International Journal of Control Theory and Applications

ISSN : 0974-5572

© **International Science Press**

Volume 10 • Number 30 • 2017

Fragmentary Chronological Transmission with Order Bit Select to Reduce PAPR in OFDM System

Gayathri K.M[a] S. Bhargavi[b] and Thangadurai. N[c]

[a] *Research Scholar, Department of Electronics and Communication Engineering School of Engineering and Technology, Jain University, Bangalore, India*

[b] *Professor and Head of the Department, Department of Telecommunication Engineering, S.J.C.I.T, Chickballapur, India*

[c] *Associate Professor, Department of Electronics and Communication Engineering School of Engineering and Technology, Jain University, Bangalore, India*

Abstract: Peak to Average Power Ratio (PAPR) is one of the important component to be considered in any advanced digital communication system. Continuous efforts have been applied in the direction to reduce PAPR. The system proposed here for Orthogonal Frequency Division Modulation (OFDM) to reduce the PAPR and improve the Bit Error Rate (BER). In this technique an encoding technique has been incorporated followed by Fragmentary Chronological Transmission (FCT), Order bit selector and Trellis Structure to achieve the desired results. The generated output has been further given to OFDM. The output obtained from the proposed system has been compared with existing system for obtained PAPR and also for the BER plot. It has also been observed that the performance of the system considerably improved as compared to the system implemented in the recent past.

Keywords: *Order Bit Selector, Viterbi decoder, Trellis Structure, Quadrature Amplitude Modulation.*

1. INTRODUCTION

In 1966 Robert W Chang has introduced a new method called Orthogonal Frequency Division Multiplexing (OFDM) for multi channel data transmission of band limited orthogonal signals. The principle behind the OFDM is to split the frequency selective channel into number of analogous sub channels. Every sub channel is a narrow band which has a less fading; hence the receiver design is less complex. Even though the sub channels are overlapped, due to orthogonality the bandwidth efficiency is increased and robustness against frequency selective channel. Hence in multicarrier modulation, OFDM is acceptable for new generation high speed wireless communication systems. Therefore, OFDM is implemented in international standards such as IEEE 802.11, IEEE 802.16, IEEE 802.20, Digital Video Broadcasting (DVB) and Digital Audio Broadcasting (DAB). But the application of OFDM is limited to certain extent because of its enormous amount of Peak Average Power Ratio (PAPR) which deteriorates the power amplifier efficiency. Due to its high PAPR it demands for expensive transmitter power amplifier which has a very good linear range. It also increases the design complexity of Analog/Digital Converter (A/D) and Digital/Analog Converters (D/A). OFDM has many autonomous sub carriers, which builds a scenario of high PAPR. It is not worth to transmit high peak amplitude signal without reducing it. Hence it is essential to reduce the peak power of amplitude. An enormous approach have been proposed for PAPR reduction which includes Hadamand transforms, clipping and filtering, Tone rejection, Tone injection, Active Constellation Extension (ACE), selected mapping technique, Partial transmit sequence and so on. These techniques achieves PAPR reduction with a cost of increase in bit error rate, loss of data rate, transmit signal power and computational problem. In this paper we describe a novel method of scaling down PAPR for multi carrier transmission[1].

1.1. Peak Average Power Ratio

Let us assume a collection of data series of M sub carriers $Y = \{Y_0, Y_1, Y_2, \ldots\ldots\ldots, Y_{N-1}$, where M is a number of subcarriers represented as a vector. Each symbol in the vector Y modulates one set of subcarriers. Let f_m, $m = 0, 1, 2, \ldots\ldots., M-1$, the subcarriers in OFDM system must be orthogonal to each other *i.e.*, $f_m = m\Delta f$, where Δf is denoted 1/MT and hence T is a duration of symbol in vector Y. Hence the intricate wrap of the OFDM transmitted signal is written as

$$Y(t) = \frac{1}{\sqrt{M}} \Sigma_{m=0}^{M-1} Y_m \, e^{j2\pi m\Delta f},$$

$$0 \le t \le MT \tag{1}$$

Where j is given by $\sqrt{}$-1, f is the subcarrier spacing, and MT is given by the effective data block duration. PAPR is described as the proportion of maximum instantaneous power to its average power during an OFDM symbol duration.

The PAPR of OFDM symbol can be represented as

$$\text{PAPR} = \frac{\max_{0 \le t \le NT[|x(t)|^2]}}{1/NT\int_0^{NT} |x(t)|^2 \, dt} \tag{2}$$

where $x(t)$ is input signal.

The idea behind scaling down PAPR is to minimize the max $x(t)$. Since majority of the system involves discrete-time signals, dealt is sampled amplitude in many peak average power reduction methods. If some time the signal peak missies, symbol spaced sampling shown in (1) produces an optimistic decision for the PAPR. With a factor of L on oversampling (1) signal samples are obtained which come close to the true PAPR. The time domain L-times oversampled samples are derived by an LN-point Inverse Fast Fourier Transform (IFFT) of the given data block considering zero-padding[2].

1.2. CCDF of PAPR

The attainment of the PAPR is measured with a help of cumulative distribution of OFDM signal. The Cumulative Distribution Function (CDF) is commonly used technique to evaluate the effectiveness of PAPR minimization [17-19]. The cumulative distribution function of a signal is written as

$$F(z) = 1 - \exp(z) \tag{3}$$

However, instead of CDF the Complementary CCDF (CCDF) is used to measure the probability of PAPR occurrence. The CCDF is denoted as

$$\begin{aligned} P(PARR > z) &= 1 - P(PARR > z) \\ &= 1 - (F(z))^N \\ &= 1 - (1 - \exp(-z^N)) \end{aligned} \tag{4}$$

2. PAPR REDUCTION APPROACHES

There are two main categories to reduce PAPR in OFDM signal namely Signal Distortion technique and Signal scrambling Technique.

2.1. Signal Distortion Techniques

2.1.1. Amplitude Clipping and Filtering

The most effective and simple technique used to reduce PAPR is amplitude clipping and filtering technique. Let the clipping threshold value of X is B for a convoluted base band signal. Let $X = \{x_1, x_2, x_3, \ldots\ldots\ldots x_N\}$, if any value of X is greater than B then the amplitude of a signal is clipped. Hence the probability of X exceeding B is given as

$$\begin{aligned} P\{X > B\} &= \frac{B}{e^2\sigma^2} \\ \text{CCDF} &= P_C \\ &= P\{B < x < \infty\} \\ &= \frac{B^2}{e^2\sigma^2} \end{aligned}$$

or

$$-2\ln(\text{CCDF}) = \text{PAPR} \tag{5}$$

or

$$B^2 = -2\ln(\text{CCDF})\sigma^2 \tag{6}$$

Equation (5) shows the relationship between PAPR and CCDF. It shows that PAPR and CCDF are inversely proportional. Equation (6) shows the relation between CCDF and clipping threshold. If the CCDF decreases the clipping threshold increases and PAPR reduces. If the threshold value is more, than the samples clipped will be less which decreases the CCDF.

The Clipping threshold is written as

$$\begin{aligned} &x = B \\ \text{if}\quad &x > B \\ &x = x \\ \text{if}\quad &x \leq B \\ &x = -B \\ \text{if}\quad &x < -B \end{aligned} \tag{7}$$

Clipping is a non linear process, where the distortion is viewed as noise. There are two types of distortion in-ban distortion and out-band distortion. In-band distortion points to bit error rate performance degradation and out-band distortion points to spectral efficiency degradation. By filtering, out-band distortion can be reduced with a cost of regrowth of crest factor, which exceeds the threshold value of clipping. To reduce the entire regrowth the cascade stages of clipping and filtering is used. The generation of clipping noise is known process which can be restored and removed at the receiver [3].

2.1.2. *Peak Windowing*

The peak windowing is one of the approaches used to reduce the PAPR. Here the Gaussian shaped window is multiplied to a huge signal peak to minimize PAPR. The other window function such as Cosine, Kaiser and hamming window can also be used provided the spectral efficiency are good. The obtained spectrum is a convolution of indigenous OFDM and window spectrum. In time domain the window should be very narrow, else the signal samples are distorted which raises the bit error performance. This technique scales down PAPR at a demand of raise in bit error rate.

2.2. Signal Scrambling Techniques

2.2.1. *Linear Coding*

To reduce PAPR the linear coding is also used. The key factor to reduce PAPR is to select a proper codeword for transmission. Coding scheme uses a known data block with constellation modulation such as QPSK and MPSK. The code word which is having high peak power is blocked from transmission. This blocking can be done by delineating a 3-bit data word to a 4-bit code word. This method the best code selection is very difficult and also it requires large amount of space to store code word. This method has only encoder but not the error correction. It is easy to implement but computational complexity is more in order to select a proper code word. Further improvement can be seen using Gooley complementary code and Reed Muller code. This method is useful only for limited number of sub carriers where PAPR reduction is achieved.

2.2.2. *Tone injection*

The fundamental objective of tone injection approach is to magnify the constellation size and map the indigenous constellation into analogues points in that. For every symbol in the data block there are many constellations which are mapped in extended constellation. Assume 'C' is a translation vector which is written as

$$\mathrm{C} = (\dot{\mathrm{X}}) \bmod (x) \tag{8}$$

This method does not demand any extra side information but the receiver should know how to map back the larger constellation into a original constellation. Another way to move the constellation is by using FFT. The amount of scaling down PAPR is dependent on the modified symbols in the data block. As this method occupies the same frequency band for injected signal, it is more complicated when compared to tone reservation. Due to injected signal the power and the implementation complexity increase.

2.2.3. *Tone Reservation*

Tone reservation is one of the efficient methods used for minimization of PAPR. The idea in this technique is it reserves the tone both at transmitter and receiver. In tone reservation the main objective is to find the value of time domain signal 'C' with the help of convex optimization problem which can be solved using linear programming. The summation of time domain signal 'C' and indigenous time domain signal 'x' minimizes the PAPR.

Let us represent the complex symbol $\mathrm{C} = \mathrm{C}_n$ where $n = 0, 1, \ldots\ldots..n-1$ for the reserved tone. After the tone reservation the data vector is given as $x + \mathrm{C}$. Hence a OFDM signal can be represented as

$$= \mathrm{IFFT}\,(x + \mathrm{C})$$

$$= \dot{\mathrm{X}} + \mathrm{C}$$

where $$\mathrm{C} = \mathrm{IFFT}(c) \tag{9}$$

In wireless communication system there is no unused reliable channel, but while reserving the subcarriers the bandwidth requirement will be more.

2.2.4. Active constellation Extension

Equivalent to tone injection technique, Active constellation technique is used for PAPR reduction. The outer signal constellation is expanded toward outside of the indigenous constellation so the PAPR is scaled down. This can be implemented in different modulation techniques such as QAM, QPSK and MPSK. If we use QPSK modulation the constellation points will lie in all quadrants in a complex plane. This is equidistance from real and imaginary axes. The decision regions in all four quadrants are bounded by the axes. Hence the received data is mapped on to the quadrant from which the symbol is observed. The combination of additional signals can be used for peak cancellation. This method reduces the bit error rate and no side information is required for transmission. But it demands for a larger constellation size modulation technique[4-12].

2.3. Selected Mapping Technique

Selected Mapping is one of the probabilistic schemes used for PAPR reduction. This method generates parallel OFDM signals in time domain which are asymptotically independent. For these parallel input data the phase sequence are multiplied and then IFFT is applied for each data. Out of that the one having a less PAPR is selected and transmitted. Figure 1 depicts the block diagram of SLM technique.

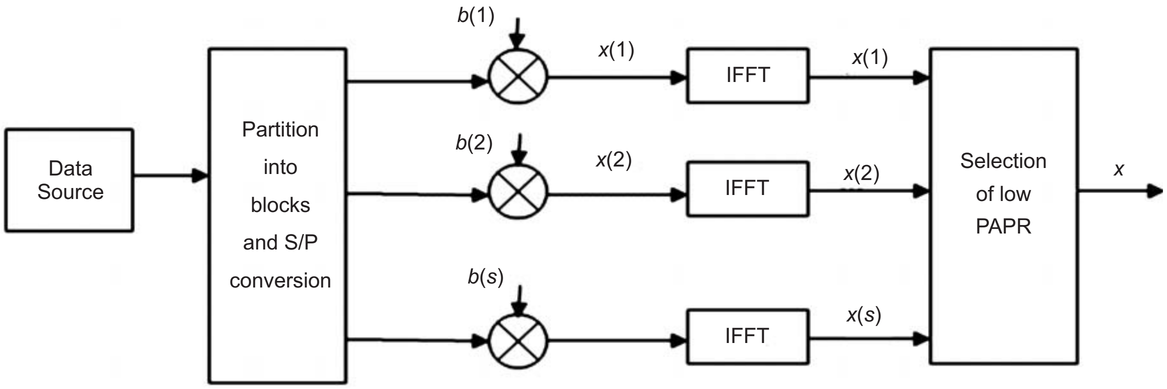

Figure 1: Block diagram of SLM technique

Each data block is expanded with a ‘S’ unique phase sequences each of length *n*.

$$B(S) = [b_{s0}, b_{s1}, \ldots\ldots\ldots, b_{sn-1}]$$

where $s = 1, 2, \ldots\ldots S,$

which results in ‘S’ different blocks of data. Thus after multiplication the phase sequence is given as

$$X[S] = [X_0 b_{s0}, X_1 b_{s1}, \ldots\ldots\ldots X_{N-1} b_{sN-1}]$$

where $s = 1, 2, \ldots\ldots S.$

Hence the OFDM transmitting signal is written as

$$X^{(u)}(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x_n b_{x,n} e^{i2\pi n \Delta f t}$$

$$0 \le t \le NT,$$

$$s = 1, 2, \ldots S$$

Among with these altered data block the one with less PAPR is chosen for transmitted along with the corresponding phase vector as side information. To recover the original data block the reserve operation is done. In order to implement this method we require S IFFT block and for every data block the necessary side information is $[\log_2{}^{S}]$. The reduction of PAPR relies on the design of phase factor and number of phase sequences. The improved version of SLM technique is used to minimize PAPR.

2.4. Partial Transmit Sequence

In OFDM the powerful probabilistic based PAPR reduction technique is Partial Transmit Sequence (PTS). The sketch of Partial Transmit Sequence is depicted in Figure.2. In this scheme the original data X is divided into N non-overlapping sub blocks. In each sub-block the sub carriers are weighted by a phase factor. The selection of phase factors make sure that the PAPR is reduced[13-16].

The divided input data X is given by

$$\begin{aligned} X^{(m)} &= [X^{(m)}_{0}, X^{(m)}_{1}, X^{(m)}_{2}, \dots\dots\dots, X^{(m)}_{N-1}] \\ m &= 1, 2, \dots, M \end{aligned} \tag{5}$$

The summation of every the sub blocks is the original signal, which is given by

$$X = \sum_{m=1}^{M} X^{(m)} \tag{6}$$

1. The stages of PTS algorithm is narrated below.
2. The OFDM sub carrier is split into M non overlapping sub blocks.
3. For every sub block the OFDM signal is generated by taking IFFT.
4. The OFDM signal combined with weighted phase factor b_i.
5. By using optimization algorithm the phase factors are generated.
6. To retrive the data at the receiver, receiver should know the generation scheme.

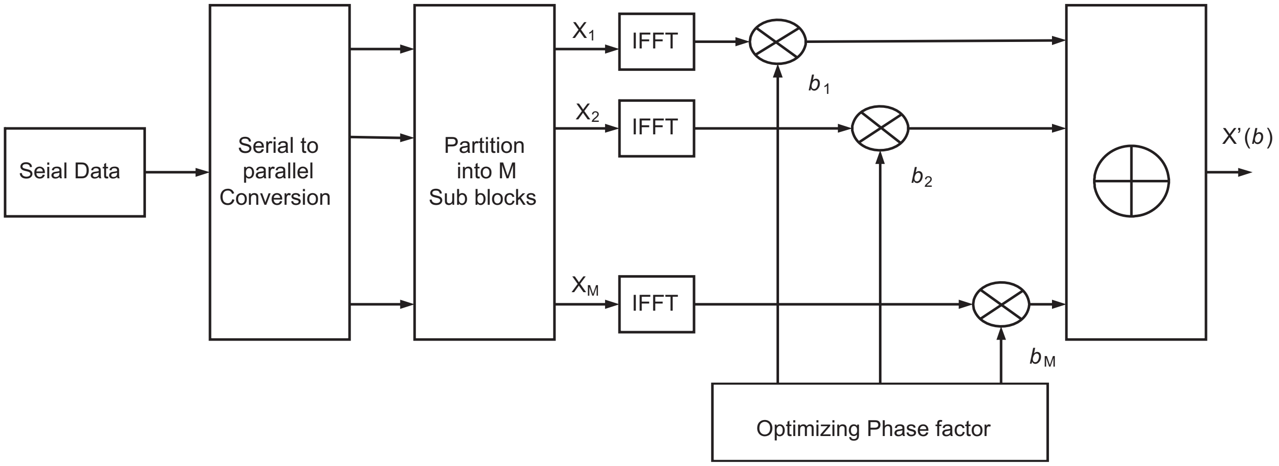

Figure 2: PTS scheme

3. THE PARAMETERS CONSIDERED FOR THE SELECTION OF PAPR REDUCTION

In most of the techniques used earlier has a tradeoff between PAPR and distinct factors such as bandwidth bit error rate computational complexity and so on.

3.1. Power Consumption

In techniques like Tone Rejection and Tone Injection the power increase after the PAPR is minimized. In TI it uses an expanded constellation where original constellation is mapped. For this expanded constellation the power required is more than the primary constellation. So the transmitted signal will have more power. Hence the transmit signal must be normalized back else error rate performance increases.

3.2. Bit Error Rate

It is also a key parameter related with power inflation in transmitted signal. BER is calculated at the end of receiver. To maintain BER the power level should be large enough. In some methods such as PTS, SLM and interleaving, if the side information is erroneous then the data is absent at a cost of increase in BER.

3.4. Computational complexity

The implementation of the design is another important parameter considered for PAPR reduction. In PTS technique after much iteration the PAPR is reduced but the complexity of the design is high.

3.5. Data Rate Loss

Bandwidth is another important parameter. If the bandwidth is expanded the loss of data will be more due to side information. Channel encoding is employed to avoid the erroneous reception of side information at the receiver. The loss in data rate is increased when the channel encoding is used.

3.6. Other Parameters

The design of non linear devices such as power amplifier, DAC should be taken care. The amplifier should have a good linear range to avoid the performance degradation of DAC. At the same time the design should be cost effective.

4. PROPOSED TRANSMITTER

Figure 3 depicts the block diagram of proposed transmitter design. The transmitter block consists of conversion of data into binary bits followed by a channel coding *i.e*., convolution coding suitable for noisy channel. The order bit selector is used to select the QAM constellation such a way that the PAPR is scaled down. The output of modulation is given as input to the FCT block. Then IDCT and IWPT are applied in order to minimize PAPR in the OFDM system. The digital to analog convertor is used for conversion followed by RF up conversion then for transmission of data through channel.

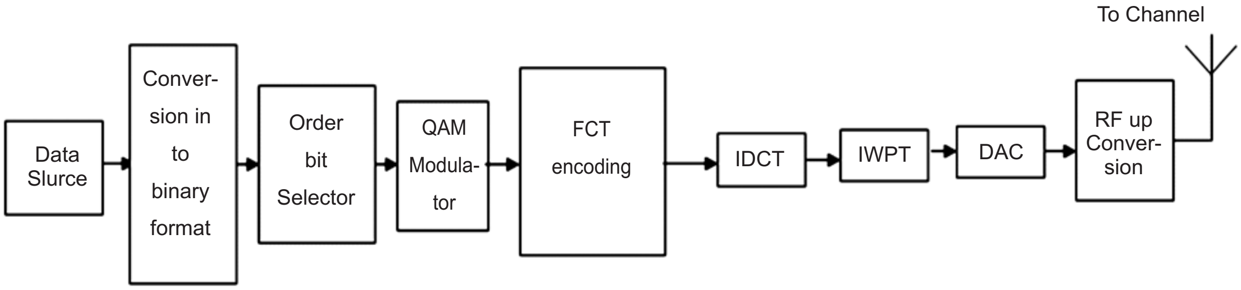

Figure 3: Proposed transmitter design

4.1. Order Bit Selector

In communication systems the simplest way of channel coding technique is Convolution coding. By virtue of its high coding gain and performance it is frequently used in wireless communication systems. The convolution coding is suitable for noisy channel such as Additive White Gaussian Noise (AWGN). In order to control the error the channel encoding is used. The basic building block of the convolution encoder is a shift register. It requires less hardware and storage memory. The convolution encoder is mainly defined by 3 variables namely: n, k, L where n is number of input bits, k is number of output bits and L is number of shift registers used as memory elements which are also called as constraint length. The code rate r is given by $r = k/n$. figure 4 shows the block diagram of convolution encoder for (n, k, L) = (2, 1, 2).

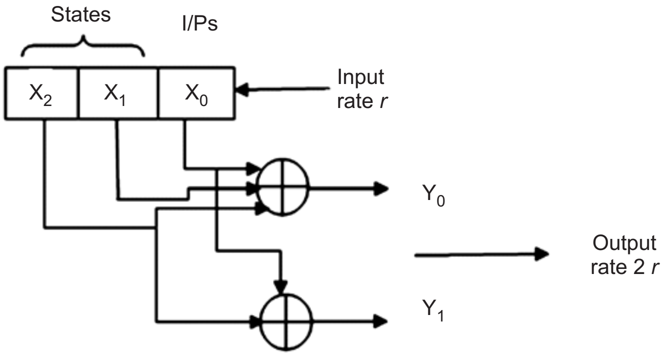

Figure 4: Block diagram of convolution encoder

To produce output at the encoder the two previous input bits and one present input bit are used. The output y_0 and y_1 is generated by using modulo-2 addition which is denoted by

$$y_0 = x_0 \oplus x_1 \oplus x_2$$
$$y_1 = x_0 \oplus x_2$$

After convolution coding the order bit selector is used to select the QAM constellation such that the PAPR is reduced.

4.2. Different Types of channel

4.2.1. Additive White Gaussian Noise (AWGN) Channel

This is the basic channel prototype in wireless commutation systems. It is a linear addition of white noise with a uniform spectral density. The mathematical expression of the AWGN channel is written as

$$R(t) = X(t) + N(t)$$

Where X(t) is transmitted signal

X(t) is background noise

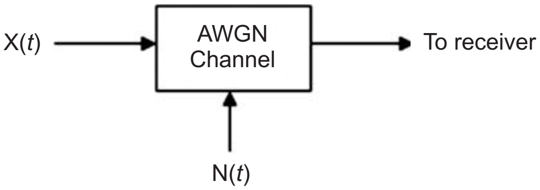

Figure 5: Input/output of AWGN model

Figure 5 shows the block diagram of AWGN noise channel. AWGN channel is a standard reference for comparison of the performance evaluation of communication system. The Additive White Gaussian Noise (AWGN) channel suits for satellite communication links. It is not worth for terrestrial links as multipath and interference are not considered.

4.2.2. Rayleigh fading channel

When a signal is transmitted and it is received at the receiver through multipath propagation phenomenon. The multipath fading occurs because of ionospheric effects, and obstacles such as buildings and mountains. The Rayleigh fading model uses a Rayleigh distribution which models the fading effects of propagation environment on a transmitted signal. It does not influence the propagation along line of sight.

4.2.3. Rician fading model

Rician fading is more suitable for line of sight is present between transmitter and receiver. This is similar to Rayleigh fading model, here the propagation may be direct or scatters before it reaches the receiver.

5. RECEIVER DESIGN

Figure 6 presents the block diagram of proposed receiver design. The reverse working of the transmission will happen here. Receives the data from the channel, then converts into digital for processing WPT and DCT. The PTS decoder is used with the support of FFT and serial to parallel conversions. The decoded data is demodulated either with BPSK or QAM depending on modulation technique used. The channel decoding is done using viterbi decoder also called as trellis coding or shaping. Conversion from binary to a required format either image or random data.

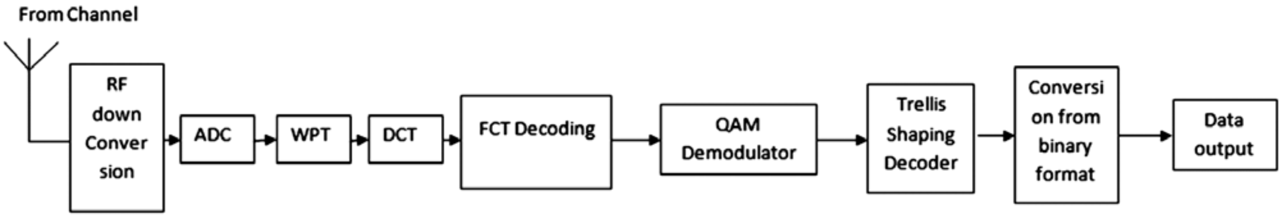

Figure 6: Proposed receiver design

5.1. Trellis diagram with Viterbi decoder

At receiver for convolution encoder viterbi decoder is used. Viterbi decoder uses two basic operation synchronization and quantization. The synchronization is used to know the range limits of code word and symbol. The quantization is used to quantize the analog signal and converter to digital using quantization square. There are two types of quantization techniques used in viterbi decoder. They are

1. Hard decision
2. Soft decision

1. **Hard decision :** The decoding process uses the trellis diagram and Hamming distance. It is quantized into one bit precision either 0 or 1. The Hamming distance is used to measure the distance between the expected data at the decoder and the data sent from the encoder.

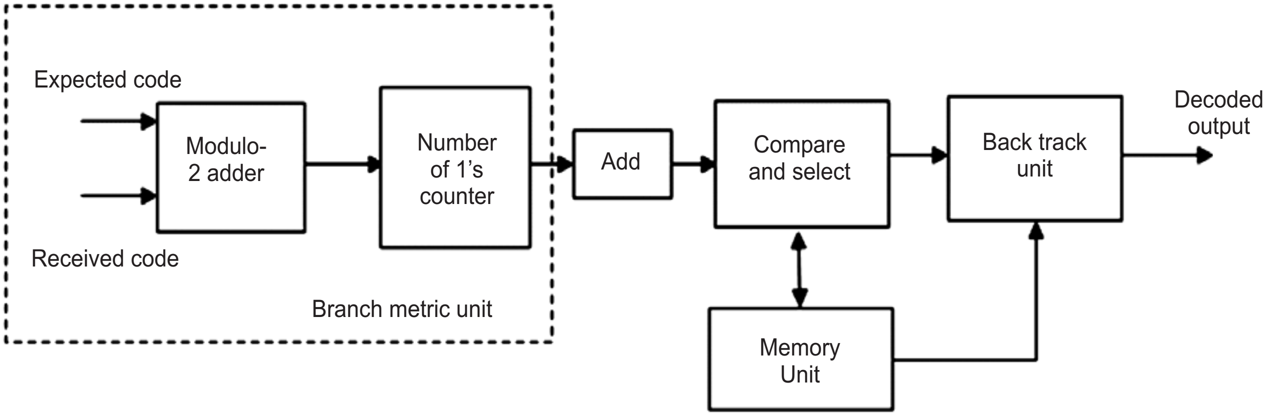

Figure 7: Internal Architecture of Viterbi decoder

2. **Soft decision :** The information, when transmitted over a Gaussian channel is decoded using probability decoding. It uses multi bit quantization for received bits. If there 3 or 4 bits of quantization the performance is better than the hard decision. The Euclidian distance is used to measure the distance between the bits. Figure 7 shows the internal flow diagram of viterbi decoder. The functional blocks of viterbi decoder are Branch metric unit, add compare and select unit, memory unit and back track unit.

The steps involved in the viterbi decoder are as follows:

1. The two parallel bits are inputs to the viterbi decoder.
2. The Hamming distance of the expected code and received cod is calculated by using modulo 2 additions. Number of one's is counted to measure the distance.
3. The previous stage and present values are added and compared to select with the minimum path value to reach the next node.
4. The each stage calculation is stored in the memory for further processing.
5. The back track unit is used to compare and track the optimal path value and the corresponding output is produced.

5.2. Trellis diagram

Figure 8 shows the general trellis diagram used in decoder. It has four rows of horizontal dots where each row depicts one state of encoder. The solid line joining the dots illustrate the input transition bit is one and the dotted line connecting the dots represent when the input transition bit is zero. To achieve better performance soft decision is used. The distance between the received codes and all possible codes are computed. Here the Hamming distance is used to compute the distance. The computation of Hamming distance is easy; it counts how many bits are different from received code to the all possible codes. The output of the Hamming distance can be 0, 1 or 2. At each unit of time the Hamming distance is computed and it is called as Branch Metric. These values are stored and accumulated to compute the optimal path.

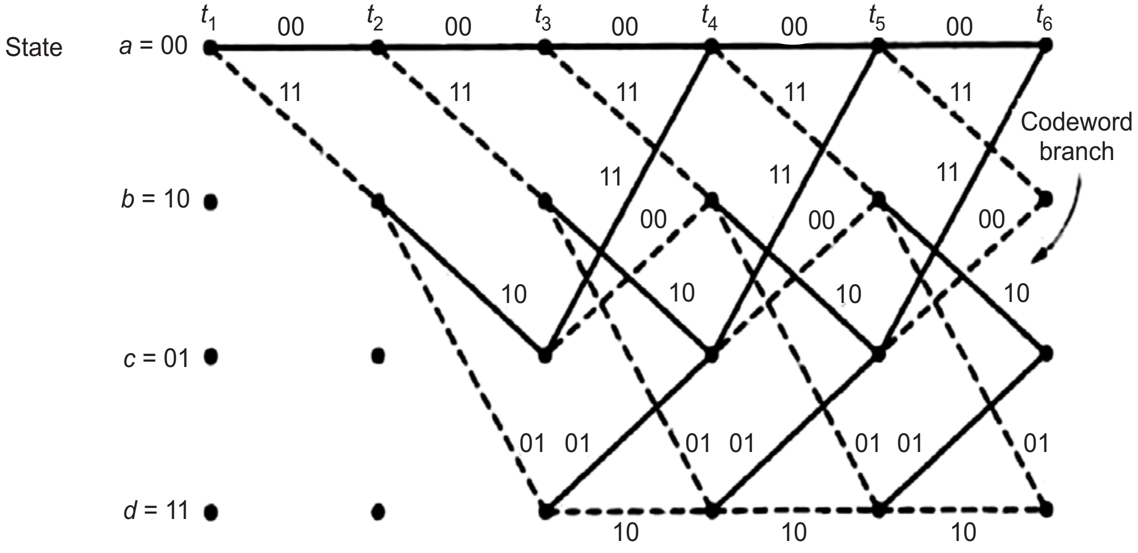

Figure 8: Trellis Structure

6. SIMULATION RESULTS AND DISCUSSION

Figure 9 and 10 shows the plot between SNR and BER for 16 QAM of Rayleigh and AWGN channel. It can be noticed that the presented method has less BER when compared with other techniques. It has been observed that the behaviour of the presented method will vary according to the channel. But still it's better for both channel conditions.

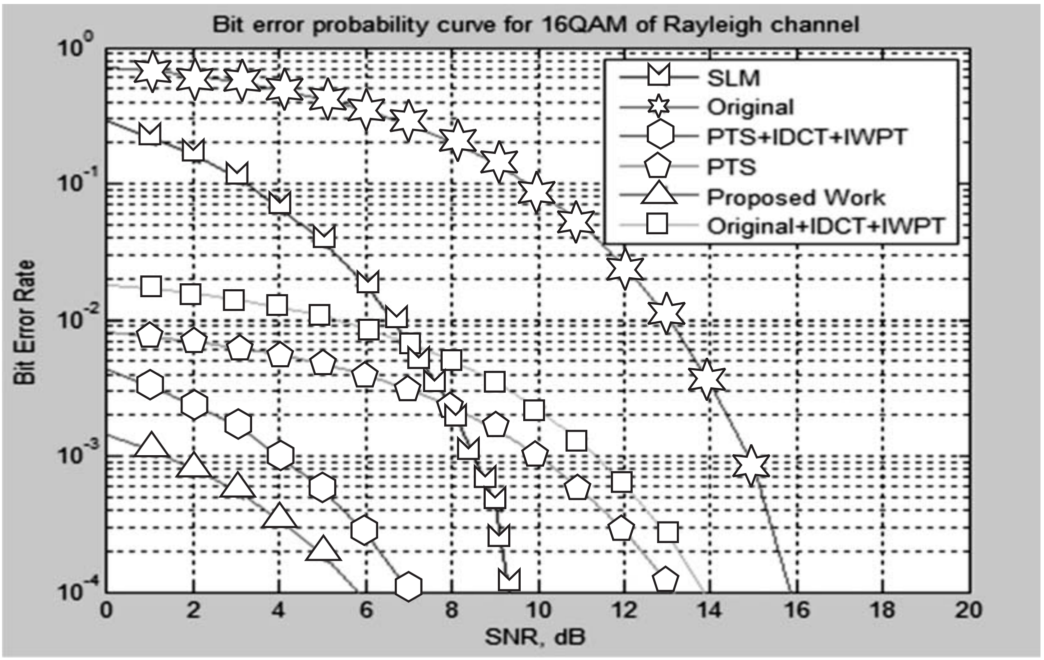

Figure 9: BER vs SNR for 16 QAM Rayleigh channel

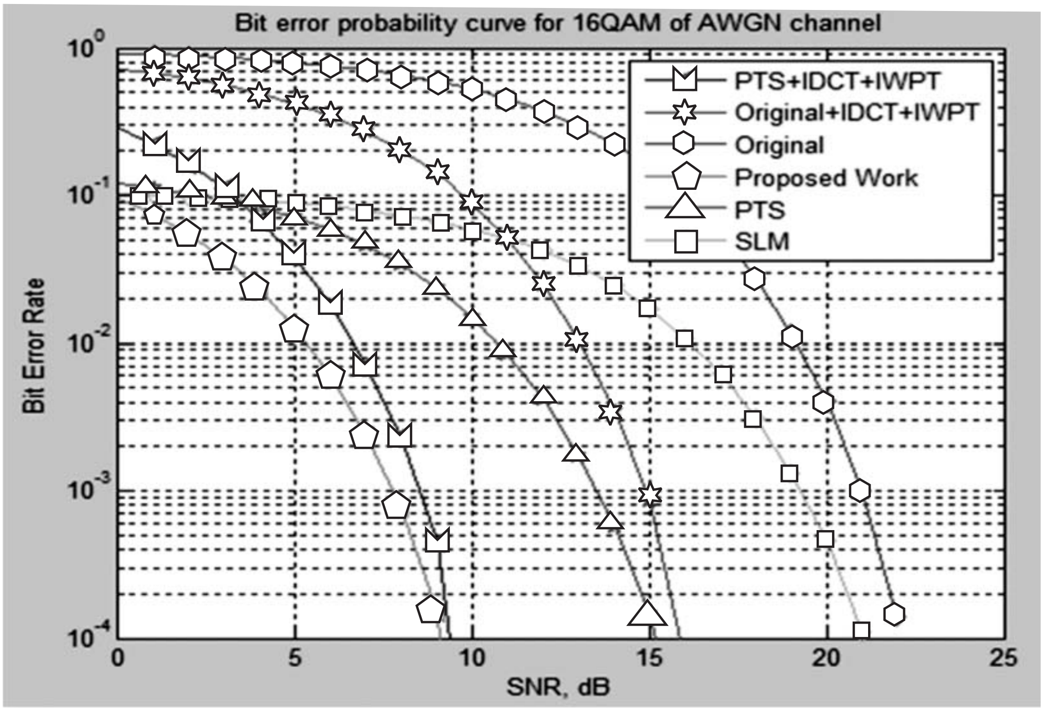

Figure 10: BER vs SNR for 16 QAM AWGN channel

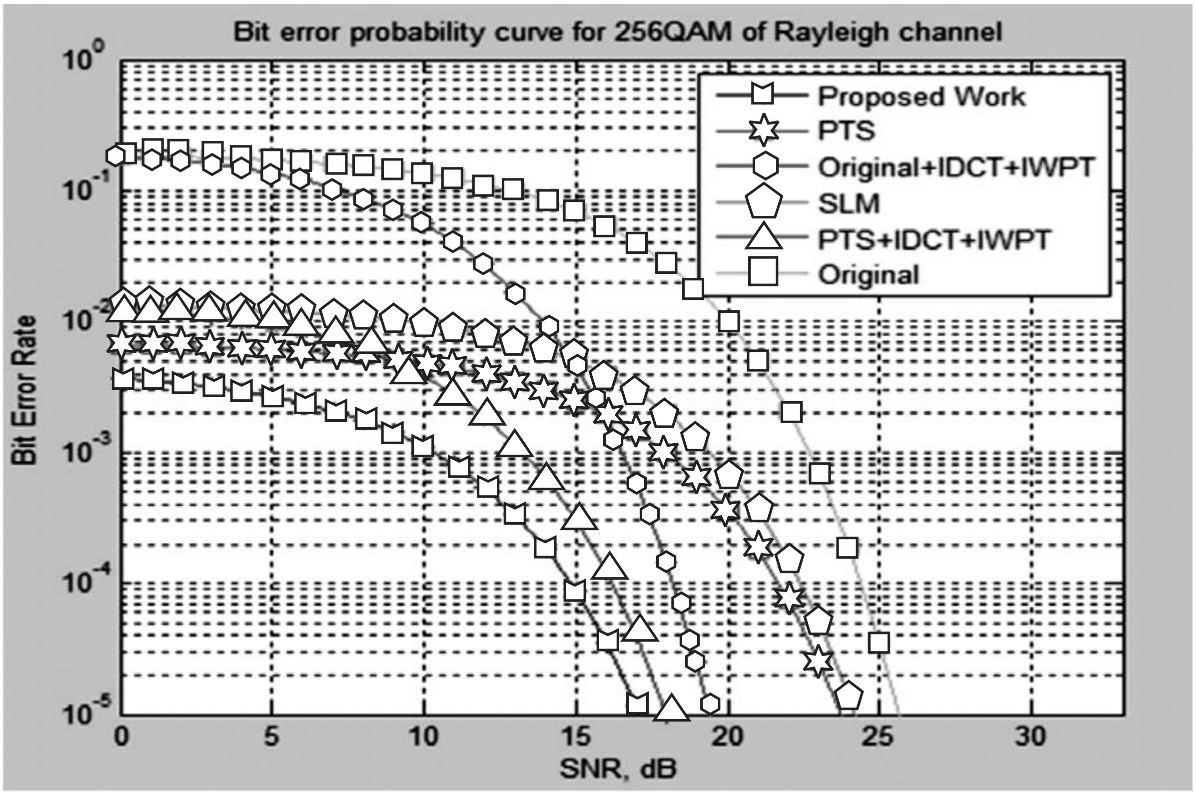

Figure 11: BER vs SNR for 256 QAM Rayleigh channel

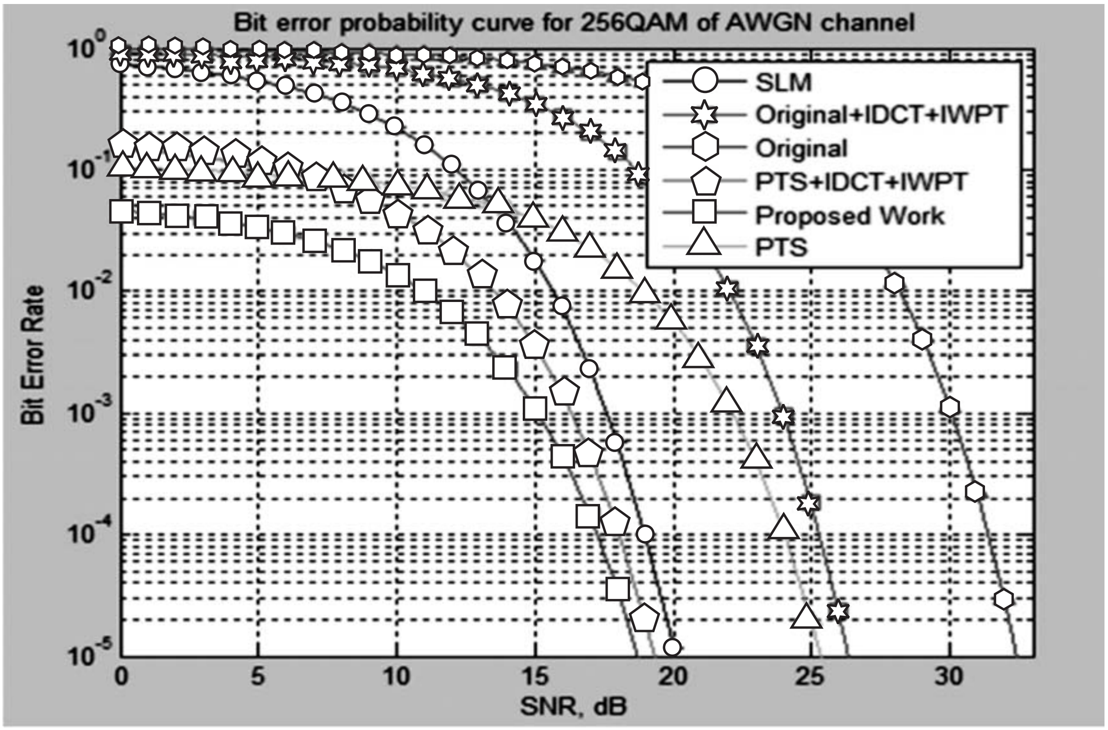

Figure 12: BER vs SNR for 256 QAM AWGN channel

Here a higher constellation of QAM is used. Figure 11 and 12 shows the plot between SNR and BER for 256 QAM of Rayleigh and AWGN channel. It can be noticed that the presented work has less BER when compared with other techniques. It can be observed that the performance is better in different channel when compared with other techniques. We can observe from the Figure 15 snapshot that the PAPR for the proposed system is having the least value as compared to the other PAPR plots for system without PTS. Figure 16 shows the normalized curve of original OFDM and proposed work. Figure 17 depicts the Time response curve of Original and proposed system. Figure 18 shows the signal constellation of QAM modulation. Table 1 shows the comparison of PAPR reduction of different techniques.

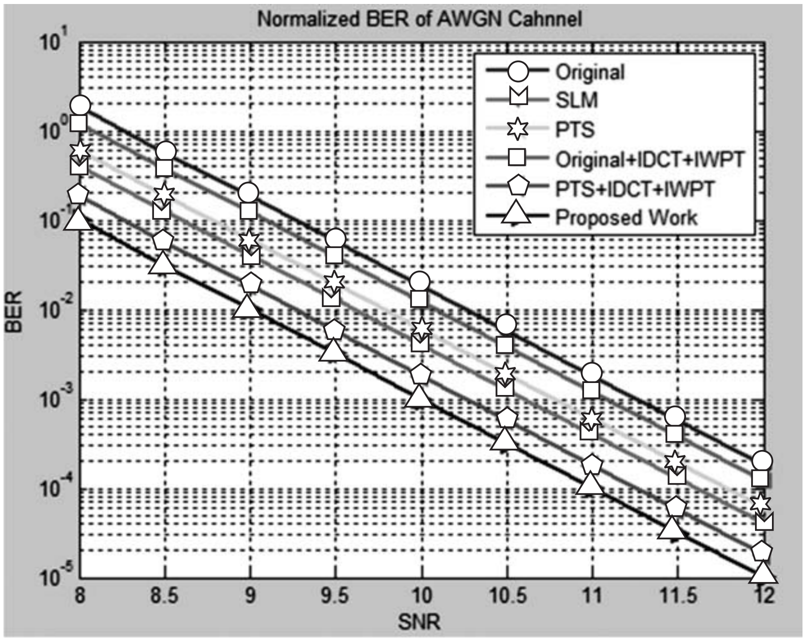

Figure 13: Normalised BER vs SNR for AWGN channel

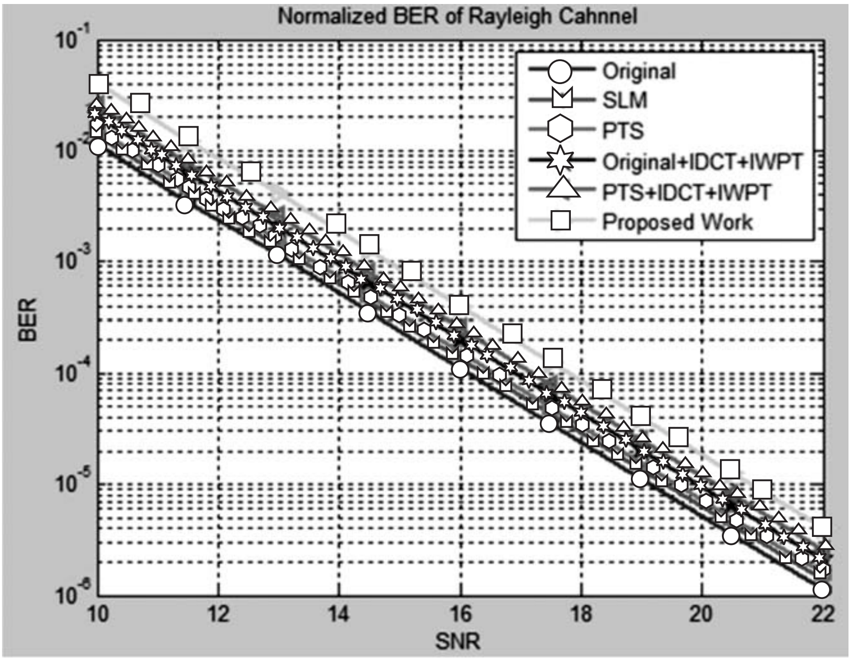

Figure 14: Normalised BER vs SNR for Rayleigh channel

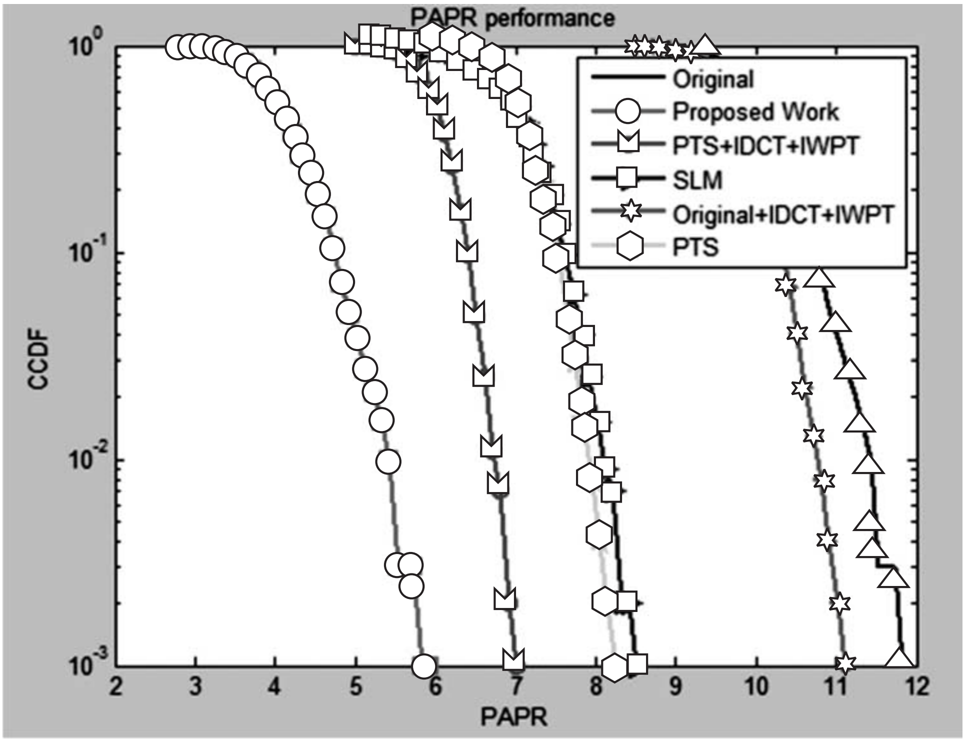

Figure 15: PAPR along with CCDF

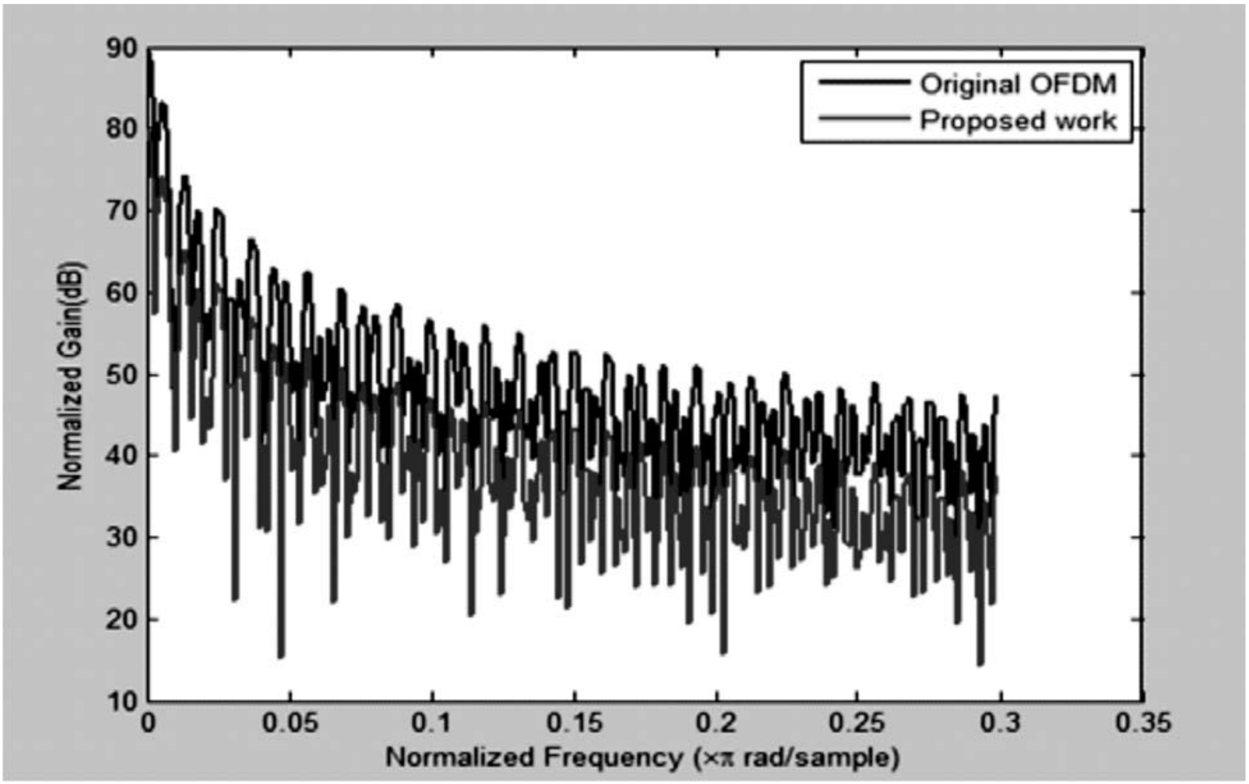

Figure 16: Normalised Curve

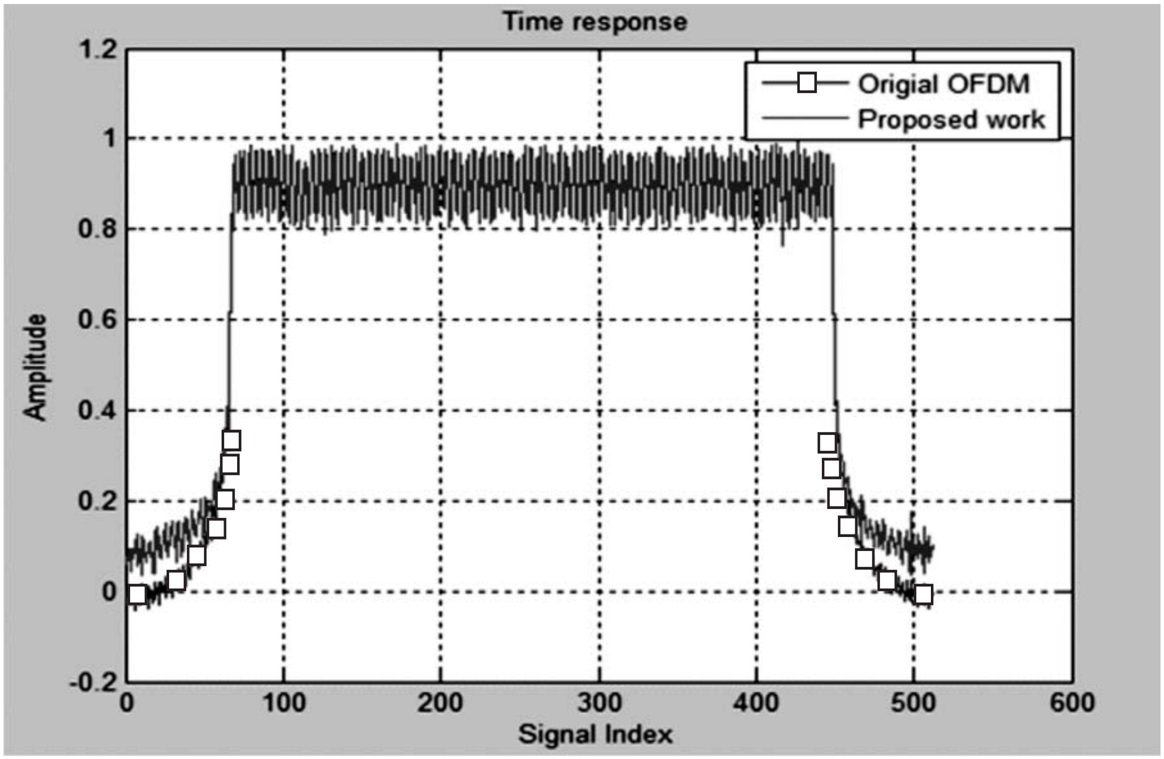

Figure 17: Time Response Curve

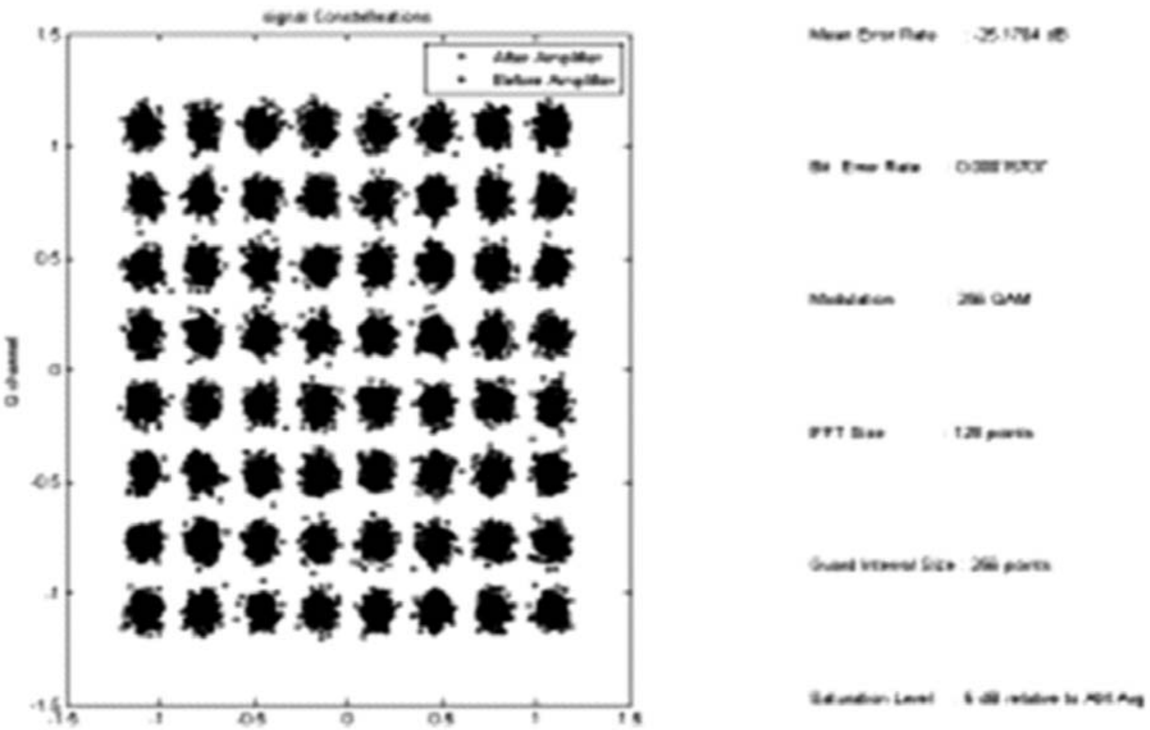

Figure 18: Signal Constellation diagram

Table 1
Comparison of PAPR for different techniques

Parameters / *Different technique*	*Complexity*	*Bandwidth Expansion*	*BER*	*SNR*	*PAPR*
OFDM	Less	No	High	High	Very High
OFDM with SLM	High	Yes	Moderate	Moderate	High
OFDM with PTS	High	Yes	Moderate	Moderate	Moderate
OFDM with DCT & WPT	High	Yes	Low	Low	Low
Proposed Work	High	Yes	Low	Very Low	Very Low

7. CONCLUSION

A complete OFDM System that composed of a transmitter and a receiver has been designed in the proposed work. One of the major contributions during the development of the proposed system is the involvement of FCT, Order bit selector and trellis structure. It can be observed in the result that it has been able to achieve the reduction in the PAPR as compared to other implementations. The system has also been tested for the BER and it can be concluded that the presented system with novel architecture has better BER with almost minimal data loss. This has been achieved due to the better encoding and decoding scheme at the transmitter and receiver before OFDM. The overall performance of the system is improved and we can say that the presented system is efficient and better in terms of reduction of PAPR and improvement in BER.

REFERENCES

[1] Wu Y., Zou W. Y., "Orthogonal frequency division multiplexing: A multi-carrier modulation scheme", IEEE Trans. Consumer Electronics, vol. 41, no. 3, pp. 392–399, Aug. 1995.Van Nee R., Prasad R., "OFDM for Wireless Multimedia Communications", Artech House, 2000.

[2] Jiang T., Wu Y., "An Overview: Peak-to-average power ratio reduction techniques for OFDM signals", IEEE Trans. Broadcasting, vol. 54, No. 2, pp. 257–268, Jun. 2008.

[3] Armstrong, J., "Peak-to-average power reduction for OFDM by repeated clipping and frequency domain filtering," Electronics Letters, vol. 38, No. 5, pp. 246–247, Feb. 2002.

[4] Wang X. B., Tjhung T. T., Ng C. S., "Reduction of peak-to-average power ratio of OFDM system using a companding technique", IEEE Transaction on Broadcasting, vol. 45, No. 3, pp. 303–307, Sept. 1999.

[5] Gayathri K M, Dr.S.Bhargavi, Dr. Thangadurai, "Modified PAPR Reduction Scheme by Integrating DCT & WPT with Partial Transmit Sequence", Indian Journal of science and technology, Vol 10, 2016.

[6] Jiang T., Yang Y., Song Y., "Exponential companding transform for PAPR reduction in OFDM systems", IEEE Transaction on Broadcasting, vol. 51, No. 2, pp. 244–248, June 2005.

[7] Huang J. L., Zheng J., Letaief K. B., Gu J., "Companding Transform for Reduction in Peak-to-Average Power Ratio of OFDM Signals", IEEE Transaction on Wireless Communications, Vol. 03, No. 6, pp. 2030-2039, November 2004.

[8] Sulaiman A. A., Ehab F. B., Mohamed Darwish A. E., "Linear Companding Transform for the Reduction of Peak-to-Average Power Ratio of OFDM Signals", IEEE Transaction Broadcasting, Vol. 55, No. 1, pp. 195-200, March 2009.

[9] Hou, J., Ge J. H., Li J., "Trapezoidal companding scheme for peak-to-average power ratio reduction of OFDM signals," Electronics Letters, Vol. No. pp 1349 – 1351, Dec. 2009.

[10] Jeng S. S., Chen J. M., "Efficient PAPR reduction in OFDM system based on a companding techniques with trapezium distribution", IEEE Transaction on Broadcasting, Vol. 57, No. 2, pp. 291-298, June 2011.

[11] Muller, S. H., Huber, J. B., "OFDM with reduced peak-to-average power ratio by optimum combination of partial transmit sequences", Electronics Letters, Vol. 33, No. 5, pp. 36–69, Feb. 1997.

[12] Bäuml R. W., Fischer R. F. H., Huber J. B., "Reducing the peak-to average power ratio of multicarrier modulation by selected mapping", Electronics Letters., Vol. 32, No. 22, pp. 2056–2057, Oct. 1996.

[13] Jayalath A. D. S., Tellambura C., "SLM and PTS peak-power reduction of OFDM signals without side information," IEEE Transaction on Wireless Communication., Vol. 4, No. 5, pp. 2006–2013, Sep. 2005.

[14] Cimini Jr. L. J., and Sollenberger N.R., "Peak-to-Average Power Ratio Reduction of an OFDM Signal Using Partial Transmit Sequences with embedded side information", Proc IEEE GlobeComm'00, , pp 740-750, Nov. 2000.

[15] Breiling M., Muller-Weinfurtner S., Huber J., "SLM peak power reduction without explicit side information", IEEE Communication Letters, Vol. 5, No. 6, pp. 239–241, Jun. 2001.

[16] Le Goff S. Y.,.Al-Samahi S.S, Boon K. K., Tsimenidis C. C., Sharif B. S., "Selected Mapping without Side Information for PAPR reduction in OFDM", IEEE Transaction on Wireless Communications, Vol. 8, No. 7, pp. 3320–3325, July 2009