Survey on Signal Scrambling PAPR ReductionTechniques With Explicit Side Information in OFDM

Karuna A. Mahajan[1], Amit C. Raval[2], Rina S. Parikh[3]
IDS, Nirma University,Ahmedabad-382481,Gujrat India
Email : karuna_mahajan@nirmauni.ac.in

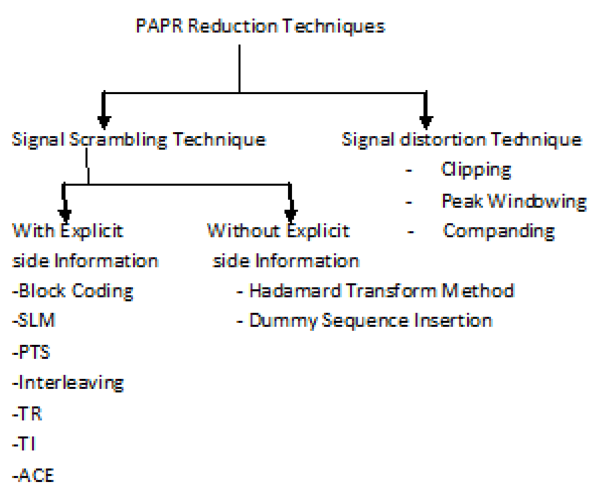
***Abstract*— An OFDM is an attractive modulation technique for transmitting large amounts of digital data over radio waves. One major disadvantage of OFDM is the time domain OFDM signal which is a sum of several sinusoids leads to high peak to average power ratio (PAPR). Number of techniques have been proposed in the literature for reducing the PAPR in OFDM system, among which Signal Scrambling Techniques which provides PAPR reduction without data rate loss are discussed and compared in this paper. Here more emphasis is given on SLM and PTS techniques as they are considered to be more powerful techniques for reducing PAPR. In SLM different phase rotations are used and alternate OFDM signals are generated by multiplying same data block with different phase rotations and one with minimum PAPR is selected for transmission while in PTS different combinations of phase rotations are used and the combinations of phase factors with minimum PAPR is selected.**

Keywords-Orthogonal frequency division multiplexing (OFDM), peak-to-average power ratio (PAPR), Partial transmit sequence (PTS), Selected Mapping(SLM) .

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a promising solution for high data rate transmission in frequency-selective fading channels. A major drawback of OFDM at the transmitter side is the high peak-to-average power ratio (PAPR) of the transmitted signal. High peaks of OFDM signals occur when the sinusoidal signals of the subcarriers are added constructively. These high peaks necessitate using larger and expensive linear power amplifiers. Since high peaks occur irregularly and infrequently, this means that power amplifiers will be operating inefficiently.

A large number of solutions have been proposed to in literatures to solve the PAPR problem in OFDM. Basically these techniques can be classified into two types, signal scrambling techniques and signal distortion techniques. Signal distortion techniques are the simple techniques but provides the distorted output where as signal scrambling techniques are somewhat complex techniques but they gives the distortionless output. Clipping, Peak Windowing and Companding techniques are coming under the head of signal distortion techniques where as signal scrambled techniques which are nothing but all variations on how to scramble the codes to decrease the PAPR are further classified into techniques with and without explicit side information. Techniques with explicit side information may have the disadvantage of reduction in effective throughput. The examples of these techniques are Selected Mapping(SLM), Partial Transmit Sequence(PTS), Interleaving, Tone reservation(TR), Tone Injection(TI) and Active Constellation Extension(ACE). All these techniques are probability based schemes, the example of coding based schemes is block coding scheme. The classification of PAPR reduction techniques is given as follows.



Clipping OFDM signal before amplification is a simple solution [1]. However, clipping may cause inter-modulation among subcarriers and undesired out-of-band radiation. Another solution uses block coding [2], where the data sequence is embedded in a larger sequence and only a subset of all the possible sequences are used, specifically, those with low peak powers. While block coding reduces PAPR, it also reduces transmission rate, significantly so for a large number of subcarriers. The Tone Reservation method [3] is based on adding a data-block-dependent time domain signal to the original multicarrier signal to reduce its peaks. This time domain signal can be easily computed at the transmitter and stripped off at the receiver. In Active Constellation Extension(ACE) technique [4], some of the outer signal constellation points in the data block are dynamically extended toward the outside of the original constellation such that the PAPR of the data block is reduced, and other distortionless PAPR reduction techniques are Selected mapping (SLM) scheme[5],[6], and Partial transmit sequence (PTS) schemes[7]–[11]. Among these schemes, the SLM and PTS scheme have been considered the most attractive schemes due to its high PAPR reduction performance without incurring additional signal distortion.

The rest of the paper is organized as follows. Section II describes about OFDM while section III gives description about OFDM Model. In Section IV problem of Peak to Average Power Ratio is discussed. Section V describes about different PAPR Reduction Techniques. Finally, conclusion is presented in Section VI.

II. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

OFDM is a Multicarrier Transmission technique which divides the available spectrum into many carriers each one being modulated by a low data rate stream. OFDM is similar to Frequency Division Multiple Access (FDMA) in which the multiple user access is achieved by sub-dividing the available bandwidth into multiple channels, which are then allocated to users. However OFDM uses the spectrum much more efficiently by spacing the channels more closely together. This is achieved by making all the carriers orthogonal to one another, preventing interference between them.

In FDMA each user is typically allocated a single channel which is used to transmit all the user information. The bandwidth of each channel is typically 10-30 kHz for voice communication. However, the minimum required bandwidth for speech is only 3 kHz. The allocated bandwidth is made wider than the minimum amount required to prevent channels from interfering with one another. This extra bandwidth is to allow for signals of neighboring channels to be filtered out and to allow for any drift in the center frequency of the transmitter or receiver. In a typical system up to 50% of the total spectrum is wasted due to the extra spacing between channels. This problem becomes worse as the channel bandwidth becomes narrower and the frequency band increases. Time Division Multiple Access (TDMA) overcomes this problem by using wider band width channels which are used by several users. The subcarriers in an OFDM signal are spaced close as is theoretically possible which maintain orthogonality between them.

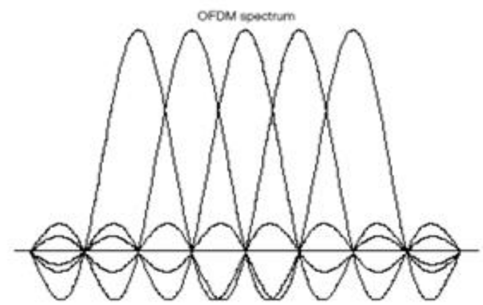


Fig.1. Orthogonality of subcarriers

The orthogonality of the carriers means that each carrier has an integer number of cycles over a symbol period. Due to this the spectrum of each carrier has a null at the center frequency of each of the other carriers in the system. This results in no interference between the carriers, allowing them to be spaced as close as theoretically possible.

III. OFDM SYSTEM MODEL

To generate OFDM successfully the relationship between all the carriers must be carefully controlled to maintain the orthogonality of the carriers. For this reason, OFDM is generated by firstly choosing the spectrum required based on the input data, and modulation scheme used. Each carrier to be produced is assigned same data to transmit. The required amplitude and phase of them are calculated based on the modulation scheme. The required spectrum is then converted back to its time domain signal using an Inverse Fourier Transform (IFT). In most applications, an Inverse Fast Fourier Transform (IFFT) is used. The IFFT performs the transformation very efficiently and provides a simple way of ensuring the carrier signals produced are orthogonal. The Fast Fourier Transform (FFT) transforms a cyclic time domain signal into its equivalent frequency spectrum. This is done by finding the equivalent waveform, generated by a sum of orthogonal sinusoidal components. The amplitude and phase of the sinusoidal components represent the frequency spectrum of the time domain signal. The IFFT performs the reverse process, transforming a spectrum (amplitude and phase of each component) into a time domain signal. An IFFT converts a number of complex data points, of length that is a power of 2, into the time

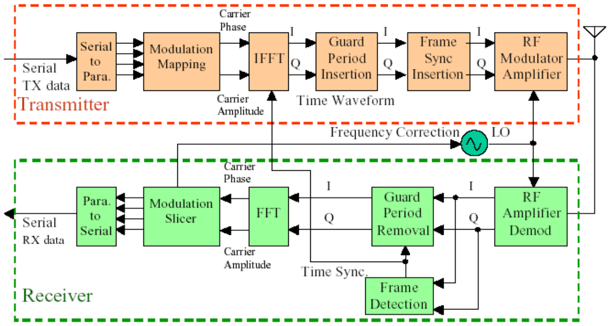


Fig.2. OFDM Transceiver Structure

domain signal of the same number of points. Each data point in frequency spectrum used for an FFT or IFFT is called a bin. The orthogonal carrier required for the OFDM signal can be easily generated by setting the amplitude and phase of each frequency bin, thus performing the IFFT.

Fig.2 shows the configuration for a basic OFDM Transmitter and Receiver. The signal generated is at base band and so to generate an RF signal, the signal must be filtered and mixed to the desired transmission frequency.

IV. PEAK-TO-AVERAGE POWER RATIO

A multicarrier signal is the sum of many independent signals modulated onto sub channels of equal bandwidth. Let us denote the collection of all data symbols Xn, n = 0, 1… N – 1, as a vector $X = [X_0, X_1 ... X_{N-1}]^T$ that will be termed a data block. The complex baseband representation of a multicarrier signal consisting of N subcarriers is given by

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n . e^{j2\pi n \Delta f t} \quad , 0 \leq t < NT \qquad (1)$$

Where $j = \sqrt{-1}$, f is the subcarrier spacing, and NT denotes the useful data block period. In OFDM the carriers are chosen to be orthogonal (i.e., f = 1/NT). The PAPR of the transmit signal is defined as

$$\text{PAPR} = \frac{\max\limits_{0 \leq t < NT} [x(t)]^2}{1/_{NT} . \int_0^{NT} [x(t)]^2 dt} \qquad (2)$$

In principle, PAPR reduction techniques are concerned with reducing max x(t). However, since most systems employ discrete-time signals, the amplitude of samples of x(t) is dealt with in many of the PAPR reduction techniques. Since symbol spaced sampling of (1) sometimes misses some of the signal peaks and results in optimistic results for the PAPR, signal samples are obtained by oversampling (1) by a factor of L to approximate the true PAPR better. The L -times oversampled time-domain samples are obtained by an LN - point inverse discrete Fourier transform (IDFT) of the data block with zero-padding. It was shown in [12] that L= 4 is sufficient to capture the peaks.

V. PAPR REDUCTION TECHNIQUES

Several techniques have been proposed in the literature to reduce the PAPR. These techniques can mainly be categorized in to signal scrambling techniques and signal distortion techniques. Signal scrambling techniques are all variations on how to scramble the codes to decrease the PAPR. Coding techniques can be used for signal scrambling. However with the increase in the number of carriers the overhead associated with exhaustive search of the best code would increase exponentially. More practical solutions of the signal scrambling techniques are Selective Level Mapping (SLM) and Partial Transmit Sequences (PTS). Signal scrambling techniques with side information reduces the effective throughput since they introduce redundancy. The signal distortion techniques introduce both In-band and Out-of-band interference to the system. The signal distortion techniques reduce high peaks directly by distorting the signal prior to amplification. Clipping the OFDM signal before amplification is a simple method to limit PAPR. However clipping may cause large out-of -band (OOB) and in-band interference, which results in the system performance degradation. More practical solutions are peak windowing, peak cancellation, Peak power suppression, weighted multicarrier transmission, companding etc. Basic requirement of practical PAPR reduction techniques include the compatibility with the family of existing modulation schemes, high spectral efficiency and low complexity.

The different Signal Scrambling PAPR reduction techniques with explicit side information in OFDM are Selected Level Mapping, Partial Transmit Sequence, Interleaving, Tone Reservation, Tone Injection and Active Constellation Extension.

A. Selected Mapping Technique

In the SLM technique, 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 [5, 6]. A block diagram of the SLM technique is shown in Fig. 3.

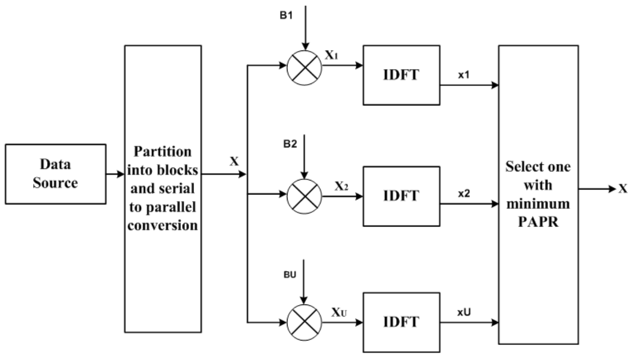


Fig. 3. Block diagram of SLM scheme[5].

Each data block is multiplied by U different phase sequences, each of length N, $\mathbf{B}^{(u)} = [b_{u,0}, b_{u,1}, \ldots, b_{u,N-1}]^T$, $u = 1, 2, \ldots, U$, resulting in U modified data blocks. To include the unmodified data block in the set of modified data blocks, we set $\mathbf{B}^{(1)}$ as the all-one vector of length N. Let us denote the modified data block for the u^{th} phase sequence $\mathbf{X}^{(u)} = [X_0 b_{u,0}, X_1 b_{u,1}, \ldots, X_{N-1} b_{u,N-1}]^T$, $u = 1, 2, \ldots, U$. After applying SLM to $\mathbf{X}$, the multicarrier signal becomes

$$X^{(u)}(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n \, b_{u,n} . e^{j2\pi n \Delta f t} \quad , 0 \le t < NT \qquad (3)$$

Where u = 1,2,…..U.

Among the modified data blocks $\mathbf{X}^{(u)}$, $u = 1, 2, \ldots, U$, 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. At the receiver, the reverse operation is performed to recover the original data block. For implementation, the SLM technique needs U IDFT operations, and the number of required side information bits is $\lfloor \log_2 U \rfloor$ for each data block. This approach is applicable with all types of modulation and any number of subcarriers. The amount of PAPR reduction for SLM depends on the number of phase sequences U and the design of the phase sequences.

Table I. Performance Analysis SLM for different subcarriers

No. of Sub-carriers	PAPR before SLM in dB	PAPR after SLM for different subcarriers				Diff. in PAPR-dB
64	6.32	5.13	5.55	5.22	4.20	2.01
128	7.16	5.43	5.19	5.07	4.21	2.95
256	8.04	4.79	5.44	5.06	4.25	3.78

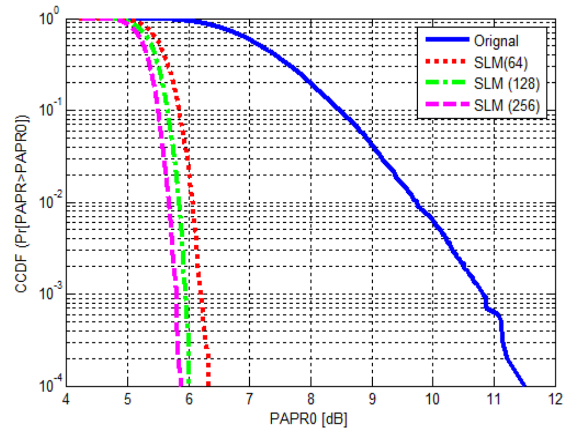


Figure 2. Comparison of PAPR for different subcarriers

B. Partial Transmit Sequence Technique

In the PTS technique, an input data block of N symbols is partitioned into disjoint subblocks. The subcarriers in each subblock are weighted by a phase factor for that subblock. The phase factors are selected such that the PAPR of the combined signal is minimized.

Fig. 4 shows the block diagram of the PTS technique. In the ordinary PTS technique [7] input data block X is partitioned into M disjoint subblocks $\mathbf{X}_m = [X_{m,0}, X_{m,1}, \ldots, X_{m,N-1}]^T$, $m = 1, 2, \ldots, M$, such that $\sum_{m=1}^{M} X_m = X$ and the subblocks are combined to minimize the PAPR in the time domain. The L-times oversampled time domain signal of $\mathbf{X}m$, $m = 1, 2, \ldots, M$, is denoted as $\mathbf{x}_m = [x_{m,0}, x_{m,1}, \ldots, x_{m,NL-1}]^T$. $\mathbf{x}_m$, $m = 1, 2, \ldots, M$, is obtained by taking an IDFT of length NL on $\mathbf{X}_m$ concatenated with $(L-1)N$ zeros. These are called the partial transmit sequences. Complex phase factors, $b_m = e^{j\phi m}$, Where $m = 1, 2, \ldots, M$, are introduced to combine the PTS. The set of phase factors is denoted as a vector b = $[b_1, b_2, \ldots, b_M]^T$. The time domain signal after combining is given by

$$X'(b) = \sum_{m=1}^{M} b_m . X_m \qquad (4)$$

Where $\mathbf{x}'(b) = [x_0'(b), x_1'(b). \ldots x_{NL-1}'(b)]^T$. The objective is to find the set of phase factors that minimizes the PAPR. Minimization of PAPR is related to the minimization of $\max_{0 \le k \le NL-1} [x'_k(b)]$. In general, the selection of the phase factors is limited to a set with a finite number of elements to reduce the search complexity. The set of allowed phase factors is written as

$$P = \{ e^{j2\pi l/W} \mid l = 0, 1, \ldots, W-1 \} \qquad (5)$$

Where W is the number of allowed phase factors. In addition, we can set $b_1 = 1$ without any loss of performance. So, we should perform an exhaustive search for $(M-1)$ phase factors. Hence, W^{M-1} sets of phase factors are searched to find the optimum set of phase factors. The search complexity increases with the number of subblocks M. PTS needs M IDFT operations for each datablock, and the number of required side information bits is $\lfloor \log 2 W^{M-1} \rfloor$, where $\lfloor y \rfloor$ denotes the exponentially smallest integer that does not exceed y. The amount of PAPR reduction depends on the number of subblocks M and the number of allowed phase factors W. Another factor that may affect the PAPR reduction performance in PTS is the subblock partitioning, which is the method of division of the subcarriers into multiple disjoint subblocks. There are three kinds of subblock partitioning schemes: adjacent, interleaved, and pseudo-random partitioning. Among them, pseudo-random partitioning has been found to be the best choice. The PTS technique works with an arbitrary number of subcarriers and any modulation scheme.

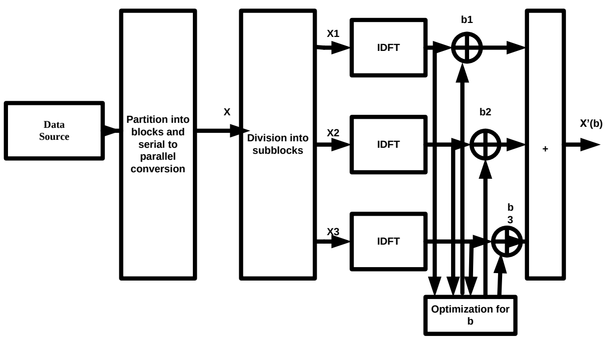


Fig. 4. Block diagram of PTS scheme [7].

Here, we show a simple example of the PTS technique for an OFDM system with eight subcarriers that are divided into four subblocks.

The phase factors are selected in $P = \{\pm 1\}$.

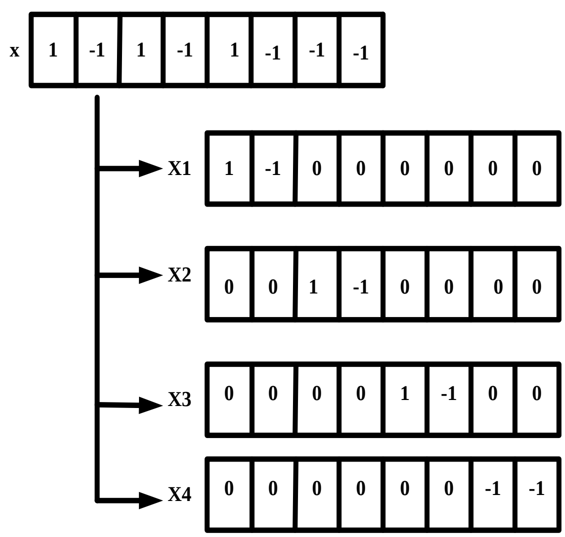


Fig. 5 An example of adjacent subblock partitioning

Fig.5 shows the adjacent subblock partitioning for a data block **X** of length 8. The original data block **X** has a PAPR of 7.5 dB. There are 8 (= 2^{4-1}) ways to combine the subblocks with fixed $b1 = 1$. Among them $[b1, b2, b3, b4]^T = [1, -1, -1, -1]^T$ achieves the lowest PAPR. The modified data block will be X' = $\sum_{m=1}^{M} b_m . X_m$ = [1, –1, –1, 1, –1, 1, 1, 1]^T whose PAPR is 6.3 dB, resulting in a 1.2 dB reduction. In this case, the number of required IDFT operations is 4 and the amount of side information is 3 bits. The side information must be transmitted to the receiver to recover the original data block. One way to do this is to transmit these side information bits with a separate channel other than the data channel. However this results in a data rate loss.

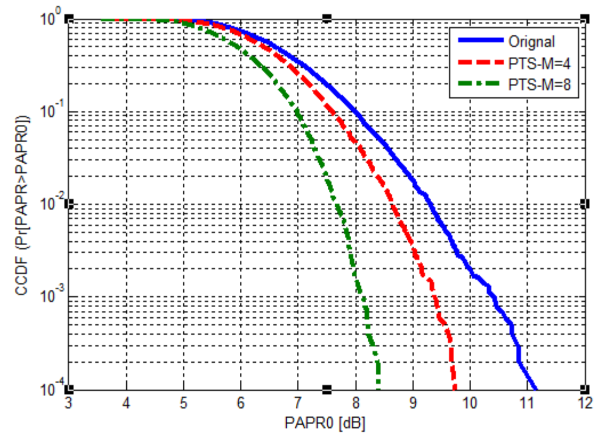


Fig. 6 Comparison of PAPR for different phase factors

C. *Interleaving Technique*

The interleaving technique for PAPR reduction is very similar to the SLM technique. In this approach, a set of interleavers is used to reduce the PAPR of the multicarrier signal instead of a set of phase sequences. An interleaver is a device that operates on a block of N symbols and reorders or permutes them; thus, data block $\mathbf{X} = [X_0, X_1, \ldots, X_{N-1}]^T$ becomes $\mathbf{X}' = [X_{\pi(0)}, X_{\pi(1)}, \ldots, X_{\pi(N-1)}]^T$ where $\{n\} \leftrightarrow \{\pi(n)\}$ is a one-to-one mapping $\pi(n) \in \{0, 1, \ldots, N-1\}$ and for all n. 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 are computed using K IDFT operations; the 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 $\lfloor \log_2 K \rfloor$. Both the transmitter and receiver store the permutation indices $\{\pi(n)\}$ in memory. Thus, interleaving and deinterleaving can be done simply. The amount of PAPR reduction depends on the number of interleavers $(K-1)$ and the design of the interleavers.

The most important aspect of this method is that it is less complex than the PTS method but achieves comparable results. The scheme does not provide the guaranteed PAPR reduction and for the worst case PAPR value of N. Therefore, higher order error correction method should be used in addition to this scheme.

D. Tone Reservation Technique

In this method the basic idea [3], is to reserve a small set of tones for PAPR reduction. The problem of computing the values for these reserved tones that minimize the PAPR can be formulated as a convex problem and can be solved exactly. 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 multi-carrier transmission, and shows that reserving a small fraction of tones leads to large reductions in PAPR ever with simple algorithm at the transmitter, and with no additional complexity at the receiver. When the number of tones N 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 advantages of being less complex, no special receiver operation, and no need for side information. Tone reservation is based on adding a data block dependent time signal to the original multicarrier signal to reduce its peaks. This time domain signal can be easily computed at the transmitter and stripped off at the receiver.

E. Tone Injection Technique

The basic idea here is to increase the constellation size so that each of the points in the original basic constellation can be mapped into several equivalent points in the expanded constellation [13]. Since each symbol in a data block can be mapped into one of several equivalent constellation points, these extra degrees of freedom can be exploited for PAPR reduction. This method is called tone injection because substituting a point in the basic constellation for a new point in the larger constellation is equivalent to injecting a tone of the appropriate frequency and phase in the multicarrier signal.

The TI technique may be more problematic than the TR technique since the injected signal occupies the same frequency band as the information bearing signal. The TI technique may also result in a power increase in the transmit signal due to the injected signal.

F. Active Constellation Extension Technique

This technique [4] for PAPR reduction is similar to Tone Injection Technique. In the active constellation extension technique, some of the outer signal constellation points in the data block are dynamically extended towards the outer side of the original constellation such that the PAPR of the data block is reduced. The main idea of this scheme is easily explained in the case of a multicarrier signal with QPSK modulation in each sub-carrier. In each sub-carrier there are four possible constellation points that lie in each quadrant in the complex plane and are equidistant from the real and imaginary axes. Assuming white Gaussian noise, the maximum likelihood decision region are the four quadrants bounded by the axes, thus, a received data symbol is absorbed. Any point that is farther from the

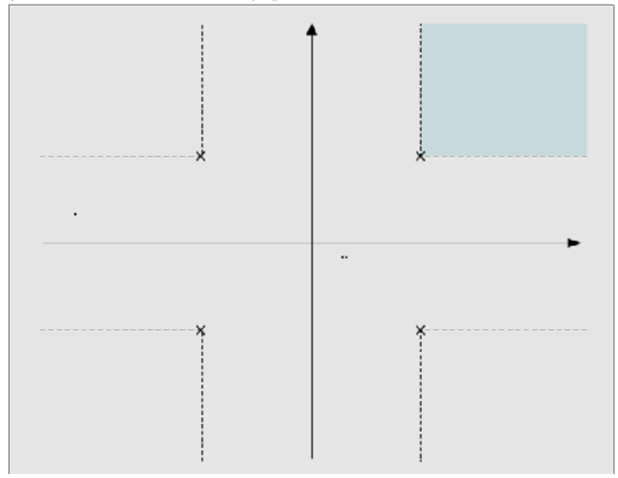


Fig. 7 The ACE technique for QPSK modulation[4]

decision boundaries than the normal constellation point (Proper quadrant) will offer increased margin which guarantees a lower BER.

This principle is illustrated in Fig. 7, where the shaded region represents the region of increased margin for the data symbol in the first quadrant. If adjusted intelligently, a combination of these additional signals can be used to partially cancel time domain peaks in the transmit signal. The Active Constellation Extension (ACE) idea can be applied to other constellation as well such as QAM and MPSK constellation, because the data points that lie on the outer boundaries of the constellation have room for increased margin without degrading the error probability for other data symbols.

This scheme simultaneously decreases the BER slightly while substantially reducing the peak magnitude of the data block. Further more there is no loss in data rate and no side information is required. However these modification may increase the transmit signal power for the data block and usefulness of the scheme is restricted to a modulation with a large constellation side.

G. Block Coding Technique

The paper by, Wilkinson and Jones [14] proposes a block coding scheme for the reduction of the peak to mean envelope power ratio of multicarrier transmission systems in 1995. The main idea behind this paper is that PAPR can be reduced by block coding the Data such that set of permissible code words does not contain those which result in excessive peak envelope powers (PEPs). There are three stages in the development of the block coding technique. The first stage is the selection of suitable sets of code words for any number of carriers, any M-ary phase modulation scheme, and any coding rate. The second stage is the selection of the sets of code words that enable efficient implementation of the encoding /decoding. The third stage is the selection of sets of code words that also offer error deduction and correction potential. There are a number of approaches to the selection of the sets of code words. The most trivial brute force approach is sequential searching of the PEP for all possible code words for a given length of a given number of carriers. This is simple and appropriate for short codes because it requires excessive computation. Most sophisticated searching techniques such as natural algorithms can be used for the selection of longer code words. The encoding and decoding, with sets of code words selected from searches, can be performed with a look up table or using combinatorial logic exploiting the mathematical structure of the codes.

VI. CONCLUSION

Orthogonal frequency division multiplexing is a form of multi carrier modulation technique with high spectral efficiency, robustness to channel fading, immunity to impulse interference. Despite of its many advantages, OFDM has two main drawbacks Viz: high peak to average power ratio (PAPR) and frequency offset. High PAPR causes saturation in power amplifiers, leading to inter modulation products among the sub carriers and disturbing out of band energy. Therefore, it is desirable to reduce the PAPR. Several techniques have been proposed Among which signal scrambling PAPR reduction techniques with explicit side information are discussed here at length. These all are distortion less techniques. SLM and PTS are more powerful distortionless techniques among these but they gives more PAPR reduction at the cost of increased complexity.

Hence no specific PAPR reduction technique is the best solution for all multicarrier transmission systems. Rather, the PAPR reduction technique should be carefully chosen according to various system requirements. In practice, the effect of the transmit filter, D/A converter, and transmit power amplifier must be taken into consideration to choose an appropriate PAPR reduction technique

REFERENCES

[1] X. Li and L. J. Cimini, Jr., "Effect of Clipping and Filtering on the Performance of OFDM," *IEEE Commun.Lett.*, vol. 2, no. 5, May 1998, pp. 131–33.

[2] A. E. Jones, T. A. Wilkinson, and S. K. Barton, "Block Coding Scheme for Reduction of Peak to Mean Envelope Power Ratio of Multicarrier Transmission Scheme," *Elect. Lett.*, vol. 30, no. 22, Dec. 1994, pp. 2098–99.

[3] B. S. Krongold and D. L. Jones, "An Active Set Approach for OFDM PAR Reduction via Tone Reservation," *IEEE Trans. Sig. Proc.*, vol. 52, no. 2, Feb. 2004, pp. 495–509.

[4] B. S. Krongold and D. L. Jones, "PAR Reduction in OFDM via Active Constellation Extension," *IEEE Trans. Broadcast.*, vol. 49, no. 3, Sept. 2003, pp. 258–68.

[5] R. W. Bäuml, R. F. H. Fisher, and J. B. Huber, "Reducing the Peak-to-Average Power Ratio of Multicarrier Modulationby Selected Mapping," *Elect Lett.*, vol. 32,no. 22, Oct. 1996, pp. 2056–57

[6] H. Breiling, S. H. Müller–Weinfurtner, and J. B. Huber, "SLM Peak-Power Reduction without Explicit Side Information," *IEEE Commun. Lett.*, vol. 5, no. 6, June 2001, pp. 239–41.

[7] S. H. Müller and J. B. Huber, "A Novel Peak Power Reduction Scheme for OFDM," *Proc. IEEE PIMRC '97*, Helsinki, Finland, Sept. 1997, pp. 1090–94.

[8] A. D. S. Jayalath and C. Tellambura, "Adaptive PTS Approach for Reduction of Peak-to-Average Power Ratio of OFDM Signal," *Elect. Lett.*, vol. 36, no. 14, July 2000, pp. 1226–28.

[9] L.J. Cimini, Jr. and N. R. Sollen berger, "Peak-to-Average power Ratio Reduction of an OFDM Signal Using Partial Transmit Sequences," *IEEE Commu. Lett.*, vol. 4, no. 3, Mar. 2000, pp. 86–88.

[10]] C. Tellambura, "Improved Phase Factor Computation for the PAR Reduction of an OFDM Signal Using PTS," *IEEE Commun. Lett.*, vol. 5, no. 4, Apr. 2001, pp. 135–37.

[11] S. H. Han and J. H. Lee, "PAPR Reduction of OFDM Signals Using a Reduced Complexity PTS Technique," *IEEE Sig.Proc. Lett.*, vol. 11, no. 11, Nov. 2004, pp. 887–90.

[12] C. Tellambura, "Computation of the continuous-time PAR of an OFDM signal with BPSK subc arriers," *IEEE Commun. Lett.*, vol. 5, pp.185–187, May 2001.

[13] J. Tellado, "Peak to Average Power Reduction for Multicarrier Modulation", *Ph.D. dissertation, Stanford Univ*., 2000.

[14] Wilkison, T.A. and Jones, A.E., "Minimazation of the peak to mean envelope power ratio of multicarrier transmission schemes by block coding*", IEEE Vehicular Technology Conference, Vol.2.*, Jul 1995

[15] Ahn, H., Shin, Y.m and Im, S., "A block coding scheme for peak to average power ratio reduction in an orthogonal frequency division multiplexing system", *IEEE Vehicular Technology Conference Proceedings*, Vol.1, May 2000

[16] Park, M., Heeyong, J., Cho, N., Hong, D, and Kang, C., "PAPR reduction in OFDM transmission using Hadamard transform", *IEEE International Conference on Communications*, Vol.1, Jun 2000

[17] Ryu, H., Lee, J., and Park, J., "Dummy Sequence insertion (DSI) for PAPR reduction in the OFDM communication system", *IEEE Transactions on Consumer Electronics*, Vol.50, Feb. 2004

[18] Wang, X., Tjhung, T.T., Ng, C.S., "Reduction of peak to average ower ratio of OFDM system using a companding technique", *IEEE transactions on broadcasting*, Vol.25, Sep 1999.

[19] L.J.Cimini, Jr, "Analysis and Simulation of a Digital Mobile Channel using OFDM", *IEEE Trans. On Communications*, vol.Com-33, no.7, pp.665-675, July 1985.

[20] May, T., and Rohling , H., "Reducing the peak to average power ratio of OFDM", radio transmission system", *IEEE Vehicular Technology Conference*, Vol. 3, May 1998.

[21] Van Nee, R., and Wild, A., "Reducing the peak to average power ratio of OFDM", *IEEE Vehicular Technology Conference*, Vol.3, May 1998