CHAPTER 3 CONVENTIONAL METHODS FOR PAPR REDUCTION

Orientation of the chapter includes discussion of various PAPR reduction taxonomies, efficient schemes and their performance criteria based on literature survey. The simulation of various popular conventional schemes is done in Matlab (R2010) environment. The performance of the proposed combinational approach is also compared with other conventional schemes.

3.1 PAPR reduction taxonomy

The approaches of PAPR reduction are classified in terms of different taxonomies shown as in Figure 3.1-

3.1.1 Coding

The coding schemes identify codeword for minimizing the PAPR. It can be achieved through the addition of parity bit [Jones et al. (1994)] in original sequence. Generally, frequency-domain finds the set of permissible [Wulich (1996)] code words as shown in Figure 3.2. Various coding schemes are described as follows-

- Linear Block coding [Jones et al. (1994)],
- Golay complementary sequence [Davis and Jedwab (1999)], and
- Turbo code codes [Akaidi et al. (2007)] etc.

Linear block coding: The rate cyclic code [Jones et al. (1994)] is used for mapping of 3 into 4 bits. An exhaustive search is required for finding suitable code for encoding and decoding needs large lookup tables [Yang and Chang (2003)].
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**Figure 3.2:** PAPR reduction using coding scheme

**Golay complementary sequence:** A pair of two sequences whose periodic autocorrelations sum is zero in all out-of-phase positions [Daoud and Alani (2009)]. The combination of block and Golay sequence is not limited to control the PAPR, but also incorporates Forward Error Correction (FEC) [Wulich (1996)].

**Turbo coding:** One way to exploit turbo code for PAPR reduction is to implement the probabilistic approach with the candidates generated by a turbo encoder through various interleaves [Akaidi et al. (2007)].

Error control capability and easy implementation are the main advantages of coding schemes. On the other hand, the drawback of these techniques is suitable codeword selection at the cost of coding rate loss.

**3.1.2 DFT-Spreading**

The transform plays an important role to generate orthogonal subcarrier frequency in OFDM. The concept of spreading is to add an extra block of M point FFT before N point IFFT as shown in Figure 3.3. It is considered as a DFT-pre coded or DFT-spread Orthogonal Frequency Division Multiple Access (OFDMA). In general, is lower than , in case of Single Carrier-FDMA (SC-FDMA) [Myung et al. (2006)].
Figure 3.3: DFT-spreading based SC-FDMA technique

SC-FDMA deals with the assignment of multiple users to a shared communication resource. The approaches of assigning subcarrier among users are as follows-

- **DFDMA (Distributed FDMA)**: Distributes DFT outputs onto the entire band with zeros filled in unused subcarriers.
- **LFDMA (Localized FDMA)**: DFT outputs to consecutive subcarriers in subcarriers.
- **IFDMA (Interleaved FDMA)**: Distributes DFT outputs with equidistance, where is a bandwidth spreading factor.

Although SC-FDMA shows low PAPR and less sensitivity towards non-linear distortion, but suffers from high Carrier Frequency Offset (CFO) and complexity due to extra DFT processing. Therefore, SC-FDMA is adopted as uplink transmission in the Third Generation Partnership Project Long Term Evolution (3GPP LTE) standard.

### 3.1.3 Distortion

The key initiative of distortion philosophy is to identify high amplitude samples above predefined threshold value in transmitted envelop. The most well-known distortion techniques are clipping, non-linear companding, peak windowing and peak cancellation.

**Clipping**: It is the simplest method among PAPR reduction taxonomy; employs a clipper that limits the signal envelope to a predetermined clipping level if the signal exceeds that level. Otherwise, the clipper passes the signal without any change and is defined as-

\[ M_{pt} \text{ FFT} \]

\[ \text{S/P} \]

\[ \text{M pt FFT} \]

\[ \bar{x}[n] \]

\[ \text{P/S} \]

\[ \text{N pt IFFT} \]

\[ \text{Subcarrier Mapping} \]

\[ X[K] \]
where is clipping or threshold level. Clipping is a non-linear process as shown in Figure 3.4 and receiver need to estimate the location of samples and threshold level [Li and Cimini (1998)]. There are several effects of clipping such as out-of-band radiation and non-linear distortion. This enhances the spectral re-growth of the system [Chakrapani and Palanisamy (2012)].

**Figure 3.4:** Clipping method for the PAPR reduction

The proposal of filtering [Armstrong (2002)] is introduced to remove the spectral spreading. On the other hand, clipping may cause some peak re-growth, i.e. the signal after clipping and filtering will exceed the threshold level at some points. To reduce peak re-growth, a repeated clipping and filtering operation can be used to obtain a desirable PAPR at the cost of increased computational complexity [Sharif et al. (2003)]. Hence, non-iterative clipping and filtering methods are used for reduction in computational complexity.

**Non-linear Companding Transform (NCT):** The companding transforms [Wang et al. (1999)] are widely used in speech processing. However, tones have different level of amplitude and their optimization is also required for bit per sample. The NCTs perform as a strict monotone increasing function. Therefore, the companded signals at the transmitter can be recovered correctly through the corresponding inversion of the nonlinear transform function at the receiver. The advantage of the scheme is to enlarge the small signals while compressing the large signals to increase the immunity of small signals from noise [Jiang and Wu (2008)].
**Peak windowing:** The process of peak windowing [Kim et al. (2005)] is an interaction of window function to OFDM as depicted in Figure 3.5. Unlike clipping where the predetermined threshold limits the amplitude, windowing uses weighting function to multiply with peak samples. Hamming, Hanning and Kaiser are most commonly use window functions for PAPR reduction [Saxena and Joshi (2011)].

**Peak cancellation:** The objective of method is to choose sample when the magnitude exceeds a certain threshold level [Prasad (2004)]. The process is handled by comparator for checking operation as shown in Figure 3.5.

![Figure 3.5: Peak cancellation and peak windowing approach for the PAPR reduction](image)

The distortion approach is easy to implement, but suffers from in-band distortion and out-of-band radiation. It also disturbs the orthogonality between subcarriers.

### 3.1.4 Probabilistic

The term probabilistic is also known as scrambling in multi-carrier communication [Bauml et al. (1996)]. Through this approach, input data is scrambled and multiplied with suitable phase to obtain minimum PAPR sequences. It consist the following techniques –

- Tone leaving [Jayalath and Tellambura (2000)],
- Tone reservation (TR) [Tellado (1999)],
- Tone Injection (TI) [Tellado (1999)],
- SeLective Mapping (SLM) [Bauml et al. (1996)],
- Partial Transmit Sequence (PTS) [Muller and Huber (1997)] and
- Active Constellation Extension (ACE) [Krongold and Jones (2003)].
**Interleaving:** The theme of technique is to replace the phases of the original sequence by particular interleaves as shown in Figure 3.6. In this method, the permutation principle is used to produce interleaves phenomena. The multiple frequency-domain OFDM signals are generated that carry same information, but the lowest PAPR symbol is selected for transmission [Jayalath and Tellambura (2000)].

![Interleaving scheme](Figure 3.6: Interleaving scheme)

The scheme requires interleaves and IFFT blocks for subcarrier OFDM signals. Therefore, channel side information of a particular interleave has to send at receiver correspond to the permutation schemes performed at an OFDM transmitter.

**Tone Reservation (TR):** The concept of method is based on adding a dependent data in time-domain signal to the original multi-carrier signal as illustrated in Figure 3.7. The prime objective is to choose Peak Reduction Tone (PRT) or Peak Reduction Carrier (PRC) [Tellado (1999)] which provides a reduction in peak of original time-domain signal. The time-domain signal can be easily computed at the transmitter and stripped off at the receiver. On the other hand, frequency-domain processing is used for linear addition of reserved tone.
To find the value of reduction tone, it is required to have a solution for a convex optimization problem that can easily be framed as a linear programming problem. The locations of PRCs need to be known to the receiver and, therefore, are transmitted as overhead information. Since the subcarriers are orthogonal, these additional signals cause no distortion on the data bearing subcarriers. For OFDM systems with small subcarriers, the number of reserved tones will not be negligible thereby leading to loss in data rate [Tellado (1999)].

**Tone Injection (TI):** This scheme maps constellation into one of several equivalent points in the expanded constellation, which results in extra degrees of freedom and can be exploited for PAPR reduction. The TI implies that substituting a point in the basic constellation to a new point in the larger constellation is equivalent to injecting a tone of the appropriate frequency and phase of the multi-carrier signal. TR and TI for PAPR reduction methods prevent distortion by reducing the PAPR before the HPA. In TR the additional complexity is only in the transmitter. Suboptimal solutions to the PAPR minimization problem were presented which successfully reduced the complexity without sacrificing the amount of PAPR to a great degree [Tellado (1999)]. TI technique requires no channel side information at all and, consequently, there is no loss of bit rate. Also the complexity has added at the receiver is negligible since only two modulo-$D$ operations are required for the real and imaginary parts of the received symbol [Jiang and Wu (2008); Rahmatallah and Mohan (2013)].
3.2 Popular PAPR reduction techniques

3.2.1 Selective Mapping (SLM)

SLM, proposed by Bauml et al. in 1996, creates partitions in the sequence which are then multiplied by different phase array and sequence with minimum PAPR chosen from all blocks [Bauml et al. (1996)]. The OFDM sequence is divided into blocks having the same size as shown in Figure 3.8. All individuals blocks are multiplied by phase sequence, have the same length as the original OFDM sequence. This produces the new modified sequence, i.e. $x[n]$. The IFFT of all block sequences are computed as:

$$x'[n]$$

Among which, the one, with the lowest peak power is chosen from equation (3.2) for transmission i.e.

$$x[n]$$
The selective phase sequences are transmitted to a receiver for recovering the original OFDM sequence, called as channel side information. This can be represented as-

$$\bar{U} = \arg\min_{u=1,2,...,U} \left( \max_{n=0,1,...,N-1} |x^u[n]| \right)$$

(3.4)

### 3.2.2 Partial Transmit Sequence (PTS)

The PTS method, proposed by Muller and Huber, had multiple disjoint sub blocks and each of which multiplied with a suitable phase vector to minimize the PAPR [Muller and Huber (1997)]. The search of phase vector using candidate sequence is interdependent as compare to SLM [Bauml et al. (1996)]. Initially, PTS uses the Optical Binary Phase Sequence (OBPS) [Muller et al. (1997)] with arbitrary number of subcarriers. The combination of the cyclic shift of IFFT with partial sequences introduces the concept of adaptive OBPS [Hill et al.(2000)]. Cyclically shifted PTS increases the number of alternative transmit sequences with trivial operations by cyclically shifting the data before or after they are phase rotated. A sub-optimal Iterative Flipping Algorithm (IFA) [Cimini and Sollenberger (2000)] is combined with PTS shows poor performance but reduced complexity. A little bit increase in complexity occurs due to phase optimization [Tellumbura (2001)]. The phenomenon of optimization can be possible by the quantized phase factor. For a small number of sub blocks the proposed algorithm performs better than OBPS and if the number of sub blocks is large it performs similar to OBPS.

The OFDM sequences partitions into $V$ disjoint sub blocks $X[K] = [X^1, X^2, ..., X^V]^T$, which are consecutively located as shown in Figure 3.9. The sub blocks of equal in size with zero padding at vacant position, known as partial sequence, are transformed into time domain and collected the phase information from the respective sub block. With the help of phases of partial sequence, the new complex phase vectors $p^\nu = e^{j\theta^\nu}, \nu = 1, 2, ..., V$ are generated. The set of allowed phase is $p = e^{j2\pi\theta/W}, \theta = 0, 1, ..., W - 1$, while $W^{V-1}$ sets should be searched to find the optimum phases. The phase vector is selected in such a way so that the PAPR can be minimized, which is shown in equation-

$$\bar{x}[n] = \sum_{\nu=1}^{V} p^\nu x^\nu$$

(3.5)
Then, the time-domain signal with the lowest PAPR, shown in equation (3.5) is transmitted along with side information of phases to recover the original OFDM sequence.

\[(3.6)\]

Hence, PAPR performance through the PTS is lowest among other methods. However, selection of optimum phase factor is limited to a set of phase available. There are many parameters which affect the method such that number of sub blocks. It should also be noted that the data can be divided into sub blocks in different ways as depicted in Figure 3.10. Different PTS sub block structures have varying performance with pseudo random having the best and interleaving having the worst. Of course, there is a trade off with complexity, interleaved sub blocks are the least complex PTS structure to implement. It implements by using the Cooley-Tukey FFT [Proakis and Manolakis (2011)] algorithm. Therefore, adjacent sub bock partition is used throughout the research because it maintains the trade-off between complexity and performance.
Although SLM can produce multiple time domain symbols that are asymptotically independent, but the alternative symbols generated by PTS are interdependent. Therefore, PAPR reduction in PTS is better than SLM. The main difference between the SLM and PTS is

![Diagram showing types of partial sequence schemes: (a) Interleaved, (b) Pseudo-random, (c) Adjacent.](image)

**Figure 3.10:** Type of partial sequence scheme (a) Interleaved (b) Pseudo-random (c) Adjacent
scrambling [Eetvelt et al. (1996)], which applied to all subcarriers and each sub block respectively. Therefore, the search complexity increases exponentially with the number of sub blocks. On the other hand, PTS and SLM techniques require and bits of channel side information respectively [Han and Lee (2004); Goff et al. (2008)].

3.2.3 Active Constellation Extension

The ACE, proposed by Krongold and Jones in 2003, is a convex problem whose solution is guaranteed to be a global minimum PAR solution given with ACE constraints [Krongold and Jones (2003)]. The main principle of this technique is to shift the outer constellation points towards the exterior of original constellation generating an alternative representation of the same symbol. It can be applied to QPSK, and QAM constellations as depicted in Figure 3.11 (a) and Figure 3.11(b) respectively. The shaded regions are called allowable regions for extensions of symbols, because if a conventional constellation point is reassigned to another location inside the corresponding feasible region, the minimum Euclidean distance is guaranteed. However, 16-QAM constellation, the exterior non-corner constellation points the feasible regions are straight lines starting at the point itself and extend to infinity.

In general, ACE is min max problem and represent as follows-

\[(3.7)\]
where $C$ represents the set of extension vectors $C_k$ and $c$ represent the constrained space of allowable ACE vectors. In a literature [Krongold and Jones (2003)], two variances of ACE algorithms are presented, i.e. Projection Onto Convex Sets (POCS) [Jones (1999)] and Approximate Gradient Project (AGP) [Krongold and Jones (2003)].

**Project onto convex sets (POCS):** POCS have two convex sets that determine the extended constellation and interior points. The two convex sets can be as follows:

- $S_A$ represent for some positive constant $A$
- $S_C$ satisfy data-dependent ACE constraints [Gather and Polley (1998)].

The technique perform clipping at predefined level $A$ but the phase remains same as modulated sequence $x[n]$ as follows:

$$
\tilde{x}[n] = \begin{cases} 
   x[n] & |x[n]| \leq A \\
   4Ae^{j\theta[n]} & |x[n]| > A 
\end{cases}
$$

(3.8)

where $x[n] = |x[n]|e^{j\theta[n]}$. The second step is to convert clipped time–domain signal into a frequency-domain signal i.e. $\tilde{X}[K]$. The main task of the algorithm is to apply ACE constraints on updating sequence i.e. frequency-domain. It means restoring all interior constellation points to original location and project exterior points to the outer side of constellation as illustrated in Figure 3.1 through following conditions:

$$
\Re\{\tilde{X}[K]\} \geq \Re\{X[K]\} \tag{3.9}
$$

$$
\Im\{\tilde{X}[K]\} \geq \Im\{X[K]\} \tag{3.10}
$$

At last, perform iteration until PAPR is essentially minimized or no points are clipped. This generally leads to slow for convergence. Therefore, for situations in which the goal is to minimize the peak value, rather than achieve a fixed, maximum peak level, a related gradient-project algorithm can be developed [Jones (1999)].

**3.4. Approximate Gradient Project**

Steepest gradient direction is used in the AGP algorithm to minimize the peak value. The gradient step maximizes the time-domain peak reduction and is precisely proportional to the change that shrinks the peak by a very small amount. Therefore, rather than clipping of peaks in the POCS algorithm, it scales the largest time-domain peaks by a small amount and then project
them exactly as above to enforce the margin-preserving frequency-domain constraints. Such an algorithm is guaranteed to converge to a minimal peak level, due to the convexity of the constraints, with a vanishingly small scaling (gradient) step size [Krongold and Jones (2003)]. The final sequence is computed as below-

\[
\text{(3.11)}
\]

where \( n \) is number of iteration having maximum value up to \( N \) and \( \alpha \) is gradient size. The constellation extension by POCS and AGP are demonstrated in Figure 3.12 (a) and (b) respectively.

![Figure 3.12: Constellation extension for QPSK symbols through (a) POCS (b) AGP](image)

### 3.4 Proposed combinational schemes

Combinations of linear method present better PAPR reduction with moderate increase of computation complexity [Cuteanu and Isar (2012); Duanmu and Chen (2014)]. ACE techniques provide change in constellation and extend it in proper direction to minimize the PAPR. On the other hand, phase optimization techniques are used to scramble the OFDM symbols, multiply with phase factors and select one of them with the minimum PAPR. In fact, frequency-domain is used in constellation whereas scrambling performs in time-domain. These fundamental methods provide four possible combinational schemes as shown in Figure 3.13. As per earlier discussion the schemes such as AGP and PTS show a better PAPR reduction compared to POCS and SLM respectively. This implies that AGP-PTS scheme is best among four combinational techniques.
The serial and parallel combination of AGP and PTS scheme is known as Probabilistic Constellation Extension (PCE) and Partial Approximate Gradient Constellation (PAGC) respectively [Patidar et al. (2015)]. The block diagram of transmitter section of first proposed i.e. PCE technique is shown in Figure 3.14.

3.4.1 Probabilistic Constellation Extension (PCE)

The steps involved in proposed PCE algorithm [Patidar et al. (2015)] are as follows–

- **AGP Module:**
  1. Get an OFDM frame in frequency-domain signal and corresponding time-domain .
  2. Start with iteration, $t = 0$. Apply clipping by level that help to maintain constant envelop signal. Although phase is same as original sequence.

$$\text{(3.12)}$$

where

3. Obtain Clipped signal portion

$$\text{(3.13)}$$

4. Apply FFT on time domain signal to obtain

5. Enforce all AGP constraint to which is acceptable extension for given mapped constellation and set all other interior point to original location. Apply IFFT to obtain .

6. Determine suitable gradient and compute new sequence by equation –

$$\text{(3.14)}$$
7. Perform check operations using two conditions. First PAPR should be acceptable and compared to original, second maximum iteration count has been reached. Update.

8. Apply FFT to obtain new extended constellation sequence i.e.

![Block diagram of transmitter in PCE technique](image)

**PTS Module:**

9. Divide $X_{A}[K]$ into $V$ disjoint sub block with adjacent partition of equal size-

$$X_{A}[K] = \text{Partition into equal Sub block}$$  \(\text{(3.15)}\)

10. Obtain time domain signals using $V$ number of IFFT operation on partial sequences-

$$x[n] = F^{-1}\{X[n]\}$$  \(\text{(3.16)}\)

11. Generate set of phase vector

12. Multiply with partial sequence with corresponding phase factor.

13. Perform check operation equal to candidate sequence i.e. for minimum PAPR symbol to original signal.

14. Send minimum PAPR partial sequence with addition of all partial sequences-
\[ \bar{x}[n] = \sum_{\nu=1}^{V} \bar{p}^{\nu} \times x^{\nu}[n] \]  

(3.17)

15. Prepare side information for receiver to know corresponding phase factors.

\[ [\bar{p}^1, \ldots, \bar{p}^V] = \arg\min_{n = 0, 1, \ldots, N - 1} \left| \sum_{\nu=1}^{V} p^{\nu} x^{\nu}[n] \right| \]

(3.18)

### 3.4.2 Partial Approximate Gradient Constellation (PAGC)

This second proposed can be treated as the parallel switching between PTS and AGP as shown in Figure 3.15. The OFDM subcarriers corresponding to symbols are first divided in two equal halves and consequently their peak power are evaluated. The sequence of half OFDM symbols, which possess higher peak power is fed to AGP block and the other half is moved to PTS block as shown in Figure 3.15. Finally, the output sequences of both the blocks are combined and show a better performance as compared with individual scheme. The step involved in algorithm of the proposed scheme is summarized as follows:

1. Divide original OFDM subcarriers \( X[K] \) into two equal halves (i.e. \( X_1[K] \) and \( X_2[K] \)).

2. Apply AGP on selected half subcarriers \( X_1[K] \) (from step 3 to 9) and simultaneously PTS on rest half number of subcarriers \( X_2[K] \) (from step 10 to 14).

*AGP module:*

3. Set initial iteration \( t = 0 \). Compute IFFT i.e. \( x_a^t[n] \) and select optimum iterations as conventional technique.

4. Apply clipping by level \( C \) that help to maintain constant envelop signal. Although phase is same as in the original sequence –

\[ \bar{x}_a[n] = \begin{cases} x_a^t[n] & |x_a^t[n]| < A \\ A e^{j\theta[n]} & |x_a^t[n]| \geq A \end{cases} \]

(3.19)

where \( x_a^t[n] = x_a^t[n] e^{j\theta[n]} \)

5. Obtain clipped signal portion-
and transform into frequency domain.

6. Enforce all AGP constraint to which are acceptable extensions for given mapped constellation and set all other interior point to original location. Apply IDFT to obtain new extended constellation.

7. Assume suitable gradient and compute new sequence –

8. Calculate PAPR of . Update , and perform check operations using following two conditions. First PAPR should be minimum and second maximum iteration count has been reached.

9. Compute DFT on to get optimum reduced PAPR sequence.

**PTS Module:**

10. Apply PTS on (Figure 3.15) with same partition as in conventional technique i.e. V disjoint sub block of equal size having adjacent partitioning. Now, new partial sequence is.

11. Generate set of phase vector and multiply with partial sequence. Compute IFFT of new sequence i.e.

12. Perform check operations equal to candidate sequence for minimum PAPR symbol from partial sequence.

13. Consider minimized PAPR sequence as follows:

---

Figure 3.15: Block diagram of transmitter in PAGC technique
\[ x_p[n] = \sum_{v=1}^{V} p^v \times x^v[n] \]  

(3.22)

14. Prepare side information from equation (3.23) for receiver as-

\[ P_{rx} = \arg \min_{[p^1, \ldots, p^V]} \left( \max_{n=0, 1, \ldots, N-1} \left| \sum_{v=1}^{V} x^v_p[n] \right| \right) \]  

(3.23)

15. Finally, arrange both the optimum half sequences with minimized PAPR in time domain i.e. according to their original location-

\[ X_{out}[K] = [x_a[n] \ x_p[n]] \]  

(3.24)

3.4 Computational and time complexity

The PTS scheme requires \( \{V \times (N/2) \times n\} \) complex multiplication and \( \{(M + (4 \times V) + 2) \times N \times n\} \) complex addition, where \( V \) is number of sub block, \( N \) is number of OFDM subcarrier, \( n \) is the number of binary bit sequence and \( M \) is number of phase candidate sequence. On the other hand, AGP scheme utilizes \( \{t \times (\log_2(N/2) \times n)\} \) and \( \{t \times (4 \times N + N \times n)\} \) complex multiplication and complex addition respectively where \( t \) is number of iteration. Therefore, computational complexity of PCE technique is addition of computation required in both the techniques as shown in Table 3.1 [Patidar et al. (2015)].

<table>
<thead>
<tr>
<th>Operation</th>
<th>PTS</th>
<th>AGP</th>
<th>Proposed techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PCE</td>
<td>PAGC</td>
<td></td>
</tr>
<tr>
<td>IEEE 802.11a (N=52)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complex Multiplication</td>
<td>593</td>
<td>504</td>
<td>1097</td>
</tr>
<tr>
<td>Complex Addition</td>
<td>24307</td>
<td>1009</td>
<td>25316</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10474</td>
</tr>
<tr>
<td>IEEE 802.16e (N=200)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complex Multiplication</td>
<td>3058</td>
<td>2329</td>
<td>5386</td>
</tr>
<tr>
<td>Complex Addition</td>
<td>125359</td>
<td>4658</td>
<td>130017</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>56608</td>
</tr>
</tbody>
</table>

The PAGC technique requires the number of complex multiplications and complex additions as \( [V \times (\log_2(N/2) \times N/2) + t \times (N + (\log_2(N/2) \times N/2))] \) and \( [M + (4 \times V) + \)
Table 3.1 illustrates the computational complexity of conventional and both the proposed techniques on assuming , 2, , and is depends on the OFDM standard .

The polynomial time computation is also one of the important parameter to analyze the proposed techniques. The PCE needs more time to compute because AGP and PTS are run separately as shown in Figure 3.16 (a) and (b). On the other hand, PAGC requires less computation time than conventional techniques due parallel structure.

![Figure 3.16](image)

**Figure 3.16:** Polynomial time chart (a) WLAN (b) WiMAX

### 3.5 Simulation and Results

The proposed techniques have been validated through IEEE 802.11a and IEEE 802.16e standards using 64 and 256 respectively. The other simulation parameters are shown in Table 3.2.

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Name of Parameters</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>OFDM symbols</td>
<td>20000</td>
</tr>
<tr>
<td>2</td>
<td>Modulation</td>
<td>QPSK</td>
</tr>
<tr>
<td>3</td>
<td>Channel Model</td>
<td>AWGN</td>
</tr>
<tr>
<td>4</td>
<td>AGP and POCS clipping level ( ) in WLAN and WiMAX</td>
<td>0.2 and 0.1</td>
</tr>
<tr>
<td>5</td>
<td>AGP and POCS iteration ( ) and AGP gradient ( )</td>
<td>2 and 20</td>
</tr>
<tr>
<td>6</td>
<td>PTS and SLM sub block (V and U)</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>Phase factor (p)</td>
<td>1+i, 1-i, -1+i, -1-i</td>
</tr>
</tbody>
</table>
Figure 3.17: CCDF distribution in PCE technique (a) WLAN (b) WiMAX

**PCE technique:** In Figure 3.17 (a) it is shown that proposed method reduces PAPR by 0.4 dB compared to PTS method and 0.2 dB to POCS-PTS. This technique further reduces the PAPR on increasing the subcarriers i.e. in WiMAX. It is also shown in Figure 3.17 (b) that the reduction of 1 dB is achieved compared to PTS and 0.5 dB to POCS-PTS.
Figure 3.18: BER performance in PCE technique (a) WLAN (b) WiMAX

Figure 3.18 (a) and (b) illustrates that the PCE technique approximately maintains the same BER compared to other combinational techniques in both the standard i.e. WLAN and WiMAX.
Figure 3.19: Performance of power spectrum in PCE technique (a) WLAN (b) WiMAX

Figure 3.19 (a) and (b) illustrated that the proposed PCE technique not only allows smaller in-band ripples but also shows less out-of-band radiations as compared to conventional schemes for both the standard. Therefore, proposed technique avoids the possibilities of spectral spreading.
PAGC technique: Figure 3.20 (a) shows that a very small reduction of PAPR is achieved in proposed method compared to other conventional techniques working with less number of subcarriers i.e. in WLAN case. But if the number of subcarrier increases, a significant reduction in PAPR is visible as shown in Figure 3.20 (b).
Figure 3.21: BER performance in PAGC technique (a) WLAN (b) WiMAX

Figure 3.21 (a) clearly shows that the proposed PAGC method approximately follows the BER performance of conventional schemes for WLAN. On the other hand in Figure 3.21 (b) it is almost same as other conventional techniques for WiMAX. Therefore, for large number of subcarrier PAPGC shows better performance.
Figure 3.22: Performance of power spectrum in PAGC technique (a) WLAN (b) WiMAX

The PSD graphs of proposed PAGC method for both the OFDM standards are shown in Figure 3.22 (a) and b respectively. In proposed method, though the in-band-ripples have values more than other conventional scheme but it is restricted below -10dB. Therefore, proposed method also preserves spectral spreading.
Summary: Two combinational approaches for PAPR reduction in OFDM system viz. PCE and PAGC are proposed. The PCE is serial combination of AGP and PTS scheme. It provides smaller PAPR compared to each conventional technique without much deviation of BER performance. Contrary to PCE, PAGC is a combination approach which combines AGP and PTS in parallel structure. On comparison, PAGC outperforms PCE in all respect such as PAPR, BER, spectral efficiency and computational complexity. Moreover, PAGC technique requires less polynomial time (due to parallel structure) than PCE (serial structure) technique.

Unfortunately, in both the techniques, optimized phases are required at receiver to extract the original OFDM symbols. As a result, the accumulation of channel side information reducing the data rate significantly, which is a prime concern of proposed techniques. Therefore, major consequences of the proposed combinational techniques are high computational complexity and data rate loss. To maintain data rate in PAPR reduction scheme is the motivation of next chapter.