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PEAK-TO-AVERAGE POWER RATIO (PAPR) REDUCTION IN MULTIPLE-INPUT MULTIPLE OUTPUT (MIMO) WITH ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM) SYSTEMS: A REVIEW

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Abstract

Multiple-input multiple-output technology together with orthogonal frequency division multiplexing (MIMO-OFDM) is one of the most appealing techniques for mobile radio communications. It is an effective technique to combat multi-channel fading and to improve bandwidth efficiency. Simultaneously, it also increases the system's ability to provide reliable transmission. However, the main disadvantage of OFDM is the high peak-to-average-power ratio (PAPR), which, if not mitigated, will negatively impact practical applications. Algorithms to mitigate PAPR generally increase the complexity and an increase in the Bit Error Rate. Coding, phase rotation, and clipping are among the many techniques employed to reduce the PAPR. In this review, we will mainly investigate the advantages and disadvantages of MIMO-OFDM system and PAPR reduction performance with different PAPR reduction methods in MIMO-OFDM system. The main objective of this review is to enable researchers entering this field become familiar with the problem as well as the techniques to mitigate this problem. We classify MIMO-OFDM PAPR methods into three categories: Signal Distortion, Signal Scrambling, and Coding. This review discusses each category and its impact on the transmitter and receiver and summarizes the discussion in a table. We also briefly describe some of the methods used to reduce PAPR in MIMO-OFDM.

1. Introduction

Telecommunication systems should offer an overall end-to-end and secure solution since they are required to provide voice, data, and multimedia to the users at anytime and anywhere with and must satisfy the need for ever-increasing higher data rates. Bandwidth resources in mobile communications are expensive, and hence it is imperative for network architects to improve spectrum efficiency and attain the highest data rates possible using advanced modulation techniques. Among several factors that contribute to improving the spectral efficiency, MIMO technique and PAPR reduction techniques form a couple of key factors [1], [2]. Therefore, mobile communications systems next generation need more advanced amendment system and the transmission of information on the structure. Driven multimedia applications based on the expected future wireless systems requiring high data rate capable of high speeds techniques of movement.

In a MIMO-OFDM system, the output is the superposition of several sub-carriers and, consequently, the output signal magnitude may fall outside the linear range of the power amplifier. High PAPR is one of the most important problems that must be addressed in designing a MIMO-OFDM system. To transmit signals with high PAPR without distortion, power amplifiers are required with a linear range extending over a large range of input power. These types of amplifiers are very expensive to design. No matter how large the linear range of the power amplifier is, whenever the signal falls outside of it, non-linear distortion results causing performance degradation. [2], [3]. In this paper, the generated carriers with high data rate can provide meaningful sources in telecommunication systems such as 4G LTE, 5G Massive MIMO [4,5,6,7]. Furthermore, it can also help determine the properties and factors affecting most types of channels and antennas [8,9].

To combat high PAPR, researchers have proposed numerous algorithms in the literature. In this review, some currently available and promising PAPR reduction methods are studied and compared. This review is organized as follows: Section II introduces MIMO-OFDM system model along with the basic structure, and discusses the advantages and disadvantages. In Section III, PAPR problem, its definition and a classification are given. Three different types of PAPR reduction techniques are introduced. In Section IV, we focus on some of the PAPR reduction techniques available in the literature. A comprehensive investigation, analysis, and comparison are conducted in terms of all possible influencing factors and PAPR reduction performance. We also compare some algorithms with respect to additional information and PAPR reduction performances. Finally, some suggestions for further work and conclusions are provided.

2. System Model

2.1 OFDM System

OFDM becomes a very common multi-carrier modulation technique for the transmission of signals over wireless channels. It converts a set of frequency-selective fading channels into a set of parallel flat regular fading sub channels [10]. When orthogonality is maintained between different sub channels through transmission, it becomes become possible to isolate the signals very simply at the receiver side. With traditional or conventional FDM, which is presented in Fig.1, by injecting or inserting guard bands between sub-channels isolation of signals at the receiver side becomes possible [10], [11], and [12].

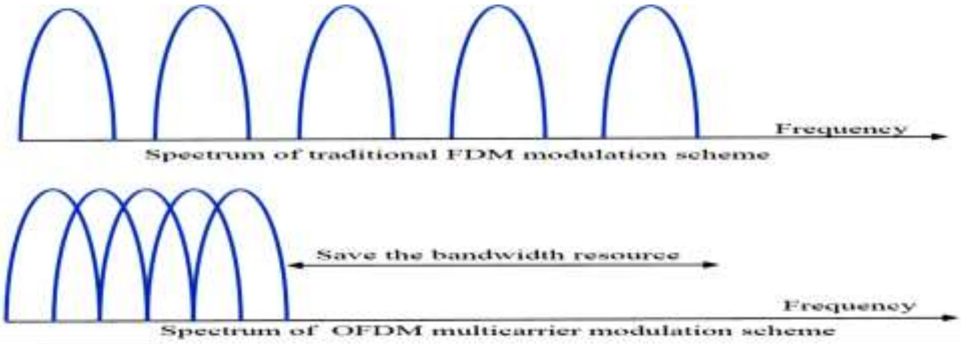

Fig. 1 Comparison between conventional FDM and OFDM.

Fig.2 illustrate that OFDM due to the orthogonality of subcarriers, the sidebands of the discrete carriers overlap and yet the signals are received at the receiver without inter-carrier interference (ICI). The receiver acts as a bank of demodulators, translating data carried by each subcarrier down to baseband [13], [15].

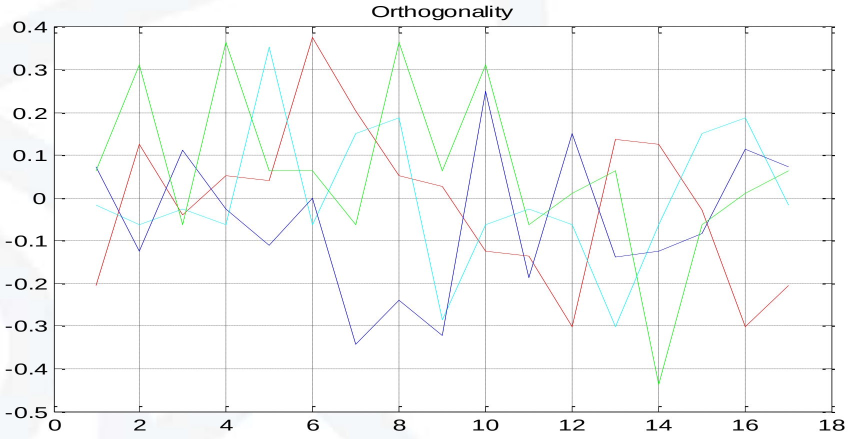

Fig.2 OFDM Orthogonality

Therefore, the available bandwidth is used very effectively in OFDM system without producing the ICI. By amalgamating various low-data-rate subcarriers, OFDM system can provide a combined high-data-rate with long symbol duration. That serves to remove and eliminate the inter-symbol interference (ISI), which frequently happens along with signals of short symbol period in a multipath channel. Basically, the advantages and disadvantages of OFDM system can be summarized as follows [12], [13]. The advantages of OFDM system are: simple implementation by Fast Fourier transform (FFT), high spectral efficiency, low receiver complexity, high flexibility in terms of link adaptation, robustness for high-data-rate transmission over multipath fading channel, and low complexity multiple access schemes such as orthogonal frequency division multiple access. Disadvantages of OFDM system are [3], [12]: high peak-to-average power ratio compared to single carrier system, which results in reduced power efficiency of the radio frequency (RF) power amplifier, and increases the susceptibility of the OFDM system to frequency offsets, timing errors, and phase noise. Fig.3 shows an OFDM system block diagram [10]. At the transmitter, the input, a binary data stream, is mapped into symbols by using digital modulation, for example, Quadrature Phase Shift Keying (QPSK), or Quadrature amplitude modulation (QAM). Some of the more common QAM modulation techniques include 4QAM, 16 QAM, 32QAM, and 64QAM and these symbols are modulated using N orthogonal subcarriers. Sampling rate equals N/T_u, where T_u is useful OFDM symbol duration. Eventually, samples on each subcarrier are summed together to form an OFDM symbol. An OFDM symbol generated by N-subcarriers consists of N samples, and the k-th sample of an OFDM symbol is given by [12], [16], and [17].

$$x_k = \sum_{n=0}^{N-1} X_n e^{j2\pi kn/N} \qquad 0 \le k \le N-1 \tag{1}$$

The X_n is the modulated data symbol of the n-th subcarrier. Equation (1) is equal to the N-point inverse discrete Fourier transform (IDFT) working on the data sequence. It is familiar that IDFT can be executed efficiently using inverse fast Fourier transform (IFFT); IFFT is used to convert the frequency domain signals to time domain signals [10].

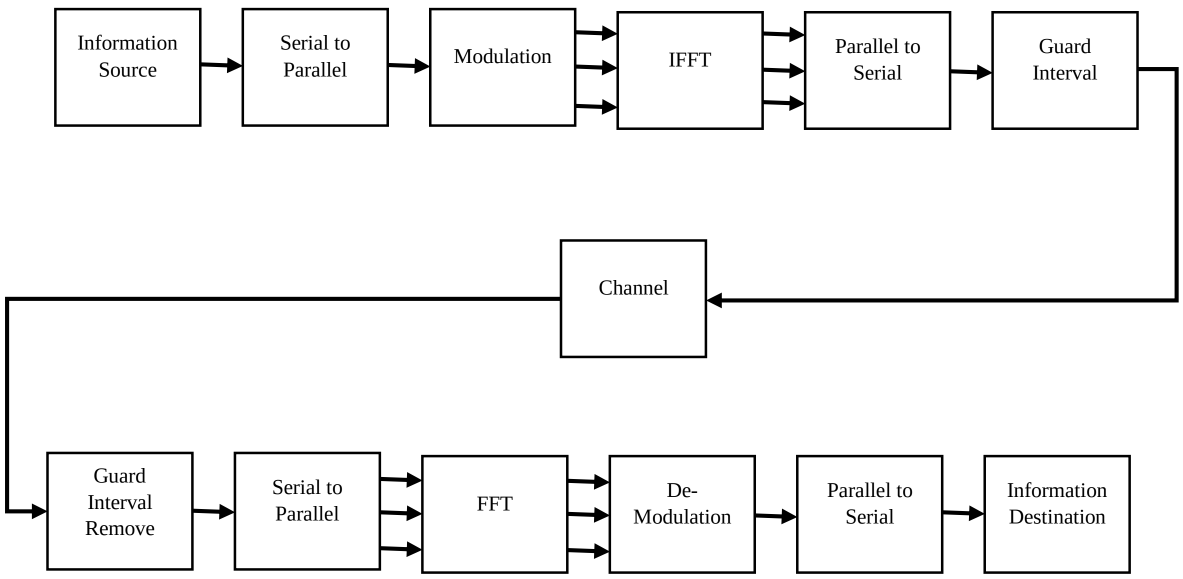

Fig. 3 OFDM system block diagram.

Then, a guard interval is incorporated into the transmitted symbol to reduce inter-symbol interference (ISI). Then, the transmitted symbols are passed across the channel model [14].

At the receiver, the demodulation process follows the reverse steps performed at the transmitter. The guard interval is removed from the received symbols, and the symbol is then transformed from the time domain to the frequency domain by Fast Fourier Transform (FFT). Eventually, the signal is parallel to serial transformed and delivered to a demodulator to get the expected output data [18].

2.2 MIMO System

MIMO signaling was developed by Jack Winters of Bell Laboratories in 1984. Various antenna structures are utilized in describing space-time systems. In a MIMO system, a set of multiple of antennas is located at the transmitting and receiving ends. The distance between various base station antennas can be set as roughly ten times the carrier wavelength and mobile station antennas can be detached or separated by half carrier wavelength. In this manner, independent and distinct channels between the transmitting and receiving ends are created so as to meet the diversity or space division multiplexing requirements. The concept is to recognize spatial multiplexing and data channel by evolving spatial diversity, which is formed by multi-transmitting and receiving antennas [19]. Essentially, there can be multiple types of channels in wireless communication.

1-Free Space Path Loss: This type focuses on power loss of electromagnetic wave when there is a free line-of-sight path occurs between transmitter and receiver. The unobstructed power received by the receiving antenna, at a distance d from the transmitting antenna, is given by

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \qquad (2)$$

where P_t is the transmitted power, G_t, the transmitting antenna gain, P_r (d), the received power, G_r, the receiving antenna gain, d, is the distance between the transmitter and receiver in meters, λ, the wavelength in meters and L, the loss factor. The gain of an antenna is related to its effective aperture via

$$G = \frac{4\pi A_e}{\lambda^2} \qquad (3)$$

where A_e denotes the effective aperture area of antenna in meters square, λ, the wavelength of the carrier and λ=cf, f, the carrier frequency in Hz, and c, the speed of light in meters/sec (3×10^8 m/sec).

2. Shadow Fading: Huge obstructions such as hills or big buildings obscure the main signal route between the transmitter and the receiver, thereby causing shadowing and amplitude variation and fluctuation of received signals. Actually, free-space path loss and shadow fading constitute slow fading or large-scale fading.

3. Multipath Fading Small-Scale: This refers to fast fluctuation of amplitude and phase over small interval of time. Small-scale fading can be commonly associated with reflection, deflection and scattering. These three propagation techniques cause fading at a particular position [20]. Rayleigh fading is a useful model to characterize small-scale fading when there is no predominant propagation beside the line-of-sight between the transmitter and receiver. If there is a predominant propagation beside the line-of-sight, Rician fading model is appropriate.

2.3 MIMO System Capacity and Space-time Coding:-

System capacity can be explained as the maximum transmission data rate achievable in the presence of noise and therefore some receiver error probability, however small it might be. Telatar and Foschini in their papers about MIMO system mentioned that system capability or capacity can be increased linearly by setting up several space sub-channels which associate the transmitter and receiver [21] [22]. The transmitted signal bandwidth is very narrow and so its frequency response can be close to being flat.

To describe the channel matrix **H, which** is *Nt* x *Nr* complex matrix, the elements of which are fading measurements from the *j-th* transmit antenna Tx to the *i-th* receive antenna Rx. The relationship between **x,** the input to the channel, and **y**, the output from the channel, of a MIMO system can be expressed as:

$$\mathbf{y} = \mathbf{Hx} + \mathbf{n}, \tag{4}$$

where **x** is $N_T \times 1$ transmitting vector, **y** is $N_R \times 1$ receiving vector, **n** is additive white Gaussian noise. Assume that the signals transmitted by independent antennas are separated from each other, with a mean value of 0 and a variance of 1. The scheme of flat MIMO channel is shown in Fig.4. MIMO system capacity can be explain as [22]:

$$C = max_{T_r(\boldsymbol{R}_{ss})} = N_T\{log_2[\det(\boldsymbol{I}_{NR} + \frac{1}{\sigma^2}\mathbf{H}\boldsymbol{R}_{ss}\mathbf{H}^{\mathrm{H}})]\} \tag{5}$$

where $()^{\mathbf{H}}$ denotes Hermitian transpose, $\mathbf{R}_{\mathrm{SS}}$ is the covariance matrix, and **I** is identity matrix. The system capacity C unit is bit/s/Hz, det $(\cdot)$ denotes the determinant of the argument matrix. If channel information for the transmitter is unknown, and the signals transmitted from every antenna have equivalent powers, that is, $\mathbf{R}_{SS}=\mathbf{I}$, the system capacity can be rewritten as [23]:

$$c = log_2[\det(\boldsymbol{I}_{NR} + \frac{E_S}{N_T N_0}\mathbf{H}\mathbf{H}^{\mathrm{H}})] \tag{6}$$

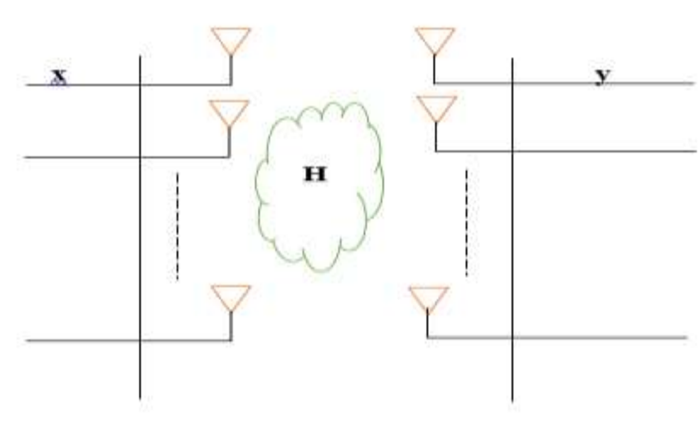

Fig. 4 Flat fading MIMO channel.

The resulting formulations show that multi-antenna system has actually improved the channel capacity compared to conventional single-antenna system. The enhanced channel capacity can be utilized to increase the information transmission rate or enhance the reliability of communications systems by improving information redundancy. Usually, a hybrid approach may be adopted by combining these two approaches.

Space-time coding technique is particularly a two-dimensional coding technique involving both space and time [24]. Multiple antennas for transmission and reception in space are used to obtain high data rates and increase wireless communication systems capacity. In time-domain, various signals can be transmitted at various time slots by using similar antennas at the same time. Correlation of space and time is represented between signals transmitted by various antennas and so the receiver antennas can recognize diversity reception. Consequently, space-time coding is mainly intended for higher encoding gain without utilizing more bandwidth which successfully improves capacity of wireless systems. MIMO systems can be usually categorized into Spatial Multiplexing (SM) and Space-Time Coding (STC). Traditional STC includes Space-Time Block Code (STBC) and Space-Time Trellis Code (STTC). STTC fulfills entire diversity through fading channel and displays a good coding gain. STBC can also fulfill an entire diversity gain through execution of maximum decoding algorithm. A model for spatial multiplexing (SM) technique is layered space-time structure, it was first suggested by Bell Labs [25]. The best basic system is V-BLAST architecture [26], which is extensively utilized in the flat fading channel. However, it cannot get spatial diversity gain.

2.4 MIMO-OFDM Structure

Due to the importance of OFDM and MIMO systems, it is essential to integrate both to realize high speed wireless communication system of 5G and beyond. OFDM can be used to convert frequency-selective MIMO channel into equivalent or parallel flat MIMO channel. MIMO-OFDM systems can achieve coding gain and diversity gain by space-time coding, MIMO-OFDM system has become the technology for 4G and 5G mobile communication systems. At the transmitting termination, an unspecified number of antennas are utilized. Data bit stream is encoded using space-time coding [23], and modulated by OFDM and eventually fed to antennas for transmission. At the receiver, arriving signals are fed into a signal discoverer and handled before recovering the prime signal. Fig.5 shows the basic structure of a MIMO-OFDM system [27].

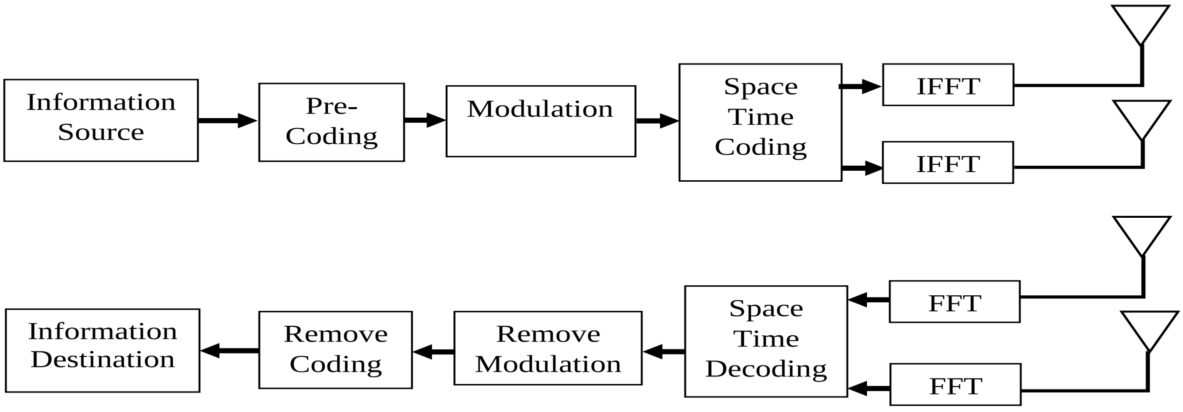

Fig. 5 MIMO-OFDM Structure

The frequency response of *k-th* sub-carrier of MIMO-OFDM system of can be expressed as follows:

$$H_k^{(q,p)}(n) = \sum_{l=1}^{L-1} h_l^{(q,p)}(n) W_K^{kl} \tag{7}$$

Where $h^{(q,p)}$ (n) is the impulse response of the *l-th* channel from the *p-th* transmitter antenna to *q-th* receiver antenna, for $k = 0,\ldots, K-1$. K is the total number of sub-carriers and n is number of the symbol. Let $W_K = e^{-j2\pi/K}$, M and N are respectively, the total number of receiver and transmitter antennas. The output of the *q-th* receiver antenna can be expressed as:

$$y_k^{(q)}(n) = \sum_{p=1}^{M} H_k^{(q,p)}(n) x_k^{(p)}(n) + \zeta_k(n) \tag{8}$$

$q=1\ldots N$; $k=0\ldots K-1$ and ζ_k (n) is zero-men Gaussian noise with variance δ_n^2.

3. Peak-to-Average Power Ratio (PAPR) Problem

The output of an OFDM system frequently has large variation or fluctuations compared to conventional single-carrier systems. This imposes new requirements on system devices like power amplifiers, D/A converters and A/D converters, which are forced to have huge linear dynamic ranges and hence increased cost. If the requirements are not met, a series of unwanted interferences such as inter-modulation distortion and large out-of-band radiation take place when the peak signal swings into the non-linear range of the devices at the transmitter. Therefore, PAPR reduction techniques have become very important in OFDM systems [28].

In theory, PAPR, sometimes referred to as PAR, is defined as [29]:

$$PAPR = \frac{P_{peak}}{P_{average}} = 10log_{10} \frac{\max[|x_n|^2]}{E[|x_n|^2]} \tag{9}$$

Where P_{peak} represents peak power of output, $P_{average}$, average power of output. $E\,[\cdot]$, the expected value, and x_n, the transmitted OFDM signals which are achieved by taking IFFT procedure of the modulated input symbols X_k. x_n is expressed as:

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k W_N^{nk} \tag{10}$$

The peak power of received signals for an OFDM system with N sub-carriers is equal to the number of sub-carriers the average power in a subcarrier when the phases are the same. The PAPR will theoretically become maximum at $PAPR\ (dB)$ =10log N. For instance, a 32 sub-carriers system, the maximum PAPR is 15 dB. Actually the probability of attaining this maximum value is very low. Fig.6 demonstrations the amplitude of an OFDM system with N (32 sub-carriers). Relatively to the figure, the maximum level of the OFDM signals is fewer than the higher limit value and PAPR is also lower than the theoretical maximum 15dB.

The particular case occurs when signal sub-carriers are modulated through symbols which have the similar initial phase. Assumption that input binary sequence include “1” for the entire sequence. After Phase Shift Keying (PSK) constellation mapping and IFFT operation, instantaneous power reaches its maximum value. Fig.7 displays the result when input binary sequence includes 32 “1”, signified by [111111….1]. In this situation, the PAPR can be calculated from $PAPR\ (dB)$ =10log N and in this case it is 15dB.

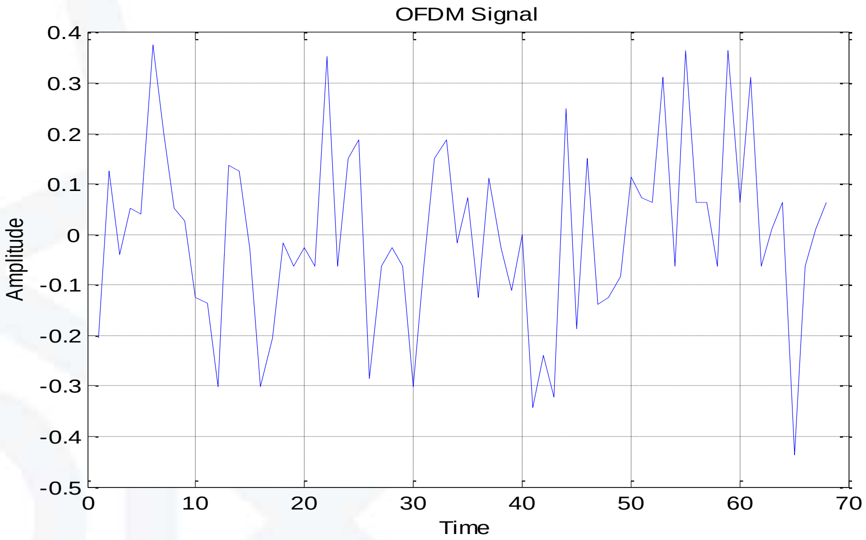

Fig.6 OFDM Signal Waveform in Time Domain

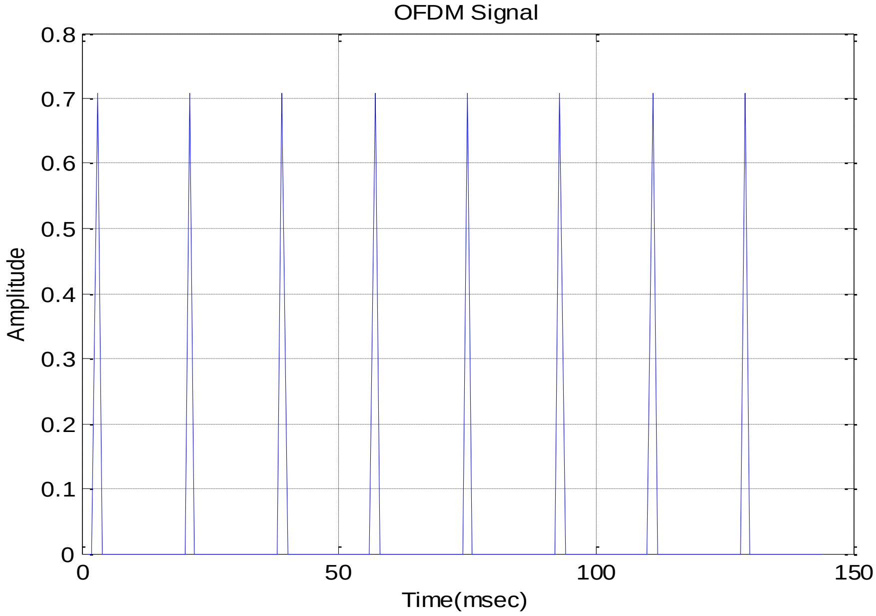

Fig. 7 High PAPR when sub-carriers are modulated by same symbols.

3.1 Probability Distribution Function of PAPR

In multi-carrier signal because of a large number of sub-carriers, the central limit theorem holds, and hence the imaginary and real part of sample magnitudes in time domain will follow Gaussian distribution with variance of 0.5 and mean value of 0. Thus, the amplitude of multi-carrier signals obeys Rayleigh distribution with a variance of N times the variance of one complex sinusoid and zero mean [30]. Cumulative Distribution Function (CDF) is expressed as follows

$$F(x) = 1 - e^{-x} \tag{11}$$

Suppose that the sampling values of various sub-channels are independent and canceling oversampling operation, the probability distribution function for PAPR less than a particular threshold value, is expressed as

$$P(PAPR < x) = [F(x)]^N = (1 - e^{-x})^N \tag{12}$$

Actually, it is favored to take the probability of PAPR above a threshold as measurement to describe the distribution of PAPR. This can be defined as "Complementary Cumulative Distribution Function" (CCDF), expressed as

$$P(PAPR > x) = 1 - P(PAPR \leq x) = 1 - F(x)^N = 1 - (1 - e^{-x})^N \tag{13}$$

.

3.2 Classification of PAPR Reduction Techniques

There are several techniques that have been suggested to solve the high PAPR problem of MIMO –OFDM system. These techniques fall into three categories. Reference [3] provides a survey and taxonomy of PAPR reduction schemes.

1. Signal Distortion Techniques

Clipping and filtering technique forms one of the most realistic and easy-to-implement approach for reduction of PAPR, which can limit the signal amplitude at the transmitter so as to remove the high peaks to a fixed level. Clipping can be applied to the samples prior to digital-to-analog-convertor (DAC) [1]. Because of the nonlinear distortion obtainable by this process, orthogonality will be damaged due to some serious out-of-band noise as well as well as in-band noise. Out-of- band noise decreases the bandwidth efficiency but use filtering can be working to decrease the out-of-band power. In-band noise cannot be eliminated by filtering and it decreases the bit error rate (BER) performance. Also, it could cause the peak to increase. To remove this drawback, the process is repeated several times till a desired result is obtained.

2. Signal Scrambling Techniques

The principle behind this method is to scramble every signal with various scrambling sequence structures and select one which has the minimum PAPR value for transmission. Partial Transmit Sequences (PTS) and Selective Mapping (SLM) are most familiar kinds of this technique. SLM method uses scrambling all sub-carriers individually while PTS technique only selectively scrambles part of the sub-carriers. These two approaches can be applied to OFDM systems without constraint on type of modulation and the number of sub-carriers. Nevertheless, for recovery of the signal at the receiver, extra information is needed (side information), which causes loss in bandwidth and high hardware complexity.

3. Coding Techniques

In this technique forward error correction method is applied particularly to remove the OFDM signals with high PAPR. The classical schemes include linear block code and Golay codes and Reed-Muller code [32] [33]. Linear block coding technique is most appropriate to the situation when the system has only a small number of sub-carriers, and hence they only find limited applicability. Reed-Muller code is an efficient coding scheme. A lower bound for PAPR for the second order code has been derived via categorizing the code words using the Walsh-Hadamard transform (WHT). By utilizing Reed-Muller code, PAPR can be minimized to 3dB at a maximum with acceptable error correcting capability.

4. PAPR Reduction Techniques in Literature Review for MIMO-OFDM Systems

For future communication systems, an amalgamation of multiple-input/ multiple-output with orthogonal frequency division multiplexing, indicated as MIMO-OFDM, is one of the most prominent candidates [2]. As pointed previously, the main disadvantage of MIMO-OFDM is the high peak-to-average power ratio (PAPR) of the transmitted signals. We characterize and describe here some of the PAPR reduction methods available in the literature. The literature review presents some techniques for PAPR reduction of MIMO-OFDM systems by improving and adapting several PAPR reduction techniques.

Recently, different techniques have been suggested to reduce the PAPR for OFDM systems in the literature, for instance clipping [34], selected mapping (SLM) [35], partial transmit sequence (PTS) [36], constellation shaping [35] and adaptive all-pass filters [38]. Meanwhile, several techniques were suggested to minimize the PAPR of MIMO-OFDM signals in [39].

In [40], the authors suggest an adaptive clipping mechanism to minimize PAPR of Alamouti-coded MIMO-OFDM systems. Results show that the technique provides efficient approach for PAPR reduction and best bit error rate (BER) realization. PAPR reduction and BER achieved compare favorably with those achieved by SISO-OFDM systems. The results show that the spectral spreading due to the suggested method is less than that due to traditional clipping. In any case, BER performance degrades due to in-band and out-band distortions [40]

In [41], the author's propos a parallel artificial bee colony (P-ABC) algorithm based on a new search strategy. Accomplishment of the P-ABC is verified for peak-to-average power ratio (PAPR) reduction problem utilizing selective mapping (SLM) system in mutually orthogonal frequency division multiplexing (OFDM) and multiple-input multiple-output (MIMO)-OFDM systems. The results suggest that P-ABC provides excellent PAPR and bit-error-rate reduction together with low computational complexity.

Reference [42] proposes two PTS schemes. These schemes estimate peak power within each sub-block using samples from that sub-block. These schemes exhibit reduced complexity and a better PAPR and BER performances that compare favorably to that of SFBC MIMO-OFDM.

A novel phase offset selected mapping (SLM) scheme is proposed in [43] to reduce the peak-to-average power ratio (PAPR) in Alamouti-coded MIMO-OFDM systems and to recover the phase rotation sequences without requiring additional bits for the transmission of side information.

Reference [44] proposes novel alternative multi-sequence (AMS) scheme for the peak-to-average power ratio (PAPR) reduction in multiple-input–multiple-output orthogonal frequency-division multiplexing (MIMO-OFDM) systems with space–frequency block coding (SFBC). The scheme maintains the advantage of the structure of the SFBC to generate some AMSs through a combination of signals in different transmission antennas. Precisely, when the proposed scheme is used in systems with QAM modulation, one of the major advantages is that there is no need for side information to be transmitted to the recipient. Theoretical and simulation results show that the proposed scheme has the capability to offer significant reductions in PAPR, lower bit error rate, and low computational complexity [44].

In [45], the authors propose a scheme that generates signal candidates (SCs) by mapping the subparts of OFDM symbols onto multiple antennas under the criterion of reducing correlation among the SCs. The proposed scheme provides good PAPR performance and allows a low-complexity detection of the transmitted SC without side information [45]. In this proposed method, they design a PAPR reduction scheme for Frequency switched transmit diversity (FSTD) based MIMO-OFDM systems, not only improving the PAPR but also allowing a simple detection of the transmitted SC without SI.

5. Conclusion and Suggestion

This review is an overview of the multiple input and output technology (MIMO) with orthogonal frequency division multiplexing (OFDM). Also, it discussed the advantages and disadvantages of OFDM system through the analysis and compare it with other traditional adjustment plans. In this work, we focus the review on investigating one of the drawbacks of MIMO-OFDM, viz., high peak to average power ratio (PAPR) of the output signal, and discuss how to reduce it by various effective algorithms. Among the various proposals, we focus primarily on three techniques (Signal Distortion, Signal Scrambling, and Coding), and verification of theoretical analysis by monitoring the MATLAB simulation results. Simultaneously, we are getting some guidance and meaningful conclusions through a comparative analysis of these results as well as simulation. A comparison of some optimistic proposals with estimate to proportional factors is given in Table 1.

Table 1 Comparison of adaptable PAPR reduction suggestions

Techniques	**Data Rate Loss**	**Power Increase**	**Distortion**	**Requirements in TX & RX**
Clipping	No	No	Yes	TX: Clipping. RX: None
Coding	Yes	No	No	TX: Coding. RX: Decoding
PTS	Yes	No	No	TX: K Times IFFTs. RX: Side information extraction and inverse PTS
SLM	Yes	No	No	TX: K Times IFFTs. RX: Side information extraction and inverse SLM

One of the main conclusions is that most researchers and developers are focusing on traditional methods, the SLM and the PTS algorithms. A string of outcomes detailed comparison of these two schemes in terms of performance to minimize the PAPR, and redundancy of additional information, as well as the system complexity.

MIMO-OFDM as a multi-carrier modulation method is particularly suitable for high-speed wireless communication. The review focuses mainly on our assessment of the various methods for PAPR reduction in MIMO-OFDM system. Nevertheless, there are still several technical problems to be solved despite the excellent properties exhibited in almost all aspects of wireless communications. In this review, all the results obtained under ideal conditions, but in fact, the OFDM system has a lot of practical problems, such as channel estimation and synchronization, Thus, to realize a more complete and effective system, one can add channel estimation and synchronization techniques for OFDM systems.

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