AN OVERVIEW OF TECHNIQUES FOR REDUCING PEAK TO AVERAGE POWER RATIO AND ITS SELECTION CRITERIA FOR ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING RADIO SYSTEMS

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ABSTRACT

The concept of Orthogonal Frequency Division Multiplexing (OFDM) has been known since 1966, but it only reached sufficient maturity for deployment in standard systems during 1990s. OFDM is an attractive modulation technique for transmitting large amounts of digital data over radio waves. One major disadvantage of OFDM is that 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 systems. In this paper the various techniques proposed for reducing the PAPR and the selection criteria for choosing these techniques have been discussed. The goal is to convey the fundamental ideas and intuitive understanding of the concept introduced. This is done primarily to give an overview of the various techniques known today for PAPR reduction.

Keywords: Orthogonal frequency division multiplexing, peak to average power ratio, signal scrambling, signal distortion.

1. INTRODUCTION

New Technologies and thereby new applications are emerging not just in wired environment but also in the wireless arena. The next generation mobile systems are expected to provide a substantially high data rate to meet the requirements of future high performance multimedia applications. The minimum target data rate for the 4G system is expected to be at 10-20 Mbps and alteast 2 Mbps in the moving vehicles. To provide such a high data rate with high spectral efficiency, a new modulation scheme is to be used. A promising modulation technique that is increasingly being considered for adoption by 4G community is OFDM [1]. Existing 3G systems uses single carrier modulation technique whereas OFDM which is otherwise known as Multicarrier Modulation (MCM) / Discrete Multitone Technique (DMT) sends a high speed data stream by splitting it up to multiple lower speed stream and transmitting it over a lower bandwidth subcarriers in parallel. OFDM has several favourable properties like high spectral efficiency, robustness to channel fading, immunity to impulse interference, uniform average spectral density, capacity to handle very strong echoes and less non-linear distortion. OFDM is the modulation technique used in many new broadband communication systems. In recent years OFDM has emerged as the standard of choice in a number of important high data applications.

OFDM is employed in Digital Television Broadcasting (such as the digital ATV Terrestrial Broadcasting) [2], European Digital Audio Broadcasting (DAB) and Digital Video Broadcasting Terrestrial (DVB-T) [3], Wireless Asynchronous Transfer Mode (WATM) [4] and numerous Wireless Local Area Networks (e.g. IEEE 802.11a operating at 5 GHz) [5] and European Telecommunications Standard Institute (ETSI) Broadband Radio Access Networks (BRAN)'s High Performance Radio Local Area Network (HIPERLAN) Type-2 standard [6].

Table 1: OFDM Systems

	Hiperlan 2	DAB	802.11 a/b	DVB-T
No.of carriers	48 subcarriers	1705 subcarriers in 2k DFT	48 subcarriers in 64 FFT	1705subcarriers in 2k DFT, 6817subcarriers in 8k DFT
Modulation Schemes	16-QAM/ 8PSK	DQPSK	64-QAM	64-QAM
Capacity	25 Mbps	2 Mbps	54 Mbps	12-24 Mbps
Bandwidth	25 MHz	1.526 MHz overall	20 MHz	8 MHz RF channel
Spectral Region	5.2 GHz	Band 3: 174-240 MHz Band L:1452-1492 MHz	802.11a in 5.8 GHz, 802.11b in 2.4 GHz	VHF / UHF band
Technology	WLAN	Broadcasting	Wireless Technology	Broadcasting Technique

2. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM):

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 that 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 closer together. This is achieved by making all the carriers orthogonal to one another, preventing interference between the closely

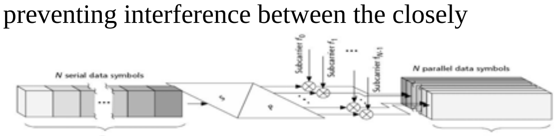


Fig.1. Multicarrier Transmission Technique

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.

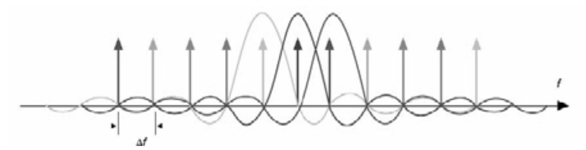


Fig.2. Orthogonality of subcarriers

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 interferrence between the carriers, allowing them to be spaced as close as theoretically possible.

3. 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 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.

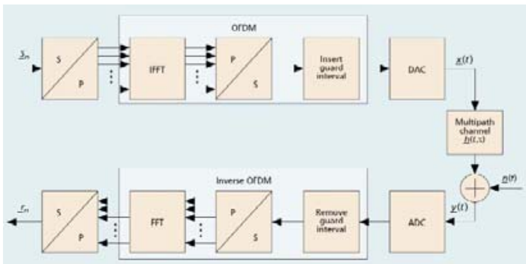


Fig.3. OFDM Transceiver Structure

Fig.3 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.

4. PROBLEM OF PEAK-TO-AVERAGE POWER RATIO IN OFDM SYSTEMS

High Peak-to-Average Power Ratio has been recognized as one of the major practical problem involving OFDM modulation. High PAPR results from the nature of the modulation itself where multiple subcarriers / sinusoids are added together to form the signal to be transmitted. When N sinusoids add, the peak magnitude would have a value of N, where the average might be quite low due to the destructive interference between the sinusoids. High PAPR signals are usually undesirable for it usually strains the analog circuitry. High PAPR signals would require a large range of dynamic linearity from the analog circuits which usually results in expensive devices and high power consumption with lower efficiency (for e.g. power amplifier has to operate with larger back-off to maintain linearity).

In OFDM system, some input sequences would result in higher PAPR than others. For example, an input sequence that requires all such carriers to transmit their maximum amplitudes would certainly result in a high output PAPR. Thus by limiting the possible input sequences to a smallest sub set, it should be possible to obtain output signals with a guaranteed low output PAPR.

The PAPR of the transmit signal x(t) is the ratio of the maximum instantaneous power and the average power.

By definition,
$$PAPR = \max_{0 \le t \le T} \frac{[x(t)]^2}{E\{|x(t)|^2\}} \qquad (1)$$

where E{.} denotes expectation operator.

If a signal is a sum of N signals each of maximum amplitude equal to 1 Volt, then it is conceivable that we could get a maximum amplitude of N Volts, that is, all N signals add at a moment at these maximum points.

For an OFDM signal, that has 126 carriers each with normalized power of 1W, then the maximum PAPR can be as large as 10 log10 126 or 21 db. This is at the instant when all 126 carriers combine at their maximum point unlikely but possible. The RMS PAPR will be around half of the number as 10-12 db.

The large amplitude variation increases in-band noise and increases the Bit Error Rate (BER) which the signal has to go through amplification nonlinearities.

The crest factor is widely used in the literature as well, which is defined as the square root of the PAPR.

Crest Factor,
$$C.F. = \sqrt{PAPR} \qquad (2)$$

High PAPR / crest factor could cause problems when the signal is applied to a transmitter which contains non-linear components such as High Power amplifier (HPA) in the Transmitter chain. The PAPR has the worst case value PAPRWC which depends on the no. of subscribers N. The non-linear 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. The in-band interference increases the Bit Error Rate (BER) of the received signal, while the out-of-band interference causes adjacent channel interference through spectral spreading. A better solution is to prevent the occurrence of such nonlinear distortion by reducing PAPR of the transmitted signal with some manipulation of the OFDM signal itself.

Table 2: PAPRWC Vs No. of Subcarriers

No. of sub-carriers	2	4	8	16	32	64	128	256
$PAPR_{WC}$ (db)	3.01	6.02	9.03	12.04	15.05	18.06	21.07	24.01

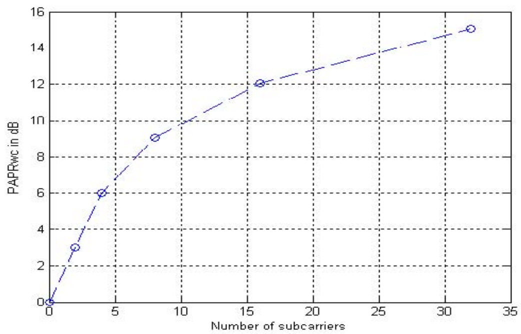


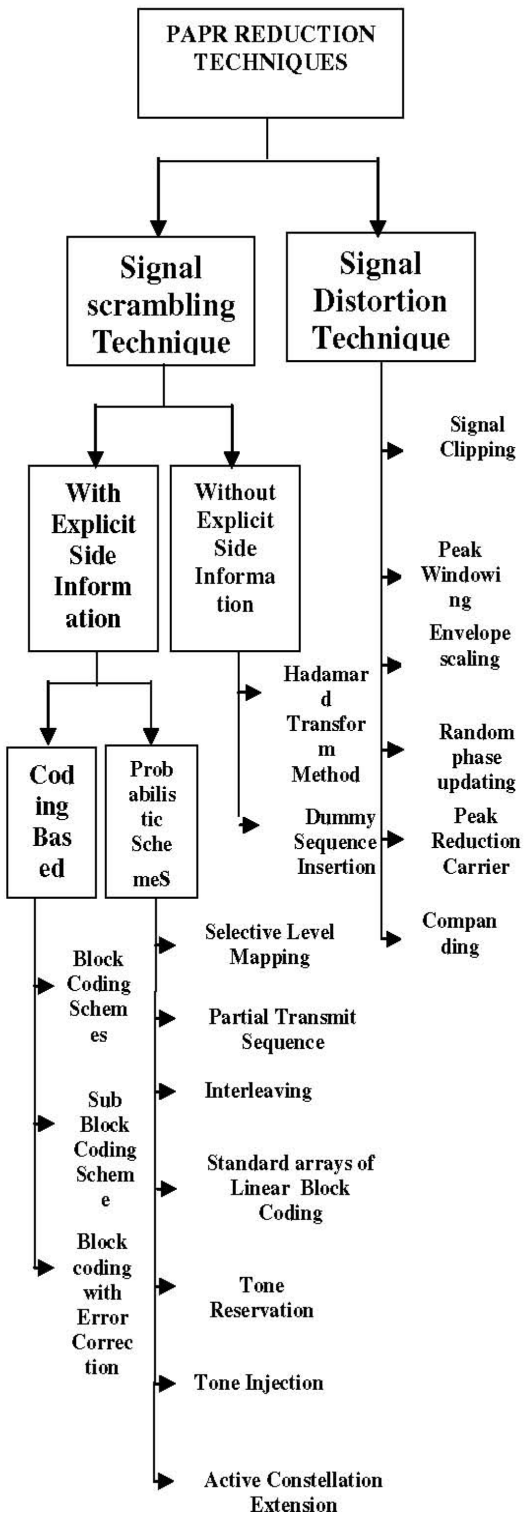
Fig.4: PAPRWC Vs No. of Subcarrier

5.0. 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. Golay complementary sequences, Shapiro-Rudin sequences, M sequences, Barker codes can be used efficiently to reduce the PAPR. 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 block coding, 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 and complexity 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-bandinterference, 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

Table 3: PAPR Reduction Techniques



5.1. SIGNAL SCRAMBLING TECHNIQUES

5.1.1 BLOCK CODING TECHNIQUES:

The paper by, Wilkinson and Jones [7] 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.

5.1.2. SUB BLOCK CODING TECHNIQUES:

The paper, by Zhang, et.al., [8] proposes the sub-block coding scheme and its two extensions, in the form of redundant bit location optimized sub-block coding and combination-optimized sub-block coding, for reducing peak to average power ratio of an OFDM signal. The proposed scheme for reducing the PAPR of OFDM has low complexity and is found that more than 3dB reduction in PAPR can be achieved when the code rate is ¾.

The introduction of Sub-block coding (SBC) is based on the observation that all ¾ rate systematically coded block codes with the last bit as an odd parity checking bit demonstrate lowest peak envelope power. This coding scheme is termed as systematic odd parity checking coding (SOPC). It is found that both SOPC and block coding schemes are not effective in terms of PAPR reduction when the frame size is large, however, large PAPR reduction can still be obtained if the long information sequence is divided in to several sub-blocks, and each sub-block encoded with SOPC. There are many possible locations, where the odd parity checking bits can be inserted into each frame to reduce PAPR. Redundant bit location optimized sub-block coding (RBLO-SBC) optimizes these locations for further reduction of PAPR. Combination optimized sub-block coding scheme (COSBC) optimizes the combination of the coded sub-blocks, where two coding schemes instead of one is used to encode the same information source.

5.1.3. BLOCK CODING SCHEME WITH ERROR CORRECTION:

The paper, by Ahn, et.al., [9] present a new block coding scheme for reduction of peak to average power ratio (PAPR) of an OFDM system, with error correction capability. In block coding approach, the PAPR of the OFDM symbol can be reduced by selecting only those code words with small PAPR. The main idea of the scheme proposed in this paper is that well designed block codes can not only reduce the PAPR, but also provide error correction capability. In the transmitter of the system, a k bit data block (e.g. say 4-bit data) is encoded by a (n, k) block code with a generator matrix G, followed by the phase rotator vector b to yield the encoded output x = a.G + b (mod 2)

To obtain the proper generator matrix and phase rotator vector that ensure the minimum PAPR for the OFDM system, check all the 2^n codes and select only 2^kcodes that achieve the minimum PAPR. Then the generator matrix G and the phase rotator vector b g are generated which are utilized to provide mapping between these symbol combination and the input data vector a.

In the receiver system, the converse functions of the transmitter are performed. The parity check matrix H is obtained from the generator matrix G, with an exception that the effect of the phase rotator vector b is eliminated before calculations of syndromes.

Unlike the method in [7], which only provides error detection; this method provides error correction capability and can improve the overall system performance.

5.1.4. SELECTED MAPPING (SLM):

The paper, by Bauml et.al., [10] proposes a method for the reduction of peak to average transmit power of multicarrier modulation systems with selected mapping in 1996. In selected mapping (SLM) method a whole set of candidate signals is generated representing the same information, and then the most favorable signal as regards to PAPR is chosen and transmitted. The side information about this choice needs to be explicitly transmitted along with the chosen candidate signal.

SLM scheme is one of the initial probabilistic approaches for reducing the PAPR problem, with a goal of making occurrence of the peaks less frequent, not to eliminate the peaks. The scheme can handle any number of subcarriers and drawback associated with the scheme is the overhead of side information that needs to be transmitted to the receiver.

5.1.5. PARTIAL TRANSMIT SEQUENCE (PTS):

The paper, by Muller and Hubber, [11] proposes an effective and flexible peak power reduction scheme for OFDM system by combining Partial Transmit Sequences (PTS) in 1997. The main idea behind the scheme, is that, the data block is partitioned into non-overlapping sub blocks and each sub block 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.

PTS is also probabilistic scheme of reducing PAPR. PTS scheme can be interpreted as a structurally modified case of SLM scheme and, it is found that the PTS schemes performs better than SLM schemes. When differential modulation is used in each subblock, no side information needs to be transmitted to the receiver.

5.1.6. STANDARD ARRAYS OF LINEAR BLOCK CODES:

The paper by, Yang et.al., [12] proposes a method to reduce the PAPR reduction by using the standard arrays of linear block codes. In this scheme, a signal with minimum PAPR from U distinct signals is chosen as the transmit signal, where U distinct signals are constructed by scrambling a codeword with the properly selected co-set leaders. Because the co-set leaders are used only for scrambling, no side information is required to be transmitted and the received signals can be easily decoded by syndrome decoding.

The key idea is to use the standard array of block codes for reduction of the PAPR in OFDM system, not for error correction. This is possible by choosing a vector that yields low (possibly minimum) PAPR in each co-set as its co-set leader, instead of a minimum weight vector. This scheme is a modified version of SLM, in which the transmit signal is selected as a signal with minimum PAPR from differently scrambled signal of the information by a number of random sequences. It is found that the proposed scheme has slightly better performance in PAPR reduction than the SLM method. The most important aspect of the scheme is that it achieves better performance than SLM without transmitting any side information.

5.1.7. INTERLEAVING:

The paper, by Jayalath and Tellambura, [13] presents interleave based technique for improving the peak to average power ratio of an OFDM signal. Highly correlated data frames have large PAPR, which could thus be reduced, if long correlation patterns were broken down. The paper proposes a data randomization technique for the reduction of the PAPR of the OFDM system.

The paper also proposes an adaptive technique to reduce the complexity of the scheme. The key idea in adaptive interleaving is to establish an early terminating threshold i.e. the search is terminated as soon as the PAPR value reaches below the threshold, rather than searching all the interleaved sequences. The low threshold will force the adaptive interleaving (AIL) to search for all the interleaved sequences, whereas for the large threshold value, AIL will search only a fraction of the interleaved sequences.

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.

5.1.8. HADAMARD TRANSFORM:

The paper, by Park et.al., [14] proposes a scheme for PAPR reduction in OFDM transmission using Hadamard transform. The paper focuses on the relationship between correlation properties of OFDM input sequence and PAPR probability. The proposed hadamard transform based scheme reduces the occurrence of the high peaks comparing the original OFDM system. It is found that the PAPR can be reduced to about 2dB in 16 QAM OFDM system without any power increase and side information and little increase in system complexity. The idea to use the Hadamard transform is to reduce the autocorrelation of the input sequence to reduce the peak to average power problem and it requires no side information to be transmitted to the receiver.

5.1.9. DUMMY SEQUENCE INSERTION:

The paper, by Ryu, et.al., [15] proposes a scheme for PAPR reduction in OFDM transmission using dummy sequence insertion(DSI) method. In this method, dummy sequence is added into the input data for the PAPR reduction before IFFT stage. Complementary sequence, correlation sequence, and other specific sequence may be used as the dummy sequence that does not work as the side information unlike the PTS and SLM methods. So there is no BER degradation due to side information error. PAPR threshold technique is combined into this DSI method. If the PAPR of IFFT output is lower than a certain prescribed PAPR threshold level, the IFFT output data is transmitted. Otherwise, dummy sequence is inserted to lower the PAPR. The block code based schemes for PAPR reduction suffers from the overhead of large side information to be transmitted to the receiver. In the proposed scheme dummy variables are inserted in the transmitted data for the reduction of PAPR of the OFDM signal. The receiver can simply discard the dummy data sequence, as it is does not contain any information.

BER performance of the DSI scheme is independent of the error in the dummy data sequence. The DSI method demonstrates improved BER performance as compared to the conventional PTS and has higher transmission efficiency for PAPR reduction than the conventional block coding. DSI method using complimentary sequence is better than the other methods.

5.1.10. TONE RESERVATION [22]

In this method, the basic idea 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 with in 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. TR 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.

5.1.11. TONE INJECTION [22]

This is an additive method, which 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 into several equivalent points in the expanded constellation, Since each information unit can be mapped into one of several equivalent constellation points, these extra degrees of freedom can be exploited for PAPR reduction. The method is called Tone Injection, as substituting the points in the basic constellation for the new points in the larger constellation is equivalent to injecting a tone of the appropriate phase and frequency in the multi-carrier symbol.

5.1.12. ACTIVE CONSTELLATION:

The paper by, Knongold and Jones [23] proposes a technique for PAPR reduction 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 decision boundaries than the normal constellation point (Proper quadrant) will offer increased margin which guarantees a lower BER. 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.

6.1. SIGNAL DISTORTION TECHNIQUES:

6.1.1. CLIPPING & FILTERING:

The paper, by May and Rholing, [16] proposes the method of PAPR reduction by manipulating the OFDM signal with a suitable additive correcting function. In this approach, the amplitude peaks are corrected (or signal is modified) in such a way that a given amplitude threshold of the signal is not exceeded after the correction.

The OFDM signal is corrected by adding it with a corrective function k(t). This correction limits the signal s(t) to A0 at positions of tn of amplitude peaks. This method produces no out-of-band interference and causes interference of the OFDM signal with minimal power. If the OFDM signal is not oversampled, then the correction scheme is identical with clipping and each correction of an amplitude peak causes interference on each sub carrier and the power of the correcting function is distributed evenly to all sub carriers. To apply this correcting scheme, the signal s(t) is oversampled by a factor of four and normalized so that the signal power is one. Then the signal is corrected with k(t). For the correction the amplitude threshold A0 is set according to the input bakeoff. After the correction, the signal is limited to the amplitude A0 in order to take into account the limitation of amplitude peaks which may have remained. The signal can be corrected by multiplicative Gaussian function or additive sinc function. The interesting part of the scheme is that it can be used for any number of subcarriers and it does not need any redundancy. The PAPR is reduced at the cost of small increase in the total in-band distortion.

6.1.2. PEAK WINDOWING:

The paper, by van Nee and Wild [17] proposes that as large PAP ratios occur only infrequently, it is possible to remove these peaks at the cost of a slight amount of self interference. Clipping is one example of a PAPR reduction technique creating self interference. Peak Windowing technique provides better PAPR reduction with better spectral properties than clipping. Peak windowing can achieve PAPR around 4dB for an arbitrary subcarriers, at the cost of slight increase in BER and out-of-band (OOB) interference.

In windowing technique a large signal peak is multiplied with a certain window, such as Gaussian shaped window, cosine, Kaiser and Hamming window. Since the OFDM signal is multiplied with several of these windows, the resulting spectrum is a convolution of the original OFDM spectrum with the spectrum of the applied window. Ideally the window should be as narrow band as possible, on the other hand the window should not be too long in the time domain because that implies that many signal samples are affected increasing the BER. With windowing method, PAPR can be reduced down to about 4dB, independent of the number of sub carriers. The loss of SNR caused by the signal distortion is limited to about 0.3dB. A backoff relative to maximum output power of about 5.5dB is required in order to keep undesired spectra distortion at least 30dB below the in-band spectral density.

6.1.3. ENVELOPE SCALING:

The paper, by Foomooljareon and Fernando, [18] proposed an algorithm to reduce PAPR by scaling the input envelope for some sub carriers before they are sent to IFFT. The main idea behind the scheme is that the envelopes of all the subcarriers input, with PSK modulation, are equal. The envelope of the input in some subcarriers can be scaled to obtain the minimum PAPR at the output of IFFT. The final input that gives the lowest PAPR will be sent to the system. The input sequences has the same phase information as the original one but the envelopes are different. So the receiver can decode the received sequence without any side information.

The main idea behind the scheme is that the envelope of the input in some subcarriers is scaled to obtain the minimum PAPR at the output of the IFFT. The scheme seems only suitable to PSK schemes, where all the envelope of all subcarriers input are equal. When the OFDM system implements the QAM modulation scheme, 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.

6.1.4. RANDOM PHASE UPDATING:

The paper, by Nikookar and Lidsheim, [19] proposes a novel random phase updating algorithm for the peak to average power ratio (PAPR) reduction of the OFDM signal. In the random phase updating algorithm, a random phases generated and assigned for each carrier. The random phase update is continued till the peak value of the OFDM signal is below the threshold. The threshold can be dynamic and the number of iterations for the random phase update is limited.

After each phase update, the PAPR is calculated and the iteration is continued till the minimum threshold level is achieved or the maximum number of iterations has been reached. The random phase increments distribution can be considered uniform or Gaussian. The phase shifts have to be known at the transmitter and the receiver. In this scheme, the BER performance won't degrade only if the receiver knows all the phase changes. This implies a large amount of side information. The efficiency of the algorithm is mainly related to the selected threshold level and consequently number of iterations and not the number of carriers. The algorithm can be improved using the quantization and grouping of phases, and with dynamic threshold.

6.1.5. PEAK REDUCTION CARRIER:

The paper, by Tan and Wassell, [20] proposes the use of the data bearing peak reduction carriers (PRCs) to reduce the effective PAPR in the OFDM system. The technique involves the use of a higher order modulation scheme to represent a lower order modulation symbol. This allows the amplitude and phase of the PRCs to lie within the constellation region representing the data symbol to be transmitted. For example, to use a PRC that employs a 16 PSK constellation to carry QPSK data symbol, the 16 phases of the 16 PSK constellations are divided into four regions to represent the four different values of the QPSK symbol.

This technique uses the higher order modulation schemes for representing lower order modulation scheme data. This will incur the penalty of an increased probability of error, thus worsening the overall BER performance. So there exists a tradeoff between PAPR reduction and BER performance when selecting the constellation of the PRCs.

6.1.6. COMPANDING:

The paper, by Wang et.al, [21] proposes a simple and effective companding technique to reduce the PAPR of OFDM signal. The OFDM signal can be assumed Gaussian distributed, and the large OFDM signal occurs infrequently. So the companding technique can be used to improve OFDM transmission performance. -law companding technique is used to compand the OFDM signal before it is converted into analog waveform. The OFDM signal, after taking IFFT, is companded and quantized. After D/A conversion, the signal is transmitted through the channel. At the receiver end then the received signal is first converted into digital form and expanded. Companding is highly used in speech processing where high peaks occur infrequently. OFDM signal also exhibit similar characteristic where high peaks occur infrequently. Companding technique improves the quantization resolution of small signals at the price of the reduction of the resolution of large signals, since small signals occur more frequently than large ones. Due to companding, the quantization error for large signals is significantly large which degrades the BER performance of the system. So the companding technique improves the PAPR in expense of BER performance of the system.

7. CRITERIA FOR SELECTION OF PAPR REDUCTION:

There are many factors that should be considered before a specific, PAPR reduction technique is chosen. These factors include PAPR reduction capability, power increase in the transmit signal, BER increase at the receiver, loss in data rate, computation complexity increase and so on. Let us briefly discuss each of them.

7.1. PAPR REDUCTION CAPABILITY:

Clearly this is the most important factor in choosing a PAPR reduction technique. Careful attention must be paid to the fact that some techniques result in other harmful effects. For example the amplitude clipping technique clearly removes the time domain signal peaks but results in in-band distortion and out-of-band radiation.

7.2. POWER INCREASE IN THE TRANSMIT SIGNAL:

Some techniques require a power increase in the transmitted signal after using PAPR reduction techniques. For example Tone reservation (TR) requires more signal power because some of its power must be used for the peak reduction carriers (PRC). Tone injection (TI) uses a set of equivalent constellation point for an original constellation point to reduce PAPR. Since all the equivalent constellation points require more power than the original constellation points, the transmit signal will have more power after applying Tone injection (TI). When the transmit signal power should be equal to or less than that before using a PAPR reduction technique, the transmit signal should be normalized bach to the original signal power level resulting in BER performance degradation for these techniques.

7.3. BER INCREASE AT THE RECEIVER:

This is also an important factor and closely related to the power increase in the transmit signal. Some technique may have an increase in BER at the receiver if the transmit signal power is fixed or equivalently may require large transmit power to maintain the BER after applying the PAPR reduction techniques. For example the BER after applying Active constellation Extension (ACE) will be degraded if the transmit signal power is fixed. In some techniques such as SLM, PTS and Interleaving, the entire data block may be lost if the side information is received in error. This also may increase BER at the receiver.

7.4. LOSS IN DATA RATE:

Some techniques require the data rate to be reduced. In block coding technique one out of four information symbol is to be dedicated to controlling PAPR. In SLM and PTS and Interleaving, the data rate is reduced due to the side information used to inform the receiver of what has been done in the transmitter. In these techniques the side information may be received in error, unless some form of protection such as channel coding is employed. When channel coding is used the loss in data rate due to side information is increased further.

7.5. COMPUTATIONAL COMPLEXITY:

Computational complexity is yet another important consideration in choosing a PAPR reduction technique. Technique such as PTS find a solution for the PAPR reduced signal by using many iteration. The PAPR reduction capability of Interleaving technique is better for large number of Interleavers. Generally more complex techniques have better PAPR reduction capabilities.

7.6. OTHER CONSIDERATIONS:

Many of the PAPR reduction techniques don't consider the effect of the components in the transmitter such as the transmitter filter, digital to analog converters (D/A) and transmit power amplifier. In practice PAPR reduction techniques can be used only after careful performance and cost analysis for realistic environment.

Table 4: Comparison of PAPR Reduction Techniques

Type / Parameter	Distortion less	Power Increase	Data Rate loss
Clipping & Filtering	No	No	No
Coding	Yes	No	Yes
Partial Transmit Sequence(PTS)	Yes	No	Yes
Selected Mapping	Yes	No	Yes
Interleaving	Yes	No	Yes
Tone Reservation	Yes	Yes	Yes
Tone Injection	Yes	Yes	No
Active Constellation Extension	Yes	Yes	No

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, uniform average spectral density capacity of handling very strong echoes and less non linear distortion. It is recently being used for both wireless and wired high rate digital data communications. 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 such as clipping, windowing, coding, pulse shaping, tone reservation, tone injection, companding etc. But most of these techniques are unable to achieve simultaneously a large reduction in PAPR with low complexity, with low coding overhead, without performance degradation and without Transmitter and Receiver symbol handshake.

Basic requirement of practical PAPR reduction techniques include the compatibility with the family of existing modulation schemes, high spectral efficiency and low complexity. There are many factors to be considered before a specific PAPR reduction technique is chosen. These factors include PAPR reduction capacity, Power increase in transmit signal, BER increase at the receiver, loss in data rate, computational complexity increase and so on. No specific PAPR reduction technique is the best solution for all multi carrier transmission. Rather the PAPR reduction technique should be carefully chosen according to various system requirements

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