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Low Complexity Partial Transmit Sequence Based Implementation to Reduce Peak to Average Power Ratio in OFDM Systems

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Abstract— ***Orthogonal frequency division multiplexing is a extremely useful and one of the most widely used wireless technology. Its high spectral efficiency, low inter symbol interference and very less cross talk makes it highly used in TV broadcasting or wire line systems like ADSL (Asymmetric digital subscriber line). The increasingly useful OFDM (Orthogonal frequency division multiplexing) systems too suffer from one major disadvantage of having a high PAPR, which is due to the superposition of N sub carriers. In this letter we counter the high PAPR (Peak to Average Power ratio) using PTS (Partial Transmit Sequence) algorithm, which is a more efficient technique than some other PAPR reducing techniques like SLM (Selected Mapping), clipping and amplitude filtering. We have lowered the complexity of the algorithm making it highly reliable and much more sharper in terms of lowering the PAPR. Our paper analyzes the PAPR plot in terms of CCDF (complimentary cumulative distributive function) by varying the sub carriers and the sub-blocks in PTS. We also carry out the phase optimization in PTS algorithm by using exhaustive search algorithm and modified exhaustive search algorithm so as to reduce PAPR to a greater extent in OFDM systems.***

Index Terms—***CCDF, OFDM, PAPR, Phase optimization, PTS, Sub carriers***

I. INTRODUCTION

After the advent of wireless communication, huge change has been observed in the lifestyle of people.

In wireless communication, initially data transfer was implemented using analog domain but now days it is mostly done in digital domain. Instead of a single carrier in the system multiple sub-carriers are implemented to make the process easier.

Orthogonal frequency division multiplexing is such multi carrier technology that has been proposed and developed for TV broadcasting and high-speed wireless networks. Despite the many advantages of OFDM like low ISI and high spectral efficiency, it still suffers from limitations such as sensitivity to carrier frequency offset and a large Peak to Average Power Ratio (PAPR). Superposition of N independent equally spaced subcarriers at the output of the Inverse Fast Fourier Transform (IFFT) in the transmitter is the main reason for high PAPR in the OFDM system. A large PAPR is a problem, as it reduces the efficiency of high power amplifiers. PAPR also affects the portability of the system, as due to high PAPR the HPA require a large battery backup, which in turn increases the systems complexity.

A number of solutions have been proposed to solve the PAPR problem in OFDM. Clipping OFDM signal before amplification is one such simple solution. But, clipping may cause inter-modulation among subcarriers and undesired out-of-band radiation. Another solution makes use of block coding, in which the data sequence is embedded in a larger sequence and only a subset of all the possible sequences are used, specifically, those with low peak powers. While block coding reduces PAPR, it also reduces transmission rate, significantly so for a large number of subcarriers. Furthermore, there is no efficient coding scheme for a large number of subcarriers. Recently, a promising technique for improving the statistics of the PAPR of OFDM signals has been proposed: the partial transmit sequence (PTS) technique.

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II. PEAK TO AVERAGE POWER RATIO

PAPR (Peak to average power ratio) basically shows the ratio of the peak values to the RMS (Root mean Square) values. It occurs when the different subcarriers of a multi-carrier system are out of phase with each other. Due to the occurrence of a large number of independently modulated subcarriers, the peak value of the system may become very high as compared to the average of the system.

The PAPR of a system is given by:

$$PAPR = \frac{\max|x(t)|^2}{E[|x(t)|^2]} \quad (1)$$

where E[] is the expectation operator.

The large peaks cause saturation in power amplifiers, which leads to intermodulation products among the subcarriers and disturbing out of band energy.

High PAPR increases the complexity in the analog to digital and digital to analog converter. Thus, it is highly desirable to reduce the PAPR.

There are several techniques to tackle this problem like 'Selected Mapping (SLM)', 'Clipping', 'Amplitude filtering', 'Interleaving', etc. but at the cost of increased BER, higher complexity, transmit signal power increase, loss of data rate, and so on. One promising solution is Partial transmit sequence, which effectively reduces PAPR overcoming the shortcomings of other techniques.

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III. PARTIAL TRANSMIT SEQUENCE

Peak to average power ratio is one of the major problems of OFDM. Many techniques have been proposed over the time to counter it. However no technique is fully efficient. Clipping OFDM signal before amplification is a simple solution, but it causes inter-modulation among sub carriers and undesired out of band raiations. Another solution to the same is block coding technique, where the data sequence is embedded in a larger sequence and only a subset of all the possible sequences are used, specifically, those with low peak powers. It reduces PAPR, but it also reduces transmission rate for a large number of subcarriers degarding the system performance.

One technique which is doing the rounds recently and promises to efficiently reduce PAPR and account for the disadvantages of previous technique is PTS (Partial transmit sequence).

A. Algorithm In Detail

- The data input block is partitioned into sub-blocks, representing certain portion of the actual information.
- Then the sub-blocks are passed on to IFFT and multiplied by a corresponding phase value and then added up to get the output signal whose PAPR will be comparatively less.
- Binary Phase Shift Keying (BPSK) or Quadrature Phase Shift Keying (QPSK) or Quadrature Amplitude Modulation (QAM) is used to modulate the input and the modulated signal as input for the proposed block diagram of PTS
- The modulated input is divided into different sub blocks, wherein each subset carries part of the original information.
- The phase values can be chosen from (±i, ±l). The subsets are subjected to IFFT and the outputs are multiplied by the phase value.
- To get optimized phase vector, optimization phase vector algorithms are applied.

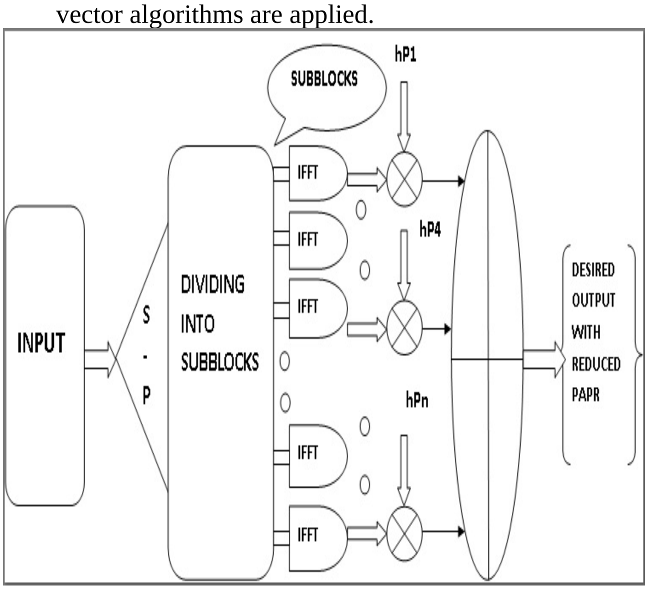

Figure 1: block diagram of pts

B. Implementation of PTS

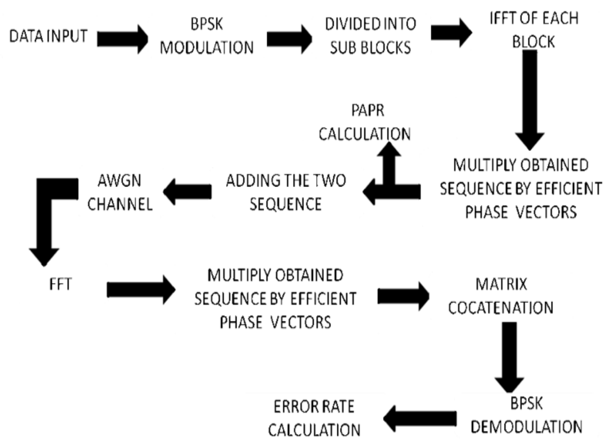

Figure 2: work flow of pts implementation

IV. PHASE OPTIMIZATION IN PTS TECHNIQUE

To reduce the PAPR to a greater extent, we need optimization. The objective is to optimize the phase factors with the aim of minimiziing the PAPR. PTS requires an exhaustive search over all combinations of allowed phase factors.

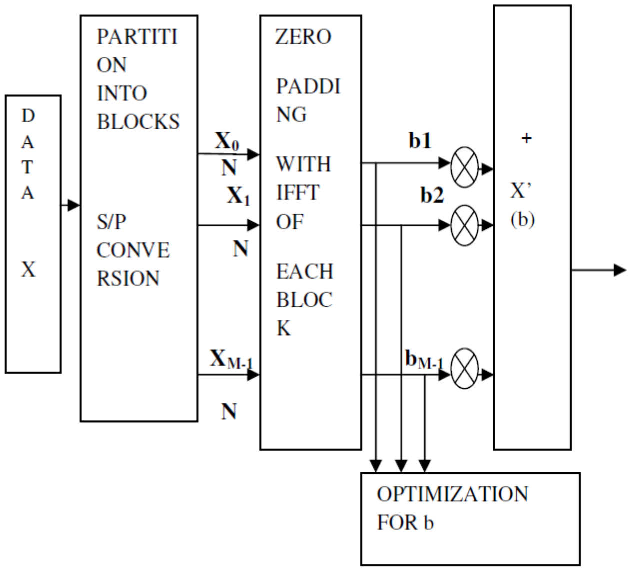

Figure 3: phase optimization in pts

A. Optimal Binary Phase Sequence (OBPS) Algorithm

In this approach, the phase factors are between 0 and pi and hence an exhaustive search can be carried out over all combinations of permissible phase factors. A drawback to this approach is that the complexity of the OBPS search increases exponentially with the number of sub blocks.

- In the PTS approach, the input data vector is partitioned into disjoint sub blocks as, $\{X_m, m = 1,2,\ldots,M\}$, and these are combined to minimize the PAR. Now, suppose that for, $m = 1,\ldots,M$, $A_m = [A_{m,1}, A_{m,2},\ldots,A_{m,N}]^T$ is the zero-padded IFFT of X_m. These are the Partial transmit sequence.

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- The objective is thus to combine these with the aim of minimizing the PAR. The signal samples at the output of the PTS combiner can be written as

$$S = \begin{bmatrix} A_{11} & A_{21} & \cdots & A_{M1} \\ A_{12} & A_{22} & \cdots & A_{M2} \\ \cdots & \cdots & \cdots & \cdots \\ A_{1LN} & A_{2LN} & \cdots & A_{MLN} \end{bmatrix} \begin{bmatrix} e^{i\varphi_1} \\ e^{i\varphi_2} \\ \vdots \\ e^{i\varphi_M} \end{bmatrix} \quad (1)$$

Where $S = [S_1(\varphi), \ldots\ldots, S_{LN}(\varphi)]^T$ contains the optimized signal samples. We shall write the phase factors as a vector, $\varphi = [\varphi_1, \varphi_2, \ldots\ldots, \varphi_M]^T$. The phase factors $\{\varphi_k\}$ are chosen to minimize the peak of the signal samples $|S_k(\varphi)|$. So the minimum PAR is related to the problem,

Minimize,

$$\max_{0 \le k \le LN} |S_k(\varphi)|$$

subject to, (2)

$$0 \le \varphi_m < 2\pi, \quad m = 1, \ldots\ldots, M$$

- The phase factors are restricted to a finite set of values and hence is approximated by the problem

$$\varphi_m \in \left\{ \frac{2\pi l}{W} \,\middle|\, l = 0, \ldots\ldots, W-1 \right\} \quad (3)$$

- If the number of rotation angles W is "sufficiently" large, the solution of (3) will approach that of (2). Furthermore, φ_1 can be fixed without any performance loss. Now, there are only M-1 free variables to be optimized and hence distinct W^{M-1} phase vectors, ϕ_l, need to be tested. As such, (3) is solved using W^{M-1} iterations; the ith iteration involves computing LN signal samples, each of which is denoted by, $S_k(\phi_l)$ using (1) and choosing the maximum $S_k(\phi_l)$ value.
- At the end of each iteration, the phase vector is retained if the current value of max $S_k(\phi_l)$ is less than the previous maximum. The phase vector that is retained after all the iterations are completed will be an approximation to the global optimal solution of (2).

B. New Modified Exhaustive Search Algorithm

The need for a new algorithm arises from the following observation. For given ϕ, we have the ith row of (1) as

$$S_i(\phi) = A_{1i}e^{j\varphi_1} + A_{2i}e^{j\varphi_2} + \cdots + A_{Mi}e^{j\varphi_M} \quad (4)$$

$$A_{ri}, r = 1,2,3, \ldots M$$

are fixed complex numbers dependent only on the input data frame.

- If we sort $|A_{ri}|$ as

$|A_{r_1i}| > |A_{r_2i}| > \cdots > |A_{r_Mi}|$

Where $\{r_1, \ldots, r_M\}$ is a permutation of { 1,….M}

and choose

$$\phi_{r_l} = -\angle A_{r_l i} \qquad l = 1,3, \ldots\ldots$$

$$\phi_{r_l} = \pi - \angle A_{r_l i} \qquad l = 2,4, \ldots\ldots \quad (5)$$

Where $\angle$ denotes the phase angle of a complex number, then the minimum amplitude sample is given by

$$S_i(\phi) = |A_{r_1i}| - |A_{r_2i}| + |A_{r_3i}| - \cdots \quad (6)$$

The phase selection (5) yields nearly always the maximum amount of amplitude cancellation for the ith signal sample.

- Thus, it is very easy to find ϕ that will nearly always minimize the amplitude of a single signal sample. Let ϕ_i be the solution (5) that nearly always minimizes S_i. Each ϕ_i can be viewed as a reasonable—but not necessarily the optimal— solution for (2).
- Next step is to compute all LN such solutions and choose the one that minimizes the maximum signal samples.
- Similar to the SES algorithms for (3), the new algorithm can be applied in LN iterations to obtain a solution for (2); the ith iteration involves computing LN signal samples $S_k(\phi_i)$ using (1) and choosing the maximum of $S_k(\phi_i)$. At the end of each iteration, the phase vector is retained if the current value of max $S_k(\phi_i)$ is less than the previous maximum.

There are two main differences between the SES algorithms and the new algorithm.

- First, the number of iterations changes from $W^{(M-1)}$ to LN
- Second, the phase vectors are computed differently. The phase factors from (5) are not restricted to 0 and pi, which is the case for SES with W=2. Rather, they are continuous variables between 0 and 2pi.

V. SIMULATIONS AND RESULTS

A. To Plot The CCDF Graph For 4 Sub Blocks In OFDM Systems UsingPTS Algorithm And Without PTS Technique And Observe The Difference In Plots.

In figure 4, We see that the proability of PAPR being greater than 7 dB(mean value) is 0.4549 without PTS technique and after applying PTS the proability of PAPR being greater than 7 dB(mean value) is 0.3001, much lesser than that without PTS.

N=64, M=16, W=4

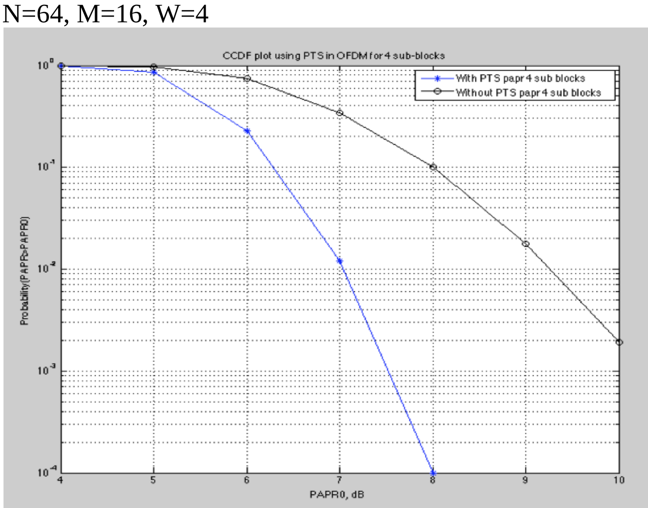

Figure 4: ccdf plot for 4 sub blocks in ofdm system with and without pts

B. To Plot The CCDF Graph For 8 Sub Blocks In OFDM Systems UsingPTS Algorithm And Without PTS Technique And Observe The Difference In Plots.

In Figures 4 and 5 PTS is implemented for 4 sub blocks and 8 sub blocks respectively.

In figure 5, We see that the proability of PAPR being greater than 8dB(mean value) is 0.3845 without PTS technique and after applying PTS the proability of PAPR being greater than 8dB(mean value) is 0.1984, much lesser than that without PTS.

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These clearly show that on applying PTS algorithm the CCDF of the system is less which implies reduction in Peak to Average power ratio of the system, thus improving the systems overall performance.

C. To compare the CCDF plots with respect to the number of sub blocks in the PTS algorithm and see how does the PAPR fare in the OFDM system on increasing the sub blocks.

The figure 6 shows that the CCDF for 8 sub blocks is less that 4 sub blocks on applying the PTS algorithm.

Thus we conclude that as the no. Of sub blocks increases there will be more reduction in the PAPR.

N=64, M=16, W=8

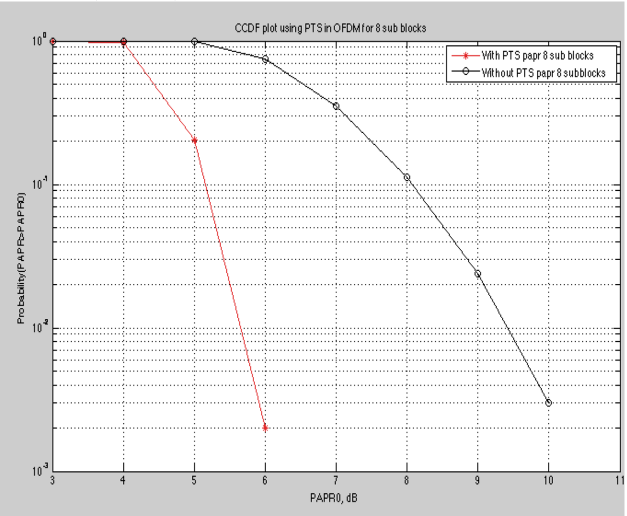

Figure 5: ccdf plot for 8 sub blocks in ofdm system with and without pts

D. To compare the CCDF plots with respect to the number of sub carriers in the OFDM system.

The figure 7 shows that as the value of N (Sub carriers) increases, PAPR0, dB increases.

The above CCDF clearly shows that as the sub carriers increased from 64 to 128 the CCDF graph shifted towards the left.

N=64, M=16

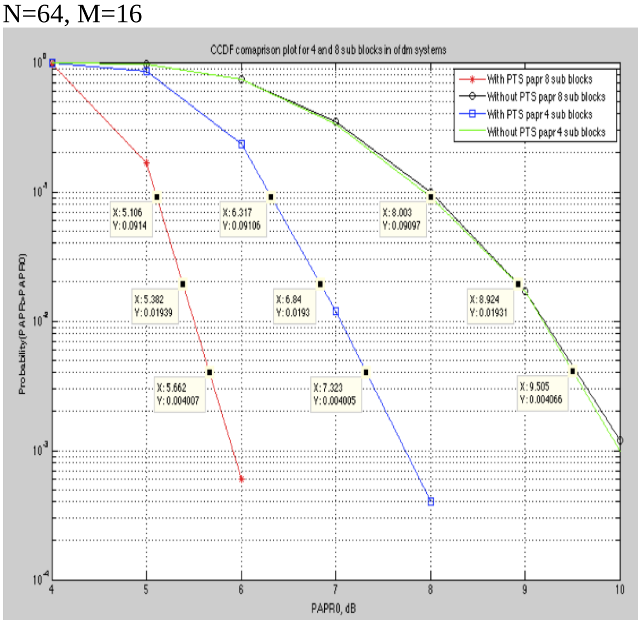

Figure 6: ccdf comparison plot for 4 and 8 sub blocks in pts technique

E. To compare the phase optimization technique (OTBS and new modified search) in PTS. (4 Sub blocks)

From figure 8 we see that the proability of PAPR being greater than 9.5dB(mean value) is 0.2266 in OBPS technique whereas it is 0.1751 in the new modified phase optimization scheme. Thus the new modified technique to optimize the phase in PTS is more efficient and yields less PAPR than the optimum binary phase sequence technique in PTS.

F. To compare the phase optimization technique (OTBS and new modified search) in PTS. (8 Sub blocks)

Similar to 4-sub block simulation we see that the proability of PAPR being greater than 6.5dB(mean value) is 0.4675 in OBPS technique whereas it is 0.2682 in the new modified phase optimization scheme. Thus the new modified technique to optimize the phase in PTS is more efficient and yields less PAPR than the optimum binary phase sequence technique in PTS.

From figure 8 and 9 we conclude that the modified exhaustive search technique to optimize the phase in PTS is more efficient than the simple OBPS method.

M=16, W=4

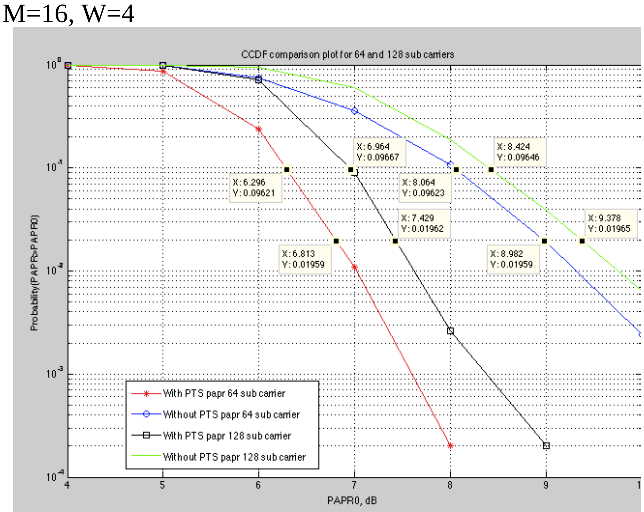

Figure 7: ccdf comparison plot for 64 and 128 sub carriers

N=64, M=16, W=4

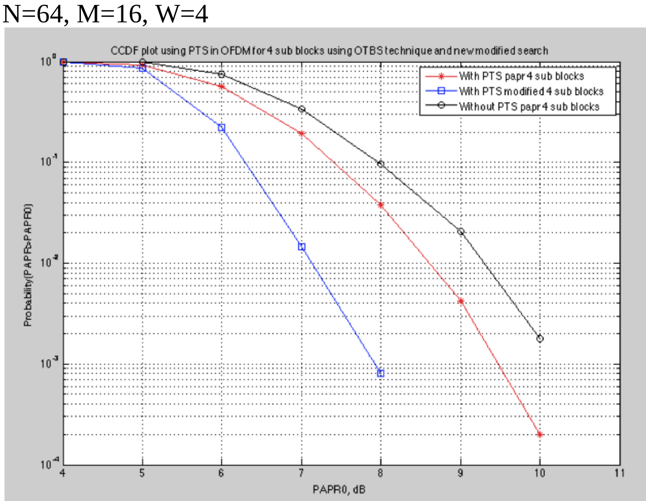

Figure 8: Comparison of phase optimization technique in pts for 4 sub blocks

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N=64, M=16, W=8

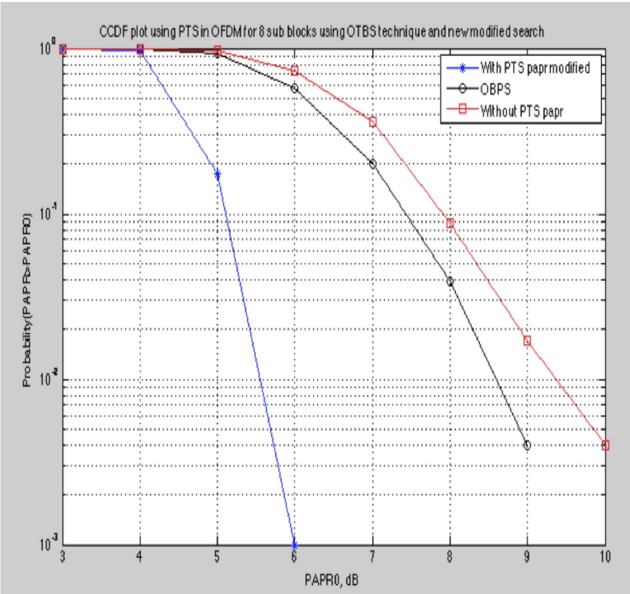

Figure 9: Comparison of phase optimization technique in pts for 8 sub blocks

VI. CONCLUSIONS

OFDM is a very attractive technique for multicarrier transmission and has become one of the standard choices for high – speed data transmission over a communication channel. It has various advantages; but also has one major drawback: it has a very high PAPR. We have aimed at reducing the high PAPR in OFDM systems and have thus implemented PTS technique to counter the high PAPR. We have lowered the complexity of our algorithm, which makes it easier to implement and also optimizes our results to reduce PAPR. In our study we plotted the CCDF using PTS algorithm for 4 sub blocks and 8 sub blocks. Our study also compared the CCDF plots with respect to the number of sub blocks in the PTS algorithm and saw how the PAPR fared in the OFDM system on increasing the sub blocks. We found that the PAPR reduces on increasing the sub blocks in the PTS algorithm. We also compared the CCDF(PAPR) of the system by varying the number of OFDM sub carriers, and found that on increasing the sub carriers the PAPR increased. Next, our study discussed about the phase optimization algorithms used in PTS. We implemented two algorithms (Optimum binary phase sequence and new modified exhaustive search) to optimize the phase in PTS. We found that the new modified search algorithm yielded a lower PAPR CCDF plot than the OBPS and it was more fast and efficient. Hence forth, we have implemented the PTS and seen that it efficiently reduces the PAPR, and also the PAPR behavior with respect to phase optimizing algorithms, sub carriers and sub blocks have been duly studied in the PTS technique.

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