CHAPTER 4

PEAK TO AVERAGE POWER RATIO (PAPR)
REDUCTION TECHNIQUES FOR OFDM-MIMO SYSTEM

4.1 INTRODUCTION

In the previous chapter, to get high data rate transmission, High Throughput techniques were analyzed for OFDM-MIMO System. OFDM-MIMO systems based on OFDM symbols suffer from the problem of inherent Peak to Average Power Ratio (PAPR). The peak power of a multi carrier OFDM signal is a critical design factor for band limited communication systems, and it is necessary to reduce it as much as possible. A modified form of Interleaving, Selected Mapping, Partial Transmit Sequences and Tone Reservation PAPR reduction techniques are also proposed. The proposed techniques for PAPR reduction grant an improvement over the existing technique.

4.2 LITERATURE SURVEY

The PAPR is defined as the ratio of the peak power of the signal to its average power, which is a measure of the amplitude fluctuations of the signal. Any multicarrier subcarriers may have a high PAPR due to addition of subcarriers. In High Throughput WLAN environment, the OFDM signal exhibits high PAPR in multiple antenna configurations, which results in undesirable spectral emissions into adjacent channels and in BER degrading. In literature, a lot of methods of PAPR reduction techniques for
OFDM-MIMO system are used. Some of the techniques are Amplitude Clipping, Clipping and Filtering, Coding, Tone reservation, Tone Injection, Active Constellation Extension, Interleaving, Selected Mapping and Partial Transmit Sequence. These techniques achieve PAPR reductions at the expense of increased transit power, reduced data rate, boosted BER, computational difficulty and additional process at transmitter as well as receiver. PAPR reduction techniques literature survey shows that Partial Transmit Sequence, Selected Mapping, and Interleaving techniques are having high BER compared with other techniques. To retain a high throughput concept the resultant system BER value should be as low as possible.

4.2.1 Clipping and Filtering Technique

Amplitude clipping is the simplest technique for PAPR reduction. Amplitude Clipping limits the peak envelope of the input signal to a predetermined value. Li and Cimini (2002) portray about the clipping and filtering method in the easiest way to limit the maximum magnitude of transmitted signals. But clipping causes distortion resulting in increased BER and out-of-band spectral radiation. Heiskala and Terry (2002) declared in their book that the distortion caused by amplitude clipping can be viewed as another source of noise and falls both in in-band and out-band. Filtering after clipping can reduce out-band distortion but causes some peak regrowth of the signal. This unfortunately further increases the PAPR. Saeedi et al (2002) employs the method of over sampled signal reconstruction, which is used to compensate for SNR degradation due to clipping and filtering technique. ‘Iterative estimation and cancellation of clipping noise for OFDM signal’ technique is projected by Chen and Hainovich (2003). This technique explains the fact that clipping noise generated by a known process can be recreated at the receiver be subsequently removed.
Armstrong (2002) described a method based on K-times repetition of the clipping and filtering process and named this method as repeated clipping and filtering. Therefore both PAPR and adjacent spectral emissions are reduced. The main drawback of repeated clipping and filtering method is its high complexity. For each frequency domain filtering, two FFT calculations are necessary. A method named simplified clipping and filtering (Wang and Tellambura 2005) gives almost the same PAPR reduction as repeated clipping and filtering, but the complexity is significantly reduced. Only 3 FFT’s are required for the PAPR reduction equivalent to iterative method using arbitrary technique. Deng and Lin (2007) proposed a modified RCF (Repeated Clipping and Filtering) method, in the form of Recursive Clipping and Filtering with Bounded distortion by limiting the distortion on each tone of the OFDM, so that both low PAPR and low error can be achieved. Al-Kebsi et al (2009) suggested a simple solution to eliminate the degradation in the Symbol Error Rate (SER) performance that caused by clipping part of the OFDM signal and provided it to the receiver to recover the original signal. The clipping process is characterized by the Clipping Ratio (CR), defined as the ratio between the clipping threshold and the root mean square (rms) level of the OFDM signal. It is possible to use low CR to get efficient PAPR reduction. But it is important to make appropriate selecting of the CR to minimize the amount of the transmitted copies of the clipped parts of the original OFDM signal to avoid wasting the valuable bandwidth.

4.2.2 Coding Technique

Coding is the popular and attractive topic used to reduce the PAPR. A simple idea introduced by Jones et al (1994) is to select codewords to minimize or reduce the PAPR for transmission. However, this approach suffers from the need to perform an exhaustive search to find the best codes
and to store large lookup tables for encoding and decoding, especially for a large number of subcarriers. Moreover, this approach does not address the problem of error correction. A more sophisticated approach proposed by the same authors is to use codewords drawn from offsets from a Linear Code. The idea is to choose the code for its error correcting properties and the offset to reduce the PAPR of the resulting coded signals. This approach enjoys the twin benefits of PAPR reduction and error correction, and is simple to implement, but it requires extensive calculation to find good codes and offsets. PAPR reduction using coding and error correction was also anticipated in the earlier stage by Wilkinson and Jones (1995) and Van Nee (1996) using Block codes, but it sacrifices the data rate. Ochiai and Imai (1997) planned the Block coding scheme based on complementary sequences for multicarrier OFDM signals. Davis and Jedwab (1999) introduced the Peak-to-Mean Power Control in OFDM using the codes of Golay Complementary Sequences and Reed-Muller Codes.

Kang et al (1999) provided a Novel approach of combined techniques to Subblock Partition Scheme for Partial Transmit Sequence technique. Wang et al (1999) introduced a new technique of Companding Technique. This technique is practical and can be implemented easily in integrated circuit design. The PAPR value of an OFDM system and the optimal companding coefficient to attain the minimum quantization error are derived. Error probability performance of the system after the companding is evaluated. Its’ simulation results exhibit that the system with the suggested scheme has nearly the same performance as the systems with the µ-law or A-law companding techniques.

Ahn et al (2000) present a new Block coding scheme for PAPR reduction with error detection and correction process. A computationally efficient geometrical approach to offset selection is introduced by Tarokh and
Jafarkhani (2000), but there is no guarantee about the amount of PAPR reduction that can be obtained with this approach. The usefulness of these techniques is limited to multicarrier systems with a small number of subcarriers and the required exhaustive search for a good code is intractable, while the actual benefits of the coding for PAPR reduction for practical multicarrier systems are limited. Do Horng Guo and Chan Yun Hsu (2006) proposed a new merged coding using the parity check code with block coding technique. A Combined selective mapping and binary cyclic codes for PAPR reduction was introduced by Chen and Liang (2007).

Yung et al (2008) proposed the turbo coding and decoding with the analysis of error rate calculation. Inderjeet Kaur et al (2008) projected a new coding technique for OFDM system. It is shown that cyclic shift and codeword inversion cause no change to peak envelope power. The encoding rule for the proposed code comprises of searching for a seed codeword, shifting the register elements, and determining codeword inversion, eliminating the look-up table for one-to-one correspondence between the source and the coded data. Its simulation results show that OFDM systems with the proposed code have the minimum PAPR. Omar Dauod and Omar Alani (2009) used the Low Density Parity Check (LDPC) code as a alternative to turbo code for PAPR reduction technique.

4.2.3 The Tone Reservation Technique

In Tone Reservation method, the basic idea is to reserve a small set of tones for PAPR reduction. The amount of PAPR reduction depends on the numbers of reserved tones, their location within the frequency vector, and the amount of complexity. This method describes an additive method for reducing PAPR in multicarrier transmission, and shows that reserving a small fraction of tones leads to large reductions in PAPR even with simple algorithm at the transmitter, and with no additional complexity at the receiver.
When the number of tones is small, the set of tones reserved for PAPR reduction may represent a non-negligible fraction of the available bandwidth and can result in a reduction in data rate. Tone Reservation method has the advantage of being less complexity, no special receiver operation, and with no need for the ‘side information’. In wireless systems, a set of subcarriers must be reserved regardless of received SNRs, resulting in a bandwidth sacrifice.

In the earlier stage, Gatherer and Polley (1997) and Tellado (1999) reveal that Tone Reservation reduces the PAPR using a small set of pre allocated tones that wastes the bandwidth. Lawrey (1999) introduced a major problem of multiuser OFDM-MIMO system that shows a great sensitivity to nonlinear distortions. In-band and out-of-band interferences caused by nonlinear distortions degrade BER performance of the system and give rise to interference to adjacent frequency bands, respectively. The Tone Reservation and the tone Interjection are two efficient techniques to reduce the PAPR of a multicarrier signal as proclaimed by Tellado in his research report in the year of 2000.

Krongold and Jones in the year of 2003 put forth the Constellation techniques for PAPR reduction by changes in the constellations to combat large signal peaks of the signal. It doesn’t need any redundant information, but results in increased average power and high complexity. Krongold and Jones (2003), Kou et al (2003) suggested that large PAPR value not only occur in simple OFDM system but also in adaptive OFDM system where bit and power allocations are applied. To solve this problem, Detwiler and Jones (2005) use Active Constellation Extension (ACE) technique, which modifies constellation points of mapped tones. By this method, the minimum Euclidean distance of BPSK/QAM symbols is retained and BER degradation is avoided. Petermann et al (2009) provides a solution by the optimization for ACE and Tone reservation combined techniques. But this algorithm ACE leads the
problem in terms of tone injection scenario, use more approximation rules and introduces additional IFFT and FFT operations, which in turn slightly increases the complexity. As a solution instead of using ACE technique, optimization may focus only on reserved tones.

4.2.4 The Tone Injection Technique

The Tone Injection method achieves PAPR Reduction of multicarrier signals with no data rate loss. The basic idea is to increase the constellation size so that each of the points in the original basic constellation can be mapped onto several equivalent points in the expanded constellation. Since each information unit can be mapped into one of several equivalent points, these extra degrees of freedom can be exploited for PAPR reduction. The method is called Tone Injection, as substituting the points in the larger constellation for the new points in the larger constellation is equivalent to injecting a tone of the appropriate phase and frequency in the multicarrier symbol. The amount of PAPR reduction depends on the number of modified symbols in a data block. The tone Injection technique may be more problematic than the Tone Reservation technique since the injected signal occupies the same frequency band as the information bearing signal. The Tone Injection technique may also result in a power increase in the transmit signal due to the injected signal.

Han et al (2006) proposed the use of the Hexagonal constellation method to achieve PAPR reduction without increasing signal power. Mizutani et al (2007) suggested a new concept in PAPR reduction of OFDM signal using Hopfield Neural Network with tone injection technique. With this proposed technique PAPR is sufficiently reduced. But, the ‘side information’ was transmitting to receiver. Tone injection does not reduce the transmission rate by increasing the average power of the transmitted signal. Nima Reisi and
Mahmoud Ahmadian (2008) introduced the suboptimal technique to reduce the complexity of the Tone Injection scheme.

4.2.5 The Interleaving Technique

In the interleaving technique for PAPR reduction, a set of interleavers is used to reduce the PAPR of the multi carrier signal instead of a set of phase sequence as in partial transmit sequences technique announced by Hill et al (2000) and Jayalath and Tellambura (2000). In the year of 2002 and 2004, Prasad and Hari presented a new OFDM system based on interleaving technique. The proposed system promises higher code rate compared with the conventional OFDM system without bandwidth expansion, without increasing number of subcarriers and with moderate increase in computational complexity. But it is affected by the synchronization error. Clipping is an efficient and simple method to reduce the PAPR. But it causes high distortion and out of band radiation. Haimovich and Chen (2003) provide the solution to this problem by combining interleaving with clipping method. Urban, and Marsalek (2007) used a combination of data interleaving with repeated clipping and filtering method to increase the overall performance for the PAPR reduction.

Many research efforts on Interleaving PAPR reduction methods are used to reduce computational complexity. Roman Marsalek (2006) presented a method based on adaptive symbol selection principle, with several replicas of signal created using set of interleavers incorporated inside an IFFT block at OFDM transmitter. For PAPR reduction, Fedra et al (2007) presented the improvement of MSR (Multiple Signal Representation) technique, where multiple signal representations are produced by different interleavers. The interleavers used in this approach are optimized and integrated with phase rotation. Sakran et al (2009) combines Interleaving and Companding techniques to reduce PAPR. Hassan et al (2009) proposes a new interleaving
scheme for the Continuous Phase Modulation (CPM) based on OFDM system, called Chaotic leaving. CPM is an attractive scheme for wireless communication because of its constant envelope and its ability to improve the diversity of the multipath channel.

An interleaver is a device that operates on a block of $N$ symbols and reorders or permutes them; data block $S = [S_0, S_1, \ldots S_{N-1}]^T$ becomes $S_{\pi} = [S_{\pi(0)}, S_{\pi(1)}, \ldots, S_{\pi(N-1)}]^T$. To make $K$ modified data blocks, Interleavers are used to produce permuted data blocks from the same data block. The PAPR of $(K-1)$ permuted data blocks and that of the original data block with the lowest PAPR is then chosen for transmission. To recover the original data block, the receiver need only know which interleaver is used at the transmitter, thus, the number of required ‘side information’ bits is $\lceil \log_2 K \rceil$. This normal Interleaving technique is illustrated in Figure 4.1.

![Figure 4.1 Block diagram of interleaving technique](image)

Thus, interleaving and de-interleaving can be done simply. The amount of PAPR reduction depends on the number of Interleavers and the design of the Interleavers.
4.2.6 The Selected Mapping Technique

Bauml et al proposed a method for the reduction of PAPR of multicarrier modulation systems with Selected Mapping method in 1996. In this method, several independent OFDM symbols representing the same information are generated and the OFDM symbol with the lowest PAPR is selected for transmission. The independent OFDM symbols are generated by multiplying the information sequence by a set of fixed vectors. The receiver must know which multiplying vector has been used. This vector sequence is transmitted as ‘side information’. It leads to data rate loss at the receiver and it is eliminated by the scrambling method described by Breiling et al (2001). An improved form of Selected Mapping technique is commenced by Breiling et al (2001). In this approach, the transmitter generates a set of sufficiently different candidate data blocks, all representing the same information as the original data block, and selects the most favorable for transmission. The number of the chosen block must be sent to the receiver as ‘side information’. Since an error in decoding ‘side information’ means loss of the entire block, ‘side information’ must be protected by coding (Breling 2001).


A General block diagram of the Selected Mapped Technique is shown in Figure 4.2. Each data block is multiplied by U different phase sequences, each of length N, \( B(u) = [b_{u,0}, b_{u,1}, \ldots, b_{u,N-1}]^T, \ u=1,2,3,\ldots,U, \) resulting in U modified data blocks. To include the unmodified data block in
the set of modified data blocks, set $B(1)$ as the all one vector of length $N$. The modified data block for the $u^{th}$ phase sequence $S(u) = [S_{0b_{u,0}}, \ldots, S_{N-1b_{u,N-1}}]^T$, $u=1,2,3,\ldots,U$. Among the modified data blocks $S(u)$, $u = 1,2,3\ldots,U$, the one with the lowest PAPR is selected for transmission. Information about the selected phase sequence should be transmitted to the receiver as ‘side information’. The block diagram of Selected Mapping is shown in Figure 4.2.

![Figure 4.2 Block diagram of the selected mapping technique](image)

At the receiver, the reverse operation is performed to recover the original data block. For implementation, the Selected Mapping technique needs $U$ IDFT operations, and the number of required ‘side information’ bits is $\lceil \log_2 U \rceil$ for each data block. This approach is applicable with all types of modulation and any number of subcarriers. The amount of PAPR reduction for Selected Mapping depends on the number of phase sequences $U$ and the design of the phase sequences.

### 4.2.7 Partial Transmit Sequence Technique

In 1996, Bauml et al and in 1997, Mullar and Huber made clear two different topics such as Selective Mapping and Partial Transmit Sequence respectively. These techniques transmit the lowest peak power signal among
several candidates and it requires redundant bits to detect the information bits in the receiver. Muller and Hubber recommended an effective and flexible peak power reduction scheme for OFDM system by Partial Transmit Sequences in 1997. The main idea behind the scheme is that the data block is partitioned into non overlapping subblocks and each subblock is rotated with a statistically independent rotation factor. The rotation factor which generates the time domain data with the lowest peak amplitude is also transmitted to the receiver as ‘side information’.

Jayalath and Tellambura (2000) describes the above technique in a little alternative way as below. The OFDM data blocks of N symbols is partitioned into Y subblocks. Each of the subblocks is then multiplied by one of the P rotational factors, which is generated randomly. The rotational factors are chosen such that they have unit magnitude. If the PAPR of the resulting OFDM symbol is less than the threshold, the signal is transmitted. If not, another set of rotational factors is generated and the PAPR of the OFDM symbol is compared with the threshold. This process is repeated till the PAPR of the OFDM symbol becomes less than the threshold or the maximum number of iterations is reached. $\log_2(Y)$ bits are transmitted as ‘side information’, in order to decode the transmitted sequence at the receiver. These rotational factors are embedded along with the data sequence and accounts for the redundancy. Higher PAPR reduction can be achieved with the increase in the number of subblocks Y but this requires the use of Y separate IDFTs.

Seung and Jae (2004), Lim et al (2005), Yang et al (2006), and Trung and Lampe (2008) also used the Partial Transmit Sequence technique to achieve the low PAPR with low computational complexity. A nonlinear iterative PTS method is proposed to search the optimal combination of phase factors with low complexity (Gao and Xie 2009). In this technique Metropolis
criterion is adopted to avoid the search of optimum phase factor being trapped in local optimum phase factor, thus the PAPR performance can be further improved. Moreover, the search is repeated, and the effect of initial phase factor on PAPR performance is eliminated significantly. Simulation results show that the proposed algorithm can yield good PAPR reduction with low computational complexity.

Figure 4.3 shows the block diagram of the Partial Transmit Sequence technique. The input data block \( S \) is partitioned into \( Y \) disjoint subblocks \( S_y=[S_{y,0}, S_{y,1}, \ldots, S_{y,N-1}]^T \), \( y = 1, 2, \ldots, M \), such that \( \sum S_y = S \) and the subblocks are combined to minimize the PAPR in the time domain. The time domain signal \( s_y=[s_{y,0}, s_{y,1}, \ldots, s_{y,N-1}]^T \) is obtained by taking IDFT of \( S_y \). These partial transmit sequences are combined with the complex phase factors \( b_y=\exp(j\varphi_y) \). The set of phase factors is denoted as vector \( b=[b_1, b_2, \ldots, b_y]^T \). The time domain signal after combining is given by \( s'(b)=\sum b_y s_y, \ y = 1, 2, \ldots, y \), where \( s'(b)=[s'_0(b), s'_1(b), \ldots, s'_{N-1}(b)]^T \). The objective is to find the set of phase factors that minimizes the PAPR. i.e. Minimization of \( \max |x'_k(b)|, \ k = 0, 1, \ldots, N-1 \).

![Figure 4.3 Block diagram of the partial transmit sequence technique](image)
Based on the above discussion Table 4.1 gives the comparison on Performance measure of PAPR Reduction Technique.

**Table 4.1  Comparison on performance measure of PAPR reduction technique**

<table>
<thead>
<tr>
<th>Types</th>
<th>Reduced Data rate</th>
<th>Increased Transmit power</th>
<th>Boosted BER</th>
<th>Distortion less</th>
<th>Additional Process at Transmitter and Receiver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clipping and Filtering</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Transmitter: Clipping and Filtering process</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Receiver: Clipping compensation process</td>
</tr>
<tr>
<td>Coding</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Transmitter: Coding process</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Receiver: Decoding process</td>
</tr>
<tr>
<td>Tone Reservation</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Transmitter: Find and set reserved carrier.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Receiver: Remove the reserved carrier and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Inverse process of Transmitter</td>
</tr>
<tr>
<td>Tone Injection</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Transmitter: Tone Injection</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Receiver: Inverse process of Transmitter</td>
</tr>
<tr>
<td>Interleaving</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Transmitter: Interleaving process</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Receiver: Inverse process of Transmitter</td>
</tr>
<tr>
<td>Selected Mapping</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Transmitter: Selected Mapping</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Receiver: Inverse process of Transmitter</td>
</tr>
<tr>
<td>Partial Transmit Sequences</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Transmitter: Partial Transmit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sequences generation Receiver: Inverse process of Transmitter</td>
</tr>
</tbody>
</table>
For OFDM signal PAPR Reduction process, from the table following points are observed. Clipping & Filtering techniques have the high signal distortion due to the clipping process compared to other techniques. Coding technique has high data loss due to redundancy. Tone Reservation technique has high transmit power and high data loss due to reserved subcarriers. Tone Injection technique has high transmit power and design complexity due to injected signal. The injected signal occupy the same frequency band of information bearing signal and modify the symbols in the data block. The challenging techniques Interleaving, Selected Mapping and Partial Transmit Sequence techniques have boosted BER with reduced data rate.

### 4.3 PROPOSED PAPR REDUCTION TECHNIQUES

Based on the literature survey, for High Throughput OFDM-MIMO System in WLAN environment, BER value should be as low as possible and data rate should be as high as possible. As a result, some modifications are needed to Interleaving, Selected Mapping and Partial Transmit Sequence techniques to satisfy the High throughput theory, in addition to the modified form of Tone reservation technique also selected for PAPR performance analysis.

In OFDM-MIMO system, an OFDM frame is formed by the superposition of many sinusoid signals of different orthogonal frequencies. Some of these subcarriers can add up constructively resulting in a peak, whose instantaneous power is much larger than the average power of the OFDM symbol. Consider $M_t$ transmitter antennas, over which the independent OFDM frames are communicated with $N$ subcarriers, each $M_t$ antenna employed with IFFT, converts the frequency domain OFDM frames into time domain OFDM samples. Because of the statistical independence of the carriers, the time domain OFDM samples are denoted by
\( s_{\mu n} \), where \( \mu = 1, 2, \ldots, M_t \) and \( n = 1, 2, \ldots, N \) are approximately complex Gaussian distributed.

The PAPR of the transmitted OFDM sample of the \( \mu^{th} \) antenna is defined by Golay (2000), Rappaport (2001), Sakran et al (2009) as

\[
\text{PAPR}_{\mu} = \frac{\max_n |s_{\mu n}|^2}{\frac{1}{N} \sum_{n=1}^{N} |s_{\mu n}|^2} = \frac{\max_n |s_{\mu n}|^2}{\sigma_x^2}
\]

(4.1)

where \( |s_{\mu n}|^2 \) and \( \frac{1}{N} \sum_{n=1}^{N} |s_{\mu n}|^2 \) represents peak instantaneous power and the average power of time domain OFDM sample respectively. The maximum value of PAPR is expressed as

\[
\text{PAPR} = \max_{\mu = 1, 2, \ldots, M_t} \text{PAPR}_{\mu} = \frac{\max_{\mu,n} |s_{\mu n}|^2}{\sigma_x^2}
\]

(4.2)

and it is called worst case of PAPR.

As a performance measure, the Complementary Cumulative Distribution Function (CCDF) of PAPR denotes the probability that the PAPR of a OFDM frame exceeds a given threshold \( \text{PAPR}_0 \) and is expressed by

\[
\text{CCDF} = \Pr(\text{PAPR} > \text{PAPR}_0) = 1 - \left(1 - \exp\left(-\text{PAPR}_0\right)\right)^N
\]

(4.3)

for the conventional (Single antenna) OFDM system, where \( \Pr(\cdot) \) denotes the probability. The worst case of PAPR depends on the number of the subcarriers \( N \). In MIMO configuration OFDM system, \( M_t \) transmitter antennas are used to transmit the signal, since \( M_t \cdot N \) instead of \( N \) time domain frames are present, then CCDF of PAPR becomes

\[
\text{CCDF} = \Pr(\text{PAPR} > \text{PAPR}_0) = 1 - \left(1 - \exp\left(-\text{PAPR}_0\right)\right)^{M_t N}
\]

(4.4)
In the same reduction process, each OFDM frame may multiply with U independent sequences. Then they are transformed to time domain by U IFFTs to transmit the ‘best’ OFDM frame from the transmitter. In this case the worst PAPR becomes

\[ \text{CCDF} = \Pr(\text{PAPR} > \text{PAPR}_0) \left(1 - \left(1 - \exp\left(-\text{PAPR}_0\right)\right)^{\text{MN}}\right)^U \]  

In the OFDM-MIMO system, a few OFDM frames would result in higher PAPR than others. In this case the OFDM frame may be divided into smallest subsets, and after the reduction process the resultant subsets may combine together. It should be possible to obtain output signals with a guaranteed low output PAPR. In general, PAPR reduction techniques employs more numbers of IFFTs at the transmitter to convert the frequency domain OFDM frames into Time domain Samples.

### 4.3.1 Proposed Modified Interleaving Technique

A modified Interleaving technique proposed is illustrated in Figure 4.4. The interleaving patterns for the Interleavers are obtained by OGA (Orthogonal Genetic Algorithm) optimization algorithm. The generated Interleavers are mapped with original OFDM frame and generate the permuted data block. The PAPR of permuted data block are computed using IDFT operations. The data block with the lowest PAPR is then chosen for the transmission. Therefore the Interleaver designed at transmitter is simplified by the generation of interleaving pattern generation with the help of optimization technique.
The definition of the optimization problem is to find the best interleaving pattern from the pair of vectors containing numbers from 1 to N, where each number represents the subcarrier index and the random vector corresponds with interleaving pattern. The algorithm begins with a random set of solutions called population. In each generation, new population is made from old ones. New individuals are made by crossing parents. The probability that the individual becomes a parent depends on its fitness function.

The mutation is introduced to prevent falling in local optimum. The population of 20 individuals and permutation encoding is used for implementing the Interleaving pattern. In permutation encoding, every individual is presented by two strings of numbers 1 to N that represents a position after interleaving. The fitness function is evaluated for each individual. Crossover is made by multi crossover point selection, the permutation is copied from the first parent till the first crossover point and the rest is from the second parent. If the second crossover point is reached, the coping will continue again from the first parent. The same procedure is repeated till the last crossover point. After that, the duplications of numbers in
each of the two vectors must be replaced by unused ones. The mutation is made by simple swap of two numbers from the same vector. The worst case of PAPR is fixed as fitness function. In this procedure, $K \cdot M_t$ IDFTs and $M_t \cdot \log_2 K$ bits of ‘side information’ are required. Best Interleaving pattern is individually applied to the $M_t$ parallel OFDM frames to generate the best permutated frame which results in minimum PAPR for transmission.

### 4.3.1.1 Simulation result

The performance of the proposed modified PAPR Reduction techniques is evaluated by Complementary Cumulative Distribution Function (CCDF) of PAPR with respect to threshold $\text{PAPR}_0$. The CCDF or $\Pr[\text{PAPR} > \text{PAPR}_0]$ denotes the probability of the signals having a PAPR greater than threshold $\text{PAPR}_0$. Figure 4.5 illustrates the CCDF of the PAPR versus $\text{PAPR}_0$ in dB of OFDM-MIMO system with a different number of subcarriers $N = 32, 64, 128$ and $256$. The 64QAM modulation is used on each subcarrier and the number of transmitter antenna of $M_t = 4$ are selected for the simulation.

![CCDF of the PAPR for different number of subcarriers using proposed modified interleaving technique](image-url)

**Figure 4.5** CCDF of the PAPR for different number of subcarriers using proposed modified interleaving technique
From the plots, it is observed that the performance of proposed technique CCDF of PAPR is compared with the conventional technique. From Figure 4.5, PAPR value increases significantly as number of subcarrier used in the OFDM signal transmission increases. At CCDF of $10^{-3}$, using the subcarriers 32, 64, 128 and 256, the conventional Interleaving technique PAPR value is varied from 13.2dB to 14.8dB. For the same case, the proposed modified Interleaving technique PAPR is varied from 13dB to 14dB. As a result, the CCDF of PAPR exhibits a steeper decay, increased by the number of subcarriers. If the number of subcarrier increases, the PAPR value also increases. But, high data rate WLAN environment OFDM-MIMO system use high value of subcarriers to get the High Throughput performance. From the comparison between the conventional and the proposed technique, the Modified Interleaving PAPR Reduction techniques produced the reduced PAPR effect in the OFDM signals. High PAPR reduction is achieved in the lower value of subcarrier.

In the next stage of analysis, the CCDF of PAPR performance is tested for different values of transmitter antennas as $M_t = 2, 4$ and 8 as shown in Figure 4.6. From the observation, the higher number of antennas produces a lesser value of PAPR. The proposed modified interleaving technique generates appreciably lower PAPR compared to the conventional technique. PAPR is measured only at the transmitter for the transmitted OFDM symbols. If the numbers of transmitting antennas are more, the modulated OFDM symbols are distributed to all the antennas. Therefore each individual antenna receives a less number of symbols for the transmission. Less number of symbols exhibits only the lower value of PAPR. From the plots, the conventional technique PAPR varies from 11.8dB to 14dB for CCDF of $10^{-3}$, using the number of transmitting antennas of 2, 4, 8 and 12. At the same time, proposed technique produces the reduced PAPR of 11.6dB to 13.8dB.
As a conclusion, the proposed modified interleaving technique is successful in the lower number of subcarrier with the higher number of antennas. The CCDF of PAPR performance of the proposed technique is investigated by 64 subcarriers with 12 transmit antennas for 16 user OFDM-MIMO system as shown in Figure 4.7.

Figure 4.6 CCDF of the PAPR for different number of transmit antennas using proposed modified interleaving technique

Figure 4.7 CCDF of the PAPR for proposed modified interleaving technique
The proposed technique has a greater PAPR Reduction capability than that of the existing technique. From the observation, the CCDF value of $10^{-3}$ is obtained at 10.5dB for the conventional technique and at 10dB for the proposed technique. That is an improvement of 0.5dB.

Further investigation on the proposed technique is possible by varying the number of users. If the numbers of users are increased, the same 64 subcarrier is optimally distributed to all users based on the proposed adaptive resource allocation algorithm in chapter 2. If the number of users is less, then optimally more number of subcarriers is allotted to each user. This makes high PAPR value. Figure 4.8 results the CCDF performance of 8, 12 and 16 users.

![Figure 4.8](image)

Figure 4.8 CCDF of the PAPR for different number of users using proposed modified interleaving technique

Compared with the conventional technique at the CCDF of $10^{-3}$, the proposed modified interleaving technique generates the reduced PAPR of
11dB instead of 11.6dB for 8 users. Similarly, PAPR of 10.6dB and 10dB are produced instead of 11dB and 11.6dB for 12 and 16 users respectively.

As a conclusion, the proposed modified interleaving technique creates PAPR reduction of 0.5dB with significant improvement over the conventional method.

4.3.2 Proposed Modified Selected Mapping Technique

The proposed Modified Selected Mapping Technique is illustrated in Figure 4.9. Each OFDM frame is mapped to a number of $U$ independent candidate sequences. From this one of the lowest PAPR is selected. These independent candidate sequences can be generated by multiplying carrier wise the initial OFDM frame $X$ by $U$ phase vectors, $P(u)$ is defined as $[P_1(u), P_2(u), \ldots, P_N(u)]$, $u = 1, 2, \ldots, U$. Let $P(u) = \exp(j\varphi)$ and $\varphi$ is chosen from $\{0, \pi/2, \pi, 3\pi/2\}$. The independent candidates are transformed to time domain by $x(u) = \text{IDFT}(X \Theta P(u))$, where $\Theta$ denotes element wise multiplication and their corresponding PAPRs are calculated.

![Figure 4.9 Proposed modified selected mapping technique](image-url)
The minimum PAPR value OFDM frame $x(u)$ is selected as best OFDM frame and it is transmitted. To recover the original frames at the receiver, the ‘side information’ frames are required to indicate the vector $P(u)$ which have to be communicated to the receiver. In the MIMO configuration, the selected mapping is applied to each of the $M_t$ antennas. All $M_t$ OFDM frames are simultaneously modified with the same phase vector $P_j(u) = P(u)$ for all $j = 1, 2, \ldots, M_t$. The PAPR reduction algorithm for the modified Selected Mapping technique consists of the following steps:

**Initialization**

1. Assign the number of antennas $M_t$, the number of subcarriers $N$ and the number of independent candidate sequences $U$.
2. Initialize the loop counters $\mu$ and $u$ which is equal to 1.
3. Get the OFDM frame vector $X_{\mu}$ and the calculated independent candidate vector $P(U)$.

**Iteration**

1. Select the initial independent candidate vector $P(u)$
2. Calculate the initial PAPR $\mu$ of the $M_t$ antennas using $x_{\mu} = \text{IDFT}\{X_{\mu}\}$.
3. Find the maximum value of PAPR as $\text{PAPR}_{\text{max}}$ from the calculated PAPR $\mu$. $\text{PAPR}_{\text{max}} = \max \{\text{PAPR}_1, \text{PAPR}_2, \ldots, \text{PAPR}_{M_t}\}$
4. To find the worst case PAPR, if ($\text{PAPR}_{\text{max}} < \text{PAPR}_0$), calculate $\text{PAPR}_{\text{new}}$ using $x_{\text{new}} = \text{IDFT}\{X_{\text{max}} \otimes P(U)\}$, else go to step 7.
5. Check if ($\text{PAPR}_{\text{new}} < \text{PAPR}_{\text{max}}$), then set $x_{\text{max}} = x_{\text{new}}$ and $\text{PAPR}_{\text{max}} = \text{PAPR}_{\text{new}}$. 
6. Select the next phase vector \( P(u) \) and go to step 2. Repeat the same procedure till the last vector.

7. Stop. The best OFDM frame from each branch is selected and transmitted.

In the first step the PAPR of \( M_t \) initial OFDM frames is calculated. Then, in each successive step, the OFDM frame with instantaneously highest PAPR is considered. Using a next phase vector \( P(u) \), a reduction of PAPR is tried. This procedure is continued \( M_t(U-1) \) times, but if worse case of PAPR obtained early, the algorithm may be stopped and the best OFDM frame is saved. \( M_t \cdot U \) trials are performed for one antenna and \( M_t \cdot \log_2(M_t \cdot U) \), ‘side information’ bits are required in this proposed Modified Selected Mapping PAPR reduction technique.

To find the CCDF performance of the proposed technique, the same analysis procedure for interleaving is repeated.

### 4.3.2.1 Simulation result

Initially, CCDF of PAPR performance of the proposed modified Selected Mapping for different number of subcarriers is shown in Figure 4.10. From the results obtained from Figure, at CCDF of \( 10^{-3} \), the conventional method PAPR varies from 12.2dB to 14dB for 32, 64, 128 and 256 subcarriers. Comparatively, the proposed Modified Selected Mapping technique PAPR varies from 12dB to 13.8dB. Its PAPR reduction improvement is 0.2dB. The lower value of subcarrier generates reduced PAPR. Then the next analysis of PAPR is based on the number of transmitting antennas. Figure 4.11 shows the CCDF of the PAPR performance of conventional as well as proposed techniques for different number of transmitting antennas \( M_t = 2, 4, 8 \) and 12.
Figure 4.10 CCDF of the PAPR for different number of subcarriers using proposed modified selected mapping technique

Figure 4.11 CCDF of the PAPR for different number of transmitting antennas using proposed modified selected mapping technique
From the plots, lower value of PAPR is generated by higher value of \( M_t \). the proposed as well as the conventional techniques create equal value of PAPR reduction. For the CCDF of \( 10^{-3} \), proposed technique makes the PAPR reduction vary from 11.7dB to 10dB and the conventional PAPR is in the range of 12dB to 10.2dB. In this analysis, the PAPR reduction improvement is 0.2dB.

The CCDF of PAPR performance of the proposed modified Selected Mapping technique using 64 subcarriers with 12 transmit antennas for 16 user OFDM-MIMO system is shown in Figure 4.12. Proposed technique is compared with the conventional technique. From the plots, proposed technique produces a sharp decay of PAPR values. At \( 10^{-3} \) of CCDF of PAPR, the proposed modified Selected Mapping creates 8.2dB of PAPR reduction compared to 9.5dB of Conventional Selected Mapping technique.

![CCDF of PAPR of OFDM signal](image)

**Figure 4.12** CCDF of the PAPR for proposed modified selected mapping technique

Finally CCDF of the PAPR of the proposed techniques for different number of users is analyzed as shown in Figure 4.13.
Figure 4.13 CCDF of the PAPR for different number of users using proposed modified selected mapping technique

For 8 users’ condition, the conventional technique generates the PAPR of 11.8dB at 10^{-3} of CCDF. The proposed technique creates the appreciable reduction and results at 10dB. In the same way 12 and 16 users’ conditions are also considered. In this case 10.6dB and 9.5dB of PAPR are generated by the conventional technique and these values are reduced to 9dB and 8.3dB respectively.

4.3.3 Proposed Modified Partial Transmit Sequence Technique

The OFDM frame is divided into a number of subblocks. After performing the IDFT of these parts, they are superimposed but individual phase rotation factor of these partial transmit sequences is admitted. Using OGA optimization technique, searching of the phase rotation is carried out and the phase value is restricted to a finite set of \{0, \pi/2, \pi, 3\pi/2\}. If the PAPR of the resulting OFDM symbol is less than the threshold PAPR_0, then the frame is transmitted. If not another set of phase rotation factor is generated.
and maximum numbers of iterations are repeated to get a final result. This procedure is repeated parallel to all branches. $M_t$ antennas transfer the modified best OFDM frames from the transmitter. $M_t\log_2 P$, ‘side information’ are transferred to the receiver to recover the original information.

### 4.3.3.1 Simulation result

Figure 4.14 plots the CCDF of PAPR for different values of subcarriers. From the plots, compared with the conventional method, the proposed technique generates appreciable PAPR reduction. At CCDF of $10^{-3}$, the PAPR of the proposed technique varies from 11dB to 12dB for the subcarrier variation of 32, 64, 128 and 256 respectively. For the same subcarrier values the conventional method creates high PAPR from 12.2dB to 13.8dB. From the result obtained from the plots the lower value of subcarrier produce the best result, because it starts its PAPR reduction at very low value of 6dB PAPR.

![The CCDF of the PAPR for different number of subcarriers using proposed modified partial transmit sequence technique](image)

Figure 4.14 The CCDF of the PAPR for different number of subcarriers using proposed modified partial transmit sequence technique
Figure 4.15 shows CCDF of the PAPR performance for different number of $M_t = 2, 4, 8$ and 12.

The proposed technique produces a better reduction compared to the conventional technique. High value of antenna 12 generates the high PAPR reduction. Conventional technique generates the PAPR of 12dB at CCDF of $10^{-3}$ but in the proposed technique this 12dB is reduced to 10.4dB. At $M_t = 2$ the low number of transmitting antenna, the proposed technique generates less reduction 11.8dB of PAPR compared to the conventional PAPR of 12.8dB.

The CCDF of the PAPR for Proposed Modified Partial Transmit Sequence Technique is shown in Figure 4.16.
Conventional Partial Transmit sequence PAPR reduction produces the PAPR of 8.5dB at 10^{-3} of CCDF. But the proposed technique creates PAPR of 7.3dB at the same value 10^{-3} of CCDF. It consists of an improvement of 1.2dB compared to the conventional method. Figure 4.17 illustrates the CCDF of the PAPR for different number of users using Proposed Modified Partial Transmit Sequence Technique.

The conventional method produces the PAPR of 10.3dB, 9.5dB and 8.5dB of PAPR for CCDF of 10^{-3} for 16, 12 and 8 users. These values are reduced to 9.3dB, 8.1dB and 7.3dB respectively in the proposed technique. Comparatively, 1dB of reduction improvement are achieved for all the users. Further, CCDF of PAPR performance is tested with different methods of Modulations like 64QAM, 16QAM and QPSK for the Proposed techniques of 16 users using 64 subcarriers with transmitting antenna of M_t = 12 as shown in Figure 4.18.
Figure 4.17 CCDF of the PAPR for different number of users using proposed modified partial transmit sequence technique

Figure 4.18 CCDF of the PAPR for different Modulations 64QAM, 16QAM and QPSK using Proposed Modified Partial Transmit Sequence Technique
From the observation of the plots, surprisingly the PAPR reduction response is same. It satisfies the constraint that, the PAPR problem does not disturb the types of modulation used in the system. The Throughput Enhancement scheme explained in Chapter 3 and the Resource allocation algorithm described in Chapter 2, use Adaptive modulator to implement adaptive modulation to achieve the goal of high Throughput. As a conclusion, increase in subcarrier needs the PAPR reduction technique. But increase in the number of transmitter antennas, reduce the effect of PAPR. The modulation is independent of value of PAPR. Therefore, in the proposed modified Partial Transmit Sequence technique, OFDM frames are partitioned into subblock techniques which will improve the CCDF performance by the technique.

Based on the analysis on the three proposed modified PAPR reduction techniques the following inferences are obtained and tabulated.

Table 4.2 compares the performances of CCDF of PAPR at $10^{-3}$ for the proposed three techniques in the subcarrier selections of 32, 64, 128 and 256 respectively.

**Table 4.2 CCDF of PAPR at $10^{-3}$ for different numbers of subcarrier**

<table>
<thead>
<tr>
<th>Number of Subcarriers N</th>
<th>Proposed Modified Interleaving Technique</th>
<th>Proposed Modified Selected Mapping Technique</th>
<th>Proposed Modified Partial Transmit Sequence Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Proposed</td>
<td>Conventional</td>
</tr>
<tr>
<td>32</td>
<td>13.2 dB</td>
<td>13 dB</td>
<td>12.2 dB</td>
</tr>
<tr>
<td>64</td>
<td>13.8 dB</td>
<td>13.3 dB</td>
<td>12.5 dB</td>
</tr>
<tr>
<td>128</td>
<td>14.4 dB</td>
<td>13.8 dB</td>
<td>13 dB</td>
</tr>
<tr>
<td>256</td>
<td>14.8 dB</td>
<td>14 dB</td>
<td>14 dB</td>
</tr>
</tbody>
</table>
From the observation, high PAPR reduction was generated by low value of subcarriers. Based on PAPR generations in both conventional and proposed techniques were compared. The PAPR produced by the Proposed Modified Interleaving Technique, Selected Mapping Technique and Partial Transmit Sequence Techniques were less to its corresponding conventional techniques. Also Proposed Modified Partial Transmit Sequence Techniques is superior compared to other two proposed techniques. Its improvement is approximately equal to 2dB of PAPR compared with Proposed Modified Interleaving and Proposed Modified Selected Mapping Techniques.

Table 4.3 compares the performances of CCDF of PAPR at $10^{-3}$ for the proposed three techniques in the transmit antenna selections of 2, 4, 8 and 12 respectively.

**Table 4.3** CCDF of PAPR at $10^{-3}$ for different numbers of transmit antennas

<table>
<thead>
<tr>
<th>Number of Transmit Antennas $M_t$</th>
<th>Proposed Modified Interleaving Technique</th>
<th>Proposed Modified Selected Mapping Technique</th>
<th>Proposed Modified Partial Transmit Sequence Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Proposed</td>
<td>Conventional</td>
</tr>
<tr>
<td>2</td>
<td>14 dB</td>
<td>13.6 dB</td>
<td>12.8 dB</td>
</tr>
<tr>
<td>4</td>
<td>13.4 dB</td>
<td>13 dB</td>
<td>12.6 dB</td>
</tr>
<tr>
<td>8</td>
<td>12.4 dB</td>
<td>12 dB</td>
<td>12.4 dB</td>
</tr>
<tr>
<td>12</td>
<td>11.8 dB</td>
<td>11.6 dB</td>
<td>12 dB</td>
</tr>
</tbody>
</table>

Based on the PAPR values present in Table 4.3, it concludes that increase in transmit antennas results the higher PAPR reduction. Proposed three techniques produced less PAPR compared to the conventional techniques. Comparatively the Proposed Modified Partial Transmit Sequence Techniques produced the best PAPR reduction compared to other two
proposed techniques. Its improvement is approximately equal to 2dB of PAPR compared with Proposed Modified Interleaving and Proposed Modified Selected Mapping Techniques. Table 4.4 compares the performances of CCDF of PAPR at $10^{-3}$ for the proposed three techniques in the user selections of 8, 12 and 16 respectively.

Table 4.4 CCDF of PAPR at $10^{-3}$ for different numbers of users

<table>
<thead>
<tr>
<th>Number of Users K</th>
<th>Proposed Modified Interleaving Technique</th>
<th>Proposed Modified Selected Mapping Technique</th>
<th>Proposed Modified Partial Transmit Sequence Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Proposed</td>
<td>Conventional</td>
</tr>
<tr>
<td>8</td>
<td>11.6 dB</td>
<td>11 dB</td>
<td>11.8 dB</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Conventional</td>
</tr>
<tr>
<td>12</td>
<td>11 dB</td>
<td>10.6 dB</td>
<td>10.6 dB</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Conventional</td>
</tr>
<tr>
<td>16</td>
<td>10.5 dB</td>
<td>10 dB</td>
<td>9.5 dB</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Conventional</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8.5 dB</td>
</tr>
</tbody>
</table>

From Table 4.4 information, increase in number of users results high PAPR reduction on the transmitted OFDM symbols. Based on the comparison between the three proposed techniques, it is proved that the Proposed Modified Partial Transmit Sequence Techniques is a successful technique for multi user high throughput transmission. Its improvement is approximately equal to 3dB of PAPR compared with Proposed Modified Interleaving and Proposed Modified Selected Mapping Techniques.

4.3.4 Proposed without ‘Side Information’ PAPR Reduction Techniques

The proposed Modified Interleaving, Modified Selected Mapping and Modified Partial Transmit Sequence techniques are simple to implement. These introduce less distortion in the transmitted signal and can achieve
significant PAPR reduction by the usage of optimization selection technique in the OFDM-MIMO system. All these three techniques generate a set of signals, using suitable algorithm, all of them representing the same block, and then transmitting the one with the lowest PAPR. The main drawback in these techniques is loss in data rate due to transmission of several ‘side information’ bits that are required for original data block recovery at the receiver side. The loss of such ‘side information’ bits during transmission would result in significant error performance degradation at the receiver output since the whole data block would be lost in this case. To avoid the need for explicit ‘side information’ few key modifications are proposed.

The ‘side information’ bits can be placed in the CP (Cyclic Prefix) extension of the OFDM frame. The receiver can easily identify its position and detect it and synchronization concept is achieved. In other words, ‘side information’ bits can be embedded in the transmitted symbols by extending the symbols that are located at some specific positions inside the transmitted frame. In the receiver, the role of the ‘side information’ detection block is simply to determine the locations of the extended symbols.

4.3.5 Proposed Modified Tone Reservation Technique

Based on the three proposed PAPR reduction technique PAPR reduction study, the Proposed Modified Partial Transmit Sequence Techniques proved its superiority. But its maximum PAPR is 7.3dB. In the further improvement, to get the best reduction, a simple tone reservation technique is selected and the optimal selection modifications are carried out. In the practical case for the high throughput transmission, tone reservation technique leads the spectral wastage. Because, a set of subcarriers are used only for the tone reservation purpose and not for the symbol transmission usage. But to achieve the excellent PAPR reduction and fine BER response Modified tone reservation technique is proposed.
Proposed Modified Tone reservation technique reserves a small number of subcarriers, for the purpose of low PAPR and low BER performance. The reserved subcarrier locations are determined by OGA optimization algorithm. The number of OFDM symbol carrying subcarriers equal to the difference between total number of subcarriers and Tone Reservation Subcarrier. PAPR reduction is performed on each of the transmit antennas independently. No ‘side information’ is transmitted along with the transmitted sequence, as the receiver has knowledge of the location of the reserved subcarriers. At the receiver, the symbols at the reserved subcarrier are received and extracted the OFDM symbol. It can be easily done by the proposed MIMO detection algorithm explained in the third chapter.

4.3.5.1 Simulation result

The proposed three PAPR Reduction techniques are having high BER, because of the ‘side information’ bit transfer. The BER performance with respect to SNR (E_b/N_0 in dB) for the above proposed techniques is shown in Figure 4.19.

For the analysis, the BER of 10^{-1.5} is obtained at 22.5dB of SNR for the proposed modified Interleaving technique, 20.5dB of SNR for the proposed modified Selected Mapping technique, 18dB of SNR for the proposed Partial Transmit Sequence technique, 16.5dB of SNR for the proposed without ‘side information’ PAPR reduction technique and 15.5dB of SNR for the proposed tone reservation technique.
As an inference, the last two proposed techniques approach the best BER performances. Their responses are proportional to the value of SNR. But, there is degradation in the BER performance of the system for the proposed modified Interleaving, Selected Mapping and Partial transmit sequence techniques. Comparatively, the proposed modified Partial transmit sequence results has the smaller degradation in the BER performance. The performance of partial transmitter sequence depends on the number of subblocks and the maximum number of iterations. But if one of the rotational factors is decoded incorrectly, then the entire subblock gets decoded incorrectly, which results in the high BER. These problems are eliminated by the proposed modified Tone Reservation technique. Its CCDF of PAPR response is shown in Figure 4.20.
From the observation of the plots, this tone reservation technique achieves the PAPR reduction of about 6dB and 8dB at a CCDF of $10^{-3}$ for the proposed and conventional techniques respectively. After 5.5 dB of PAPR, CCDF decreased very sharply and PAPR reduction improvement is 2dB compared to the conventional technique. The performance of the tone reservation depends on the number of reserved subcarriers. However, increasing the number of reserved subcarriers results in a better PAPR reduction and there is no loss in the BER. There is no need for the ‘side information’ transfer to decode the data at the receiver.

To make a fair comparison between the four PAPR reduction techniques PAPR at CCDF of $10^{-3}$ is listed in Table 4.5.
Table 4.5  CCDF of the PAPR at $10^{-3}$

<table>
<thead>
<tr>
<th>PAPR Reduction Techniques</th>
<th>Conventional</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed Modified Interleaving Technique</td>
<td>10.4 dB</td>
<td>10 dB</td>
</tr>
<tr>
<td>Proposed Modified Selected Mapping Technique</td>
<td>9.5 dB</td>
<td>8.2 dB</td>
</tr>
<tr>
<td>Proposed Modified Partial Transmit Sequence Technique</td>
<td>8.5 dB</td>
<td>7.3 dB</td>
</tr>
<tr>
<td>Proposed Modified Tone Reservation Technique</td>
<td>8 dB</td>
<td>6 dB</td>
</tr>
</tbody>
</table>

From the above analysis, in the first proposal of PAPR technique, Modified Interleaving technique achieved the reduced PAPR is compared to the conventional technique. However the reduction improvement is 0.4dB only. In the next proposal based on the Modified Selected Mapping technique 9.5dB of PAPR is reduced to 8.2dB and its reduction improvement is 1.3dB. Similar variation is achieved in the third proposal of Modified Partial Transmit Sequence technique. It creates 7.3dB of PAPR from 8.5dB of PAPR of conventional technique. Based on the number of subcarrier, transmit antennas and user variation analysis comparison the preferable one is Partial Transmit Sequence technique. The last proposal on the modified tone reservation technique generates less PAPR of 6dB with the reduction improvement of 2dB. The Proposed Modified Tone Reservation technique gets better PAPR reduction when compared to the other three proposed techniques.

4.4 CONCLUSION

The high throughput OFDM signal high PAPR problems are solved by the proposed methods of Modified Interleaving technique, Modified Selected Mapping technique, Modified Partial Transmit Sequences technique
and Modified Tone Reservation technique. The analysis based on varying the number of subcarriers, transmit antennas and users indicated that the proposed technique has the high PAPR reduction capability compared with the conventional techniques. This grade is achieved at the cost of slight decrease in the data rate and a negligible degradation in the bit error performance of the system. With the help of proposed Without ‘side information’ technique, Modified Interleaving, Selected Mapping, Partial Transmit Sequences techniques BER degradations performance is improved. Based on PAPR reduction performance comparison, Modified Tone Reservation provides the best result.