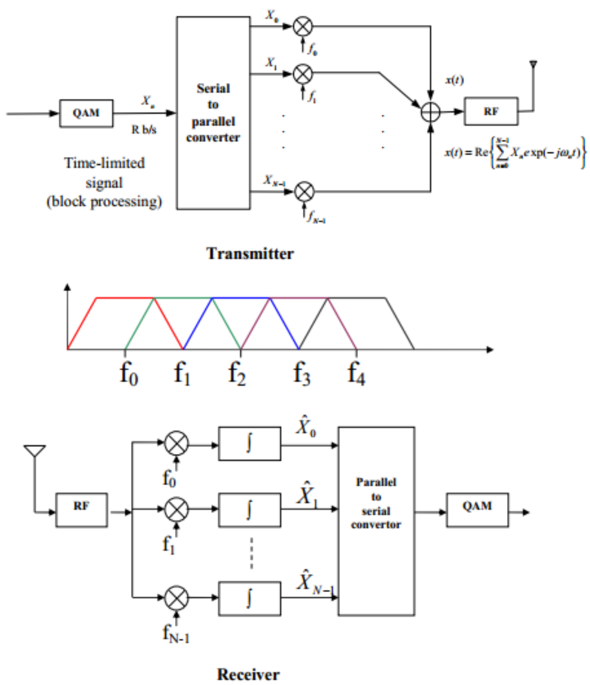

Fig. 4: Block diagram of a basic multi-carrier system [25]

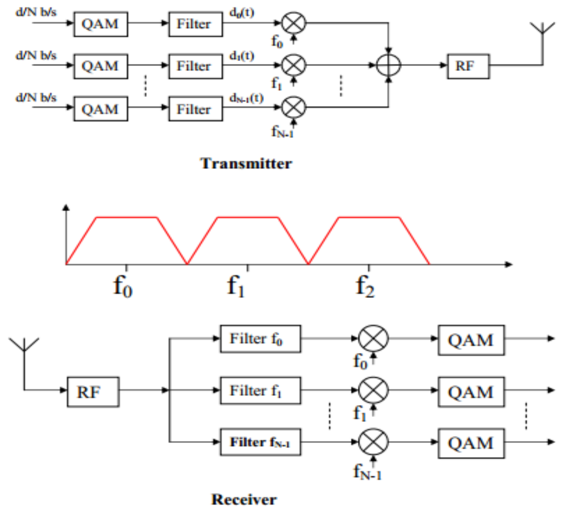

Fig. 5: Basic OFDM Transmitter and Receiver [25]

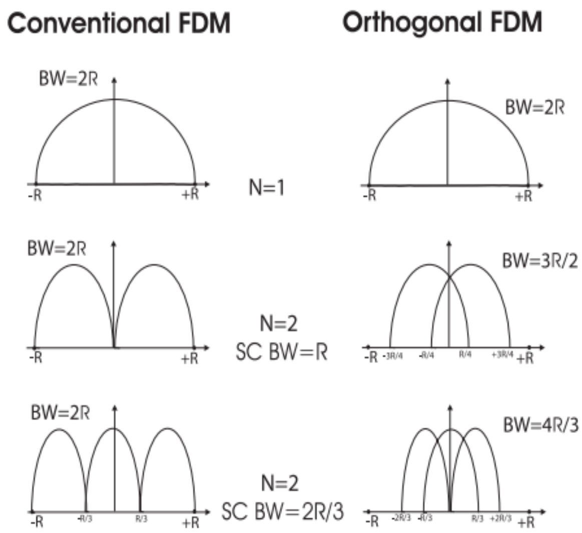

Fig. 6: OFDM signal conventional multi-carrier technique vs orthogonal multi-carrier technique [34]

IX OVERVIEW OF PEAK TO AVERAGE POWER RATIO

One of the major challenges the OFDM system has faced is its high peak-to-average power ratio (PAPR). High PAPR occurs as a result of a large dynamic range of its data symbol waveforms. It is observed that OFDM signal is produced by subjecting data symbols (sequence of bits arranged in the form of a set of subcarriers) to an Inverse Fast Fourier Transform (IFFT), the possibility that subset of these symbols adds up coherently is high, this results to the generation of some large peaks at the output. This occurrence can be referred to as peak to average power ratio (PAPR) which varies directly proportional to the number of subcarriers (N) [33], [38]. High PAPR signals are undesirable and cause large magnitude spikes which result in non-linear distortion when passed through the High Power (HPA) of the transmitter before transmission. The drawback of a large dynamic range of the peaks is that it affects the design of components such as the DAC and ADC, word length of the IFFT/FFT pair, mixer stages and most importantly the HPA. the system must be designed in other to accommodate the large peaks caused by IFFT operation. Failure to design components that will handle the irregularity caused by large peaks leads to saturation of the HPA. Saturation creates increasing BER, both in-band distortion and out-of-band distortion, or spectral splatter, which causes ACI. This results in system performance degradation. In addition, an attempt to back off the power amplifier of the transmitter to contain these spikes within the linear region reduces the efficiency of the amplifier greatly leading to a low Signal to Noise Ratio at (SNR) at the receiving end [37], [64]. However, employing a power amplifier with a large dynamic range has a high cost. Therefore, PAPR minimization is highly crucial in OFDM-based systems. [54] mathematically defined PAPR as the ratio of Peak power to Average power.

$$PAPR = \frac{Peak\ Power}{Average\ Power} \qquad (8)$$

From Equation (8), we know that the OFDM signal is generated using input symbols X_k as

$$x(t) = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} X_k\, e^{j2\pi n\Delta f t} \quad 0 \le t \le NT \qquad (9)$$

The PAPR of the continuous-time baseband OFDM transmitted signal $x(t)$ is the ratio of the maximum instantaneous power and the average power.

By definition,

$$PAPR = \frac{max\ [x(t)]^2}{E\{|x(t)|\}^2}\ , \quad for\ 0 \le t \le NT \qquad (11)$$

Where $E\{.\}$ denotes Expectation operator and $E\{|x(t)|\}^2$is the average power of $x(t)$as well as T is an original symbol period.

For a discrete OFDM signal$x(n)$, the PAPR of OFDM signal, as:

$$PAPR = \frac{max\ [x(n)]^2}{E\{|x(n)|\}^2}\ , \ for\ 0 \le t \le NL-1 \qquad (12)$$

$$PAPR\ (x) = 10log10\ \frac{max[x(n)]^2}{E\{|x(n)|\}^2} \qquad (13)$$

The Cumulative Distribution Function (CDF) is one of the most regularly used parameters to measure the efficiency of any PAPR technique. Normally, the Complementary Cumulative Distribution Function (CCDF) is used instead of CDF which helps us to measure the probability that the PAPR of a certain data block exceeds the given threshold. The CDF of the amplitude of a signal sample is given by [52] in Equation (14)

$$F(Z) = \left(1 - e^{-z^2}\right) \qquad (14)$$

Where Z is a magnitude of complex samples

The CCDF of the PAPR for the non-oversampling data block is given as

$$P(PAPR > z) = 1 - F(Z)^N$$
$$= 1 - (1 - e^{-z^2})^N \qquad (15)$$

Where N is assumed to be a large number of sub-carriers

The CCDF of the PAPR for oversampling data block is obtained by multiplying equation (32) with *N* and some constant (∝), which is expressed as-

$$CCDF = P(PAPR > z) \approx 1 - (1 - e^{-z^2})^{\propto N} \qquad (16)$$

X EFFECT OF HIGH PAPR ON HIGH POWER AMPLIFIER

High PAPR in OFDM occurs as a result of IFFT pre-processing on input data symbol (i.e., OFDM signal consists of several independently modulated sub-carriers which can add up coherently to form a large peak). Furthermore, data symbols in all sub-carriers are summed up to yield high Peak value signals, But, if the signal deviation is restricted to the dynamic or linear range, the input and output characteristics are linearly related as depicted in fig. 11 and this will still be restricted to linear amplification range. However, in the OFDM system, a slight swing from linear region to nonlinear region occurs as a result of high instantaneous power compared to mean power. The swinging of Amplifier to non-linear causes OFDM to lose all its property (i.e., orthogonality is lost), then there will be extreme intercarrier interference. Therefore, high PAPR in OFDM results in amplifier saturation, thus leading to ISI.

XI. FACTORS AND PARAMETER INFLUENCING PAPR

Many factors influence high PAPR in an OFDM system, these factors, and parameters if carefully considered, there is every possibility PAPR in the OFDM system will be decreased. These factors are: Number of subcarriers (N) in the OFDM system, Modulation Order, Constellation shape, Pulse Shaping

XII. PAPR REDUCTION METHODS

As reported by [38], [64], PAPR reduction techniques are divided into two main categories which are distortionless or scrambling techniques and distortion techniques. The former is applied before the IFFT stage and the latter is applied after the IFFT stage. [47] described that the former improves the signal characteristics in the time domain or the frequency domain to alleviate PAPR before the transmission while the latter reduces the PAPR by reducing or destroying the high peak of the OFDM signal in the time-domain before passing the signal to the HPA. The author further explained that each PAPR reduction methods differ from one another in terms of PAPR reduction performance, BER performance, power increasing, data rate loss, and computational complexity level.

A Distortionless Techniques: In this type of technique, the reduction method is applied before the IFFT stage. The concept of this method is to increase the cross-correlation of the input signal before IFFT and decrease the output of the IFFT peak value or average value. Examples of these methods are Block coding, Partial Transmit sequence, Selective mapping, Precoding.

- **Block Coding Method**

In [40], it is proposed that this technique PAPR is reduced by using different block coding and various set of code words. This scheme is most commonly used to reduce the peak to mean envelope power ratio. The input data stream is a block coded in a level that only those sets of codewords are permissible for transmission which do not contain high peak envelope powers. The PAPR is reduced and it also enables the reduction of nonlinear distortion as well as decreased spectral regrowth. The signal of the system also has a higher average transmit power with an upper limit for peak power. The major disadvantage of this technique is that it increases the bandwidth and no change in the data transfer rate. Another disadvantage of this technique is that it decreases the energy per transmitted bit while the transmit power remains the same. Therefore, with numerous disadvantages, the technique is not advisable to use when there is a higher number of subcarriers because of the exponential rise in complexity as the number of carriers increase [55].

- **Selective Mapping (SLM) Method**

The method involves multiplying the input data sequences or sequence of bits modulated by each of the phase sequences to generate substitute input symbol sequences [50]. Then for the IFFT operation, each of these alternative input data sequences is used and then the one with the lowest PAPR is selected for transmission as presented in fig. 9. The idea of SLM is that the PAPR is determined from the U alternative produced as a result of multiplying the input data source with some random phase sequence. The result of this multiplication changes the PAPR properties after the IFFT operation. Mathematically, a set of U represented pseudo-random fixed vectors is generated as a result of multiplication of original input data represented with $X\,[X_1, X_2, \ldots X_{N-1}]$ and independent phase sequences $P = \left[P_1^{(u)}, P_2^{(u)} \ldots,\ P_N^{(u)}\right](u = 0,1, U-1)$, where U is the number of phase sequences. Both input data and phase sequence have the same length N. Inverse Fourier transform (IFFT) is performed after multiplication and this will generate data block of OFDM system with different time-domain signals, with the length of U, and different PAPR values, $X(u) = \left[X_1^{(u)}, X_2^{(u)} \ldots,\ X_{N-1}^{(u)}\right]$. The PAPR among the independent data are compared and the lowest PAPR is selected [36].

- **Precoding**

In this technique, modulated input data streams are multiplied with shaping or precoding matrix before the formation of OFDM symbol (before IFFT) as shown in fig.7. This technique employs the positive feature of the frequency selective multipath channel of the OFDM system [51]. In fig. 7, the input data is firstly modulated in baseband using modulation schemes like PSK, QAM, BPSK, etc. The baseband-modulated input data stream is transformed by a precoding matrix. Different precoding matrix is used for this purpose which are Hadamard matrix, Zadoff Chu sequence, pulse shaping function, discrete cosine transformation (DCT) matrix, generalized chirp-like (GCL) sequence, etc. After that, precoded data are transmitted through IFFT and generate OFDM symbols. The precoding matrix should be carefully chosen to reduce the PAPR since modulated data is multiplied with the chosen precoding matrix so that it can reduce the PAPR. Since we are multiplying modulated data with a predefined precoding matrix, there is no need for a handshake between transmitter and receiver.

- **Partial Transmit Sequence (PTS) Method**

In this method, the original OFDM sequence is divided into several sub-sequences and then each sub-sequence is multiplied by different weights until an optimum value is chosen shown in fig.8. In addition, the technique is based on dividing the input data sequence into a set of non-overlapping sub-sequences and apply IFFT to each of them independently. The outputs are scaled and phase rotated by a set of different values, and the combination that yields the least PAPR is chosen for transmission [57].

In figure 7, the input data block of *X* of *N* of symbols is separated into disjoint sub-blocks represented as $\{X_P$, *P* = 0, 1, 2, 3… *P-1*$\}$. The input data block *X* can be written in the form as follows as expressed by [31].

$$X = \sum_{P=0}^{P-1} X_P \qquad (13)$$

where,

$X_P = \left\{X_P{}^0,\ X_P{}^1, X_P{}^2 \ldots \ldots \ldots \ldots X_P{}^{N-1}\right\}^T$

Are subblock of the same size each partitioned sub-block X_P is multiplied by a corresponding complex phase factor

$G_P = e^{jp\theta}, p = 1,2,3 \ldots \ldots . P$ Subsequently transforming into V time-domain partial transmit sequence by taking the LN- point IFFT to yield.

$$x = IFFT\left(\sum_{p=1}^{P} G_p\, X_p\right) = \sum_{p=1}^{P} G_p \,.\, IFFT\left(X_p\right)$$

$$= \sum_{p=1}^{P} G_p\, x_p \qquad (15)$$

Where (x_p) is a Partial Transmit Sequence (PTS). The phase vector should be chosen in such a way that PAPR can be minimized as given below

$$\widehat{G_0} \ldots \ldots \ldots \widehat{G_{p-1}}] = arg\ \min_{G_0 \ldots\ldots G_{p-1}} \left(\max_{n=0,1,\ldots\ldots LN-1} \left|\sum_{p=0}^{P-1} G_p\, x_v[n]\right|\right) \qquad (16)$$

Where n=(0, 1, 2, LN-1)and L is the oversampling factor.

Then, the corresponding time-domain signal with the lowest PAPR vector can be expressed as:

$$\hat{x} = \sum_{p=0}^{p-1} \hat{G}_p\, x_p \qquad (17)$$

Others Signal distortionless techniques are Tone Reservation, Interleaving Technique, Tone Injection

B. Signal Distortion Techniques

Signal distortion techniques reduce PAPR by modifying signal shape post-IFFT stage, which is far less complex than distortion-less techniques. However, they introduce a considerable drop in error performance [60]. Different methods under this category are

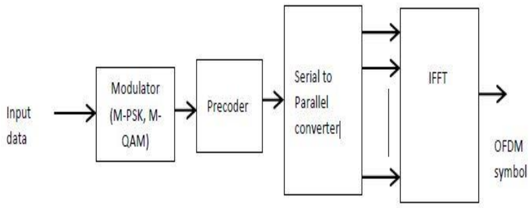

Fig. 7: Transmitter block diagram of precoded OFDM scheme [2]

- **Clipping Techniques**

This is one of the easiest techniques for PAPR reduction in an OFDM-based system for reducing PAPR in an OFDM system, the amplitude of the high peak of the OFDM signal is clipped before been passed through the power amplifier which is set on a particular threshold level. If the amplitude of the signal is greater than the threshold, the value is clipped and rests are filtered out to remove the lower PAPR value [66]. The block diagram is presented in fig.10.

$$F(x) = \begin{cases} x & |x| \leq 0 \\ Ae^{j\emptyset(x)}, & |x| > 0 \end{cases} \quad (18)$$

$F(x)$ = Amplitude value after clipping, x = the initial value, and A = Threshold value of clipping value.

- **Peak windowing**

This method is related to the clipping technique but better performance is achieved by adding some self-interference and increasing BER (bit error rate& out of band radiation). In this technique, as shown in fig.12, large peaks of the OFDM signal are multiplied with windows e.gs Gaussian-shaped window, cosine, Kaiser, etc. The signal is then multiplied by some of these windows. The resulting spectrum obtained is a convolution of the original OFDM spectrum with the spectrum of the applied window (as mentioned earlier). This means the windows should be narrow as possible. By using this technique PAPR can be reduced to 4db of each subcarrier [56].

Other signal distortion techniques are envelope scaling, Peak Reduction Carrier, Companding Techniques

XIII. FACTORS FOR SELECTING THE PAPR REDUCTION TECHNIQUE

In general, three major performance criteria have been considered in which the PAPR reduction method makes a trade-off between them. These criteria are computational complexity, spectral efficiency, and level of signal distortion level. One or two criteria can be favored at the expense of others by any PAPR reduction technique. The overall transmission Bit Error Rate (BER) of the system is affected by the level of distortion caused by PAPR reduction techniques. In addition, some techniques perform the function of transmitting side information bits to the receiver. The bits transmitted carry information regarding the parameters used by the PAPR reduction technique which helps the receiver restore the original OFDM signal. Hence, the overall spectrum efficiency of the system diminishes when bits are transmitted alongside original data. Furthermore, expensive computational hardware is needed for PAPR techniques with high computational complexity and more power is consumed for battery-operated mobile devices which makes it unfavorable [57]. Several factors should be considered when selecting the technique that can reduce the PAPR effectively as well as can maintain high-quality performance. These factors are PAPR reduction Performance, Data rate loss, Computational Complexity, Transmit Signal power increase, Increased BER at the Receiver. In summary, this factor should be carefully considered because a trade-off can arise when a technique is not properly chosen.

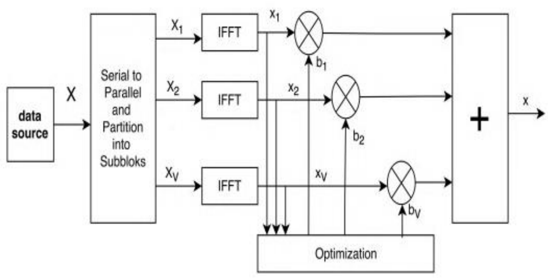

Fig. 8: Block diagram of partial transmit sequence [54]

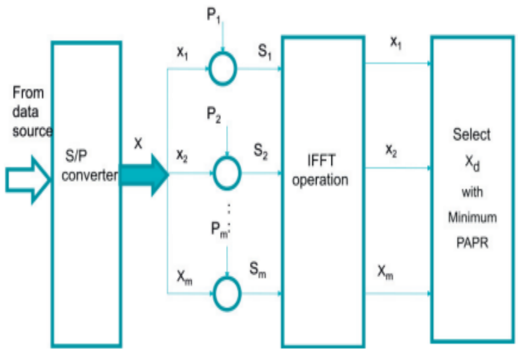

Fig. 9: Block diagram of selective mapping method [68]

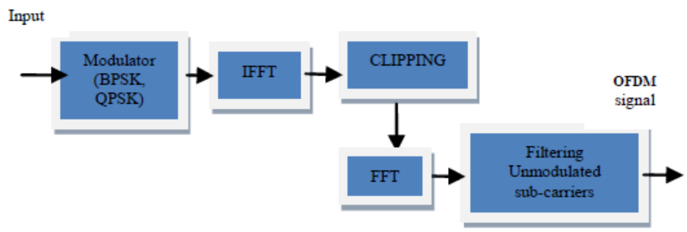

Fig. 10: Block diagram of amplitude clipping and filtering technique [66]

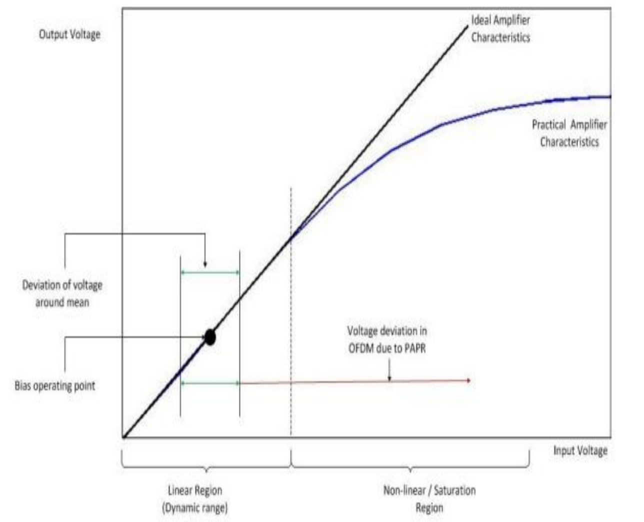

Fig. 11: Power Amplifier Characteristics [67]

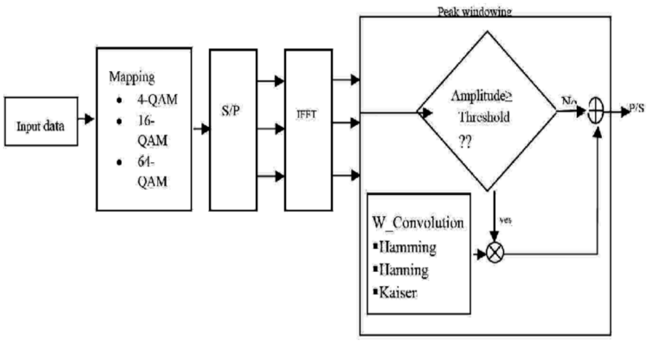

Fig. 12: Block diagram of peak windowing technique [24]

XIV REVIEW OF RELATED WORKS

A Related works on Precoding Technique

Slimane [59] proposed a method to decrease the PAPR of the OFDM system by using pulse shaping. Pulse shaping-based precoding can be used to make the PAPR of the OFDM signal very close to that of a single-carrier signal. Pulse shaping reduces the shape of the spectrum of the transmitted signal as well as reduces PAPR. This scheme is flexible and it can control the correlation between the OFDM block samples without destroying the orthogonality property between the subcarriers of the modulated signal. This technique can be used for OFDM and Discrete Multi-Tone (DMT) transmission.

Gao and Nallanathan [39] proposed nonredundant linear precoding for a developed subspace-based blind channel estimation technique for the OFDM system. The proposed method solved the problem of Multiple-input single-output (MISO) transmission which the conventional subspace method failed to solve. Various channel estimations of the matrix ambiguity and with only scalar ambiguity are considered. Simulation results clearly show the effectiveness of the proposed technique

Slimane [58] proposed a method to improve the PAPR of OFDM signal through precoding. The proposed precoding technique is less complex and data-independent. High PAPR is reduced through a proper selection of precoding schemes that distributes the power of each modulated symbol over the OFDM symbol. This technique takes the advantage of the frequency variations of the communication channel and can provide considerable performance gain in fading- multipath channels. The predefined precoding matrix is generated by RC and SQRC functions.

Hao and Lai [22] proposed an optimal precoding matrix where a theoretical condition and systematic procedure are given to generate an optimum precoding matrix. The proposed technique achieves low error probability and low PAPR in AWGN and multipath fading channels. The proposed optimum precoding method is compared with other precoding methods the proposed technique gives a better performance

Hsu and Liao [22] worked on Discrete Fourier Transform (DFT) based generalized precoding method and the method is compared with the conventional OFDM system. It is observed that the proposed techniques achieve close bit-error ratio (BER) performance and lower PAPR reduction. The result shows that the Bit error rate of the generalized DFT precoding method is superior to that of the OFDM system at a low signal-to-noise ratio. The proposed technique achieved low PAPR and low computational complexity and provide better BER performance.

Sharifi [23] proposed a discrete hartley matrix transform (DHMT) based precoding method to minimize the effect of high PAPR in OFDM systems. The result of the proposed techniques is compared with different precoding methods like Wash-Hadamard matrix transform (WHMT), Discrete cosine matrix transform (DCMT), and Vandermonde-like matrix transform (VLMT), and conventional OFDM. A DHMT-precoded OFDM with oversampling factor 4 (L = 4) is used the result shows it has the lowest PAPR compared to other precoding methods. The CCDF curves of DCMT and VLMT are almost identical which shows each method has the same effect in PAPR reduction of the OFDM system.

Chen *et al*. [21] proposed an efficient precoding matrix combining space-time block code (STBC) and orthogonal circulant matrix transform (OCT). The technique is proposed to improve the performance of multiple input multiple output-orthogonal frequency division multiplexing (MIMO-OFDM) BASED visible light communication (VLC) systems. Other's precoding matrix is compared with the proposed techniques and it is observed that proposed STBC-OCT precoding has

more excellent BER performance. It is shown that the proposed scheme can effectively mitigate the spectral limitation issue of the VLC system because a 157.5Mbit/s transmission rate is achieved for the MIMO VLC system.

Table 2: Performance Comparison of PAPR Reduction Techniques

Methods	Avr. Power	Computational complexity	Bandwidth expansion	BER Degradation	Side information
PTS	No	High	Yes	No	Yes
Clipping and filtering	No	Low	No	Yes	No
SLM	No	High	Yes	No	Yes
Coding	No	Low	Yes	No	No
Precoding	No	Low	Yes	No	No
Tone Reservation	Yes	High	Yes	No	No
Tone Injection	Yes	High	Yes	No	No

B Related works on PTS Technique

Varahram *et al.* [45] proposed a combination of dummy sequence insertion (DSI) and partial transmit sequence (PTS). The DSI was introduced to decrease the transmission efficiency (TE) and the complexity of the PTS increases as the number of subblock increases. The proposed DSI PTS requires half of IFFT
operations as compared to Conventional PTS(CPTS) which requires several IFFT operations. The performance of the proposed technique is better in terms of computational complexity and PAPR performance when compared with CPTS.

Chen [19] proposed a novel stochastic optimization approach e.g electromagnetism-like (EM) algorithm to reduce the High PAPR of OFDM signal. The method was proposed as a result of the high computational complexity caused by CPTS. The result of the proposed techniques is compared with other stochastic search techniques developed previously from the literature. The simulations show that the EM method obtains the most desirable PAPR reduction with low computational complexity.

Varahram *et al*. [45] proposed an optimum PTS method that reduces the IFFT operations. In this technique, random phase factors are multiplied with the input signal. The scheme uses QPSK modulation and the Saleh model power amplifier. This technique reduces the complexity by decreasing the number of IFFT operations to about half and the computational complexity in conventional PTS is reduced.

Gouda and Hussien [46] proposed a phase rotation PTS technique to reduce PAPR in MIMO and OFDM.
Table 2:
The proposed PTS algorithm is analyzed and compared with traditional PTS and the result solved the
the problem of computational complexity introduced by the conventional PTS. The results are further compared
with other techniques in the literature. Reduced PAPR is achieved by the proposed technique.

Kaur and Harshit [32] proposed a suboptimal combination algorithm-based pts technique for searching for phase factors which solved the complexity of the conventional pts technique especially when the number of subblocks increases. it is observed
from the simulation that as the number of subblocks increases, the PAPR decreases.

Jawhar *et al*. [47] reviewed the conventional PTS technique to reduce PAPR in OFDM signal. Computational complexity and PAPR performance are analyzed in terms of modifying the PTS technique in the frequency domain, time domain, and modulation stage. A numerical comparison of the current modified PTS technique is introduced and criteria for selecting a suitable modified-PTS technique are given. The simulation and the results of the calculations show that the cooperative PTS method is the best among the modulation stage methods, the rows exchange-interleaving PTS scheme is the best method for reducing the PAPR value with low complexly in the frequency domain, and the cyclic shift sequence PTS method achieves the superior performance in PAPR reduction and computational complexity for the time domain methods.

Fadel *et al.* [18] proposed a new algorithm named Hybrid pseudo-random and interleaving cosine wave shape (H-PRC-PTS) which is the combination of pseudo-random (PR-PTS) and the symmetrical interleaving cosine wave (S-IL-C-PTS). The scheme is proposed to solve the problem of high computational complexity caused by CPTS. The simulation result obtained shows the proposed algorithm can diminish the PAPR like the PR-PTS and the computational complexity in C-PTS is reduced significantly.

C Related works on Precoding combining with other Techniques

Baig and Jeoti [17] proposed a discrete cosine transform (DCT) precoding-based selected mapping technique for PAPR reduction in OFDM systems. The scheme is based on precoding the constellation symbols with a DCT precoder and then applying phase rotation of the SLM and performing IFFT operation on the output before being transmitted. It is observed from the simulation result that the proposed technique reduced PAPR to about 5.5dB when the number of subcarriers is 64 (N=64) and dissimilar phase rotation is 16 (V=16) at a clipping probability of 10^{-3}.

Joshi and Rajiv [65] proposed a combination method of clipping and precoding to reduce the PAPR. This combines method provides better PAPR than each method and also gives the same BER as of precoding method. Here, SQRC and better than raised cosine (BTRC) pulse shapes are used to generate the precoding matrix

Baig and Jeoti [16] proposed Zadoff chu transform (ZCT) based on precoding selected mapping (SLM). The scheme is based on precoding the constellation symbols with ZCT precoder before the Selective mapping approach. The result is compared with individual performance and it is observed that PAPR is reduced to 5.2dB when subcarriers are increased to 64 (N=64) and Dissimilar phase sequence increase to 16 (V=16). More PAPR can be reduced if the value of V is increased. care must be taken as increasing V will increase the computational complexity. The technique is signal-independent efficient, distortionless, and does not require any complex optimization.

Hsu and Liao [13] proposed a combination of precoding and nonlinear companding (Mu-law compression and expansion) for reducing PAPR of OFDM systems. The precoding technique is applied to utilize the least null subcarriers in the frequency domain and nonlinear companding by applying the mu-law characteristic in the time domain. The simulation result shows that the proposed technique is a beneficial tradeoff between PAPR reduction and out-of-band radiation emission in OFDM systems.

Shailender *et al.* [69] Proposed Zadoff-Chu transform precoding-based scheme and partial transmit sequence to reduce the PAPR OF OFDM signals. Significant reduction In PAPR is achieved with the two methods but PTS has a better PAPR reduction performance when compared to ZCT based precoding technique at the expense of data rate loss, computational complexity increase.

Aboul-Dahab *et al*. [61] proposed a precoding method with clipping. Precoded OFDM symbols are clipped and achieves low PAPR with improvement in BER performance than original OFDM. Here, Discrete Fourier Transform (DFT) is used for generating a precoding matrix.

Hassan [53] proposed Vandermonde-like matrix (VLM) and selective mapping (SLM) to decrease PAPR in OFDM systems. The VLM was introduced to reduce the autocorrelation of input data streams while SLM take the advantage of correcting the phase shift of the OFDM signal. The simulation result shows that the proposed technique performs better than the existing precoding technique. Computation complexity is low and the error performance of the system is minimized.

Agarwal *et al.* [14] compared precoding techniques with Compading techniques. The two methods of companding (A-law and μ-law) are analyzed. the simulation results show that both precoding and companding can efficiently reduce PAPR of OFDM signal compared to PAPR of conventional OFDM. The precoding technique is better than companding.it is also observed that μ-law companding gives better results than A-law.

Mounir *et al.* [15] proposed a new hybrid precoding-companding technique in 5G OFDM to reduce the bit error rate (BER) and out-of-band radiation (OOB). The simulation results show that the new scheme outperforms all previous precoding-companding techniques in terms of BER enhancement and OOB radiation reduction. It is observed from the result that the new technique reduces the error vector magnitude by 15dB compared with 10dB for the previous technique. Additionally, power amplifier efficiency (HPA) is increased by the new technique as well as PAPR reduction gain and computational complexity is better than the previous technique.

D Related works on PTS combining with other Techniques

Jayalath *et al*. [12] worked on a simplified version of partial transmit sequence (PTS) and a new scheme for selected mapping (SLM) sequences to reduce PAPR of OFDM signal. PTS is simplified by halving a set of partitions and optimizing phase values only for alternate partitions. New phase sequences are also chosen for Selected mapping to give a better PAPR reduction performance. The simulation shows that PTS with 8 partitions complexity can be decreased by 80% with 0.5dB degradation and SLM with Newman phase sequence having 256 sequences gives a better performance than the performance of optimum PTS with 16 partitions. Overall, High PAPR and high computational complexity is reduced with simplifying version of PTS and SLM.

Wang *et al*. [11] combined linear and nonlinear methods to reduce PAPR, a partial transmit sequence followed by clipping (PTS-clipping). The proposed techniques aim to reduce PAPR of Radio over Fiber and OFDM systems. The basic principle of the technique is by clipping the OFDM signal that has already been reduced by the PTS technique. The result shows that the PAPR is further reduced when clipping is applied to the PTS technique. It is observed that there are significant changes in BER performance with and without clipping. The proposed technique is suggested to have a better performance on an optic-fiber communication system.

Jayalath and Tellambura [9] worked on a simplified maximum likelihood (ML) decoder for SLM and PTS operating without side information. The ML decoder allowed the modulation symbols to belongs to their given constellation and multiple signals generated by SLM and PTS are different in hamming distance sense. Pairwise error probability is investigated and the results show that the proposed technique performs better. The ML decoder function effectively over the AWGN channel, amplifier nonlinearities, and fading channel as shown by the simulation result.

Duanmu and Chen [8] proposed a new algorithm applied on both SLM and PTS techniques, the technique utilizes the advantage of combining both SLM and PTS on a different block of OFDM before joining the two blocks to one. The results show that the proposed algorithm further reduces the PAPR of the OFDM signal. Additionally, the BER performance and computational complexity of the proposed algorithms are almost the same as with the original SLM and PTS.

Sharifi and Emami [7] proposed a new swarm intelligence algorithm called the improved flower pollination (IFP) algorithm to reduce search complexity in the PTS technique derived from the pollination behavior of flowers. The result of the IFP-PTS approach is applied to a clipped optical OFDM system. The proposed technique is evaluated and compared with a different algorithm approach. The result outperforms other methods in terms of BER performance and computational complexity

E Related works on Hybrid of precoding and PTS Techniques

Khatiwada and Joshi [30] proposed a pulse shaping method of generating matrix for hybrid precoding-PTS techniques, low PAPR is obtained from the proposed method using fewer numbers of subblocks than the PTS method. The requirement for more IFFT operations is reduced. Hence, the complexity due to the number of subblocks has been reduced. Furthermore, the expansion of bandwidth in the proposed method is less as compare to the precoding method because the PAPR of the proposed method can be decreased by increasing the number of subblocks at a constant roll-off factor. The proposed system can be made more reliable by implementing a technique to recover the original signal in a multipath environment without transmitting side information window functions like Discrete Fourier Transform (DCT), Modified Bartlett-Hanning (MBH), Discrete Hartley Transform (DHT), Zadoff- Chu Transform (ZCT), etc can be applied to generate the precoding matrix.

Sravanti and Vasantha [29] proposed precoding-PTS techniques where the performance of three different methods of generating precoding matrix such as Discrete Fourier Transform (DFT), Discrete Hartley Transform (DHT), Walsh Hadamard Transform (WHT) was verified. The simulation shows that the DHT-precoding converts input signal existent values to actual values shows noble performance.

XV Conclusion

In this paper, the importance of orthogonal frequency division multiplexing as the most efficient form of Multicarrier modulation is discussed. OFDM is the solution to provide a high data rate in wireless communication and new multimedia devices. The major problem it faced is the PAPR, its performance effect on the OFDM system studied. Numerous methods have been discussed to reduce the effect of PAPR and each method comes with its advantages and disadvantages. Many factors are put into consideration before choosing the best method. They are; increase transmit signal power, bit error rate (BER), computational complexity and loss of data rate, PAPR reduction techniques would favor one or two criteria at the cost of the others. Therefore, it is important that any method to be chosen should favor the above listed factors.

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