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# PAPR Reduction Techniques Comparison in OFDM System

Shilpa Bavi[1], Sudhirkumar Dhotre[2]

[1]P.G.Student, Dept. of ENTC, NKOCET, Solapur, India

[2]Associate Professor, Dept. of ENTC, NKOCET, Solapur, India

**ABSTRACT:** In recent years, multimedia based application which requires the technology that supports high speed data transmission is growing rapidly. To achieve this high speed communication orthogonal frequency division multiplexing (OFDM) is most widely used technology. OFDM system makes the use of orthogonal subcarriers for data transmission with efficient usage of available bandwidth. However as number of subcarriers goes on increasing, Peak to average power ratio (PAPR) of OFDM signal also increasing. This high PAPR causes significant distortions when passed through non-linear amplifier. A number of promising techniques have been proposed & implemented to reduce PAPR of OFDM signal with expense of transmitted signal power, Bit error rate (BER), complexity etc. In this paper, amplitude clipping and filtering (ACF), Iterative clipping and filtering (ICF) and interleaved OFDM techniques are implemented for PAPR reduction of OFDM signal at transmitter. Comparison of these PAPR reduction techniques is done based PAPR and BER performance of the system.

**KEYWORDS:** Orthogonal Frequency Division Multiplexing (OFDM), Peak to-Average Power Ratio (PAPR), Bit Error rate (BER), Complementary Cumulative Distribution Function (CCDF), amplitude clipping and filtering (ACF), Iterative clipping and filtering (ICF)

## I. INTRODUCTION

Demands on wireless communication services increases rapidly, as wireless communication area improving in the very fastest way. Single carrier scheme is easy to use for low data rates because of its simplicity, accuracy. Single carrier scheme saves more power since there is no need to add guard interval while transmitting the signal. Single carrier scheme may have some drawbacks for high data rates including equalizing complexity. OFDM is used to overcome the drawback of single carrier system. Multicarrier (MC) modulation is a widely adopted technique in wireless communications because of its advantages. Here the orthogonal subcarriers uses Fourier transform without addition inter-carrier interference (ICI). OFDM system have main drawback of high peak-to-average power ratio (PAPR). An inherent property of MC transmission schemes is the high dynamic range of the transmitted signal. The high dynamic range of the MC signals causes a problem in most communication systems, since the signal has to be amplified by a power amplifier (PA) at the transmitter. Practical PAs do not maintain linearity over the whole dynamic range of the MC signal, thus amplifying different parts of the signal differently. This distorts the MC signal, resulting in a reduced bit error rate (BER) performance and also in a spectral regrowth, basically radiating energy at frequencies adjacent to the signal and at higher values than originally planned [1]. A number of approaches have been proposed and implemented to reduce PAPR which falls under different categories like signal distortion techniques, multiple signaling and probabilistic techniques and coding techniques with further classification in each category [2].

## II. RELATED WORK

In [2] author gives survey that provide the readers and practitioners in the industry with a broader understanding of the high peak-to-average power ratio (PAPR) problem in orthogonal frequency division multiplexing (OFDM) systems and generate a taxonomy of the available solutions to mitigate the problem. The survey clearly defines the metrics based on

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which the performance of PAPR reduction schemes can be evaluated. This paper also provides complexity analyses for a few PAPR reduction methods to demonstrate the differences in complexity requirements between different methods. In [3], article describes some of the important PAPR reduction techniques for multicarrier transmission including amplitude clipping and filtering, coding, partial transmit sequence, selected mapping, interleaving, tone reservation, tone injection, and active constellation extension. Also, author make some remarks on the criteria for PAPR reduction technique selection and briefly address the problem of PAPR reduction in OFDMA and MIMO-OFDM. In [4], author focused on a simple clip and filter scheme used to reduce the PAPR of OFDM system. Here a simulation result shows that there is an improvement in performance of OFDM system by reducing the PAPR using clip and filter scheme. It can be observe that OFDM signal has higher PAPR and after applying this method, PAPR reduces significantly. This PAPR is decreases as the number of clip and filtering is increased from one to four levels. In [5], author used clipping and filtering technique for peak to average power ratio (PAPR) reduction in OFDM. In this paper, author concluded from simulation result that this technique removes inband and out of band distortion along with 1dB reduction in peak to average power ratio when crest ratio changes from 1.4 to 1.2. Many techniques have been suggested and in proposed technique it has been shown that PAPR is reduced upto 5dB when crest ratio changes to 1.2 In [7], author proposed the sophisticated PAPR reduction technique, named Iterative Clipping and filtering (ICF) with DCT/IDCT transformation, is proposed for OFDM system. By considering the example of OFDM, with QPSK mapping, simulation results under MATLAB environment show that the new proposed method performs well in reducing PAPR.

## III. FUNDAMENTALS OF OFDM SYSTEM AND PAPR

## IV.

In this section, we discuss about the basics concept of OFDM systems and overview of PAPR in OFDM, mathematical formula for PAPR & the motivation of reducing PAPR.

### *A. Basic OFDM*

OFDM is a combination of modulation and multiplexing which is also known as special case of multicarrier modulation (MCM) scheme. OFDM system transmits a high-speed data stream by dividing it into a number of orthogonal channels, referred to as subcarriers, each carrying a relatively-low data rate. This procedure partitions the transmission frequency band into multiple narrower subbands, where each data symbol's spectrum occupies one of these subbands. As compared to the conventional frequency division multiplexing (FDM), where such subbands are non-overlapping, OFDM increases spectral efficiency by utilizing subbands that overlap (Fig. 1).

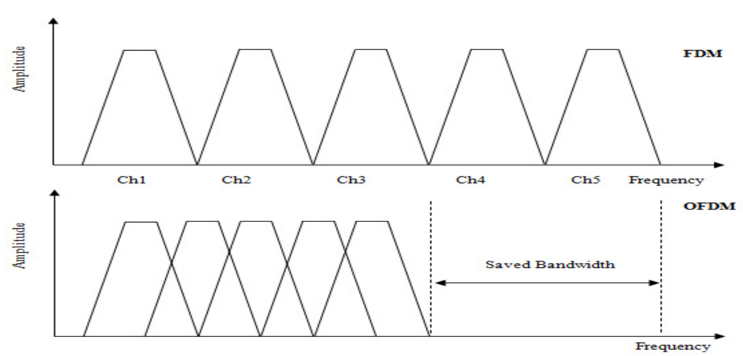


Fig.1. Comparison of the spectral utilization efficiency between FDM and OFDM scheme

To avoid interference among subbands, the subbands are made orthogonal to each other, which mean that subbands are mutually independent [2]. Also guard interval (GI) between consecutive OFDM symbols is inserted to remove effects of ISI, which is usually introduced by frequency selective multipath fading in a wireless environment.

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*B. Mathematical Formula Of OFDM Signal*

In OFDM systems, a fixed number of successive input data samples are modulated first (e.g., PSK or QAM), and then jointly correlated together using inverse fast Fourier transform (IFFT) at the transmitter side. IFFT is used to produce orthogonal data subcarriers. Let, data block of length Nis represented by a vector, $X=[X_0, X_1 \ldots XN_{-1}]^T$. Duration of any symbol $X_K$in the set $X$ is $T$ and represents one of the sub-carriers set. As the N sub-carriers chosen to transmit the signal are orthogonal, so we can have, $f_n = n\Delta f$, where $n\Delta f = 1/NT$ and $NT$ is the duration of the OFDM data block $X$. The complex data block for the OFDM signal to be transmitted is given by [3],

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n \, e^{j 2\pi n \, \Delta \mathrm{f} t} \qquad 0 \le t \le NT \qquad \text{eq.(1)}$$

Where, $j = \sqrt{-1}$ , $\Delta f$ is the subcarrier spacing and NT denotes the useful data block period.

*C. Overview Of PAPR*

When the OFDM signal is transformed to time domain, the resulting signal is the sum of all the subcarriers, and when all the subcarriers add up in phase the result is a peak N times higher than the average power. High PAPR degrades performance of OFDM signals by forcing the analog amplifier to work in the nonlinear region, distorting this way the signal and making the amplifier to consume more power [4]. The PAPR for the continuous-time signal x(t) is the ratio of the maximum instantaneous power to the average power. For the discrete-time version $x[n]$, PAPR is expressed as given in eq. (2) [2],

$$\mathrm{PAPR}(\mathrm{x[n]}) = \max_{0 \le n \le N-1} \frac{|\mathrm{x[n]}|^2}{\mathrm{E}|\mathrm{x[n]}|^2} \qquad \text{eq. (2)}$$

where E [.] is the expectation operator.

## V. PAPR REDUCTION TECHNIQUES

*A. Simple Clipping And Filtering (ACF) Technique*

Clipping and filtering is one of the simplest methods of PAPR reduction in OFDM system. This is the method of clipping the high peaks of the OFDM signal before passing it through the power amplifier (PA). This is done with the help of clipper that limits the signal envelop to the predetermined level known as clipping level(CL),if the signal goes beyond the CL; otherwise clipper passes signal without any change[2]. The clipped signal is given by eq. (3) [2]

$$,y[n\ ] = \begin{cases} -CL, & if\ x[n] < -CL \\ x[n], & if -CL \le x[n] \le CL \\ CL\ , & if\ x[n] > CL \end{cases} \qquad \text{eq. (3)}$$

Where $x[n]$ is the OFDM signal, CL is the clipping level. Fig.2 shows OFDM signal transmission block diagram using simple clipping and filtering scheme [5]. Clipping is a nonlinear process that causes the distortion as source of noise, which falls in both in-band and out-of-band distortions [4]. In –band distortion can degrade the BER performance and cannot be reduced by filtering. However, oversampling by taking longer IFFT can reduce the in-band distortion effect as portion of the noise is reshaped outside of the signal band that can be removed later by filtering [2].While the out of band distortion causes spectral spreading and can be eliminated by filtering the clipped OFDM signal which can preserve the spectral efficiency and, hence, improving the BER performance but it can results in some peak power regrowth.

*B. Iterative Clipping And Filtering (ICF) Technique*

Iterative clipping and filtering (ICF) is a widely used technique to reduce the PAPR of OFDM signals and to overcome the limitations of simple amplitude clipping and filtering method. Fig.3 shows the basic block diagram of the ICF PAPR reduction scheme [5]. However, the ICF technique, when implemented with a fixed rectangular window in the frequency-

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domain, requires much iteration to approach the specified PAPR threshold in the complementary cumulative distribution function (CCDF) [7]. The proposed clipping is performed by using following formula [7],

$$\hat{x}_m(k) = \begin{cases} C_m e^{j\theta_m k}, & |x_m(k)| > C_m \\ x_m(k)\,, & |x_m(k)| \le C_m \end{cases} \qquad \text{eq. (4)}$$

where $1 \le k \le lN$, $\theta_m$ represents the phase of $x_m$ , and $c_m$ is the clipping level in the m-th iteration. Here clipping level is recalculated in an each iteration according to a constant value known as the clipping ratio (CR) using following formula [7],

$$CR = \sqrt{PAPR_{\max}} = \frac{C_m}{\frac{1}{\sqrt{N}}\left\|x_m\right\|_2} \qquad \text{eq. (5)}$$

The filtering step is dependent upon a rectangular window with frequency response defined by [7],

$$F_m(i) = \begin{cases} 1, & 1 \le i \le N \\ 0, & N+1 \le i \le lN \end{cases} \qquad \text{eq. (6)}$$

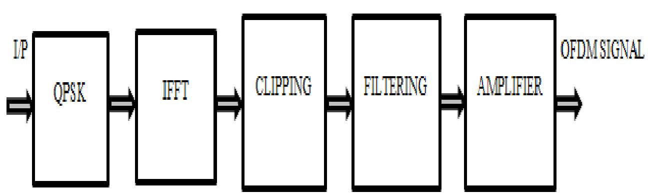


Figure. 2. OFDM signal transmission block diagram with ACF

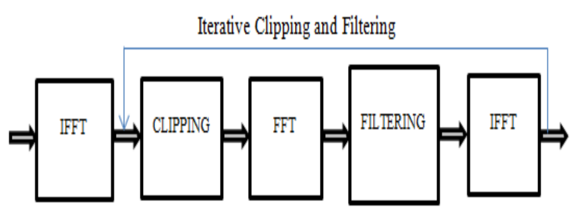


Figure 3. OFDM signal transmission block diagram using ICF

*C. Interleaved OFDM Technique*

Interleavers are the devices used to generate multiple OFDM signals that carry the same information [2]. Basically, an interleaver is a device that operates on a block of symbols and permutes or reorders them in a specific way. These Permutations can be performed on the symbols or bits. Multiple interleavers are used to generate a set of sufficient different permutations from the original data block, to achieve a substantial decrease in PAPR at the transmitter of OFDM system[2].When the interleaver operates on the block of N symbols and perform the permutation then, data block X=[$X_0$, X1,….., $X_{N-1}$]$^T$ becomes X' $= [X_{\pi(0)}, X_{\pi(1)}, \ldots\ldots, X_{\pi(N-1)}]^T$ where {n}↔{π(n)} is one to one mapping π(n) ϵ {0,1,…,N-1}and for all n [3]. Here for generating multiple OFDM signals, the IDFT is calculated individually for each one of the different permutations. Then the OFDM signal which is having the smallest PAPR is selected for the transmission.Fig.4 shows the block diagram of the interleaved OFDM transmitter. For including original data block in the comparison of PAPR of M different OFDM signals, M-1 interleavers and M IDFT blocks are required [2]. Further in this technique, transmission of [$\log_2$M] side information bits to the receiver is required since to recover the original data block the receiver need to know which interleaver was used to generate selected low PAPR signal for transmission. Receiver for such system calculates FFT of received signal and performs de-interleaving operation with the de-interleaver according the received side information. The permutation indices have to be stored in both the transmitter and receiver [2].Thus interleaving and de-interleaving can be performed easily. In this method, the amount of PAPR reduction depends upon two factors that are, the number of interleavers (M-1) and the design of interleaver [3].

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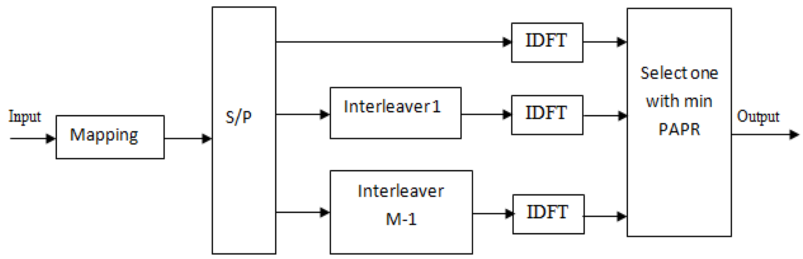


Fig.4. Block Diagram of Interleaved OFDM Transmitter

## VI. RESULTS AND DISCUSSION

The parameters used for simulation are based on IEEE 802.11a standard as shown in table.1. The simulations are conducted first for simple clipping and filtering method to reduce PAPR value of OFDM signal with QPSK modulation and a clipping ratio (CR) of 1dB, 5dB and 7dB. The CR is related to the clipping level by the expression [2],

$$CR = 20\ \log_{10}\left(\frac{CL}{E[x[n]]}\right), \qquad \text{eq.(7)}$$

Where E[x[n]] is the average of OFDM signal x[n]. The empirical CCDF is the most regularly used for evaluating the PAPR. PAPR reduction capability is measured by the amount of CCDF reduction achieved. CCDF provides an indication of the probability of the OFDM signal's envelope exceeding a specified PAPR threshold within the OFDM symbol and is given by [2],

$$\mathrm{CCDF}\left[\mathrm{PAPR}\left(x^{n}(t)\right)\right] = \mathrm{prob}[\mathrm{PAPR}(x^{n}(t) > \delta)] \qquad \text{eq. (8)}$$

Where PAPR ($x^n(t)$) is the PAPR of the $n^{th}$ OFDM symbol and δ is some threshold. Fig. 5 shows the empirical CCDF versus PAPR plot for simple amplitude clipping and filtering method with different values of CR. The performance of a modulation technique can often be measured in terms of required signal-to-noise ratio (SNR) to achieve a specific bit error rate (BER). From fig.5, it is found that as CR goes on decreasing from 7dB to 1 dB, empirical CCDF is decreasing and hence more reduction in PAPR from 7dB to 1 dB. Hence efficiency of PAPR reduction at transmitter increased from 7dB to 1dB. Fig. 6 shows the BER versus SNR plot for simple amplitude clipping and filtering method with different values of CR. Clipping the high peaks of the OFDM signal causes a substantial in-band distortion that leads to degradation in the BER performance.

Table I. Parameters Used for Simulation

| **Parameters** | **Value** |
|---|---|
| RF Band | 5 GHz |
| Channel Bandwidth | 20 MHz |
| Number of subcarriers | 52 |
| Subcarrier spacing | 312.50 KHz |
| FFT size | 64 |
| Channel model | Rayleigh channel |

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As shown in fig. 6, as CR goes on decreasing from 7dB to 1 dB, the BER performance is degraded. Hence we found that for CR equals to 1dB, we get maximum PAPR reduction but we are also getting maximum BER so BER performance is degraded.

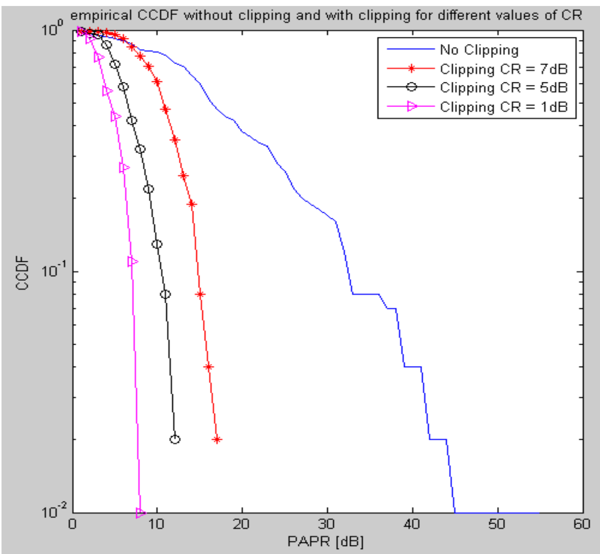


Figure 5. Empirical CCDF without clip and with clipping and filtering

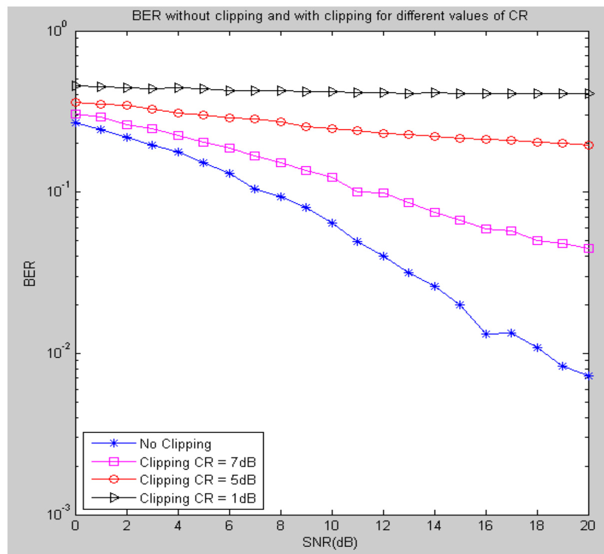


Fig.6. .BER without clipping and with clipping and filtering

Secondly, we evaluate the ICF scheme to improve the performance of simple clipping and filtering further. Fig.7 shows the CCDF versus PAPR plot of the iterative clipping and filtering with FFT/IFFT. The ICF scheme gives better performance compared with simple amplitude clipping and filtering techniques. That means it gives more reduction in PAPR than simple clipping and filtering technique with better BER performance.

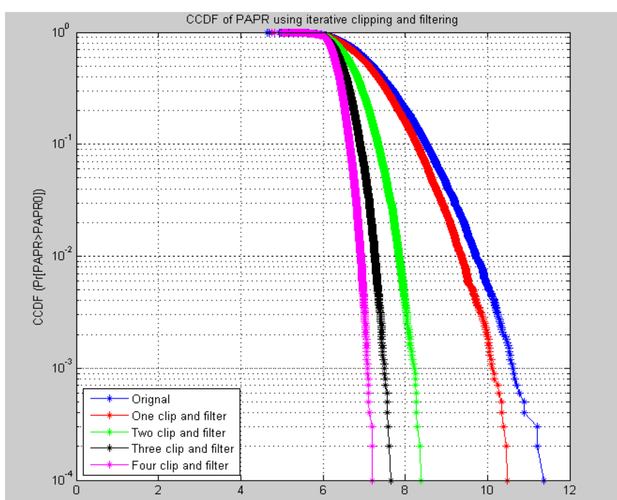


Fig. 7. CCDF of PAPR using Iterative Clipping and filtering technique

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Fig. 8 shows the BER performance and fig. 9 shows ccdf vs. PAPR plot for interleaving technique. Interleaved OFDM technique gives better BER Performance than previous method but less PAPR reduction in comparison with previous PAPR reduction techniques.

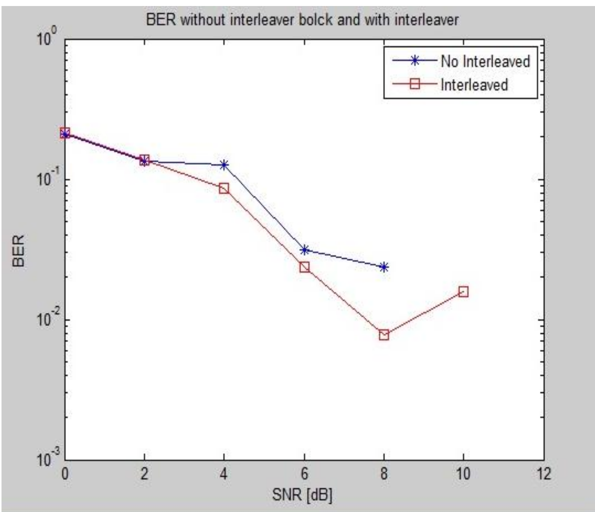


Fig.8 .BER without interleaving and with interleaving

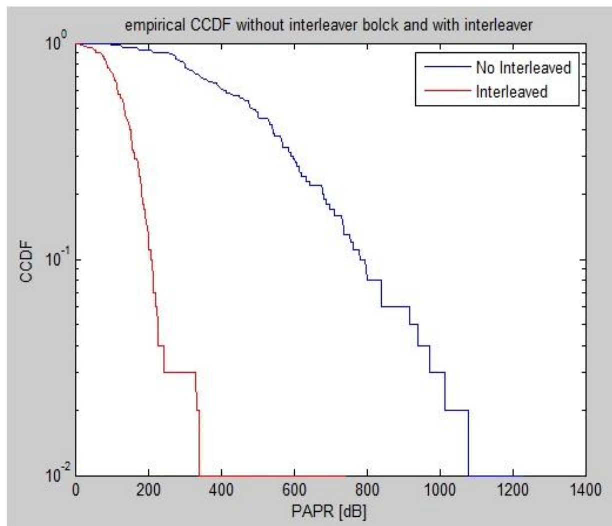


Fig.9. Empirical CCDF without interleaver and with interleaver

## VII. CONCLUSION AND FUTURE WORK

OFDM is an efficient multicarrier modulation technique for both wired and wireless applications due to its high data rates and spectral efficiency. The major drawback in OFDM system is high peak-to-average power ratio. This high PAPR drives the transmitter's power amplifier into saturation, causing nonlinear distortions and spectral spreading. In order to minimize the effects of high PAPR in OFDM systems, clipping & filtering is a simple solution among all other PAPR reduction techniques. Simple amplitude clipping and filtering method causes the in band distortion which cannot be reduced by filtering .Filtering used to reduce out of band distortion results in peak power regrowth. The proposed Iterative Clipping and Filtering reduces both in- band distortion and peak power regrowth. It can be observe that OFDM signal has higher PAPR and after applying this method, PAPR reduces significantly. Also it is observed that as the number of clip and filter is increasing from one to four levels, PAPR value goes on decreasing. Interleaved OFDM technique gives better BER performance than clipping and filtering technique but results in much complexity. One can also use ICF with DCT/IDCT transformation to improve performance. Further one can go for combination of two techniques to overcome the problems and improve performance.

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