I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) technology is one of the most attractive candidates for fourth generation (4G) wireless communication. It effectively combats the multipath fading channel and improves the bandwidth efficiency. At the same time, it also increases system capacity so as to provide a reliable transmission [1]. OFDM uses the principles of Frequency Division Multiplexing (FDM) [1] but in much more controlled manner, allowing an improved spectral efficiency [1].

The basic principle of OFDM is to split a high-rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers. These subcarriers are overlapped with each other. Because the symbol duration increases for lower rate parallel subcarriers, the relative amount of dispersion in time caused by multipath delay spread is decreased. Inter-symbol interference (ISI) is eliminated almost completely by introducing a guard time in every OFDM symbol.

OFDM faces several challenges. The key challenges are ISI due to multipath-use guard interval, large peak to average ratio due to non linearity’s of amplifier; phase noise problems of oscillator, need frequency offset correction in the receiver. Large peak-to-average power (PAP) ratio which distorts the signal if the transmitter contains nonlinear components such as power amplifiers (PAs). The nonlinear effects on the transmitted OFDM symbols are spectral spreading, inter modulation and changing the signal constellation. In other words, the nonlinear distortion causes both in-band and out-of-band interference to signals. Therefore the PAs requires a back off which is approximately equal to the PAPR for distortion-less transmission. This decreases the efficiency for amplifiers. Therefore, reducing the PAPR is of practical interest.

Many PAPR reduction methods have been proposed. Some methods are designed based on employing redundancy, such as coding [4], [5], selective mapping with explicit or implicit side information [6], [3], [5], or tone reservation [10], [12]. An apparent effect of using redundancy for PAPR reduction is the reduced transmission rate. PAPR reduction may also be achieved by using extended signal constellation, such as tone injection [10], or multi-amplitude CPM. The associated drawback is the increased power and implementation complexity. A simple PAPR reduction method can be achieved by clipping the time-domain OFDM signal. In this work, we survey the PAPR reduction techniques for OFDM. We also present PAPR reduction technique based on selective mapping (SLM) under different route number M.

The remainder of this paper is organized as follows. In section II, some basics about PAPR problem in OFDM is given. Section III describes PAPR reduction techniques. In Section IV the overall analysis of different techniques is given. Section V describes the simulation results. Conclusions are given in section VI.
II. PAPR PROBLEM IN OFDM

Expression of one OFDM a symbol starting at time t=t0, is represented as [10]:

\[ s(t) = Re\{e^{j2\pi f_c t} \sum_{m=0}^{N_s} \sum_{i=0}^{d-1} \sum_{k=k_{min}}^{k_{max}} c_{m,i,k} \Psi_{m,i,k}(t) \} \]

(2)

Where, \( \Psi_{m,i,k}(t) = \begin{cases} e^{j2\pi f_{c}(t-t_s)\Delta} & \text{if } l+68m \leq t \leq l+68m+T_s \leq l+68m+T_r \text{ and } t \in T_r \leq (l+68m+1).T_r \end{cases} \)

PAPR is usually defined as [2]:

\[ PAPR = P_{\text{peak}} - P_{\text{average}} = 10\log_{10} \frac{\max[|x_n|^2]}{E[|x_n|^2]} \]

(3)

Where \( P_{\text{peak}} \) represents peak output power, \( P_{\text{average}} \) means average output power. \( E[|x_n|^2] \) is the expected value, \( x_n \) represents the transmitted OFDM signal which are obtained by taking IFFT operation on modulated input symbols \( x_k \). Mathematical, \( x_n \) is expressed as:

\[ x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N_s-1} x_k W_n^k \]

(4)

For an OFDM system with \( N \) sub-carriers, the peak power of received signals is \( N \) times the average power when phase values are the same. The PAPR of baseband signal will reach its theoretical maximum at \( (dB) = 10\log N \).

Another commonly used parameter is the Crest Factor (CF), which is defined as the ratio between maximum amplitude of OFDM signal \( s(t) \) and root-mean-square (RMS) of the waveform. The CF is defined as [3]:

\[ CF(s(t)) = \frac{\max[|s(t)|]}{E[|s(t)|^2]} = \sqrt{PAPR} \]

(5)

In most cases, the peak value of signal \( s(t) \) is equals to maximum value of its envelope \( (t) \).

III. PAPR REDUCTION TECHNIQUES

Several PAPR reduction techniques have been proposed in the literature. These techniques are divided into two groups. These are signal scrambling techniques and signal distortion techniques.

3.1 Signal Scrambling Techniques

Block Coding Techniques [1] [11], Selected mapping (SLM) [8], Partial Transmit Sequence (PTS) [4] [9] Interleaving Technique, Tone Reservation (TR), Tone Injection (TI) etc are Signal Scrambling Techniques.

3.1.1 Block Coding Techniques

The fundamental idea is that of all probable message symbols, only those which have law peak power will be chosen by coding as valid code words for transmission. No introduction of distortion to the signals. If there have \( N \) subcarriers, they are represented by \( 2N \) bits using QPSK modulation and thus \( 2^{2N} \) messages. Using the whole message space corresponds to zero bits of redundancy. Using only half of the messages corresponds to one bit of redundancy. The remaining message space is then divided in half again and this process continues until \( N \) bits of redundancy have been allocated which corresponds to a rate one-half code for \( N \) carriers. Large PAPR reduction can be achieved if the long information sequence is separated into different sub blocks, and all sub block encoded with System on a Programmable Chip (SOPC).

3.1.2 Block Coding Scheme with Error Correction

The method is proposed that designed block codes can not only minimize the PAPR, but also give error correction capability. A \( (n, k) \) block code with a generator matrix ‘G’ in the transmitter of the system. Followed by the phase rotator vector b to produce the encoded output \( x = a + G + b (mod 2) \). After that generator matrix ‘G’ and the phase rotator vector ‘b’ are produced; which are used mapping between these symbols combination and input data vector ‘a’.

The converse functions of the transmitter are executed in the receiver system. The parity check matrix ‘H’ is achieved from the generator matrix ‘G’, with an exception that the effect of the phase rotator vector b is removed before calculations of syndromes.

3.1.3 Selected Mapping (SLM)

The probability of PAPR larger than a threshold \( z \) can be written as \( P\{PAPR > z\} = 1 - (1 - \exp(-z))^N \). Assume that \( M \) OFDM symbols carry the same information and that they are statistically independent of each other. In this case, the probability of PAPR greater than \( z \) is equals to the product of each independent candidate’s probability. This process can be written:

\[ P\{PAPR_{low} > z\} = P\{PAPR > z\}^M = ((1 - \exp(-z))^N)^M \]

(6)

In selected mapping method, firstly \( M \) statistically independent sequences which represent the same information are generated and next the resulting \( M \) statistically independent data blocks \( s_m = [s_{m0}, s_{m1}, \ldots, s_{mN_s}]^T, m = 1, 2, \ldots, M \) are then forwarded into IFFT operation simultaneously. Finally, at the receiving end, OFDM symbols \( x_m = [x_1, x_2, \ldots, x_N]^T \) in discrete time-domain are acquired, and then the PAPR of these M vectors are calculated separately. Eventually, the sequences \( xd \) with the smallest PAPR will be elected for final serial transmission.
This method can significantly improve the PAPR performance of OFDM system. The reasons behind that are: Data blocks \( S_m=[S_m,0,S_m,1,\ldots,S_m,N-1]^T \), \( m=1,2,\ldots,M \) are statistical independent, assuming that for a single OFDM symbol, the CCDF probability of PAPR larger than a threshold is equals to \( p \). The general probability of PAPR larger than a threshold for \( k \) OFDM symbols can be expressed as \( p^k \). Data blocks \( S_m \) are obtained by multiplying the original sequence with \( M \) uncorrelated sequence \( P_m \).

The key point of selected mapping method lies in how to generate multiple OFDM signals when the information is the same. First, defined different pseudo-random sequences \( P_m=[P_m,0,P_m,1,\ldots,P_m,N-1]^T \), \( m=1,2,\ldots,M \), where \( P_{m,n}=e^{j\phi_{m,n}} \) and stands for the rotation factor is also known as the weighting factor is uniformly distributed in \([0,2\pi]\). The \( N \) different sub-carriers are modulated with these vectors respectively so as to generate candidate OFDM signals. This process can also be seen as performing dot product operation on a data block \( X_n \) with rotation factor \( P_m \).

In the reality, all the elements of phase sequence \( P_l \) are set to 1 so as to make this branch sequence the original symbol. The expression is as below:

\[
S_m = [X_0P_{m,0},X_1P_{m,1},\ldots,X_{N-1}P_{m,N-1}]^T
\]

and then transfer these \( M \) OFDM frames from frequency domain to time domain by performing IFFT calculation. The entire process is given by:

\[
x_m(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n P_{m,n} e^{j2\pi m\Delta ft}, 0 \leq y \leq NT, m = 1,2,\ldots,M
\]

Finally, the one which possess the smallest PAPR value is selected for transmission. Its mathematical expression is given as

\[
x_d = \arg\min_{1 \leq m \leq M} (PAPR(x_m))
\]

Where \( \arg\min (\cdot) \) represent the argument of its value is minimized.

At the receiver, in order to correctly demodulate the received signal, it is necessary to know which sequence is linked to the smallest PAPR among \( M \) different candidates after performing the dot product. 3.1.4 Partial Transmit Sequence

The crucial idea of partial transmit sequences algorithm is to divide the original OFDM sequence into several sub-sequences and for each sub-sequence, multiplied by different weights until an optimum value is chosen. Let the sub-blocks have the same size and no gap between them, the sub-block vector is given by:

\[
\begin{align*}
\hat{X} &= \sum_{v=1}^{V} b_vX_v \\
\end{align*}
\]

Where, \( b_v = e^{j\phi_v} [0,2\pi] \) \( (v = 1,2,\ldots,V) \) is weighting factor used for phase rotation. The signal in time domain is obtained by applying IFFT on \( X_v \), that is:

\[
\hat{X} = IFFT(\hat{X}) = \sum_{v=1}^{V} b_v IFFT(X_v) = \sum_{v=1}^{V} b_v \ldots X_v
\]

Select one suitable factor amalgamation \( b=[b_1,b_2,\ldots,b_V] \) which makes the result achieve optimum. The combination can be given by:

\[
b = [b_1,b_2,\ldots,b_V] = \arg\min_{b_1,b_2,\ldots,b_V} \left( \max_{1 \leq n \leq N} |\sum_{v=1}^{V} b_v x_n|^2 \right)
\]

Where \( \arg\min (\cdot) \) is the ruling condition that output the minimum value. This way we can find the preeminent \( b \) so as to optimize the PAPR performance. The additional cost we have to pay is the extra \( V-1 \) times IFFT’s operation. In conventional PTS approach, it requires the PAPR value to be calculated at each step of the optimization algorithm, which will introduce tremendous trials to achieve the optimum value [4]. Furthermore, in order to enable the receiver to identify different phases, phase factor \( b \) is required to send to the receiver as sideband information (usually the first sub-block \( b_1 \), is set to 1). So the redundancy bits account for \((V-1)\log 2W\), in which \( V \) represents the number of sub-block, \( W \) indicates possible variations of the phase. This causes a huge burden for OFDM system, so studying on how to reduce the computational complexity of PTS has drawn more attentions, nowadays.

The optimization is achieved by searching thoroughly for the best phase factor. Theoretically, \( b=[b_1,b_2,\ldots,b_V] \) is a set of discrete values and numerous computation will be required for the system when this phase collection is very large. For example, if \( \phi_v \) contains \( W \) possible values, theoretically, \( b \) will have \( W^V \) different combinations, therefore, a total of \( V \cdot W^V \) IFFTs will be introduced.

By increasing the \( V, W \), the computational cost of PTS algorithm will increase exponentially. For instance, define phase factor \( b_v \) contains only four possible values, that means \( b_v \in \{\pm1,\pm j\} \) , then for each OFDM symbol, 2 \( V-1 \) bits are transmitted as side information. Therefore, in practical applications, computation burden can be reduced by limiting the value range of phase factor \( b=[b_1,b_2,\ldots,b_V] \) to a proper level. At the same time, it can also be changed by different sub-block partition schemes.

3.1.5 Interleaving Technique

The notion that highly correlated data structures have large PAPR can be reduced, if long correlation pattern is broken down. The basic idea in adaptive interleaving is to set up an initial terminating threshold. PAPR value goes below the threshold rather than seeking each interleaved sequences. The minimal threshold will compel the adaptive interleaving (AL) to look for all the interleaved
sequences. The main important of the scheme is that it is less complex than the PTS technique but obtains comparable result. This method does not give the assurance result for PAPR reduction.

3.1.6 Tone Reservation (TR)

The main idea of this method is to keep a small set of tones for PAPR reduction. This can be originated as a convex problem and this problem can be solved accurately. Tone reservation method is based on adding a data block and time domain signal. A data block is dependent time domain signal to the original multicarrier signal to minimize the high peak. This time domain signal can be calculated simply at the transmitter of system and stripped off at the receiver. The amount of PAPR reduction depends on some factors such as number of reserved tones, location of the reserved tones, amount of complexity and allowed power on reserved tones. This method explains an additive scheme for minimizing PAPR in the multicarrier communication system. It shows that reserving a small fraction of tones leads to large minimization in PAPR ever using with simple algorithm at the transmitter of the system without any additional complexity at the receiver end. Here, N is the small number of tones, reserving tones for PAPR reduction may present a non-negligible fraction of the available bandwidth and resulting in a reduction in data rate. The advantage of TR method is that it is less complex, no side information and also no additional operation is required at the receiver of the system.

3.1.7 Tone Injection (TI)

Tone Injection (TI) method has been recommended by Muller, S.H., and Huber, J.B. [3]. This technique is based on general additive method for PAPR reduction. Using an additive method achieves PAPR reduction of multicarrier signal without any data rate loss. TI uses a set of equivalent constellation points for an original constellation points to reduce PAPR. The main idea behind this method is to increase the constellation size. Then, each point in the original basic constellation can be mapped into several equivalent points in the extended constellation, since all information elements can be mapped into several equivalent constellation points. These additional amounts of freedom can be utilized for PAPR reduction. The drawbacks of this method are: need to side information for decoding signal at the receiver side, and cause extra IFFT operation which is more complex.

3.2 Signal Distortion Techniques

Signal distortion techniques are Peak Windowing [12], Envelope scaling [6], Peak Reduction Carrier [7], Clipping and Filtering [4].

3.2.1 Peak Windowing

The peak windowing method has been suggested by Van Nee and Wild [5]. This method, proposes that it is possible to remove large peaks at the cost of a slight amount of self interference when large peaks arise infrequently. Peak windowing reduces PAPRs at the cost of increasing the BER and out-of-band radiation. Clipping is a one kind of simple introduces PAPR reduction technique which is self interference. The technique of peak windowing offers better PAPR reduction with better spectral properties. In peak windowing method we multiply large signal peak with a specific window, for example; Gaussian shaped window, cosine, Kaiser and Hamming window. In view of the fact that the OFDM signal is multiplied with several of these windows, consequential spectrum is a convolution of the original OFDM spectrum with the spectrum of the applied window. Thus, the window should be as narrow band as possible, conversely the window should not be too long in the time domain because various signal samples are affected, which results an increase in bit error rate (BER). Windowing method, PAPRs can be obtained to 4dB which from the number of independent subcarriers. The loss in signal-to-noise ratio (SNR) due to the signal distortion is limited to about 0.3dB. A back off relative to maximum output power of about 5.5dB is needed in spectra distortion at least 30dB below the in-band spectral density.

3.2.2 Envelope Scaling

The Envelope Scaling technique has been proposed by Foomooljareon and Fernando in [6]. They anticipated a new algorithm to reduce PAPR by scaling the input envelope for some subcarriers before they are sent to IFFT. They used 256 subcarriers with QPSK modulation technique, so that envelopes of all the subcarriers are equal. The key idea of this scheme is that the input envelope in some sub carrier is scaled to achieve the smallest amount of PAPR at the output of the IFFT. Thus, the receiver of the system doesn’t need any side information for decoding the receiver sequence. This scheme is appropriate for QPSK modulation; the envelopes of all subcarriers are equal. Results show that PAPR can be reduced significantly at around 4 dB.

3.2.3 Peak Reduction Carrier

Peak Reduction Carrier technique is proposed by Tan and Wassell. The technique is to use the data bearing peak reduction carriers (PRCs) to reduce the effective PAPR in the OFDM system [7].

It includes the use of a higher order modulation scheme to represent a lower order modulation symbol. The amplitude and phase of the PRC is positioned within the constellation region symbolizing the data symbol to be transmitted. This method is suitable for PSK modulation;
where the envelopes of all subcarriers are the same. When the QAM modulation scheme will be implemented in the OFDM system, the carrier envelope scaling will result in the serious BER degradation.

To limit the BER degradation, amount of the side information would also be excessive when the number of subcarriers is large.

3.2.4 Clipping and Filtering

One of the simple and effective PAPR reduction techniques is clipping, which cancels the signal components that exceed some unchanging amplitude called clip level. However, clipping yields distortion power, which called clipping noise, and expands the transmitted signal spectrum, which causes interfering [8]. Clipping is nonlinear process and causes in-band noise distortion, which causes degradation in the performance of bit BER and out-of-band noise, which decreases the spectral efficiency [4].

Clipping and filtering technique is effective in removing components of the expanded spectrum. Although filtering can decrease the spectrum growth, filtering after clipping can reduce the out-of-band radiation, but may also cause some peak re-growth, which the peak signal exceeds in the clip level [9]. The technique of iterative clipping and filtering reduces the PAPR without spectrum expansion. However, the iterative signal takes long time and it will increase the computational complexity of an OFDM transmitter [8]. But without performing interpolation before clipping causes it out-of-band. To avoid out-of-band, signal should be clipped after interpolation. However, this causes significant peak re-growth. So, it can use iterative clipping and frequency domain filtering to avoid peak re-growth.

4. OVERALL ANALYSIS OF DIFFERENT TECHNIQUES

The PAPR reduction technique should be chosen with awareness according to various system requirements.

**Table -1**: Comparison of PAPR Reduction Techniques

<table>
<thead>
<tr>
<th>Reduction Technique</th>
<th>Parameters</th>
<th>Operation required at Transmitter (TX) / Receiver (RX)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clipping and Filtering</td>
<td>Decrease distortion: No, Power raise: No, Defeat data rate: No</td>
<td>TX: Clipping&lt;br&gt; RX: None</td>
</tr>
<tr>
<td>Selective Mapping(SLM)</td>
<td>Yes, No, Yes</td>
<td>TX: M times IDFTs operation&lt;br&gt; RX: Side information extraction, inverse SLM</td>
</tr>
<tr>
<td>Block Coding</td>
<td>Yes, No, Yes</td>
<td>TX: Coding or table searching&lt;br&gt; RX: Decoding or table searching</td>
</tr>
<tr>
<td>Partial Transmit Sequence(PTS)</td>
<td>Yes, No, Yes</td>
<td>TX: V times IDFTs operation&lt;br&gt; RX: Side information extraction, inverse PTS</td>
</tr>
<tr>
<td>Interleaving</td>
<td>Yes, No, Yes</td>
<td>TX: D times IDFTs operation, D-1 times interleaving&lt;br&gt; RX: Side information extraction, de-interleaving</td>
</tr>
<tr>
<td>Tone Reservation(TR)</td>
<td>Yes, Yes, Yes</td>
<td></td>
</tr>
<tr>
<td>Tone Injection(TI)</td>
<td>Yes, Yes, No</td>
<td></td>
</tr>
</tbody>
</table>
5. SIMULATION OF SLM SCHEME

It seems that the ability of PAPR reduction using SLM is affected by the route number $M$ and subcarrier number $N$. Therefore, simulation with different values of $M$ and $N$ and the results exhibit some desired properties of signals representing the same information. Comparison of PAPR reduction performance with different values of $M$ while $N$ is fixed at 128. Rotation factor is defined as $P_{m,n} \in \{ \pm 1, \pm j \}$. The algorithm executes 10000 times, over sampling factor is 8 and QPSK mapping is adopted as modulation scheme in each sub-carrier. Route numbers $M=2$, $M=4$, $M=8$, $M=16$ are used. Therefore, practically, compromise the computing complexity and improvement of performance, we usually take $M \leq 8$.

From Fig. 1, it can be observed that the proposed SLM method displays a better PAPR reduction performance than the original OFDM signal. If the probability is set to 1% and then the CCDF curves with different $M$ values are compared. The PAPR value of case $M=2$ is about 1dB smaller than the unmodified one $M=1$. Under the same condition, the PAPR value of case $M=16$ is about 3dB smaller than the original one $M=1$. The performance difference between $M=8$ and $M=16$ cases is less than 0.5dB. This proves that it will not be able to achieve a linear growth of PAPR reduction performance with further increase the value of $M$ (like $M>8$), the PAPR reduction performance of OFDM signal will not be considerably improved.

![Fig. 1: PAPR reductions in OFDM for different route number.](image)

6. CONCLUSION

We describe and summarize several techniques of PAPR and simulate SLM technique which is the best solution for PAPR. The selected technique provides us with a good range in performance to reduce PAPR problem. SLM algorithm adapted to any length of route number that means it can be used for different OFDM systems with different number of carriers. It is particularly suitable for the OFDM system with a large number of sub-carriers (more than 128). This research will continue in directions. Firstly, PAPR reduction concepts will be expanded for distortion less transmission and identifying the best alternatives in terms of performance increase. Secondly, PAPR reduction technique will be develop for low data rate loss and efficient use of channel. A study of the complexity issues of the PAPR reduction technique is required, especially looking at ways of further reducing the complexity of the sphere decoder.
REFERENCES


