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Modified Sliding Norm Transform based approach for PAPR optimization in OFDM Systems

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ABSTRACT

Background: Orthogonal Frequency Division Multiplexing (OFDM) is an efficient method of data transmission for high speed communication systems. However, the main drawback of OFDM system is that, it exhibits high Peak to Average Power Ratio (PAPR). OFDM consist many independent subcarriers, as a result of which the amplitude of such a signal can have high peak values. This high peak signal transmitted through a power amplifier, generates out-of-band distortions and also increases the dynamic range of the Digital to Analog Converter (DAC) and Power Amplifier (PA). **Objective:** To optimize PAPR of OFDM signals with reduced computational complexity and reduction in side information requirements. **Results:** Compared with conventional techniques, the proposed transformation effectively reduces the PAPR. The proposed technique also outperforms the existing techniques in terms of reduction in computational complexity, since it requires only one IFFT block. Further, this algorithm does not require side information to be sent to the receiver. The PAPR reduction performance of the proposed scheme is evaluated with image and audio inputs. **Conclusion:** We have proposed a Sliding Norm Transform based technique called L_3-by-3 SNT for PAPR reduction in OFDM systems. We further proposed Modified Sliding Norm Transform (MSNT) by providing additional parity bit appended before or after the data block in our system to deal with highly correlated data blocks. Inverse MSNT is proposed to recover the original data block at the receiver. When compared with conventional techniques, the proposed transformation effectively reduces the PAPR with less computational complexity.

INTRODUCTION

Multicarrier modulation, also known as Orthogonal Frequency Division Multiplexing (OFDM), is a spectrally efficient modulation technique for data transmission in channels with fading and multipath. It has many advantages such as high bandwidth efficiency, robustness against frequency selective fading channel and simple implementation. OFDM mainly used in broadband applications such as Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB), Asymmetric Digital Subscriber Line (ADSL) and Wireless LAN (IEEE 802.11a, g, n), Broadband Wireless Access (BWA), Mobile Broadband Wireless Access (MBWA)(Wu.Y and Zou.W.Y, 1995).

In a conventional OFDM system, the orthogonality between the subcarriers is achieved by means of Fast Fourier Transform (FFT). A large number of orthogonal sub-carriers are used to carry data which are closely-spaced in nature. High Peak-to-Average Power Ratio (PAPR) is one of the main drawbacks in OFDM systems (Hee & Hong, 2005). The occurrence of high PAPR causes nonlinearity in the power amplifier leading to in-band and out-of-band radiations that degrades bit error rate performance. OFDM mitigates multipath fading by dividing the data to be transmitted over a large number of relatively narrowband channels. OFDM consist of a block of 'N' data streams X_k ; (k=0, 1, ... N-1), of vector X, which will be transmitted in parallel . These 'N' parallel data streams are then used to modulate 'N' orthogonal subcarriers. Each baseband subcarrier is given as

$$\phi_k(t) = e^{j2\pi f_k t} \tag{1}$$

where f_k is the k^{th} subcarrier frequency. The sub carrier frequencies f_k are equally spaced as given by

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$$f_k = \frac{k}{NT} \quad (2)$$

where NT denotes the useful OFDM symbol period. OFDM data symbol multiplexes N modulated subcarriers *x (t)* as given as,

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \phi_k(t), \quad 0 \le t \le NT \quad (3)$$

PAPR is a random variable, because it is a function of input data, which is also a random variable. Therefore, PAPR can be calculated by finding the average number of times that the envelope of a signal crosses a given level. PAPR is defined as in equation (4),

$$PAPR = \frac{\max_{t\in[0,T]} |x(t)|^2}{E\{|x(t)|^2\}} \quad (4)$$

where E{.} is the expectation operator. In general, most of the signals works in discrete time domain, therefore; we need to oversample the continuous signal x (t) by an over sampling factor of L, which is an integer larger than or equal to one, to approximate true PAPR values. The L- times oversampled signal x_k is given in (5),

$$x_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n \phi_n(k) \quad (5)$$

where $\phi_n(k) = e^{j2\pi nk/LN}$; for k=0,1,…,LN-1.

PAPR for the signal given in (5) is expressed as in (6)

$$PAPR = \frac{\max[|x_k|^2]}{E[|x_k|^2]} \quad (6)$$

where $E[|x_k|^2]$ denotes average value over the time duration of OFDM symbol.

From the amplitude distribution of the output OFDM signal, it is easy to compute the probability that the instantaneous amplitude will be above a given threshold. This is performed by calculating Cumulative Distribution Function (CDF) and Complimentary CDF (CCDF)(Ochiai and Imai, 2001). The probability 'p' that the PAPR given by equation (7) exceeds a threshold 'P_0' known as CCDF can then be defined by

$$p(PAPR > p_0) = 1 - (1 - \exp(-p_0))^N \quad (7)$$

The rest of the paper is organized as follows. In section 2 we present a brief review of existing techniques based on probabilistic schemes. In section 3, the proposed system is discussed and section 4 gives the simulation results supporting the ideas presented. Finally conclusions are drawn in section 5.

Related Work:

Several techniques have been proposed to solve the PAPR reduction problem in OFDM systems. These include Amplitude Clipping, Filtering, Coding, Interleaving, Tone reservation (TR), Tone injection (TI), and Active constellation extension (ACE) are statistical techniques which modifies the time domain signal but introduce distortion in signals(Hee and Hong, 2005). Selected mapping (SLM)(Chin-Liang *et al*. 2010, Chai Pengli, 2005, Cimini & Sollenberger, 2000,), Partial Transmit Sequence (PTS)[Jun Hoe *et al*. 2011, Muller & Huber, 1997 and Yang *et al.* 2006) are probabilistic schemes which generates a set of sufficiently different candidate data blocks and then selects the suitable one with the minimum PAPR for transmission. This conventional probabilistic scheme reduces PAPR with some loss of data rate with increases in computational complexity. In this work performance analysis of the proposed MSNT is compared with commonly used probabilistic scheme Partial Transmit Sequence(PTS). In PTS technique, data block of N symbols is partitioned into V number of disjoint sub blocks, $X_m=[X_{m,0}, X_{m,1,\ldots\ldots} X_{m,N-1}]^T$, where m=1,2,3….V, such that $\sum_{m=1}^{V} X_m = X$ and the sub blocks are combined, to minimize the PAPR in the time domain. The L-times oversampled time domain signal X_m ; m=1,2,3……V, is obtained by taking an IFFT of length NL on X_m concatenated with (L-1)N zeros, called partial transmit sequences (Baxley & Zhou, 2007, Cimini & Sollenberger, 2000). The time domain signal after combining is given in equation (8),

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$$x'(b)=\sum_{m=1}^{v} b_m \bullet x_m \qquad (8)$$

The set of allowed phase factor (P) is given as, $p=\{e^{j2\pi l/w}\}$ where l=0, 1, 2……W-1 and W is the number of allowed phase factors. Therefore, exhaustive phase search is required to find the optimum signal *x'(b)*. PTS require V number of IFFT operations for each data block, which leads to higher computational complexity. The side information (SI) required in this scheme is given as,

$\log_2 W^{M-1}$, where m=1,2,3….M. (9)

resulting in poor bandwidth efficiency.

Proposed System:

A new Modified Sliding Norm Transform (MSNT) based on L_3-by-3 SNT is proposed to reduce the PAPR of the OFDM systems. The block diagram of the proposed OFDM system is shown in Fig.1 and Fig.2. The (N-1) number of input data is blocked based on the sub carrier requirements, then parity bit is generated and appended at the beginning of each data block. Parity enabled data block is mapped onto Quadrature Amplitude Modulation (QAM) constellation.

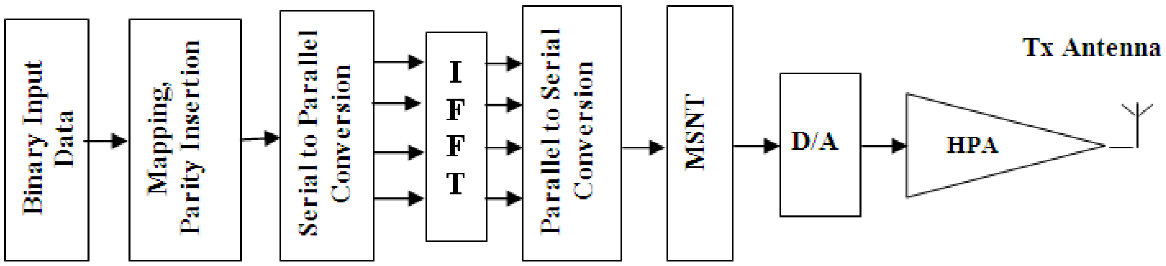

Fig.1: Proposed OFDM Transmitter with MSNT

Serial data stream is converted into parallel to enable the data to feed into IFFT. The L_3-by-3 with parity bit enabled Sliding Norm Transform called Modified Sliding Norm Transform (MSNT) is proposed at the transmitter. Proposed transformation is applied on the OFDM signals to effectively to reduce PAPR before Digital-to-Analog Converter (DAC) and High Power Amplifier (HPA). The Inverse MSNT (IMSNT) is proposed at the receiver to effectively recover the original data blocks without any SI. The performance of the proposed norm technique is evaluated in terms of PAPR reduction and compared with existing schemes.

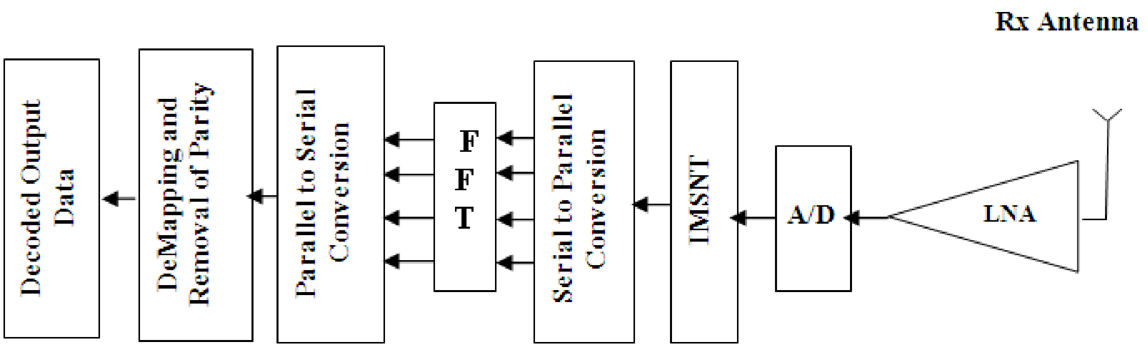

Fig. 2: Proposed OFDM Receiver system with IMSNT

3.1 L_3-by-3 Sliding Norm Transform:

Let x be the real vector with N samples, ie, $x=(x_1,x_2,x_3,...,x_N)$. The P[th] norm of x is defined as in (10),

$$\|x\|_p=\left(\sum_{i=1}^{N}|x_i|^p\right)^{1/p} \quad ; \qquad (10)$$

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where $p \geq 1.$ Let the transform $(x \longrightarrow y)$ for x with N samples is given as in (11),

$$x_n \longrightarrow y_n = \frac{x_n}{\sqrt[p]{\sum_{k=1}^{n} x_k^{\ p}}}\ ; n = 1, 2, \ldots, N; \tag{11}$$

The concept of sliding norm transform is considered with 3 samples. The input signal x_n with N samples is Transformed to y_n using the norm of 3 samples, which is given as (when P = 3),

$$\left\| x_{n-1}, x_n, x_{n+1} \right\|_3 = \left(x_{n-1}^{\ 3} + x_n^{\ 3} + x_{n+1}^{\ 3} \right)^{1/3}; \quad n = 1,2,3,\ldots, N \tag{12}$$

The parameterized form of transform is defined by introducing the parameter $\alpha \geq 0,$ which is given as in (13),

$$\left\| x_{n-1}, x_n, x_{n+1} \right\|_3 = \left(\alpha + x_{n-1}^{\ 3} + x_n^{\ 3} + x_{n+1}^{\ 3} \right)^{1/3}; \quad n = 1,2,3,.., N \tag{13}$$

The transform is defined as,

$$x_n \longrightarrow y_n = \frac{x_n}{\left(\alpha + x_{n-1}^{\ 3} + x_n^{\ 3} + x_{n+1}^{\ 3} \right)^{1/3}}; \quad n = 1,2,3,\ldots, N; \tag{14}$$

It is called the norm transform of 3 samples or L_3-by-3 SNT. The parameter α adjusts the PAPR of the transformed output. That is, for different values of α, the same input is transformed to output with different PAPR values. We found that the optimized value of α=0.3 gives better reduction with required bit error rate of 10^{-4} .It should be noted that, when x_n is zero for any n, y_n also zero, without calculating denominator. The reconstruction of vector x from y can be performed by equation (15),

$$x_n = y_n \sqrt[p]{\frac{1}{1 - y_n^{\ p}} \sum_{k=1}^{n-1} x_k^{\ p}}; \quad n = 1,2,3,\ldots, N \tag{15}$$

For each values of n, one linear equation is the system is formed. By rewriting equation (14), we get

$$x_{n-1}^{\ 3} + \left(1 - \frac{1}{y_n^{\ 3}} \right) x_n^{\ 3} + x_{n+1}^{\ 3} + \alpha = 0; \quad n = 1,2,3,\ldots N \tag{16}$$

which forms the linear equations,

$$\begin{cases} x_N^{\ 3} + \left(1 - \dfrac{1}{y_1^{\ 3}} \right) x_1^{\ 3} + x_2^{\ 3} = -\alpha \\ x_1^{\ 3} + \left(1 - \dfrac{1}{y_2^{\ 3}} \right) x_2^{\ 3} + x_3^{\ 3} = -\alpha \\ x_2^{\ 3} + \left(1 - \dfrac{1}{y_3^{\ 3}} \right) x_3^{\ 3} + x_4^{\ 3} = -\alpha \\ \qquad \cdots\cdots\cdots\cdots\cdots \\ x_{N-1}^{\ 3} + \left(1 - \dfrac{1}{y_N^{\ 3}} \right) x_N^{\ 3} + x_1^{\ 3} = -\alpha \end{cases} \tag{17}$$

In matrix form, equation (17) can be written as,

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$$\begin{pmatrix} \Psi_1 & 1 & 0 & \dots & 0 & 1 \\ 1 & \Psi_2 & 1 & \dots & 0 & 0 \\ 0 & 1 & \Psi_3 & \dots & 0 & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & \dots & \Psi_{N-1} & 1 \\ 1 & 0 & 0 & \dots & 1 & \Psi_N \end{pmatrix} \begin{pmatrix} x_1^{\;3} \\ x_2^{\;3} \\ x_3^{\;3} \\ \dots \\ x_{N-1}^{\;3} \\ x_N^{\;3} \end{pmatrix} = -\alpha \begin{pmatrix} 1 \\ 1 \\ 1 \\ \dots \\ 1 \\ 1 \end{pmatrix} \tag{18}$$

From equation (18), we have a linear equation defined as $AX = -\alpha Y$, where A is a $N \times N$ periodic tridiagonal matrix, X is a matrix of unknown vectors and Y is a matrix of ones. The solution of this linear equation is,

$$X = -\alpha A^{-1} Y; \tag{19}$$

The original value can be reconstructed as,

$$x_n = \left(+ \sqrt[3]{x_n^{\;3}} \right) . sign(y_n); \quad n = 1,2,3,\dots,N \tag{20}$$

By the definition, *sign(y*$_n$*)=sign(x*$_n$*)*. The proposed L_3-by-3 Sliding norm transform (SNT) effectively reduces the PAPR of the OFDM signals, when compared with other conventional PAPR reduction techniques. From Table 1, it has been observed that the proposed transform could not reduce PAPR when all the data symbols are same. To overcome this drawback, the parity bit is added at the beginning of each block. The L_3-by-3 SNT, which transforms the parity bit enabled data is called Modified Sliding Norm Transform (MSNT). Let the information source be,

b = (b_0, b_1, b_2,…,b_N). Now the odd parity bit can be calculated as,

$$b_0 = \mathrm{mod}_2 \left(\sum_{i=0}^{N-2} b_i \right) \tag{21}$$

The even parity bit can be calculated as,

$$b_0 = \mathrm{mod}_2 \left(1 + \sum_{i=0}^{N-2} b_i \right) \tag{22}$$

Table 1: PAPR reduction performance of SNT with different data sequences

	Data bits	PAPR (dB)	
		Original	After applying SNT
High PAPR yielding sequences	1 1 1 1 1 1 1 1	9.031	9.031
	0 0 0 0 0 0 0 0	9.031	9.031
	1 0 1 0 1 0 1 0	9.031	9.031
	0 1 0 1 0 1 0 1	9.031	9.031
Sample input sequences	1 0 1 0 1 0 1 1	6.521	4.1954
	1 1 0 1 0 1 0 1	5.256	3.218
	0 0 1 0 1 0 0 1	4.524	2.482
	1 0 1 1 0 1 1 0	5.326	3.264

Through simulation results, we concluded that, even parity bit works well as compared to odd parity. If we process a block of N symbols, the first bit is set as a parity bit which is calculated as in equation (21) &(22) and the remaining (N-1) bits are original data bits.

Power saving gain analysis:

In a practical system, the OFDM signals are sent through a Power Amplifier (PA) which is always peak-power limited (Bumman et.al., 2010, Robert Baxley &Tong Zhou, 2004). Even linear amplifiers impose a nonlinear distortion if excited by a large input that causes out-of-band radiation that affects signals in adjacent bands as well as in-band distortion that results in rotation, attenuation and offset on the received signal. The time-domain signal for any OFDM frame $x(t)$ will be clipped if $|x(t)|^2$ is larger than the saturation point of the PA at any time '*t*'. Clipping results in decoding errors, which increase the BER of the overall system at the receiver. In our analysis, we assume that the OFDM system must provide a fixed clipping probability, which approximately corresponds to a fixed BER[12]. We further assume that a probability-of-clipping level of 10^{-4} is reasonable; therefore PA is adjusted by required Input Back Off (IBO) according to PAPR of the input signal to ensure that probability of clipping will not exceed 10^{-4}. The input must be backed-off so as to operate the PA in linear region.

We have considered and analysed the power saving gain of a Class A power amplifier, which is most linear in operation. The overall efficiency is defined as $\eta_A = \frac{\overline{P_{out}}}{P_{DC}}$, where $\overline{P_{out}}$ and P_{DC} are the average output power and total DC power consumed by PA. Power amplifier efficiency in terms of OBO is given in equation (23),

$$\eta_A=0.5/OBO, \tag{23}$$

Equation (23) can also be represented in terms of PAPR as $\eta_A=0.5/PAPR$. Power saving is expresses as in (24)

$$P_{saving}=2.\overline{P_{out}}(PAPR_b-PAPR_a) \tag{24}$$

where $PAPR_b$ is the DC power consumed by PA before PAPR reduction and $PAPR_a$ is the DC power consumed by PA after PAPR reduction. Saving gain is shown in equation (25 and 26),

$$G_{saving}=P_{saving}/\overline{P_{out}} \tag{25}$$

$$G_{saving}=2(PAPR_b-PAPR_a) \tag{26}$$

In this paper, we consider the computational complexity of the PAPR reduction in terms of complex multiplications and complex additions required for IFFT. When the number of subcarriers $M=2^n$ and K the total number of IFFTs, the number of complex multiplications and complex additions required for K - IFFTs are *(M/2)nK* and *MnK* respectively. The proposed scheme requires only one IFFT block instead of K- IFFT's required for conventional SLM scheme. However, this scheme requires *M+ 1 additional operation* for appending parity bit to the data block. The Computational Complexity Reduction Ratio (CCRR) (Ho-Lung Hung, 2011, Jing Gao *et al*., 2012) of the proposed MSNT scheme as compared with conventional PTS scheme is given by,

$$CCRR = 1 - \frac{complexity \quad of \quad the \quad proposed \quad scheme}{complexity \quad of \quad the \quad conventional \quad scheme}$$

The number of complex multiplications required for conventional PTS scheme with M=64 subcarriers is 1536, and in MSNT is 321, therefore CCRR is 79%. In terms of complex additions MSNT requires 313 and for PTS it requires 3072, therefore CCRR is 83%. The analysis shows that the proposed scheme becomes computationally more efficient than the conventional schemes. The proposed method satisfies the property of one-to-one transformation necessary for reconstruction (Serkan & Artyom, 2010). Hence, there is no exhaustive phase search is needed as required in conventional PTS scheme.

Simulation Results:

Extensive simulations have been performed to compare and evaluate the PAPR reduction performance of proposed algorithm with the various existing techniques. In the simulation we used 16-QAM baseband modulation scheme. Each modulated symbol is transmitted through N= 64 , 256 , 512 and 1024 sub carriers through N point IFFT and L=4 oversampling is used to estimate PAPR precisely. The simulation parameters are given in Table 2.

Table 2: Simulation Parameters

Mapping	M-QAM
Number of data subcarriers N	64 / 256 / 512 / 1024
Over sampling factor	L=4
Number of FFT/IFFT points(NL)	L. N
Number of data symbols for simulation	$1x10^5$
Size of the message block	N
Number of parity bit(p)	01
Channel	Flat Fading

To analyze PAPR reduction and power amplifier efficiency, we consider class A power amplifier which is the most linear with power efficiency. Fig.3 to Fig.6 shows the CCDF of PAPR in MSNT and PTS with varying N=64, 256, 512 and 1024 sub carriers respectively with QAM modulation scheme. It is easy to observe that at 0.001% of CCDF the conventional PTS scheme offers 2.5dB and 4.8 dB reduction for MSNT respectively when compared to the original values. PAPR reduction performance of MSNT in comparison with

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PTS is presented in Fig.7. Power saving gain of the proposed scheme with conventional scheme is given in Figure 8. It can be observed that power saving gain of the proposed scheme is higher as compared with existing schemes.

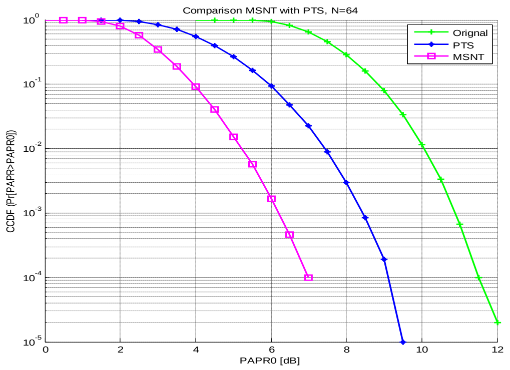

Fig. 3: CCDF performance of MSNT and PTS with N=64

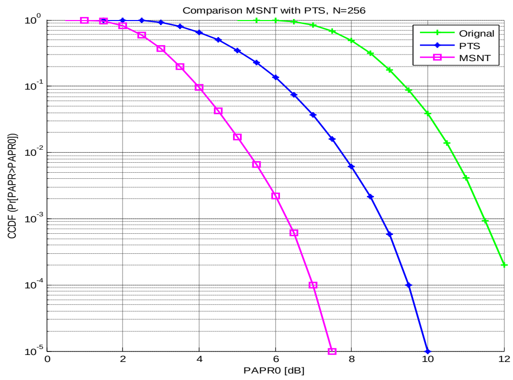

Fig. 4: CCDF performance of MSNT and PTS with N=256

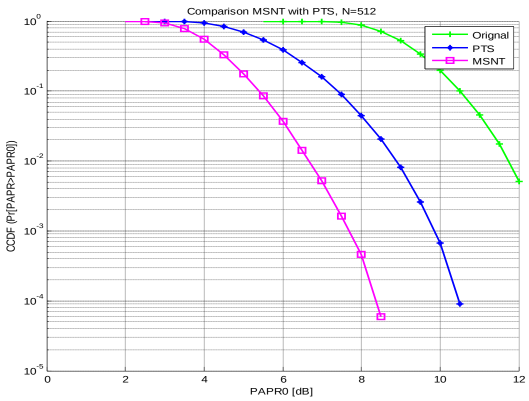

Fig. 5: CCDF performance of MSNT and PTS with N=512

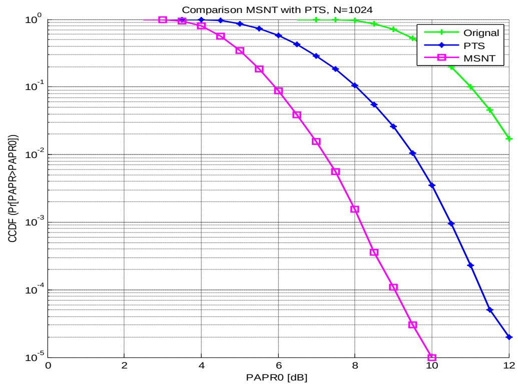

Fig. 6: CCDF performance of MSNT and PTS with N=1024

Table 3: Power saving gain analysis of MSNT with PTS at 0.001% of CCDF with varying N

No. of sub-carriers(N)		PAPR(dB)	Saving Gain	Efficiency in %
64	Original	11.8	---	3.3
	PTS	9.0	12.8	5.7
	MSNT	7.0	20.2	10
256	Original	13.2	---	2.4
	PTS	9.8	22.6	5.2
	MSNT	7.2	31.2	9.6
512	Original	14.8	---	1.6
	PTS	10.6	37.2	4.3
	MSNT	8.2	47.0	7.5
1024	Original	16.4	---	1.1
	PTS	11.8	51	3.3
	MSNT	9.0	61.4	6.3

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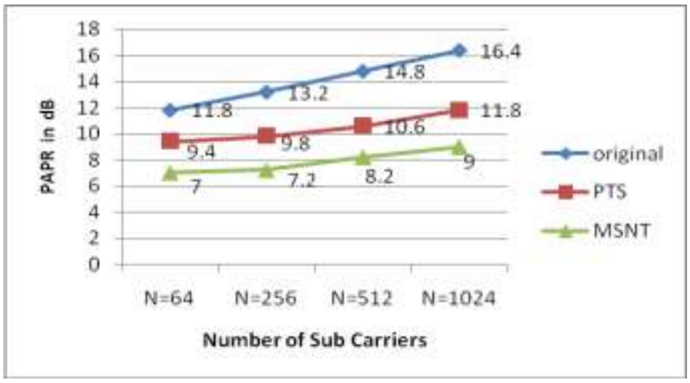


Fig.7: PAPR reduction performance at 0.001% of CCDF for MSNT and PTS

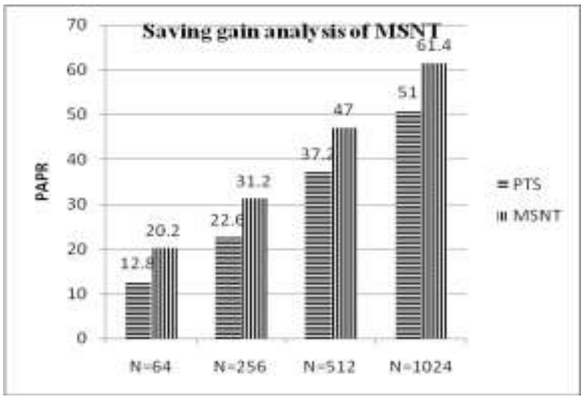


Fig. 8: Power saving gain analysis of MSNT

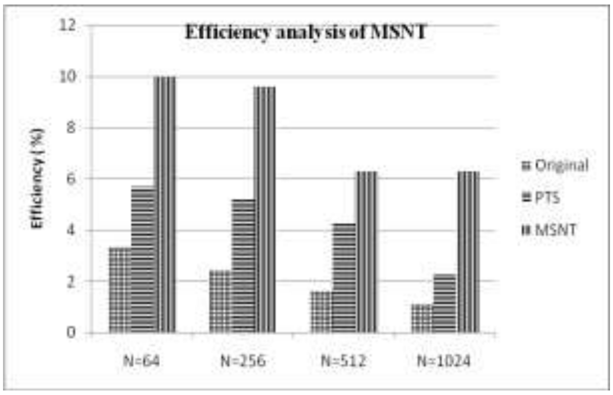


Fig. 9: Amplifier efficiency improvement (%)

Amplifier efficiency is calculated using equation (23) and values are plotted in Fig. 9. Analysis show that the transmit power amplifier efficiency increases in MSNT with better PAPR optimization.

Image Analysis of MSNT:

The PAPR reduction performance of the proposed scheme is evaluated with image and audio inputs. The sample input image, audio files and corresponding CCDF performances are given in Fig.10 and Fig.11. PAPR reduction performance of the proposed MSNT scheme is evaluated at 0.001% of CCDF for the given image and audio inputs. It is proved that the proposed technique will perform better for Multimedia inputs also.

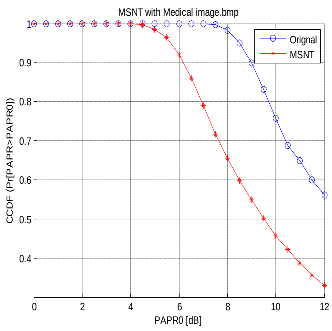
Image Input	MSNT Image Analysis	Savin g gain	%η
original input 		15.0	2.2

Fig. 10: Analysis of MSNT with image input

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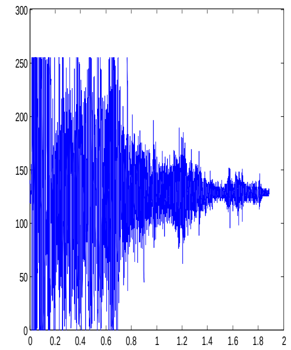
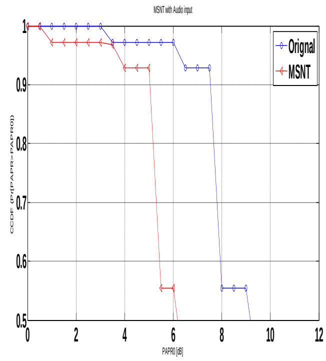
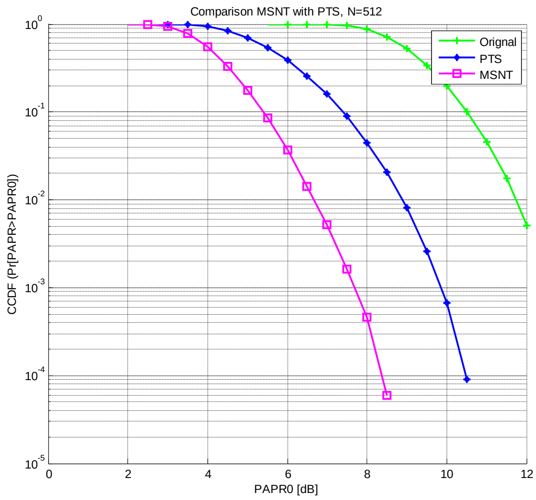
Audio Input	MSNT Audio Analysis	Power saving gain	%η Improvement
		9.46	6.82

Fig. 11: Power saving gain and Efficiency analysis of MSNT with Audio inputs

Conclusion:



We have proposed a Sliding Norm Transform based technique called L_3-by-3 SNT for PAPR reduction in OFDM systems. We further proposed Modified Sliding Norm Transform (MSNT) by providing additional parity bit appended before or after the data block in our system to deal with highly correlated data blocks. When compared with conventional techniques, the proposed transformation effectively reduces the PAPR. The proposed technique also outperforms the existing techniques in terms of reduction in computational complexity, since it requires only one IFFT block. Inverse MSNT is proposed to recover the original data block at the receiver. Further, this algorithm does not require side information to be sent to the receiver. This work can further extend into applying the proposed transformation to various standards.

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