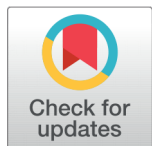


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Design and implementation of reconfigurable DCT based adaptive PST techniques in OFDM communication system using interleaver encoder

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Abstract

Objectives: To propose Reconfigurable Discrete Cosine Transform (RDCT) in Orthogonal Frequency Division Multiplexing (OFDM) high speed communication system to improve efficient spectrum utilization and mitigation of jitter, selective fading effects. The adaptive PTS method reduces Inter-Carrier-Interference (ICI), Inter-Symbol-Interference (ISI), PAPR and the computational intricacy of the communication system. To analyse and compare the performance of proposed Reconfigurable method with existing conventional OFDM communication system. **Methods:** This proposed technique employs interleaver encoder with both PTS and adaptive PTS with the Reconfigurable Discrete Cosine Transform (RDCT) in OFDM Communication system. **Finding:** A case study has been carried out and the proposed method is found to be better in CCDF performance, reliability, flexibility and accuracy. To reduce the autocorrelation between every modulated data bit, Forward error Correction in comparison with the conventional OFDM communication system. **Novelty:** The recent high-speed communication system most commonly using Orthogonal Frequency division multiplexing (OFDM) to enhance the quality of service (QoS) and Bandwidth on demand. Even though the OFDM scheme offers many advantages the signal of OFDM consists of a noise that causes variation in the amplitude resulting in high peak to average power ratio (PAPR) and since OFDM is a multi-carrier system, it is more susceptible to signal drifts. Various methods to reduce the PAPR in OFDM signal are already proposed, in this paper, a technique called interleaver encoder-based Partial Transmit sequence (IEPTS) is reviewed and the new proposed technique employs interleaving encoder utilizing in both PTS and A-PTS with reconfigurable discrete cosine transform (RDCT) in OFDM high-speed communication system.

Keywords: Interleaver encoder; adaptive partial transmit sequence (A-PTS); orthogonal frequency-division multiplexing (OFDM); reconfigurable discrete cosine transform (RDCT); partial transmit sequence (PTS)

1 Introduction

The frequency-selective channels widely make use of Orthogonal Frequency Division Multiplexing due to the inherent characteristics like high spectral efficiency, inter-symbol interference resilience, and immunity to frequency-selective fading. A major issue in an Orthogonal Frequency Division Multiplexing (OFDM) (expand it) system is high peak to average power ratio which is generated due to constructive combinations of in-phase subcarrier signals and leads to nonlinear distortions in power amplifiers which results in bit error rate performance degradation. The Peak to Average power Ratio (PAPR) (expand it) reduction problem can be solved by using either signal distortion or signal distortion fewer techniques. In signal distortion technique like clipping and filtering⁽¹⁾. The transmitted OFDM signal is distorted before power amplification to accomplish PAPR reduction. The signal distortion techniques usually have low complexity but will have limitations on error rate performance. In signal distortion less approach namely tone-reservation⁽²⁾ a small number of unused subcarriers are exploited to cancel power peaks. Whereas in PTS and SLM⁽³⁾ distortion less methods PAPR minimization is achieved by generating a number of modified OFDM signals from which one best signal to achieve high-speed data rate. The signal obtained by these methods can be used in wireless communication systems which is already proven⁽⁴⁾. OFDMA is found very much useful for 5G mobile communications and also for opportunistic spectrum utilization if PAPR reduction issues are solved. The OFDMA signal subcarriers obtained from conventional PTS technique non-contiguous can be utilized in uplink which is more effective.⁽⁵⁾ In this paper, our main interest is on PAPR control for wireless communications to preserve the error rate performance by selecting the OFDM symbols within MS techniques. In⁽⁶⁾ it is revealed the MS techniques used for minimization of instantaneous non-linear distortion will not ensure the use of PAPR criterion to improve the performance. With this clue, alternative metrics for signal selection to reduce overall distortion that improves BER performance were obtained⁽⁷⁾. The mean square error metric (MSE) and cross-correlation (CORR) method-based amplifier model can be used for predicting instantaneous output based on I/o relation. The PAPR control can also be achieved without the amplifier model. Through a survey it is found that metrics are sensitive to model mismatching. So, we propose a metric focused on performance which is simple and does not require an amplifier model for calculation. In broadband communication, OFDM finds extensive application due to its robustness and of OFDM include broadcasting, broadband wireless and wireline systems. It should be noted that OFDM does not find application in communication devices that are power-limited like, mobile and satellite communications. For instance, single carrier frequency division multiplexing is used for uplink whereas OFDM is used in downlink part of 4G networks. Integrated Internet of Things (IoT) and Massive Machine Type Communication (MMTC) find wide application in recent times MMTC includes massive number of inexpensive devices and are roughly synchronized to the network. Factory automation technology requires Mission Critical Communication (MCC) services including closed loop minimal latency are essential. These technologies concentrate on physical layer and offers solution to full connectivity in IoT scenario that 5G networks require.

OFDM is found to have limitations in catering to the needs of the future in forthcoming 5G networks. Hence, researches doubt the capability of OFDM in its support for the novel services targeted by 5G. The main limitation of OFDM include massive emission out of band which affects the presence of asynchronous equipment or services, susceptibility to noise, hardware faults, huge peak to average power ratio (PAPR). The paper also proposes a system which is a hybrid scheme-based metric to achieve better BER performance and PAPR reduction. At the end, a comparison between the proposed metric and the metric techniques mentioned in⁽⁸⁾, ⁽⁹⁾ and ⁽¹⁰⁾ is made available for clarification. The OFDM signal is a modulation and as well a multiplexing technique that offers various advantages for transmission channels as shown in Figure 1. Today the OFDM technique is used in many telecommunication technologies that require high data transmission rate and efficient bandwidth utilization. Resource allocation is one of the main roles of OFDM in 4th and 5th generation telecommunication technology. OFDM consists of multiple carriers that allow the data to be transmitted in parallel compared to the single-channel offering a high data rate and also less data interface⁽¹¹⁾.

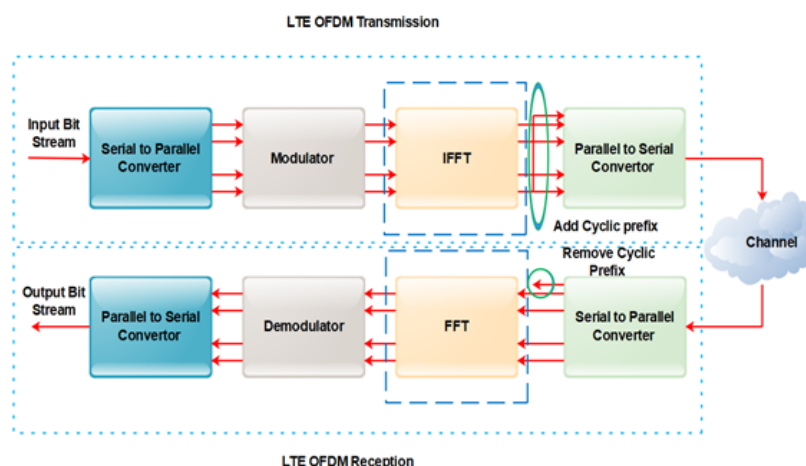


Fig 1. Fundamental Block diagram OFDM communication System in LTE platform

The 'M' orthogonal subcarriers are produced using an inverse fast Fourier transform (IFFT) for transmission^{(12), (13)}, the characteristics the channels changes after each OFDM symbol is transmitted over these 'M' orthogonal subcarriers resulting in the destruction of orthogonality which leads to additional signals getting added up causing highest peak signals that is larger than the High Power Amplifier (HPA) operating point.

The solutions to these highest peak signals are to reduce the PAPR of the signal or to use HPA that is very efficient and powerful. Using high power amplifiers increases the cost and hence it is better to make use of any techniques to reduce PAPR in the OFDM signal. There are numerous technique available to reduce PAPR^{(14), (15)} and are mainly categorized into three categories as a coding scheme, signal attenuation type and signal attenuation-less type as shown in Figure 2. The coding scheme requires the selection of the code words that reduce the PAPR during the transmission, one drawback of this approach is that it requires identifying the code words that have low PAPR and document them in a lookup table to further use in the encoding and decoding process, which decreases the system performance^{(16) (17)}.

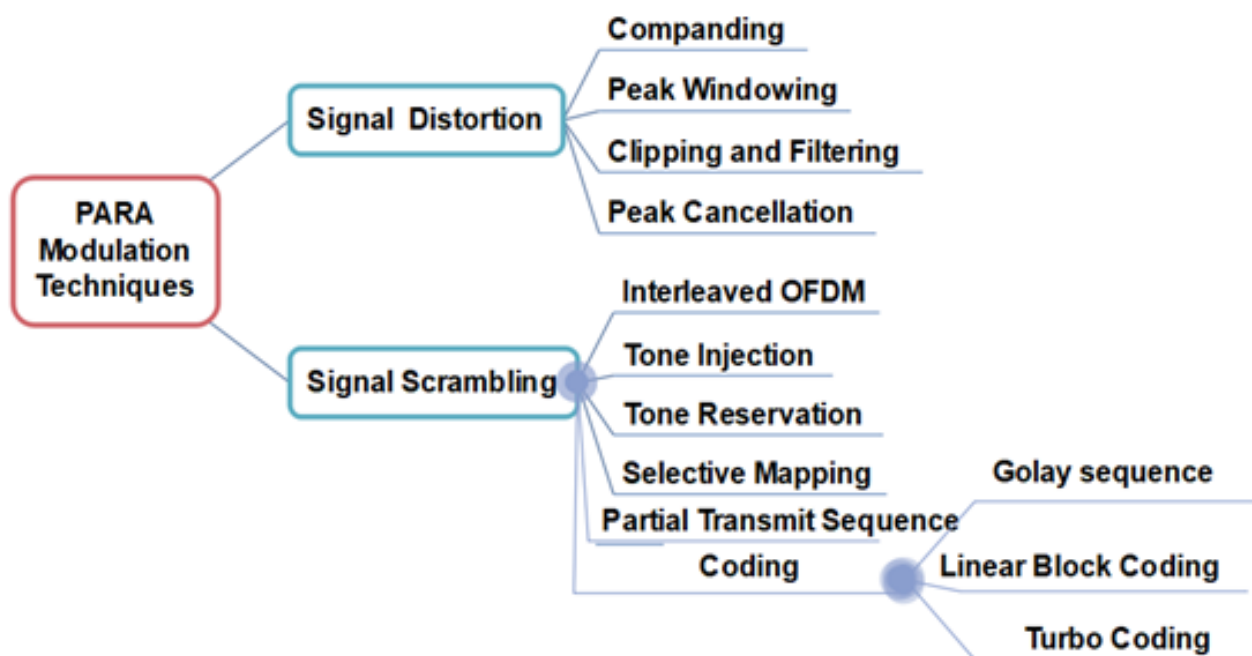


Fig 2. Types of PAPR modulation Techniques

Clipping and filtering techniques are grouped into the signal distortion type⁽¹⁸⁾. The clipping is the simplest among all other techniques, in this technique the signals that are having high peaks are clipped prior to amplification and later filtering is used to decrease the spectral splatter. The drawback of this approach is that it creates in-band and out-of-band distortion. Signal attenuation type includes two methods called Partial Transmit Sequence (PTS) And Selective level mapping (SSLM). In these methods, the OFDM symbols are scrambled to achieve the smallest PAPR. In the selective level mapping scheme, the phase factor is used to scramble the OFDM symbols and then IFFT is separately applied on the OFDM symbol^{(19) (20)}. In the partial transmit sequence scheme, the OFDM symbols are split into subsequences that are in turn multiplied with all phase factors, the number of subsequences is proportional to the phase factors. Later DCT is used together with the PTS to reduce the autocorrelation between the OFDM symbols to further reduce PAPR of the signal. The proposed technique focuses on reducing PAPR using PTS with discrete cosine transform along with the interleaving. The technical script is organized as follows: The section I gives the introduction to OFDM, Section II provides the details about the characteristics parameter of OFDM and its overheads of PAPR, section III provides the details of complementary cumulative distributed function (CCDF) and its calculation, Section IV and V provides the details of the PTS technique and adaptive PTS (A-PTS) technique, Section VI provides the details of discrete cosine transform (DCT), section VII discusses the proposed technique, the simulation result and the conclusion are provided in section VIII and IX.

2 Introduction to OFDM communication system and PAPR effect

The OFDM signal is a modulation and as well a multiplexing technique, it uses multiple carriers to carry the data^{(21) (22)} functional block diagram as shown in Figure 3. It splits the serial digital data stream into parallel low bit rate digital data that is carried by the different subcarriers using high speed IFFT blocks offering the high data stream rate and efficient bandwidth utilization. Since 'M' data blocks are assigned to 'M' subcarriers the narrow band signal is generated from the wideband signal. The 'M' blocks of data are represented as $Y_n = \{Y_1, Y_2, Y_3, \dots, Y_m\}$, the block of data following IFFT operation is represented as equation 1.

$$y(n) = \frac{1}{N} \sum_{k=0}^{M-1} Y(k) e^{i2\pi \frac{km}{M}} \quad 0 \leq m \leq M \quad (1)$$

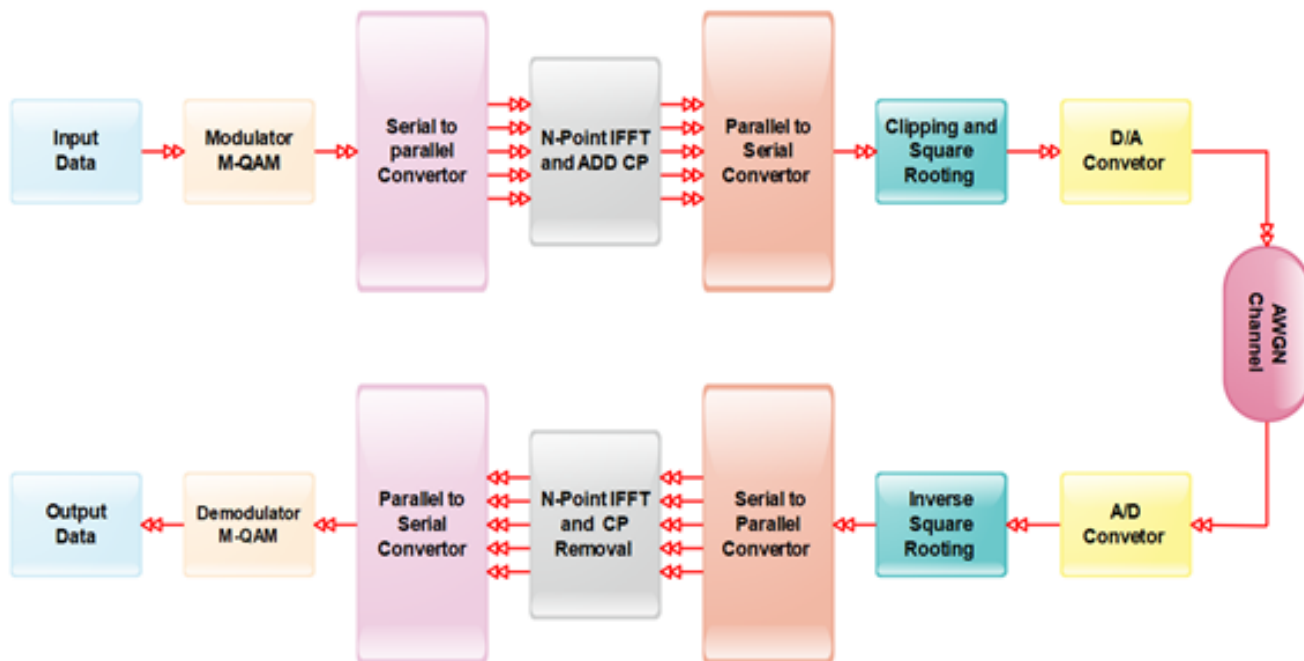


Fig 3. Fundamental Block diagram OFDM communication System to reduce PAPR Effect

The PAPR is the ratio of maximum power of the data sample of the OFDM symbol to the OFDM symbol's average power and is represented as follows.

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

Where $y[n]$ is the signal generated from OFDM and the frequency response of the operator $E[.]$ gives the mean value of the OFDM generated signals from system.

3 Characteristics of complementary cumulative distribution function in OFDM communication system

The CCDF is function that is used to find the number of OFDM signals whose PAPR is higher than the defined threshold power level; The CCDF is obtained by taking complement of cumulative distribution function (CDF) and is written as $CCDF=1-CDF$. Computing the integral of Rayleigh distribution function which is a probability density function1 (PDF) of PAPR of1OFDM signals generates the CDF. The1CCDF based on PDF procedure is represented by the following equation (3).

$$L(x) = 1 - e^{-x} \quad (3)$$

In 'M' subcarrier OFDM system if all the sampling discrete signals are not interconnected,

then CDF of 'M' subcarrier OFDM system is expressed in the following equation (4)

$$Q(X \leq x) = L[X]^M = [1 - e^{-x}]^M \quad (4)$$

CCDF is one of the important factor that is used to term the OFDM signal's peak to average power ratio. The CCDF is expressed in equation 5.

$$Q(PAPR > PAPR_0) = 1 - [1 - e^{-PAPR_0}]^M \quad (5)$$

The above equation determines the probability of OFDM symbol block's PAPR surpasses the clipping level defined by $PAPR_0$.

4 Characteristics of partial transmit sequence in OFDM communication system

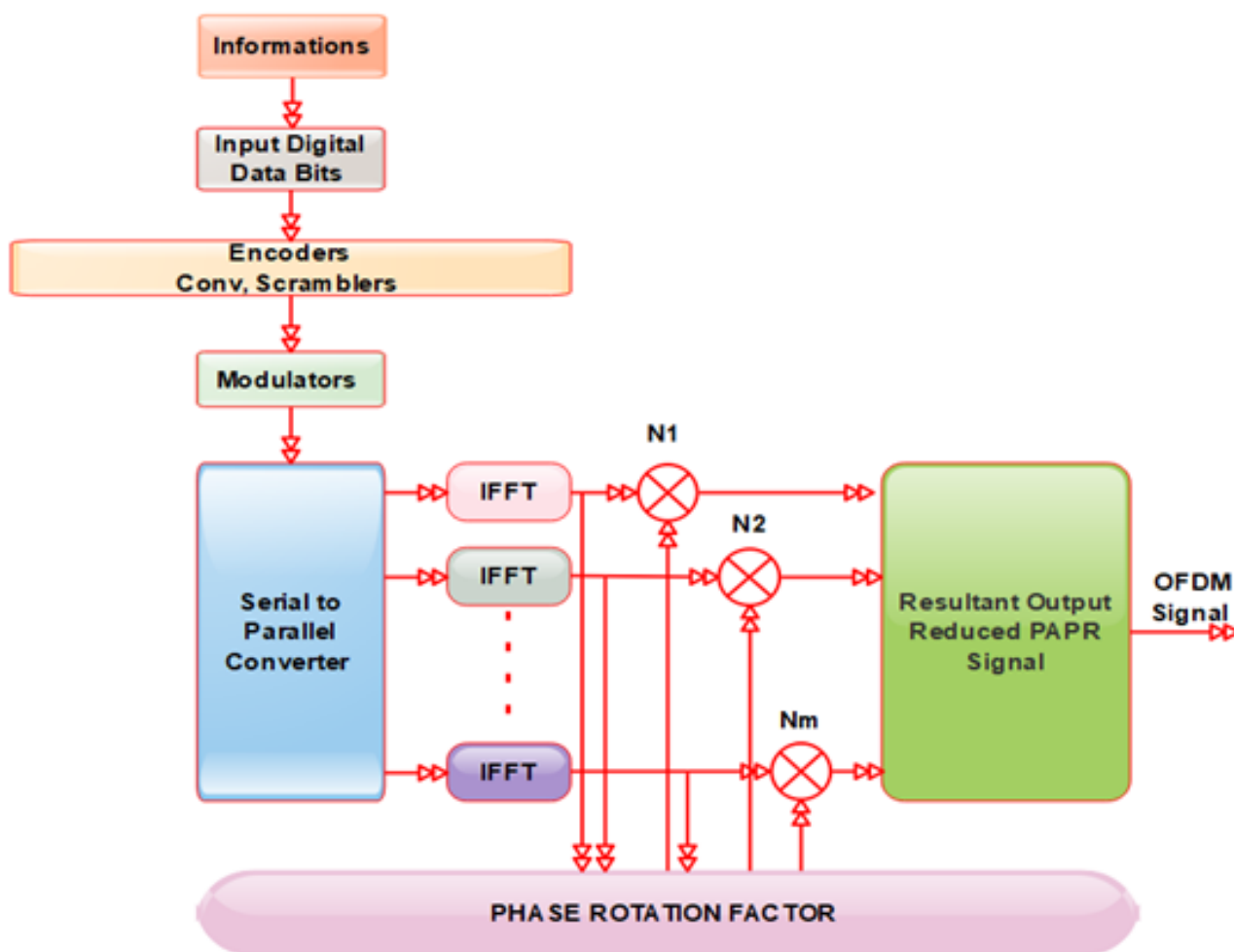


Fig 4. Functional block diagram of OFDM communication system using PTS methods

Partial Transmit Sequence (PTS) is a technique that is used to reduce the PAPR of an OFDM signal by reducing the correlation between the signals^{(23) (24)}. This technique works by splitting the OFDM sequence into numerous subsequences and then multiplying different combination phase factor to this individual subsequence till the peak value is selected as shown in the Figure 4. This technique initially treats the block of data as a vector denoted as $Y = [Y_1, Y_2, Y_3, \dots, Y_{M-1}]^T$ and then divide this vector into a uncorrelated sets which are expressed as a vector $\{Y_m, m=1,2,3,4,5,\dots,M\}$.

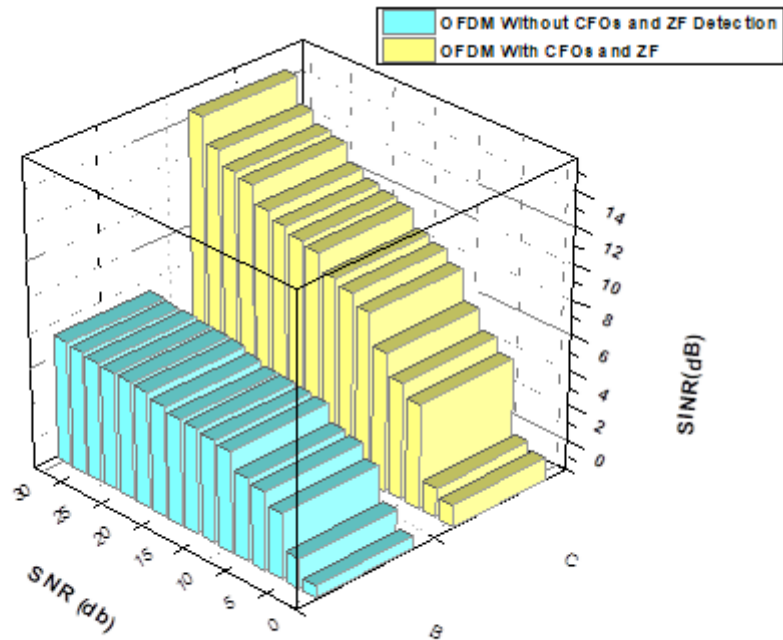


Fig 5. Comparison of analytical results for SINR in OFDM system by using with and without CFO and ZF detection

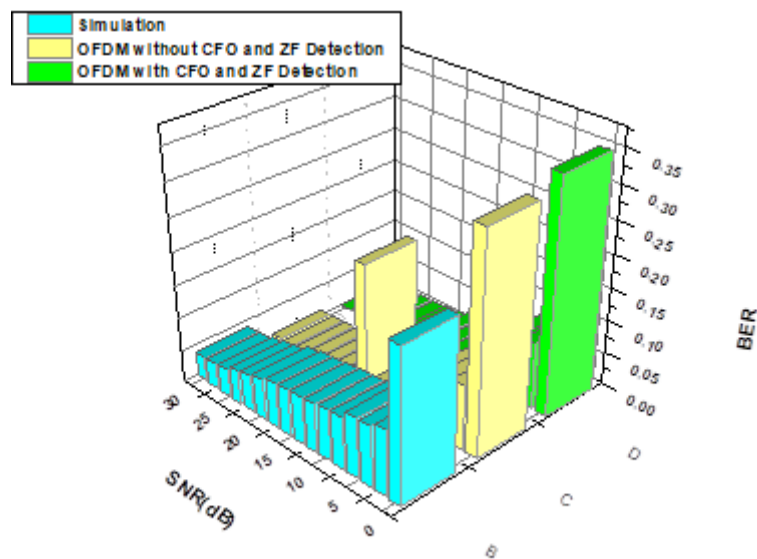


Fig 6. Comparison of analytical results for BER in OFDM system by using with and without CFO and ZF detection

It is also assumed that these equal sized data sets comprises of set of subcarriers that are adjacent Kai Deng et.al⁽²⁵⁾ ⁽²⁶⁾ is developed Distributed-Antenna OFDM communication Systems with Multiple Carrier frequency offsets (CFO) Using Zero-Forcing Detection (ZFD) to reduce the Signal to interference noise ratio (SINR) and bit error rate (BER) the performance analysis as shown in Figures 5 and 6. The objective is to get the ideal solution by combining this N data sets using equation 6.

$$Y' = \sum_{n=1}^N a_n Y_n \quad (6)$$

Where 'n' in above equation represents the weighted phase factors and its value ranges form $\{n = 1, 2, 3, 4, 5, \dots, N\}$. This weighted phase factors are rotated using different combination of values; 'Y' represents the total number of PTS⁽²⁷⁾ ⁽²⁸⁾. The PAPR can be effectively reduced by using a greater number of phase factors which in turn increase the complexity index in the computation of system.

5 Adaptive PTS (A-PTS Technique in OFDM Communication System

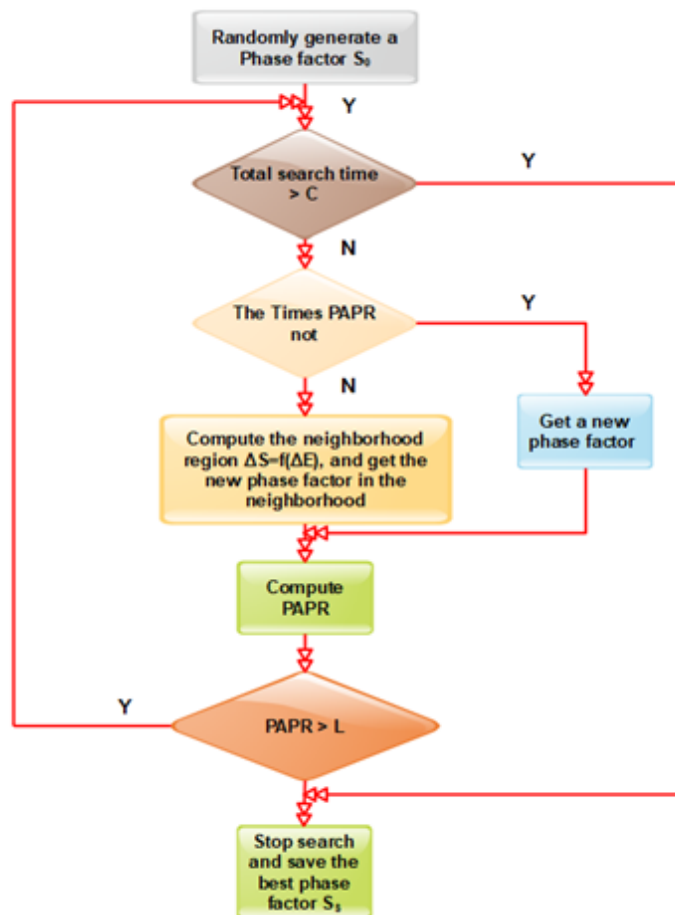


Fig 7. Functional flow chart of Adaptive PTS algorithm to reduces PARA in OFDM communicationSystem by using QAM modulation Techniques

One disadvantage of the PTS technique is that it requires a detailed search algorithm to discover the signal with minimum PAPR after multiplying with phase factor that further increases the computation complexity and time required to search the function flow chart as shown in Figure 7. To overcome this the adaptive PTS technique⁽²⁹⁾ ⁽³⁰⁾ that search the signal with minimum PAPR using neighborhood search algorithm is used.

Table 1. The comparison of PARA reduction in OFDM system on basis of subcarrier in QAM techniques

| Number of Subcarriers | PAPR in dB (CCDF at 10 ⁻³) | | | |
|-----------------------|--|------|------|------|
| | m=2 | m=4 | m=8 | m=16 |
| 1024 | 9.25 | 7.80 | 8.23 | 5.96 |
| 512 | 9.25 | 7.36 | 7.60 | 5.70 |
| 256 | 8.95 | 6.90 | 7.18 | 5.30 |
| 256 | 8.95 | 6.90 | 7.18 | 5.30 |
| 128 | 8.66 | 6.21 | 6.40 | 4.91 |
| 64 | 7.92 | 5.30 | 5.32 | 3.55 |

Duney Disney Sam, et.al⁽³¹⁾, were developed an Adaptive PTS algorithm to reduce PARA in OFDM communication System by using QAM modulation Techniques. The Performance analysis and comparison has been made on the basis of different parameters (various subcarriers, sub blocks and QAM scheme) on OFDM communication system with DCT succeeding adaptive PTS techniques. Table 1 and Figure 8 shows utilization and their performance due to different number of sub carriers and sub blocks on PAPR at CCDF 10-3 in OFDM communication system. For example, various sub blocks using 64 sub carriers shows better efficiency, reliability and accuracy compared to other lower subcarriers range. Increase in subcarrier without allocation of subblocks leads to increasing of PAPR in OFDM communication system. To overcome this overhead, we have adapted sub-blocks to allocate the subcarriers in PTS techniques to reduce the PAPR which consequently increases the complexity of the communication system.^{(32) (33)}

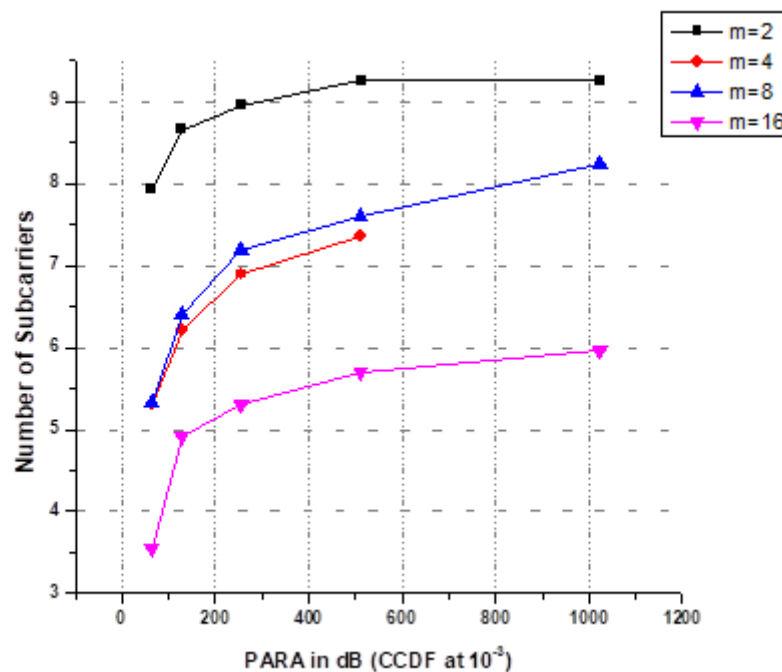


Fig 8. Modified PTS performance to PAPR reduction in OFDM communication system by using different QAM modulation techniques.

6 Characteristics of reconfigurable discrete cosine transform (RDCT) in OFDM communication system

Discrete Cosine Transform⁽³⁴⁾ is used to create the boundaries between the input data sequences using Fourier transformation that uses whole numbers. The PSD of the RDCT is computed using the relationship between the peak signal and its copy to extend the sequence of M-point data to 2M-point data sequence with the help of the mirroring technique. The RDCT generates the data which is continued on either end hence the components lower order will be ruled in the functional optimized transformed domain signal after the conversion process. The advantage of using RDCT is the compaction of signal energy and also reduces the interrelationship between the sequences of input data creating a boundary between the data sequences, which in turn reduces the PAPR of the OFDM signals. In this discussion, the brief insight of RDCT transformation is obtained. Since one-dimensional RDCT is orthogonal digital signal and does not require additional side information (authentication packet data) it is considered for the further computational process. For the input $B[k]$ the Discrete Cosine Transform is computed as follows.

$$B[k] = \gamma[k] \sum_{m=0}^{M-1} b[n] \cos \frac{\pi(2m+1)k}{2N} \quad (7)$$

The inverse of RDCT for the value of $k = 0, 1, 2, 3, 4, \dots, M-1$, is found using the following equation 8 and equation 9,

$$\gamma[k] = \frac{1}{\sqrt{N}} \text{ for } k = 0 \quad (8)$$

$$\gamma[k] = \frac{\sqrt{2}}{\sqrt{N}} \text{ for } k = 1, 2, 3, 4, 5 \dots N-1 \quad (9)$$

One Dimensional DCT produces a sequence of real and discrete-time sinusoids and is expressed by the following equation 10.

$$D_N[N, k] = \cos \frac{\pi(2n+1)k}{2N} \quad (10)$$

The RDCT comprises of M real data sequences as shown in the following equation (11) and equation (12).

$$D_M[M, 0], D_M[M, 1], D_M[M-2], D_M[M-3], D_M[M-4], \dots, D_M[M, m-1] \quad (11)$$

$$B_N = D_N \gamma \quad (12)$$

The vectors with the matrix size $M \times 1$ is represented by B and γ . The RDCT transform matrix of size $M \times M$ is represented by D_M where the columns or the rows in the matrix represents the orthogonal matrix vectors which decreases the OFDM signal's PAPR.

7 Proposed Work

7.1 OFDM signal processing by modifying the DCT method Before PTS technique with interleaver encoder used in communication system.

The RDCT based PTS technique is used to reduce the PAPR factor in the OFDM LTE signals by reducing the similarity in the data block sequences. It is even possible further to reduce PAPR using the discrete cosine transform that reduces interrelationship among the modulated data blocks.

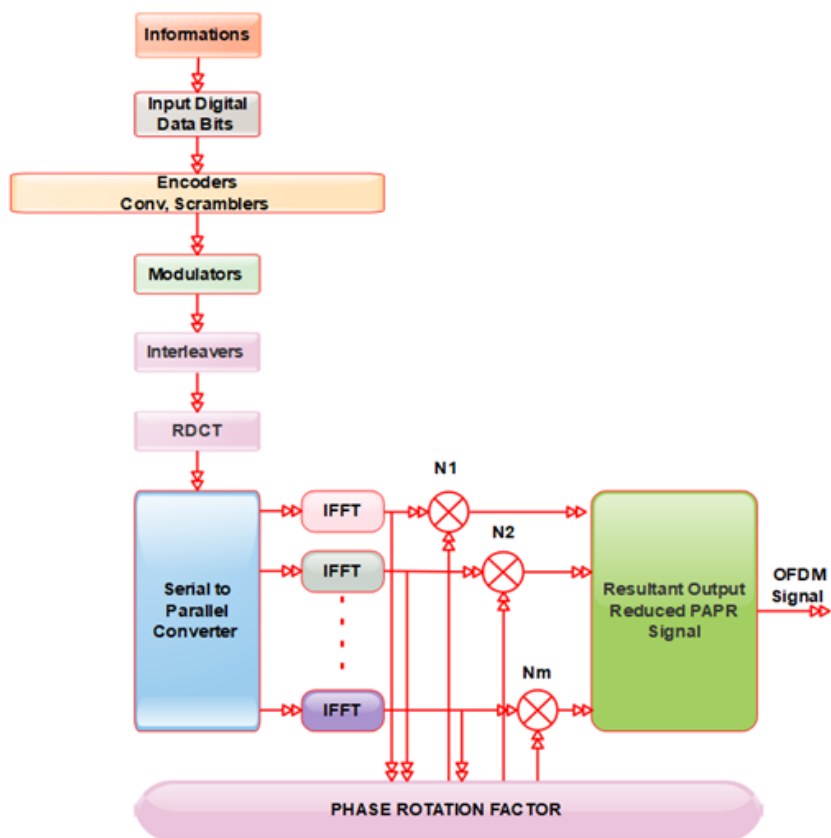


Fig 9. Functional Block diagram of OFDM communication system using RDCT before PTS methods with interleaver encoder

The Figure 9 Shows how RDCT is applied before PTS technique along with the Interleaver encoder in the proposed system. Here interleaver encoder is used to reduce the similarity by enclosing the data bits and also to get rid of the error burst and hence it is deployed along with RDCT prior to PTS technique focusing on reducing PAPR as much as possible.

7.2 OFDM signal processing by modifying the RDCT after PTS technique with interleaver encoder in communication system.

In this approach the PTS technique is used before applying RDCT as shown in the Figure 10 . This proposed work initially focus on reducing the PAPR of the OFDM signal using PTS technique and then use RDCT along with the Interleaver to reduce the interrelationship among the data blocks and also by enclosing the data bits to reduce further similarities between the data bits that are modulated to reduce PAPR in OFDM systems.

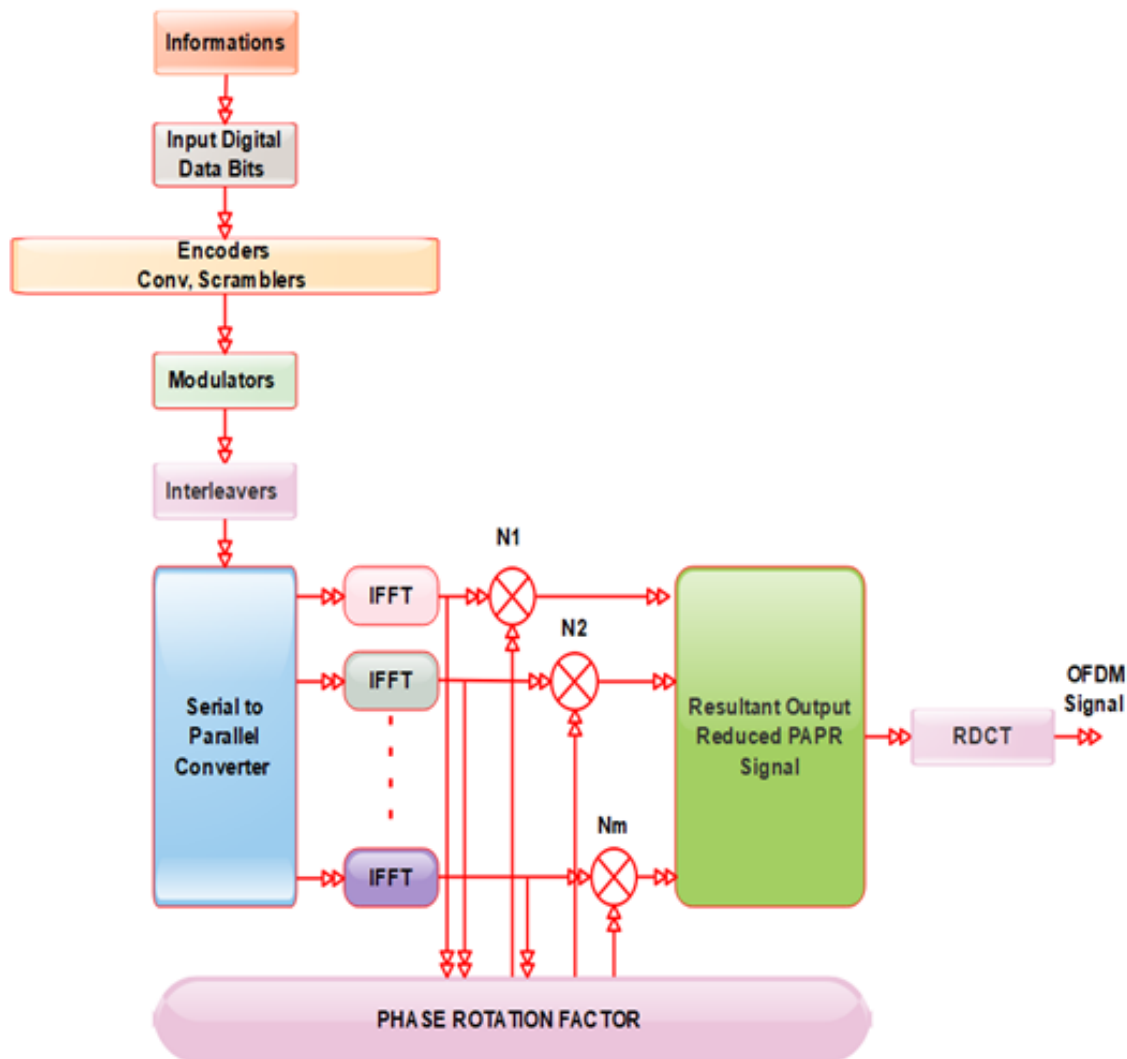


Fig 10. Block diagram of OFDM communication system using RDCT after PTS methods with interleaver encoder

8 Performance analysis and Simulation Results

We have used MATLAB software to study about the performance of the proposed system. The factors that are considered in this study are documented in the following Table 2 . The performance evaluation of the OFDM system based on RDCT along with interleaver and PTS technique is shown in the Figure 11 . The processing is carried out using QPSK scheme that uses 64 subcarriers and 4 sub-blocks system and it is found that the RDCT prior to PTS along with the interleaving has shown very effective in terms of performance when compared with

the conventional PTS technique for OFDM signal as well the RDCT after PTS along with interleaving.

Table 2. Simulation analysis criteria

| Analysis Criteria | Range and Variables |
|-------------------------|----------------------|
| Number of Phase Factors | 4 |
| Encoder | Conventional Encoder |
| Modulation Scheme | QPSK |
| Number of Subcarriers | 64 |
| Interleaver | Block Interleaver |
| Phase Weighing Factors | $i, -i, 1, -1$ |

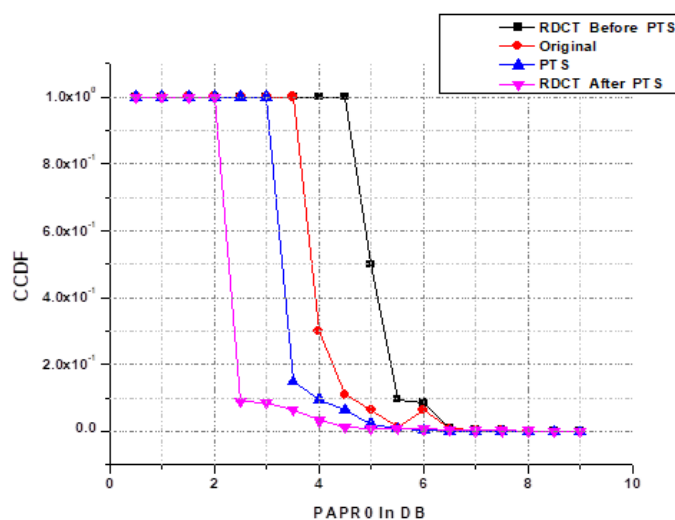


Fig 11. The performance evaluation of the OFDM system using RDCT based PTS along with interleaving, QPSK scheme, 4 sub-blocks and 64 subcarriers

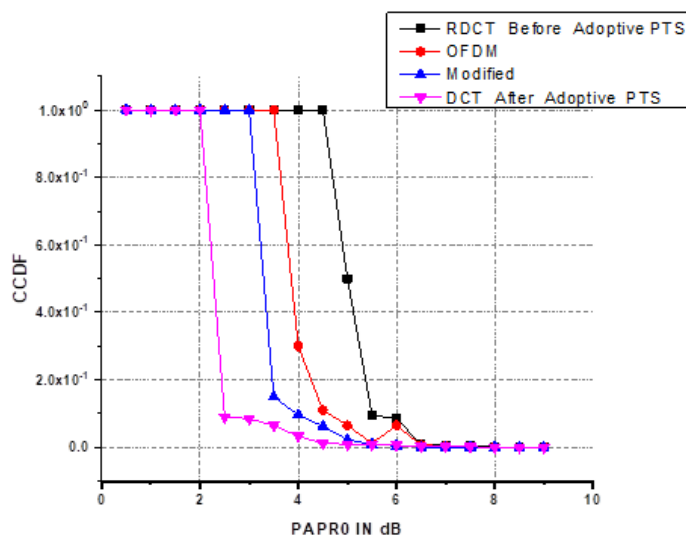


Fig 12. The performance evaluation of the OFDM system using RDCT based Adaptive PTS along with interleaving, QPSK scheme, 4 sub-blocks and 64 subcarriers

It can be seen in the graph that at the value of 10^{-3} the RDCT prior to adaptive PTS along with interleaving has a reduced PAPR of 5.1 decibels compared to other approaches like RDCT after adaptive PTS technique along with the interleaving, conventional PTS technique and normal OFDM method that has recorded the PAPR of 5.25 decibels, 5.8 decibels and 8.3 decibels.

It can be clearly observed that the RDCT prior to adaptive PTS along with the interleaving has showed the PAPR reduction of 13.79% compared to conventional adaptive PTS technique and RDCT after adaptive PTS along with the interleaving has showed the PAPR reduction of 9.48% compared to conventional PTS technique. RDCT prior to adaptive PTS along with the interleaving method has exhibited about 4.5% better performance against the DCT after adaptive PTS along with the interleaving method.

9 Conclusion

In this study, we have introduced a RDCT base adaptive PST with interleaving encoder in OFDM communication system to minimize the PAPR. The proposed method simulation was carried out using 64 subcarriers, 4 sub blocks in QPSK scheme. RDCT before PTS with interleaver encoder is used to reduce PAPR to 5.1 dB and RDCT after PTS with interleaver encoder to reduce PAPR to 5.25 dB. The conventional PTS has 5.8 dB and normal OFDM has 8.34 db. In order to further reduce PAPR, autocorrelation between data symbols have to be reduced. This can be done by application of RDCT and interleaving technique along with PTS technique.

The case study has the following observations:

- The RDCT before PTS with interleaver encoder shows 13.79% reduction in PAPR compared to conventional PTS.
- The RDCT after PTS with interleaver encoder shows 9.48% reduction in PAPR compared to conventional PTS.
- The DCT before PTS with interleaver encoder shows 4.5% better performance compared to DCT after PTS with interleaving.

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