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Abstract - Orthogonal Frequency Division Multiplexing (OFDM) is a very attractive technique for high data rate transmission in wireless and wired applications. However, implementation of the OFDM system entails several difficulties. One of the major drawbacks is the high peak to average power ratio (PAPR) of the transmitted signals. Several approaches exist to reduce PAPR of OFDM symbols. Precoding is a new method which is having less complexity compared to the other power reduction techniques and also it can reduce PAPR considerably and results in no distortion. In this paper Walsh Hadamard Transform precoding technique is proposed. The reduction in PAPR of the OFDM signal is obtained through walsh hadamard transform scheme. The obtained results show that this precoding scheme is an attractive solution to the PAPR problem of OFDM signals.

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Strictly as per the compliance and regulations of :

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Navneet Kaur [α] & Lavish Kansal [σ]

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I. Introduction

Multicarrier communications is a technique that has recently seen rising popularity in wireless and wire line applications [1, 2, 3]. In the last years wireless communications have experienced a fast growth due to the high mobility that they allow. However, wireless channels have some disadvantages, like multipath fading, that make them difficult to deal with. A modulation that efficiently deals with selective fading channels is orthogonal frequency division multiplexing (OFDM). International standards making use of OFDM for wireless. For wireless applications, OFDM based systems can be of interest because they can provide a greater immunity to impulse noise and fast fades and eliminate the need for equalizers, while efficient hardware implementations for small numbers of carriers can be realized using fast fourier transform (FFT) techniques.

Fig.1. shows the generation of an OFDM signal. To generate OFDM successfully the relationship between all the carriers must be carefully controlled to maintain the orthogonality between the carriers. OFDM is generated by first choosing the spectrum required, based on the input data and modulation scheme used. Each carrier to be produced is assigned some data to transmit.

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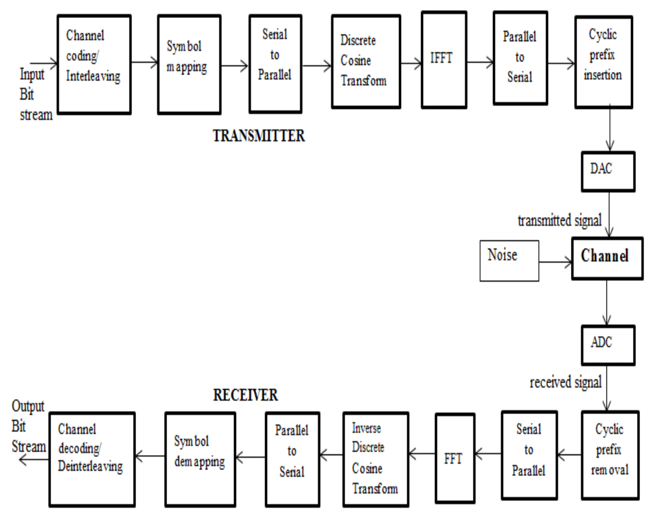

Figure 1 : Block Diagram of OFDM system

In an OFDM scheme, a large number of orthogonal, overlapping, narrow band sub-carriers are transmitted in parallel each sub-carrier is then modulated with a conventional modulation scheme such as Quadrature Amplitude Modulation (QAM) or Phase-Shift Keying (PSK) at a low symbol rate than that required for the whole data stream, but still maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth. A high-rate data stream is split into a number of lower rate streams to be transmitted simultaneously over a number of sub-carriers. Since the symbol duration increases for lower rate parallel sub-carriers, the amount of dispersion in time caused due to multipath delay is reduced. These carriers divide the available transmission bandwidth. The separation of the sub-carriers is such that there is a very compact spectral utilization and each being modulated at a low bit rate. In a conventional frequency division multiplex the carriers are individually filtered to ensure there is no spectral overlap.

One of the major drawbacks of OFDM systems is that the OFDM signal exhibits a high peak to average power ratio (PAPR). An OFDM signal consists of a number of independently modulated single carriers, which can give a large peak to average power ratio (PAPR) when added up coherently. When N signals are added with the same phase, they produce a peak power that is N times the average power. A large PAPR brings disadvantages like an increased complexity of the analog-to-digital (A/D) and digital-to-analog (D/A) converters and a reduced efficiency of the RF power amplifier. Such a high PAPR necessitates the linear amplifier to have large dynamic range which is difficult to accommodate. An amplifier with nonlinear characteristics will cause undesired distortion of the in band and out of band signals.

To reduce the PAPR, several techniques have been proposed, which can be divided into three categories. First, there are signal distortion techniques, which reduce the peak amplitudes simply by nonlinearly distorting the OFDM signal at or around the peaks. Examples of distortion techniques are clipping [6], peak windowing [7], and peak cancellation. Second, there are coding techniques that use a special code set that excludes OFDM symbols with a large PAPR. Golay complementary sequence[8], Reed Muller code[9], M-sequence[10], or Hadamard code can be used in this approach [11]. The third technique scrambles each OFDM symbol with different scrambling sequences and selecting the sequence that gives the smallest PAPR such as selected mapping (SLM) [12,13] and partial transmit sequence (PTS) [14,15].

The precoding based techniques, however, show great promise as they are simple linear techniques to implement without the need of any side information. This paper presents precoding PAPR reduction techniques namely; Walsh Hadamard Transform. The organization of this paper is as follow. Section II formulates the problem of PAPR in OFDM systems .Section III describes the precoding techniques. Simulation results will be presented in section IV and finally some conclusions are presented in section V.

II. Papr In Ofdm System

A multicarrier signal is the sum of many independent signals modulated onto sub channels of equal bandwidth. An OFDM symbol consists of N subcarriers by the frequency spacing of Δf. Thus, the total bandwidth B will be divided into N equally spaced subcarriers and all the subcarriers are orthogonal to each other within a time interval of length $T= 1/\Delta f$. Each subcarrier can be modulated independently with the complex modulation symbol $X_{m,n}$, where m is a time index and n is a subcarrier index. Then within the time interval T the following signal of the m-th OFDM block period can be described as:

$$x_m(t)=\frac{1}{\sqrt{N}}\sum_{N=0}^{N-1} X_{m,n}\, g_n(t-mT) \tag{1}$$

where, $g_n(t)$ is defined as:

$$g_n(t)= \begin{cases}\exp(j2\pi n\Delta f t), & 0 \le t \le T \\ 0, & else\end{cases} \tag{2}$$

where, $g_n(t)$ is a rectangular pulse applied to each subcarrier [16]. The total continuous time signal x (t) consisting of all the OFDM block is given as:

$$x(t)=\frac{1}{\sqrt{N}}\sum_{m=0}^{\infty}\sum_{n=0}^{N-1} X_{m,n}\, g_{n(t-mT)} \tag{3}$$

For a single OFDM symbol consider (m=0) without loss of generality. This can be shown because there is no overlap between different OFDM symbols. Since $m = 0$, $X_{m,n}$ can be replaced by X_n. Then, the OFDM signal can be described as follows:

$$x(t)=\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1} X_n e^{j2\pi n\Delta f t} \tag{4}$$

If the bandwidth of the OFDM signal is $B = N \times \Delta f$ and the signal $x(t)$ is sampled by the sampling time of $\Delta f = \frac{1}{B} = \frac{1}{N\Delta f}$, then the OFDM signal is in discrete time form and can be written as shown in :

$$x_k=\frac{1}{N}\sum_{n=0}^{N-1} X_n\, e^{j2\pi kn/N}, \quad k=0, 1\ldots N\text{-}1 \tag{5}$$

where, n denotes the index in frequency domain and X is the complex symbol in frequency domain.

Due to the presence of large number of independently modulated sub-carriers in an OFDM system the peak value of the system can be very high as compared to the average of the whole system. This ratio of the peak to average power value is termed as Peak to Average Power Ratio(PAPR). Coherent addition of N signals of same phase produces a peak which is N times the average signal. The PAPR of the transmitted signal is defined as by:

$$\text{PAPR}[x(t)]=\frac{max|x(t)|^2}{1/NT\int_0^{NT}|x(t)|^2 dt} \tag{6}$$

The instantaneous output of an OFDM system often has large fluctuations compared to traditional single-carrier systems. This requires that system devices, such as power amplifiers, A/D converters and D/A converters, must have large linear dynamic ranges. If this is not satisfied, a series of undesirable interference is encountered when the peak signal goes into the nonlinear region of devices at the transmitter, such as high out of band radiation and inter-modulation distortion. PAPR reduction techniques are therefore of great importance for OFDM systems.

The Cumulative Distribution Function (CDF) is one of the most regularly used parameters, which is used to measure the efficiency of any PAPR technique. Normally, the Complementary CDF (CCDF) is used instead of CDF, which helps 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:

$$F(z) = 1 - \exp(-z) \tag{7}$$

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However, the complementary CDF (CCDF) is used in-stead of CDF, which helps us to measure the probability that the PAPR of a certain data block exceeds the given threshold. The CCDF of the PAPR of the data block is desired is our case to compare outputs of various reduction techniques. This is given as:

$$P(PAPR > z) = 1\text{-}(F(z))^{N}$$
$$= 1 - (1 - exp(-z))^{N} \quad (8)$$

III. Precoding Techniques

The goal of precoding techniques is to obtain a signal with lower PAPR than in the case of OFDM without precoding techniques and to reduce the interference produced by multiple users. The PAPR reduction must compensate the non linearities of the HPA having as effect the reduction of the bit error rate (BER). The main characteristics of precoding based techniques are: no bandwidth expansion, no power increase, and no data rate loss, no BER degradation and distortionless. Some precoding techniques are presented in the following.

a) Walsh Hadamard Transform

The Walsh Hadamard Transform (WHT) is a non-sinusoidal, orthogonal linear transform and can be implemented by a butterfly structure as in FFT. This means that applying WHT does not require the extensive increase of system complexity. WHT decomposes a signal into set of basic functions. These functions are Walsh functions, which are square waves with values of +1 or -1 [17]. The proposed hadamard transform scheme may reduce the occurrence of the high peaks comparing the original OFDM system. The idea to use the WHT is to reduce the autocorrelation of the input sequence to reduce the peak to average power problem and it requires no side information to be transmitted to the receiver. The kernel of WHT can be written as follows:

$$\mathrm{H}_1 = [1]$$

$$\mathrm{H}_2 = \frac{1}{2}\begin{bmatrix}1 & 1\\ 1 & -1\end{bmatrix}$$

$$\mathrm{H}_{2\mathrm{N}} = \frac{1}{2\mathrm{N}}\begin{bmatrix}\mathrm{H}_\mathrm{N} & \mathrm{H}_\mathrm{N}\\ \mathrm{H}_\mathrm{N} & \mathrm{H}_\mathrm{N}^{-1}\end{bmatrix}$$

where H_N^{-1} denotes the binary complement of H_N.

The WHT is used in a number of applications, such as image processing, speech processing, filtering, and power spectrum analysis. Like the FFT, the Walsh–Hadamard transform has a fast version, the fast Walsh–Hadamard transform (FWHT). The FWHT is able to represent signals with sharp discontinuities more accurately using fewer coefficients than the FFT. Both the FWHT and the inverse FWHT (IFWHT) are symmetric and thus, use identical calculation processes.

IV. Proposed Scheme

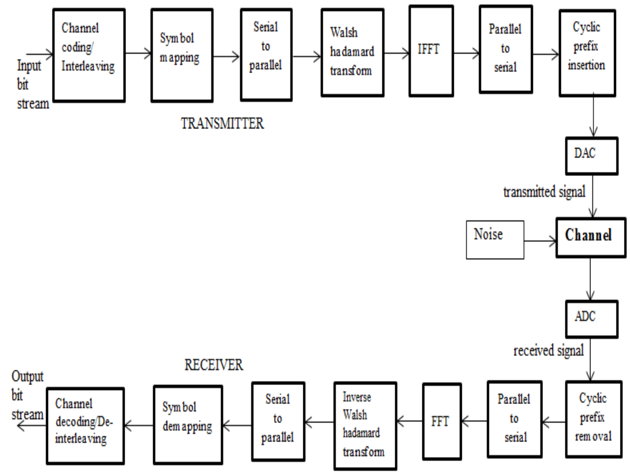

Figure 2 : Block scheme of WHT Precoding technique in OFDM system

WHT precoding based OFDM system was shown in fig. 2. In these system, the kernel of the WHT acts as a precoding matrix P of dimension $N=L\times L$ and it is applied to constellations symbols before the IFFT to reduce the correlation among the input sequence. In the precoding based systems baseband modulated data is passed through S/P converter which generates a complex vector of size L that can be written as $\mathrm{X}=[X_0, X_1, \ldots, X_{L-1}]^T$. Then precoding is applied to this complex vector which transforms this complex vector into new vector of length L that can be written as $\mathrm{Y}=\mathrm{PX}=[Y_0, Y_1, \ldots, Y_{L-1}]T$ where P is a precoder matrix of size $N=L\times L$ and Y_m can be written as follows:

$$Y_m = \sum_{l=0}^{L-1} p_{m,l} \cdot X_l \quad , m=0, 1, \ldots, L\text{-}1 \quad (9)$$

$P_{m,l}$ means m^{th} row and l^{th} column of precoder matrix. The complex baseband OFDM signal with N subcarriers can be written as:

$$x_n = \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} Y_m . e^{j2\pi m \frac{n}{N}} \quad , n=0, 1, 2, \ldots, N\text{-}1 \quad (10)$$

IV. Simulation Results

In this section, the PAPR of OFDM with WHT precoding technique has been evaluated by simulation. To show PAPR analysis of the proposed system, the data is generated randomly then the signal is modulated by M-PSK and M-QAM respectively. The block implementation is shown in Fig. 2., where the precoding matrix transform represents proposed walsh hadamard transform precoding technique used in our simulations. We can evaluate the performance of the PAPR reduction scheme using the complementary cumulative distribution (CCDF=Prob (PAPR>PAPR0) of the PAPR of the OFDM signal. The CCDF of the PAPR for WHT precoded OFDM signal is used to express the probability of exceeding a given threshold. We compared the simulation results of proposed system with WHT precoded OFDM systems and conventional OFDM systems.

a) M-PSK Modulation

In this section WHT technique is applied over OFDM system with phase shift keying modulation. We assume CCDF clip rate of 10^{-2} using M-ary PSK technique for N=2400 and M=16, 32, 64, 128, 256, 512 and 1024.

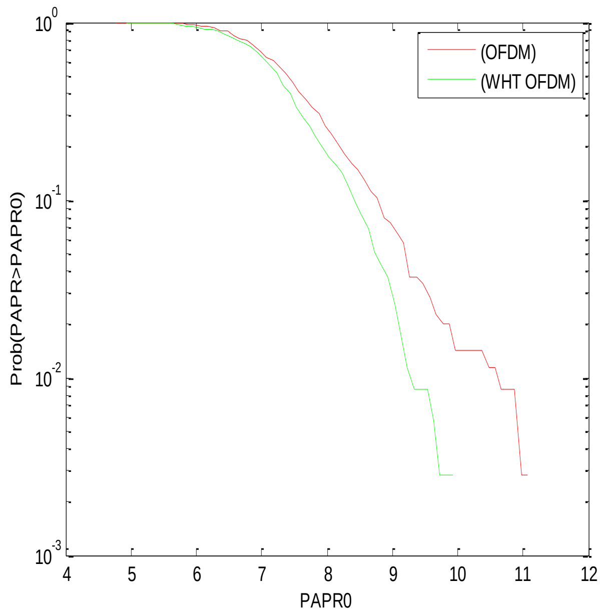

Figure 3 : CCDF for WHT precoding techniques with 16 PSK

Figure 3 shows the CCDF performance of the WHT scheme compared with that of the original OFDM signal. At CCDF clip rate of 10^{-2} and using 16-PSK modulation the WHT scheme reduces the PAPR by 1.1 dB over original system.

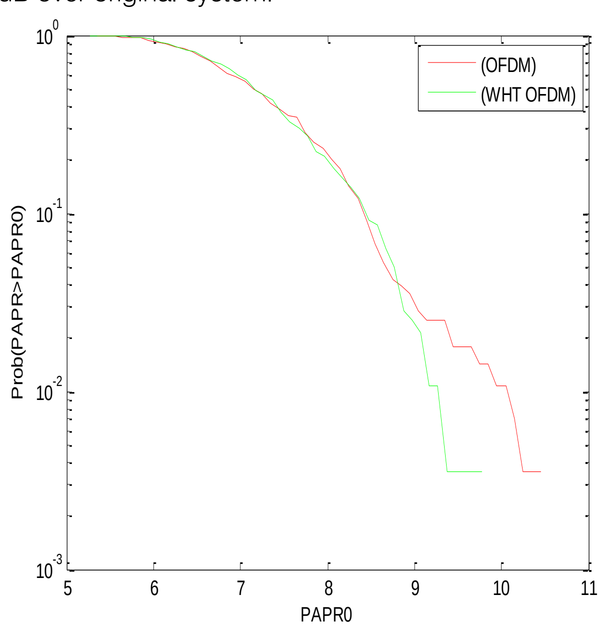

Figure 4 : CCDF for WHT precoding techniques with 32 PSK

Figure 4 shows the CCDF performance of the WHT scheme compared with that of the original OFDM signal. At CCDF clip rate of 10^{-2} and using 32-PSK modulation the WHT scheme reduces the PAPR by 1 dB over original system.

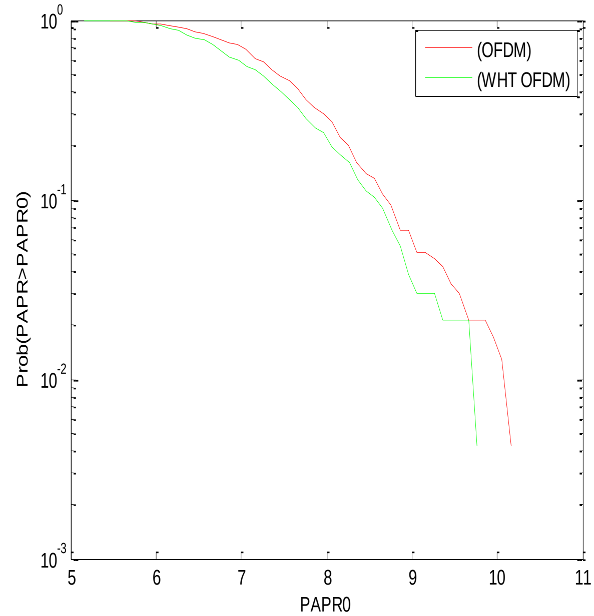

Figure 5 : CCDF for WHT precoding techniques with 64 PSK

Figure 5 shows the CCDF performance of the WHT scheme compared with that of the original OFDM signal. At CCDF clip rate of 10^{-2} and using 64-PSK modulation the WHT scheme reduces the PAPR by 0.4 dB over original system.

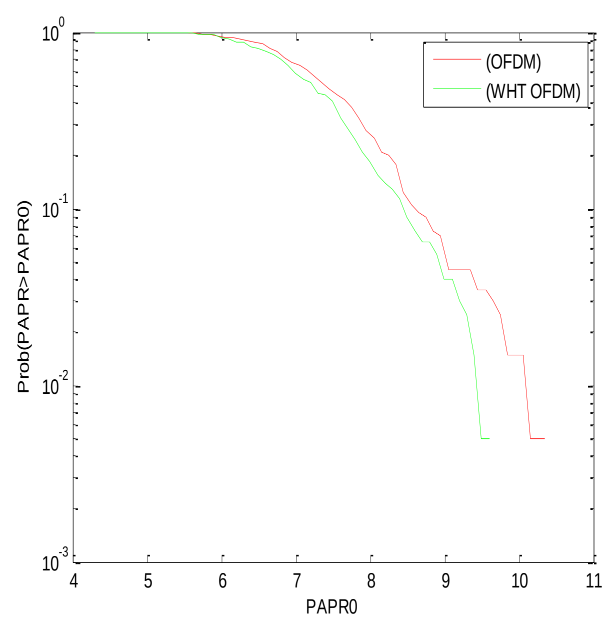

Figure 6 : CCDF for WHT precoding techniques with 128 PSK

Figure 6 shows the CCDF performance of the WHT scheme compared with that of the original OFDM signal. At CCDF clip rate of 10^{-2} and using 128-PSK modulation the WHT scheme reduces the PAPR by 0.5 dB over original system.

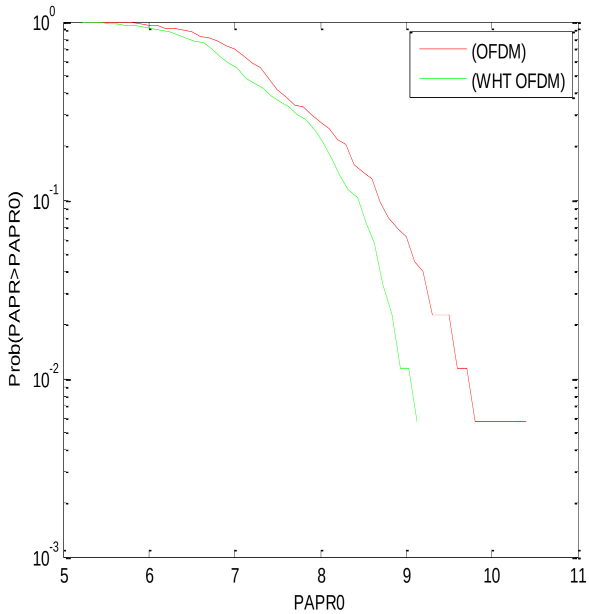

Figure 7 : CCDF for WHT precoding techniques with 256 PSK

Figure 7 shows the CCDF performance of the WHT scheme compared with that of the original OFDM signal. At CCDF clip rate of 10^{-2} and using 256-PSK modulation the WHT scheme reduces the PAPR by 0.8 dB over original system.

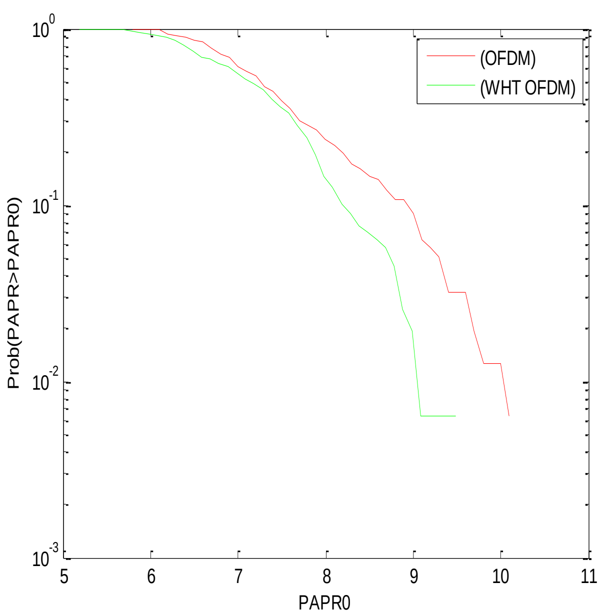

Figure 8 : CCDF for WHT precoding techniques with 512 PSK

Figure 8 shows the CCDF performance of the WHT scheme compared with that of the original OFDM signal. At CCDF clip rate of 10^{-2} and using 512-PSK modulation the WHT scheme reduces the PAPR by 1 dB over original system.

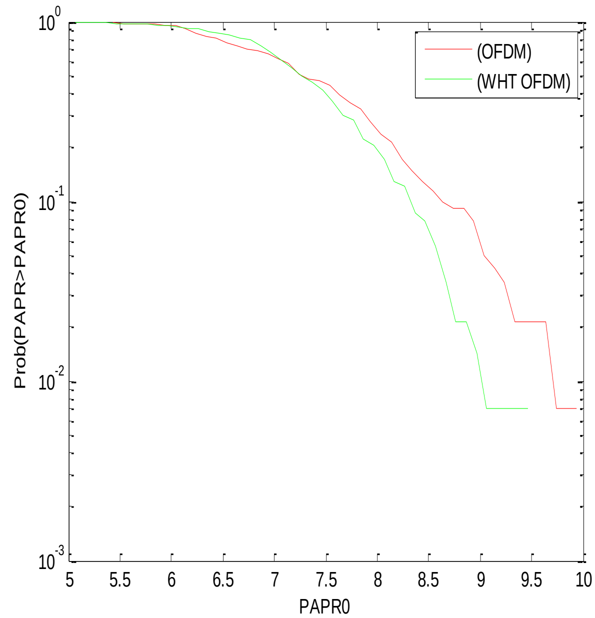

Figure 9 : CCDF for WHT precoding techniques with 1024 PSK

Figure 9 shows the CCDF performance of the WHT scheme compared with that of the original OFDM signal. At CCDF clip rate of 10^{-2} and using 1024-PSK modulation the WHT scheme reduces the PAPR by 0.7 dB over original system.

b) M-QAM Modulation

In this section we use M-ary quadrature amplitude modulation (QAM) technique for N=2400 and M=16, 32, 64, 128, 256, 512 and 1024.

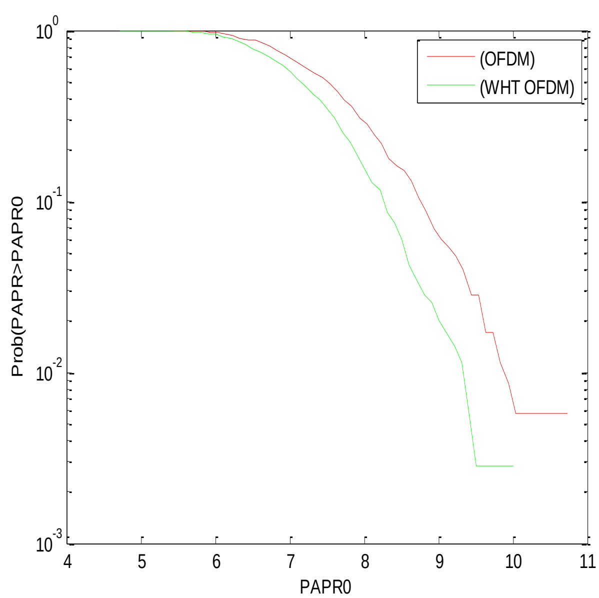

Figure 10 : CCDF for WHT precoding techniques with 16 QAM

Figure 10 shows the CCDF performance of the WHT scheme compared with that of the original OFDM signal. At CCDF clip rate of and using 16-QAM modulation the WHT scheme reduces the PAPR by 0.5 dB over original system.

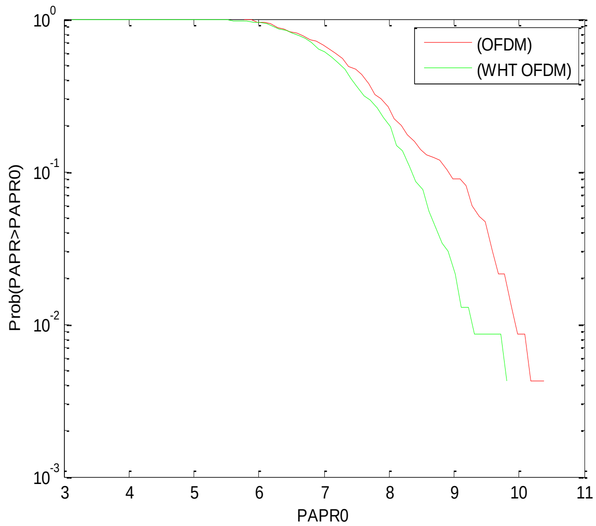

Figure 11 : CCDF for WHT precoding techniques with 64 QAM

Figure 11 shows the CCDF performance of the WHT scheme compared with that of the original OFDM signal. At CCDF clip rate of and using 64-QAM modulation the WHT scheme reduces the PAPR by 0.5 dB over original system.

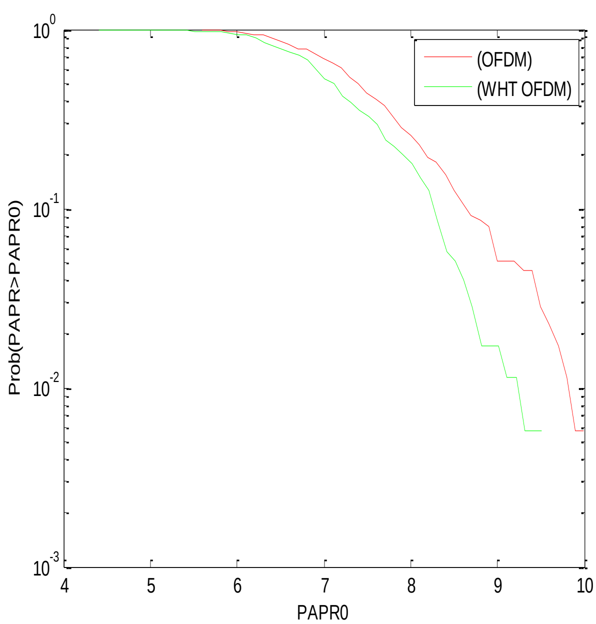

Figure 12 : CCDF for WHT precoding techniques with 256 QAM

Figure 12 shows the CCDF performance of the WHT scheme compared with that of the original OFDM signal. At CCDF clip rate of and using 64-QAM modulation the WHT scheme reduces the PAPR by 0.7 dB over original system.

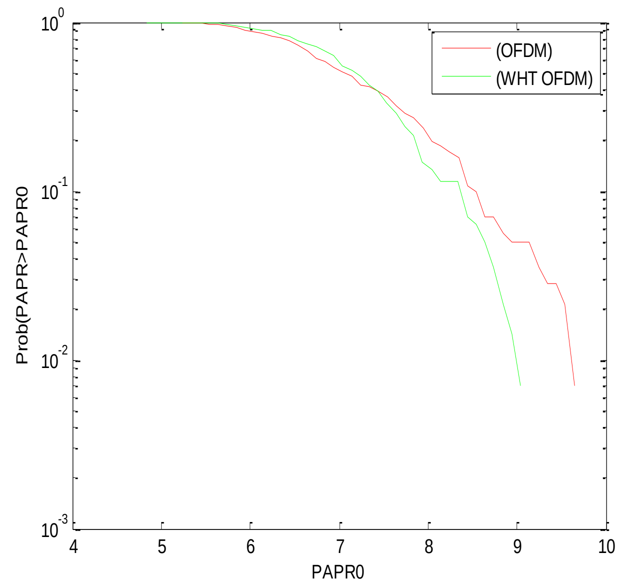

Figure 13 : CCDF for WHT precoding techniques with 1024 QAM

Figure 13 shows the CCDF performance of the WHT scheme compared with that of the original OFDM signal. At CCDF clip rate of and using 1024-QAM modulation the WHT scheme reduces the PAPR by 0.7 dB over original system.

V. Conclusion

In this paper, we evaluated WHT precoding techniques that can be used for PAPR reduction in OFDM systems. Computer simulation shows that the PAPR of the proposed system have less PAPR than the conventional OFDM uplink systems. This system produce the lowest PAPR and is efficient, signal independent, distortion less and do not require any complex optimizations representing better PAPR reduction methods than others existing techniques because it does not require any power increment, complex optimization and side information to be sent to the receiver. Additionally, these systems also take the advantage of the frequency variations of the communication channel and can also offer substantial performance gain in fading multipath channels. Thus, it is concluded that the proposed precoding scheme is more favorable than the conventional OFDM uplink systems.

VI. Acknowledgment

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