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ORIGINAL RESEARCH ARTICLE

# ENHANCEMENT OF SELECTIVE MAPPING TECHNIQUE FOR PEAK-TO-AVERAGE POWER RATIO REDUCTION IN OFDM USING NORMALIZED HILBERT MATRIX

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**ABSTRACT**

*Orthogonal Frequency Division Multiplexing (OFDM) is good multicarrier transmission system used for broadband wireless communication systems owing to it is numerous benefits such as high bandwidth efficiency, high transmission rate, and robustness against multi path problem. However, one of the hitches of OFDM high Peak-to-Average Power Ratio (PAPR) of the transmitted signal, which results in signal distortion and reduced power amplifier efficiency. Selective Mapping (SLM) is attractive distortion less method for PAPR reduction. The performance of this technique in reducing the PAPR is largely affected by the magnitude of phase rotation vectors. It also requires to transmit the selected phase rotation vectors that produce the signal with the lowest PAPR to the receiver end for the recovery of the original data. In this paper, two normalization procedures in conjunction with the Hilbert matrix are used to obtain phase rotation vectors for the SLM technique to further reduce the PAPR value. The reduction of PAPR is desirable in order to have a better power efficiency of the amplifier. The simulation results demonstrated that the enhanced SLM technique using normalized Hilbert matrix achieved a better PAPR reduction compared to SLM using Hilbert matrix without normalization with 14.0%, and 14.0% percentage improvement. Another benefit of this method is that the matrix can be generated at the receiver end to obtain the data signal, thus eliminating the transmission of side information with the original data.*



## 1.0 Introduction

OFDM is a special type of multi-carrier digital multiplexing technique scheme deployed in numerous cutting-edge wireless standards. It has been employed for many broadcast standards, for instance in Digital Audio Broadcasting (DAB) and Digital Video Broadcasting (DVB) standards. It is also used in wireless Local Area Network (LAN) standards such as WIMAX, 802.11n, and 802.11g. Moreover, OFDM is also used in cellular telecommunication standard (Mhatre and Khot, 2015). The OFDM signals can be modulated and demodulated using Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) (Sudha, 2015). However, the most famous obstacle of an OFDM system was that, it suffers high Peak–to–Average Power Ratio (PAPR). An

OFDM signal comprises of a large number of individual modulated subcarriers which can give birth to a huge PAPR when summed up constructively. When N signals aligned in phase, they yield a high instantaneous power that is N times the average power. Large PAPR of the transmitted signals results in non– linear distortions of signals, clipping of signals, Bit Error Rate (BER) performance degradation, energy leaking into adjacent channels, inter modulation effects on the subcarriers, as well as increased complexity of the analogue to digital and digital to analogue converters (Girija, et al., 2014).

Therefore, it is useful to reduce the PAPR of OFDM systems. To combat the problem of high PAPR, various techniques or schemes have been suggested in literature. The reduction schemes can be categorized into distortion and distortion less schemes. Clipping and filtering fall under distortion schemes. The distortion-based schemes minimized the PAPR of the OFDM symbol but at the expense of increasing clipping to the signal points in the subcarriers (Raja et al., 2015). Distortion schemes are considered to introduce bandwidth re-growth. They do not need any overhead side information to be sent to the receiver and they have low complexity compared to the distortion-less schemes, such as Selective Mapping (SLM) and Partial Transmit Sequence (PTS). In this technique, modulated data is multiplied with phase rotation vectors then time-domain conversion takes place through IFFT after that PAPR is calculated and finally, signal with minimum PAPR is selected for transmission. Distortion-less schemes do not host bandwidth re-growth but they need transmitted overhead side information.

Zhong and Wang, (2010) proposed the scheme with SLM using randomness in phase sequence selection. This scheme obtained significant PAPR reduction performance with that of ordinary SLM techniques. However, the work did not address the effect of large magnitude of phase rotation vectors on performance of SLM in terms of PAPR reduction, which results in high power consumption by amplifier in OFDM system.

Palanivelan et al., (2011) employed Circulant, Hadamard, and Hilbert matrices to obtain phase rotation vectors for the SLM techniques. Experimental results showed that Hilbert matrix's approach outperformed the other two matrices in terms of PAPR reduction. It is noteworthy that the researchers used the Hilbert matrix without normalization, moreover, the problem of large magnitude of phase rotation vectors which affects the performance of SLM, resulting in deterioration of power in OFMD transceiver was not considered.

Florence and Kumari, (2013) reduced the PAPR by using Hadamard SLM technique in a Multiple Input Multiple Output (MIMO) OFDM system. In this research work, the input sequence was convolved by a set of phase sequence and Hadamard transform was applied to each of the sequence. IFFT operation was then used to get the time domain signal. Computer simulations were carried out using 64 subcarriers, 16-Quadrature Amplitude Modulation (QAM), and oversampling factor of L= 4. This method had lower computational complexity.. However, no normalization was done and therefore the effect of large magnitude of phase rotation vectors on performance of SLM in term of PAPR reduction still existed.

In the conventional SLM, its performance in terms of PAPR reduction is largely affected by the magnitude of Phase Rotation Vectors (PRV) used to generate the candidates signals. Large magnitude phase rotation vectors results in the escalation of amplitudes of signals when summed up coherently, thus leading to the exhibition of peak power. Signals with peak power affect the power amplifier efficiency used in the OFDM transceiver. Normalization schemes are



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applied on rows of the Hilbert matrix in order to reduce the magnitude of PRV. Data blocks are then multiply with PRV in order to lower the amplitudes of generated signals before their summation at the transmitter and the process leads to further reduction of PAPR.

### 1.1 Orthogonality in OFDM

OFDM is a superior type of digital multiplexing technique which is mainly desirable for transmitting information over a harsh channel. Diverse carriers are orthogonal against each other by completely standing alone against each other. Two periodic signals are orthogonal if the integral of their multiplication over one complete cycle is equal to zero (Gupta et al., 2013) and for continuous time signals, they are expressed mathematically as:

$$\int_0^T \cos(2\pi nft)\cos(2\pi mft)dt = 0 \quad (1)$$

And, for discrete time signals, the expression of equation (1) becomes:

$$\sum_{k=0}^{N-1} \cos\left(\frac{2\pi kn}{N}\right)\cos\left(\frac{2\pi km}{N}\right)dt = 0 \quad (2)$$

where:

m is even integer value

n is odd integer value

N is number of sub carriers

t is time for sub carrier to complete one cycle.

f is frequency of sub carrier

Orthogonality in the context of an OFDM system can further be explained as a situation when two signals are precisely separated by an angle of ninety degrees both in frequency domain and time domain as shown in Figure 1.

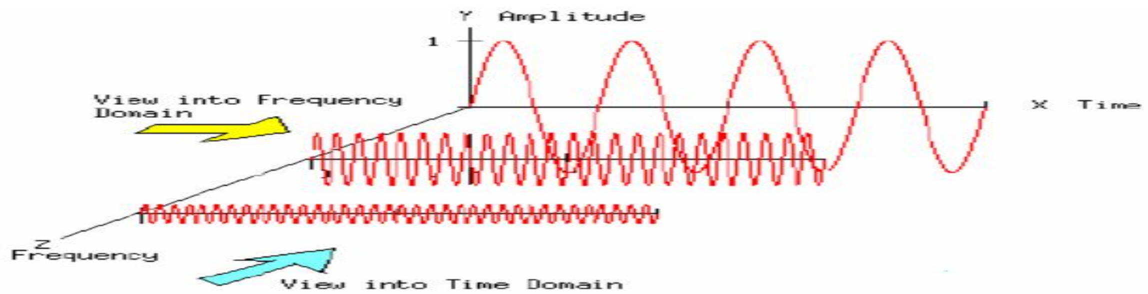


Figure1: Two Views of OFDM Signal (Abba, 2016).

### 1.2 PAPR of OFDM Signal

The PAPR of the transmitted signal X(m) can be express as the ratio of the peak instantaneous power of the signal to average power of the signal. Mathematically, the PAPR of complex pass band signal Xm is written (Kwesi et al., 2015) as:

$$PAPR(X_m) = 10\log_{10}\frac{\max|X_m|^2}{E\left[|X_m|^2\right]} \quad (3)$$

where:

$\max[X_m]^2$ is the peak signal power.

$E[X_m]^2$ is the average signal power.

The peak value arises if the number of subcarriers escalates and the peak value is directly related to the amount of subcarriers of the OFDM system (Kwesi et al.,2015). OFDM signal comprises of a number of independently modulated subcarriers, which can give rise to a high PAPR when summed up together. When N signals are aligned in the phase, they yield a high power that is N times the average power and a large PAPR of the transmitted signals leads to many problems highlighted in the last sentence of the first paragraph in the introduction section.

## 2. Materials and Methods

### 2.1 Selected Mapping (SLM)

In the SLM technique first described by Bauml et al., (1996), the input data sequences are multiplied by each of the phase rotation vectors to generate dissimilar candidates data blocks all representing the same information as the original data block. Each of these candidates' data blocks pass through IFFT operation and then the one with the lowest PAPR is selected for transmission. A block diagram of the SLM technique is shown in Figure 2. Each data block is multiplied by B number of different phase sequences, each of length N of subcarriers, resulting in B number of modified data blocks.

### 2.2. Block Diagram of SLM

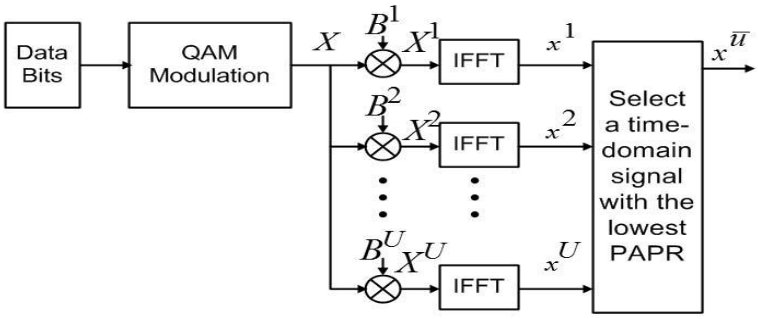


Figure 2: Block Diagram of SLM Technique (Adegbite, et al., 2014).

In the midst of the phase generated OFDM data blocks, the one with the minimum PAPR is chosen and transmitted. The scheme can handle any number of subcarriers, it minimizes PAPR without any signal distortion, support all modulation schemes, and PAPR minimization effect is better as the copy of block number U is increased. The setback of this scheme is that, it requires side information to be sent to the receiver (Harne and Zanjade, 2016) to enable the recovery of the original data. Moreover, the performance of this technique is also largely affected by design type and design of phase rotation vectors used in the generation of candidates data blocks.

One of the crucial aspects of the SLM technique is the selection of right phase sequence which is random in the presence of phase sequence sets. For instance, in Cheng et al., (2007), the Shapiro rudin sequence created recursively by Palanivelan et al., (2011) is the initial random sequence. This is also applied to the case of the phase sequence set explained by Bauml, (1996) and many other researchers. In this enhanced SLM technique used in this work, the rows of the normalized Hilbert matrix are used as the phase rotation vectors for PAPR reduction. The Hilbert matrix has



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a unique definite structure and the receiver can easily generate the matrix for proper decoding of transmitted data. Therefore, this enhanced SLM does not require the transmission of side information to the receiver for decoding the transmitted data.

### 2.3 Complementary Cumulative Distribution Function of PAPR

Complementary Cumulative Distribution Function (CCDF) is one of the top vital tool for signal analysis. It shows full analysis of peak signal power. It is a statistical technique that displays the duration of time a signal spends above any given power level. By using the plots of CCDF, one can detect the probability that a signal data block is larger than a given threshold. These CCDF plots can be further deployed to observe the PAPR characteristics of the signals used to compute the CCDF for a given data.

Mathematically, it can be expressed as (Harne &Zanjade, (2016) as:

$$CCDF = Pr\,(PAPR > PAPR \quad (4)$$

The CCDF plots can be simply simulated using MATLAB.

### 2.4 Binary Phase Shift Keying (BPSK) Modulation Scheme

Binary Phase Shift Keying BPSK is a two phase modulation scheme, where the 0's and 1's in a binary message are represented by two different phase states in the carrier signal: θ = 00 for binary 1 and θ = 1800 for binary 0. In digital modulation techniques, a set of basis functions are chosen for a particular modulation scheme. Generally, the basis functions are orthogonal to each other. Basis functions can be derived using Gram Schmidt orthogonalization procedure. Once the basis functions are chosen, any vector in the signal space can be represented as a linear combination of them. In BPSK, only one sinusoid is taken as the basis function. Modulation is achieved by varying the phase of the sinusoid depending on the message bits. Therefore, within a bit duration Tb, the two different phase states of the carrier signal are represented as

$$S_{1(t)} = A_c \cos(2\pi f_c t), \qquad 0 \leq t \leq Tb \quad \text{for binary 1} \quad (5)$$

$$S_{0(t)} = A_c \cos(2\pi f_c t + \pi), \qquad 0 \leq t \leq Tb \quad \text{for binary 0} \quad (6)$$

Where: $A_c$ is the amplitude of the sinusoidal signal, $f_c$ is the carrier frequency (Hz), t being the instantaneous time in seconds, $T_b$ is the bit period in seconds. The signal $S_0(t)$ stands for the carrier signal when information bit ak = 0 was transmitted and the signal $S_1(t)$ denotes the carrier signal when information bit ak = 1 was transmitted.

### 2.5 Enhanced slm

In this developed approach, two normalization procedures were applied on rows of Hilbert matrix to obtain the phase rotation vectors used in enhancing the SLM. The Hilbert matrix was obtained from Cauchy matrix of dimension, m × n with elements, aij derived from $1 \leq i \leq m, \text{and} 1 \leq \text{j} \leq \text{n}$ in the expression of Palanivelan et al., (2011) as:

$$a_{ij} = \frac{1}{x_i - y_j} \quad (7)$$

where:

$x_i - y_j$ are elements of field F and $x_i - y_j \neq 0$

Hilbert matrix is computed from the Cauchy matrix using the following:

$$x_i - y_j = i + j - 1 \tag{8}$$

This gives a Hilbert matrix with dimensions m = n = 8 as Palanivelan et al., (2011):

$$A = \begin{bmatrix} 1 & 1/2 & 1/3 & 1/4 & 1/5 & 1/6 & 1/7 & 1/8 \\ 1/2 & 1/3 & 1/4 & 1/5 & 1/6 & 1/7 & 1/8 & 1/9 \\ 1/3 & 1/4 & 1/5 & 1/6 & 1/7 & 1/8 & 1/9 & 1/10 \\ 1/4 & 1/5 & 1/6 & 1/7 & 1/8 & 1/9 & 1/10 & 1/11 \\ 1/5 & 1/6 & 1/7 & 1/8 & 1/9 & 1/10 & 1/11 & 1/12 \\ 1/6 & 1/7 & 1/8 & 1/9 & 1/10 & 1/11 & 1/12 & 1/13 \\ 1/7 & 1/8 & 1/9 & 1/10 & 1/11 & 1/12 & 1/13 & 1/14 \\ 1/8 & 1/9 & 1/10 & 1/11 & 1/12 & 1/13 & 1/14 & 1/15 \end{bmatrix} \tag{9}$$

The normalization procedures of this matrix was carried out using the Euclidean normalization (Helm, 2004) and normalization using determinant of matrix order Adelaide (2009) techniques.

## 2.6 Normalization Schemes.

The following are the two normalization schemes

The Euclidean normalization (Helm, 2004)

Find the square root of sum of the square of all elements in a row of a given matrix.

Let the answer you obtained in (i) to be C.

Divide each of the elements of that row by C.

Repeat steps i-iii above for the rest of the rows.

2 Normalization by using Determinant of a matrix. Adelaide (2009)

To normalize a matrix, divide each element by the determinant of the matrix

A matrix is normalized when it is norm is equal to one. The matrix is normalized by dividing each of it is elements by it is norm. For example, a matrix x given in equation (10) . (Williams, 2010)

$$x = \begin{bmatrix} 2 \\ 1 \\ 2 \end{bmatrix} \tag{10}$$

find the norm of the matrix

||x|| =√ 22 +12+22 = √ 4+1+4 =√ 9 = 3

Then, the normalized matrix x is now

$$\overline{X} = \frac{X}{\|X\|} = \begin{bmatrix} \frac{2}{3} \\ \frac{1}{3} \\ \frac{2}{3} \end{bmatrix} \tag{11}$$



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### 2.7 Process Procedures of SLM Technique

Step 1: The random data was generated.

Step 2: The generated data was modulated to produce sequence symbols using Binary Phase Shift Keying (BPSK).

Step 3: The sequence symbols were converted from series to parallel form and then they were divided into blocks of length N number of subcarriers.

Step 4: Multiplying Each OFDM data block was multiplied with different phase rotation vectors obtained from each row of normalized Hilbert matrix.

Step 5: The new OFDM data blocks formed were transformed into time domain using IFFT.

Step 6: Complementary Cumulative Density Function (CCDF) value of the PAPR of each of the block was computed and compared with the respective threshold values.

Step 7: The OFDM data block with the minimum PAPR was finally selected for transmission.

## 3. Results and Discussion

Extensive computer simulation using communication tool box inside MATLAB R2016a was carried out to assess the level of PAPR reduction of the proposed enhanced SLM in OFDM communications system with number of subcarriers to be eight on BPSK modulated data signals. The normalized Hilbert matrix from equation (11) was used for phase rotation vectors. The model simulation parameters were presented in Table 1.

Table 1: Model Simulation Parameters

| Modulation | BPSK |
|---|---|
| No of subcarriers (M) | 8 |
| Size of phase sequence | 8 |
| Carrier frequency | 10 MHz |

It is worthy to note that the choice of the parameters presented in Table 1 were selected based on consultation of literature and since the work of Palanivelan et al, (2011), that is SLM using Hilbert matrix without normalization was used to validate this research, parameters presented were adopted from their work, and varied based on the simulation and performance of the enhanced technique. Hence, the value of these parameters can be varied depending on the simulation.

The simulation results obtained using the model parameters highlighted in Table.1 for the respective techniques as shown below with the performance of the enhanced SLM highlighted in green and cyan, for two different normalization schemes used in this research work. SLM with Hilbert matrix highlighted in blue and the original OFDM signal with no SLM highlighted in red. In the simulations, BPSK was adopted as the modulation scheme for the symbols(BPSK is considered to be more robust among all the modulation schemes due to difference of 180 degree between the constellation point. This makes the scheme to withstand severe amount of channel conditions or channel fading). The size of phase rotation vector for each simulation was equated to the number of subcarriers and the inputs symbol sequence is uniformly distributed among all the symbols.

### 3.2 Computing Percentage improvement

$$\text{Percentage improvement} = \frac{cSLM - eSLM}{cSLM} \times 100 \quad (12)$$

*cSLM* means conventional SLM technique using Hilbert matrix without normalization .

*eSLM* means enhanced SLM technique using normalized Hilbert matrix

When Euclidean normalization was used. Figure 3 shows the CCDF result for the enhanced SLM technique, *SLM* with Hilbert matrix, and original OFDM signal, to select the phase rotation vector for the PAPR reduction with the oversampling factor (L) of 4 and the number of subcarriers set at 8.

L is oversampling factor, 4 gave better result than 2,while values above 4 took longer processing time.

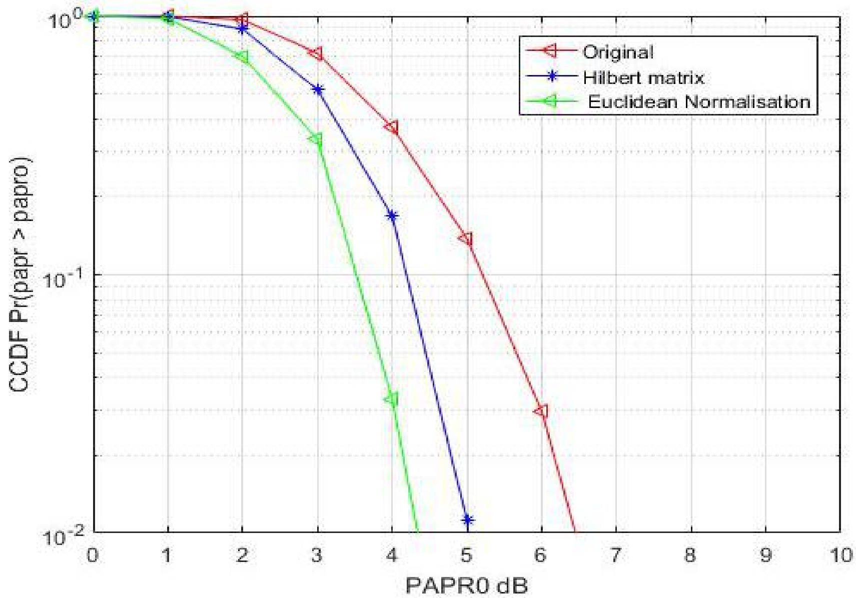


Figure 3: CCDF Plot of PAPR Using Euclidean Normalization.

It can be deduced from Figure 3 at CCDF of $10^{-2}$, the *SLM* using Hilbert matrix gave reduction of PAPR to 5.0dB, while the enhanced SLM technique using Euclidean normalization led to reduction of PAPR to 4.3 dB, which is 0.7dB less than *SLM* using Hilbert matrix. This shows that the enhanced *SLM* technique with normalized Hilbert matrix yields a better result compared *SLM* using Hilbert matrix with 14.0% improvement.

Figure 4, shows the CCDF result for the enhanced SLM technique when normalization using determinant of matrix order was used, SLM with Hilbert matrix, and the original signal, to select the phase rotation vector for the PAPR reduction with the oversampling factor (L) of 4 and the number of subcarriers set at 8.



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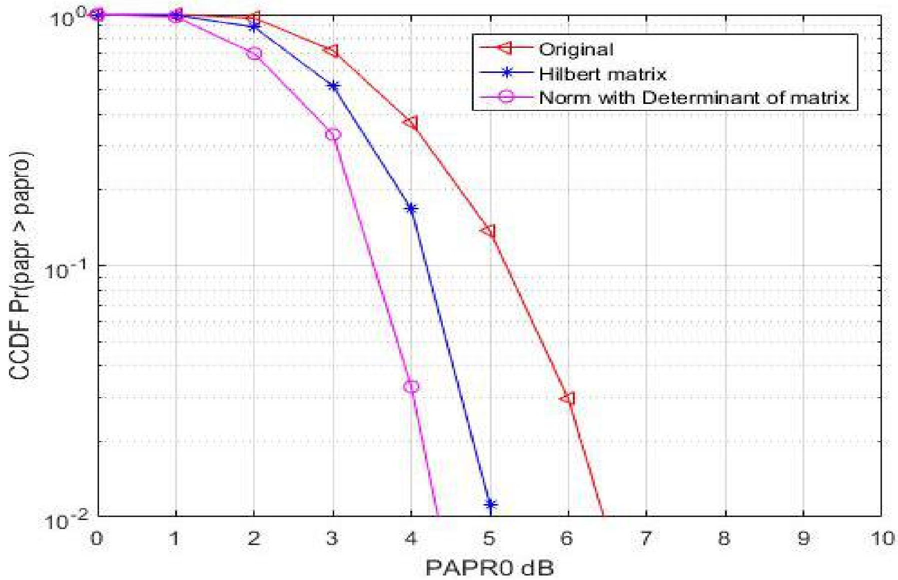


Figure 4: CCDF Plot of PAPR using Normalization with Determinant of Matrix.

It can be deduced from Figure 4 that at CCDF of $10^{-2}$, the SLM using Hilbert matrix offers reduction of PAPR to 5.0dB, while the enhanced SLM technique using normalization with Determinant of matrix offers reduction of PAPR to 4.29 dB, which is 0.71dB less than SLM using Hilbert matrix. This shows that the enhanced SLM technique with normalized Hilbert matrix yields a better result compared SLM using Hilbert matrix with 14.2% improvement.

The enhanced SLM with the two normalization procedures reduced the PAPR to 4.3dB and 4.29dB from 5.0dB. The improvement occurred due to the fact that the normalization reduced the magnitude of the matrix, which could lead to minimum phase shift when the rows of the matrix are used as phase rotation vectors to generate candidates signals. Due to this minimum phase shift, the amplitudes of sinusoidal subcarriers would not rise to peak level when these subcarriers are summed up constructively at the input of transmitter. This can lead to a lower peak-to-average power ratio reduction.

From the simulation results, it is noteworthy observed that, PAPR reduction performance of the two normalization procedures are almost the same. This is as result of the fact that, the two normalization procedures did not change internal structure of the Hilbert matrix, but rather reduced it is magnitude.

Amongst all possible CCDF values generated from the simulation results, CCDF of $10^{-2}$ was found to be the most suitable available lowest value to be used due to power and power processing issues. With this value, the *eSLM* had a better PAPR reduction when compared to SLM technique using Hilbert matrix with percentage improvement of 14.0%, 14.2%, Euclidean and Determinant normalization scheme, respectively.

## 4. Conclusions

In this paper, enhancement of SLM technique for further PAPR reduction in OFDM system using normalized Hilbert matrix has been presented. Phase rotation vectors are obtained by applying two different normalization schemes that is, using Euclidean normalization (Helm, 2004) and determinant of a matrix normalization. Adelaide (2009) and)on Hilbert matrix.

The following are the conclusions:

From simulation results, it was observed that the proposed method offers better PAPR result of 4.3dB and 4.29dB when compared to PAPR value 5.0dB offered by Hilbert matrix without normalization.

The significant PAPR reduction achieved by the enhanced SLM improved the power efficiency of amplifier more than conventional SLM scheme. The closer the value of PAPR to zero or the lower the value of PAPR, the less power consumed during amplification process of the OFDM signals by amplifier

Side information need not be transmitted to the receiver to recover the original signal.

This scheme can effectively be implemented in 4G and 5G wireless communications system.

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