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An Overview of PAPR Reduction Techniques for an MC-CDMA System

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***Abstract*- MC-CDMA is the most promising technique for high bit rate and high capacity transmission in wireless communication. One of the challenging issues of MC-CDMA system is very high PAPR due to large number of sub-carriers which reduces the system efficiency. This paper describes the various PAPR reduction techniques for MC-CDMA system. Criterion for the selection of PAPR reduction technique and also the comparison between the reduction techniques has been discussed.**

***Index Terms*- Complementary Cumulative Distribution Function (CCDF), Multicarrier Code Division Multiple Access (MC-CDMA), Peak-to-Average Power Ratio (PAPR),**

I. Introduction

Multicarrier systems like CDMA and OFDM are now days being implemented commonly. MC-CDMA (or OFDM-CDMA) multiple access has become a most likely technique for future generation broadband wireless communication system such as 4G. This scheme is a combination of both OFDM and CDMA that can provide protection against frequency selective fading and time dispersion. The CDMA part of this scheme provides multiple access ability as well as spread each user signal over the frequency domain to reduce the impact of frequency selective fading. On the other hand OFDM provides spreading across time domain of each spreading code's chip which reduces the impact of inter-symbol interference. This achieves in fulfillment of high data rate transmission, so the number of subcarrier and spreading codes must be carefully selected according to worst channel conditions [1][2].

Although MC-CDMA is a powerful multiple access technique but it is not problem free. OFDM signal has large peak to average ratio (PAPR) which severely limits its applications, and as long as basic operation of OFDM-CDMA is identical to OFDM system, this undesirable property remains. High PAPR values causes a serious problem to the power amplifier (PA) used at transmitter. The power efficiency performance at such amplifiers decreases as PAPR increases. Therefore signal suffers from non-linear distortion at transmitter and degrades BER performance at receiver. This forces the use of power amplifier with large linear range which translates into higher cost.

Therefore it is desirable to reduce PAPR by means of PAPR reduction schemes. There are number of schemes to deal with the issue of PAPR. such as, Signal Distortion, Coding, and Symbol Scrambling techniques. Signal distortion schemes reduce the amplitude by linearly distorting the MC-CDMA signal at or around the peaks. This includes techniques like clipping, peak windowing, and peak cancellation. It is the simplest technique but it causes in-band and out-band distortion. Scrambling scheme is based on scrambling each MC-CDMA signal with large PAPR. It includes techniques such as Selected Mapping (SLM), Partial Transmit Sequence (PTS). In case of PTS technique, MC-CDMA sequences are partitioned into sub-blocks and each sub-block is multiplied by phase weighting factor to produce alternative sequences with low PAPR. However large number of phase weighting factors increases the hardware complexity and makes the whole system vulnerable to the effect of phase noise. The SLM technique pseudo-randomly modifies the phases of the original information symbols in each OFDM block several times and selects the phase modulated MC-CDMA with best PAPR performance for transmission. In Code allocation techniques, based on the orthogonal sets of spreading sequences PAPR reduction schemes are developed that excludes MC-CDMA signal with large PAPR.

II. System Description

A. MC-CDMA system model

The transmitter model of downlink MC-CDMA system is shown in fig.1. The block of M complex valued symbol, $d^{(k)}=[d_1^{(k)},d_2^{(k)},...,d_M^{(k)}]$ of the k^{th} user is firstly serial-paralleled into a M-length vector as $d^{(k)}=[d_1^{(k)},d_2^{(k)},...,d_M^{(k)}]^T$, $k=1,2,\ldots,K$. After this serial to parallel conversion, each symbol is frequency domain spread by a user spreading

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code $c^{(k)} = [c_1^{(k)}, c_2^{(k)}, ..., c_L^{(k)}]$, where L denotes length of the spreading code. As spreading sequences, orthogonal sets of sequences are preferred for reducing low multiuser interference. Walsh-Hadamard (WH) sequences are used as spreading sequences in this procedure. The input of K users is summed up and is interleaved in frequency domain as $X = \sum_{k=1}^{K} X^{(k)} = [X_0, X_1, ..., X_{N-1}]^T$ to obtain the diversity effects by placing the chip symbol elements that corresponds to same symbol on subcarrier that are distance M apart. After frequency interleaving the symbol elements are fed into IFFT block of size $N = M \times L$ for OFDM operation. The resultant baseband signal for one MC-CDMA symbol is represented as

$$s(t) = \frac{1}{\sqrt{N}} \sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{l=1}^{L} d_m^{(k)} c_l^{(k)} e^{j2\pi(M(l-1)+(m-1))t/NT} \quad (1)$$

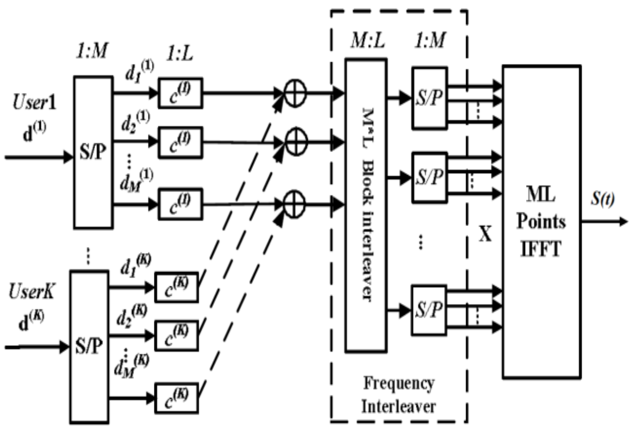

Fig.1. MC-CDMA transmitter model

B. PAPR

Although MC-CDMA is a powerful multiple access technique but it is not problem free. OFDM signal has large peak to average ratio (PAPR) which severely limits its applications, and as long as basic operation of OFDM-CDMA is identical to OFDM system, this undesirable property remains. When in time domain all the N subcarriers are added up constructively, they produce a peak power that is N times greater than the average power of the signal. PAPR can be defined as the ratio between instantaneous power and the average power of multicarrier signal. The PAPR is calculated by the following equation:

$$PAPR = \frac{p_{peak}}{p_{average}} = 10\log_{10} \frac{\max\left[|s(t)|^2\right]}{E\left[|s(t)|^2\right]} \quad (2)$$

where p_{peak} represents output peak power, $p_{average}$ means output average power. $E[\cdot]$ denotes the expected value.

Now to understand how and where the PAPR of a signal becomes problem let us consider the power amplifier characteristic curve shown in figure 2. It shows two operating regions, the linear and the saturation region. For better performance of the system the amplifier should work in the linear region. But the problem appears when the peaks of MC-CDMA signal are too large and do not fit in the linear region. In this case they are treated by the saturation region so they are non-linearly modified, causing inter-modulation among subcarriers and out-of band radiation.

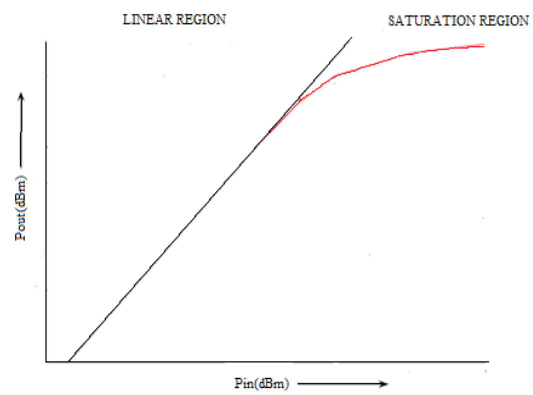

Fig. 2. Non-linear amplifier characteristic curve

To hold these peaks the operational amplifier (OA) of the transmitter needs a very large dynamic range which is very expensive and it is inefficient in this case. Besides, the larger the OA's dynamic range is, the more battery is consumed, which is another reason why increasing the dynamic range of OA is not a good solution. Therefore it is desirable to reduce PAPR by means of PAPR reduction schemes.

C. Cumulative Distribution Function

As PAPR is a random variable, an adequate statistic is needed to characterize it. The cumulative distribution function (CDF) is one of the most regularly used parameters, which is used to measure the efficiency on any PAPR technique. Normally, the Complementary CDF (CCDF) is used instead of CDF, which helps us to measure the probability that the PAPR of a certain data block exceeds the given threshold [20].

The CDF of the amplitude of a sample signal is given by

$$F(z) = 1 - \exp(z) \quad (3)$$

The CCDF of the PAPR of the data block is desired is our case to compare various reduction techniques. This is given by [21]:

$$P(PAPR > z) = 1 - P(PAPR \le z) = 1 - F(z)^N$$

$$= 1 - (1 - \exp(-z))^N \quad (4)$$

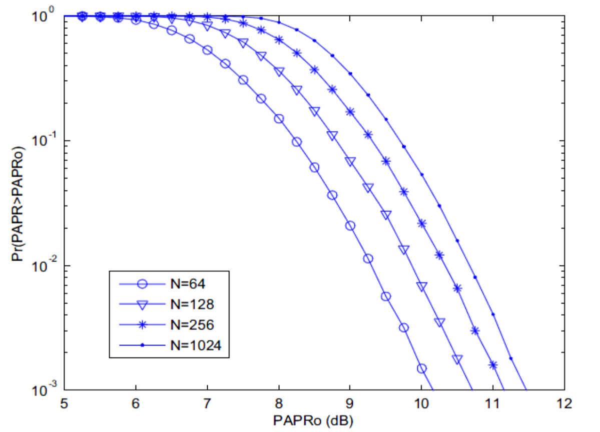

Fig. 3. CCDF of MC-CDMA signals with different number of subcarriers

III. PAPR REDUCTION TECHNIQUES

Several PAPR reduction techniques have been proposed in the literature. There are number of schemes to deal with the issue of PAPR which are divided into two groups, i.e., Signal Distortion and Signal Scrambling techniques.

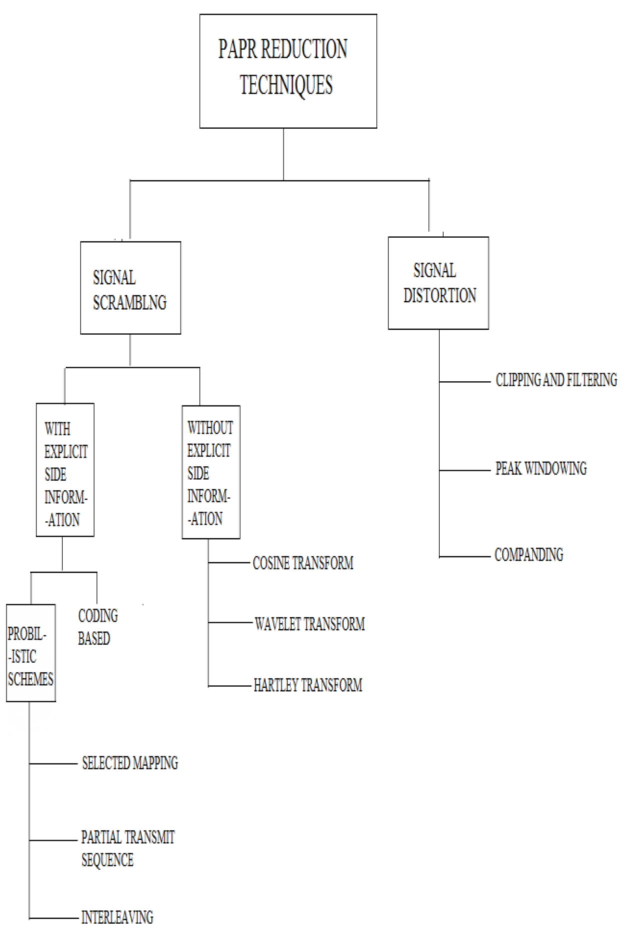

Fig. 4. Block diagram of PAPR reduction techniques

A. Clipping and Filtering

The simplest technique of PAPR reduction might be amplitude clipping [1]. Amplitude clipping limits the peak envelope of the input signal to predetermined value or otherwise passes the input signal through unperturbed, i.e., transmitted signal is clipped at amplitude A as follows

$$y = \begin{cases} -A & (if\ x < -A) \\ x & (if\ -A \le x \le A) \\ A & (if\ x > A) \end{cases} \quad (5)$$

where x denotes the signal before clipping and y denotes the signal after clipping.

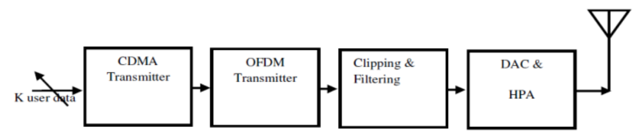

Fig. 5. MC-CDMA system using clipping

The distortion caused by amplitude clipping can be viewed as another source of noise. The noise caused by amplitude clipping falls both in-band and out-band. In-band distortion cannot be reduced by filtering and results in error performance degradation, while out-band distortion reduces the spectral efficiency [5]. Filtering after clipping can reduce the out of band radiation but, but may also cause some peak re-growth so that signal after clipping and filtering will exceed clipping level at some points [4]. To reduce the overall peak re-growth, a repeated clipping and filtering operations can be used. Generally, repeated clipping and filtering takes much iteration to reach desired amplitude level and thus it will increase the computational complexity of the transmitter.

There are few techniques to mitigate the harmful effects of the amplitude clipping. A method to iteratively reconstruct the signal before clipping is proposed [6]. This method is based on the fact that effect of clipping noise is mitigated when decisions are made in frequency domain, the signal is recovered somewhat from the harmful effects of clipping. Another way to compensate for performance degradation from clipping is to reconstruct the clipped samples based on the samples in the oversampled signals. Oversample signal reconstruction is used to compensate for SNR degradation due to clipping for low values of clipping threshold.

B. Companding

Companding is the process of compressing amplitude signal at the transmitter and expanding them at the receiver. In μ law companding technique the signals with lower amplitude are amplified with greater gain and keeping the peak signals unchanged and thus increasing the average power of the transmitted signals resulting in increasing the saturation region of HPA to make the system performance worse [29]. The non-linear transform function is given as [29]

$$C(x) = \sqrt{6}\sigma\left[1 - \exp\left(-\frac{x^2}{2\sigma^2}\right)\right] \qquad (6)$$

This non-linear companding transform of (6) belongs to exponential companding scheme. Based on this, there are two types of non-linear companding techniques- which are based on error function and exponential function [30]-[31].

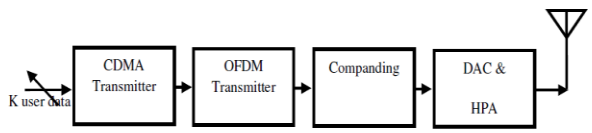

Fig. 6. MC-CDMA system using companding

Error and exponential companding schemes have much less impact on the original power spectrum of compared to μ law companding scheme. It is a major reason that the error and exponential companding schemes not only enlarge the small amplitude signals but also enlarge the large amplitude signals, while maintain the average power unchanged by properly choosing parameters which can increase the immunity of small amplitude signals from noise.

Nonlinear companding transform is a type of nonlinear process that may lead to significant distortion and performance loss by companding noise. Companding can be defined that noises are caused by peak re-growth after DAC to generate in-band distortion and out-band noise, by the excessive channel noises magnified after inverse non-linear companding transform. For out-band noise it need to be filtered and oversampled. For in-band distortion and channel noises magnified, they need to iterative estimation. Unlike AWGN, companding noise is generated by a process known and that can be recreated at the receiver and subsequently be removed.

In [32], simulation results has shown that companding scheme could offer better system performance in terms of PAPR reduction, power spectrum, BER for MC-CDMA system than OFDM system.

C. Selected Mapping (SLM)

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. In this the input data structure is multiplied by random series and resultant series with the lowest PAPR is chosen for transmission. To allow the receiver to recover the original data, the multiplying sequence can be sent as 'side information'. [7]- [8]

The block diagram of MC-CDMA system with SLM technique is shown in fig.2. The input data sequences of each user $d^{(k)} = [d_1^{(k)}, d_2^{(k)}, ..., d_M^{(k)}]$ with length M are first converted into M parallel data sequences $c^{(k)} = [c_1^{(k)}, c_2^{(k)}, ..., c_L^{(k)}]$ and then each S/P converted output is multiplied with the spreading code with length L. Multiplexed symbol sequences $X = \sum_{k=1}^{K} X^{(k)} = [X_0, X_1, ..., X_{N-1}]^T$ are multiplied by U-1 different phase sequences $b^u = [b_0^u, b_1^u, ..., b_{N-1}^u]$ whose length is equal to the number of carriers before IFFT process resulting in U-1 modified data blocks $S = \sum_{u=0}^{U-1} X_n b_n^u = [X_0 b_0^{(u)}, X_1 b_1^{(u)}, ..., X_{N-1} b_{N-1}^{(u)}]^T$. After the IFFT process, the PAPR is calculated for U-1 phase rotated symbols sequences $s(t) = \sum_{u=0}^{U-1} x_n b_n^u = [x_0 b_0^{(u)}, x_1 b_1^{(u)}, ..., x_{N-1} b_{N-1}^{(u)}]^T$ and one original sequence and then the symbol sequence with lowest PAPR is selected for transmission and the corresponding selected phase sequence $\left\{\tilde{b}^{(0)}, \tilde{b}^{(2)}, ..., \tilde{b}^{(U-1)}\right\} = \underset{\{\tilde{b}(1), \tilde{b}(2), ..., \tilde{b}(U-1)\}}{\arg\min}\left(\max_{0 \le n \le N-1}\left|\sum_{u=0}^{U-1} b^{(u)} x_n^{(v)}\right|\right)$ is also transmitted to the receiver side for transmission.

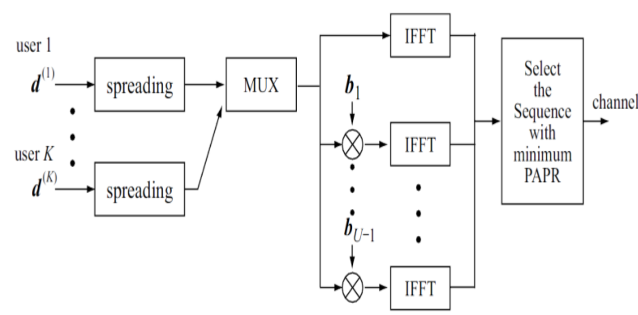

Fig. 7. MC-CDMA system using SLM

In [9], a design criterion for phase sequence in SLM is proposed. The proposed design criteria are that the sequence having low average and large variance of PAPR of the phase sequences themselves are good as phase sequences in SLM, because the occurrence probability of low PAPR becomes high because of small average and large variance of PAPR of the sequences themselves. In [10], Walsh hadamard transform is used as a phase sequences and the simulation results shows that PAPR can be reduced significantly proportional to an increase of the number of different phase sequences. In [11], a new Pseudo Random Interferometry code sequence is used as phase sequence for SLM to reduce PAPR in MC-CDMA and the simulation results shows that the proposed phase sequences can effectively reduce the PAPR compared with Walsh hadamard sequences and golay sequences.

D. Partial Transmit Sequence (PTS)

This method is based on phase shifting of sub-blocks of data and multiplication of data structure by random vectors. The main purpose behind this method is that the input data frame is divided into non-overlapping sub-blocks and each sub-block is phase shifted by constant factor to reduce PAPR [9]. In the PTS technique, an input data block of N symbols is partitioned into disjoint sub-bocks. The subcarriers in each sub-block are weighted by phase factor for that sub-block. The phase factors are selected such that the PAPR of the combined signal is minimized. There are three different kinds of sub-block partitioning schemes on which the performance of PTS technique depends: adjacent, interleaved, and pseudorandom. [12]- [13]

In the conventional PTS scheme in MC-CDMA, before applied to IFFT operation, X, i.e., the sum of all active user sequences after spreading and frequency interleaving is input to PTS model as shown in fig.2. The data block, X_n, $n=0,1,\ldots,N-1$ is defined as vector, $X=[X_0, X_1, \ldots, X_{N-1}]^T$. Then partition X into V disjoint sets, represented by vectors $X^{(v)}$, $v=1,2,\ldots,V$ such that

$$X=\sum_{v=1}^{V} X^{(v)} \tag{7}$$

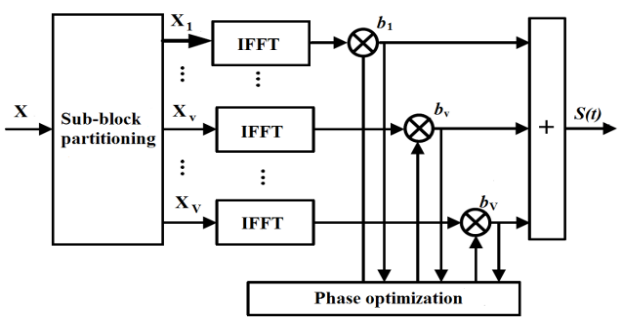

Fig. 8. Block diagram of conventional PTS scheme

Here, it is assumed that adjacent, interleaved and pseudo random sub-block partition scheme are used and each sub-block has equal size. The objective of PTS approach is to form weighted combination of V clusters.

$$S=\sum_{v=1}^{V} b^{(v)} X^{(V)} \tag{8}$$

where $b^{(v)}$, $v=1,2,\ldots,V$ are weighting factors or phase factors and are assumed to be pure rotations. After transferring in time domain equation (6) becomes

$$s(t)=\sum_{v=1}^{V} b^{(v)} x^{(V)} \tag{9}$$

The vector $x^{(v)}$ called partial transmit sequence is the IFFT of $X^{(V)}$. The weighting factors are chosen to minimize the PAPR by searching for the appropriate combination of each cluster and by corresponding weighting clusters.

$$\left\{\tilde{b}^{(1)}, \tilde{b}^{(2)}, \ldots, \tilde{b}^{(V)}\right\} = \underset{\left\{\tilde{b}(1), \tilde{b}(2), \ldots, \tilde{b}(V)\right\}}{\arg\min} \left(\max_{0 \le m \le N-1} \left| \sum_{v=1}^{V} b^{(v)} x_n^{(v)} \right| \right) \tag{10}$$

The combination with weighting factors is called rotation factor or combining sequence. Optimized transmit sequence is

$$\tilde{s}(t)=\sum_{v=1}^{V} \tilde{b}^{(v)} x_m^{(v)} \tag{11}$$

In [14], the PAPR reduction in synchronous downlink MC-CDMA is investigated with different number of active users and walsh hadamard and golay complementary sequences are used as spreading sequences. The simulation results shows that with increase in number of sub-blocks and number of admitted angles there is a considerable improvement in PAPR performance but it also results in increase in computational complexity. Furthermore, to compromise between PAPR reduction and system complexity, suboptimal algorithms are used. In [15], a novel grouping scheme is proposed in which the users are partitioned into sub-groups and generate multiple alternatives to achieve considerable PAPR reduction. The simulation results showed that the proposed technique is more effective than conventional PTS in MC-CDMA.

E. Spreading Code based Techniques

In Code allocation techniques, based on the orthogonal sets of spreading sequences PAPR reduction schemes are developed that excludes MC-CDMA signal with large PAPR. There exists an additional space in the MC-CDMA, i.e., user code space. Since the code spreading is performed in frequency domain in MC-CDMA, the PAPR is determined by the code set allocated to each user. So far, most of efforts for peak power reduction are made mainly focusing on searching a good code set achieving low PAPR. There exists a high correlation between PAPR and the code combination of simultaneous users for a given code set. This implies that we may reduce PAPR by optimum selection of code combination [16]. The PAPR reduction by user code allocation does not require any signal processing for the output signal in real-time and not require any side information or redundancy which is normally required in conventional PAPR reduction schemes.

In [16]-[19] various methods are used for the optimum selection of code combinations to achieve minimum PAPR. The code sets can be selected by various criteria, i.e. the probability that PAPR exceed a certain threshold, the maximum PAPR value, and the PAPR with a certain probability. However, we can only get these criteria from extensive simulations which require excessive amount of time.

There are number of coding schemes that offers excellent performance on PAPR reduction. In spreading code shuffling technique [19], instead of using additional code sequence, the same set of code is shuffled between different users until a low PAPR multiplexed signal is produced at output. In spreading sequence based technique [17], PAPR

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property is studied based on two orthogonal sets of sequences for spreading, i.e., Walsh Hadamard Sequences and Golay Complementary Sequences. In this a theoretical value of PAPR is considered, if the number of users are few, then PAPR of WH sequence becomes larger than the theoretical value, whereas the PAPR of CP sequence coincide with the theoretical value. While for large number of users PAPR of WH sequence becomes smaller than the theoretical value. So the symbol with low PAPR value is transmitted. In reduced search for optimum code technique[18], in order to reduce the number of code combinations to be searched, the incremental search algorithm is used which maintains the previously obtained code set for K-1 user and just find the single optimum code set for the added *k*th user.

F. Chip Interleaving

This reduction technique can be used for uplink in M-modification in MC-CDMA system. In M-modification the total number of subcarriers N_c is divided into m groups with L sub-carriers in each. For one user (uplink) each group of L subcarriers transmits one symbol spreaded with sequence of length L. the user transmits M parallel data symbols on all $N_c = M \times L$ sub-carriers. Walsh sequences are the orthogonal sequences used for spreading in this case and using it introduces some kind of redundancy to the system. For example sequence 1-1 1 will continue with -1. OFDM based systems (MC-CDMA included) are represented in time domain by sum of sinusoids. By changing the position of chip (chips) the peak value of sum of sinusoids (representing chip sequences) can be reduced. For no chip interleaving, the first chip is on first sub-carrier, the second chip on the second sub-carrier, etc. this can be represented by vector [1 2 3 4 5…N_c]. A permutation of this vector, for example [3 6 9 13 …], represents the chip interleaving pattern where the first chip is modulated on the third sub-carrier, the second chip on the sixth sub-carrier and so on.

The principle of this approach is to find the interleaving pattern that minimizes PAPR. The chip interleaving pattern must be same for all users in the system to preserve orthogonality among them the number of possible interleaving pattern corresponds with the number of sub-carriers in the system that makes direct search algorithm improper for the system with more sub-carriers. So optimum searching algorithms are applied and thus Genetic Algorithm (GA) and Ant Colony Algorithm (ACA) are used to solve this problem [22]-[23].

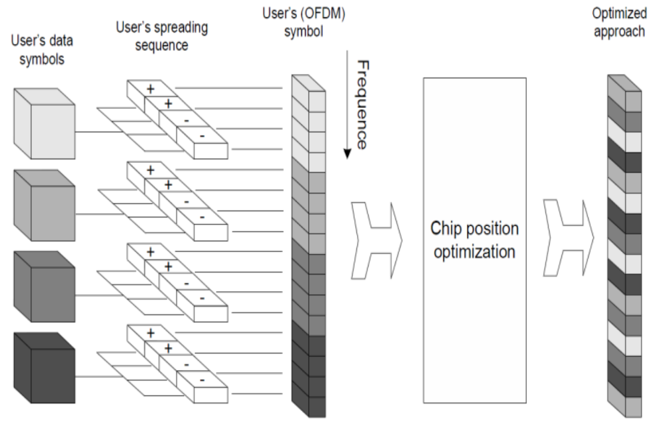

Fig. 9. M-modification of MC-CDMA and its optimization

G. Discrete Cosine Transform

The discrete cosine transform is a Fourier-like transform is used to reduce the auto correlation function of the input sequence to reduce peak-to-average power problem and it requires no side information to be transmitted to the receiver.

The 1D discrete cosine transform (1D DCT) A[k] of a sequence a[n] of length n is defined as

$$A[k] = a[k]\sum_{n=0}^{N-1} a[n]\cos\left[\frac{\pi(2n+1)k}{2N}\right] \quad \text{for k=0,1,…,}N\text{-1} \quad (12)$$

The inverse DCT is defined as

$$a[n] = \sum_{n=0}^{N-1} a[k]A[k]\cos\left[\frac{\pi(2n+1)k}{2N}\right] \quad \text{n=0,1,…,}N\text{-1} \quad (13)$$

where a[k] is defined as

$$a[k] = \begin{cases} \sqrt{\dfrac{1}{N}} & for\ k = 0 \\ \sqrt{\dfrac{2}{N}} & for\ k = 1, 2, ..., N-1 \end{cases} \quad (14)$$

The equation (11) is expressed in matrix below

$$A = C_N\, a \quad (15)$$

where A and a are both vector with N×1 and C_N is a DCT transform matrix with $N \times N$. The row (or column) of the DCT matrix C_N are orthogonal matrix vectors. Then we can use this property of the DCT matrix and reduce the peak power of MC-CDMA signals. [24]- [25]

H. Discrete wavelet transform

Wavelet transforms can be derived from Fourier transforms. The most interesting dissimilarity between these two kinds of transforms is that the individual wavelet functions are localized in space, while Fourier's sine and cosine functions are not. The space localization feature, along with wavelet's localization of frequency, makes many wavelet functions perform better in impulse interference cancellation scenarios. This is also a part of important reason why we prefer using wavelets bases to modulate symbols in MCM systems. The wavelet packet functions $w_n(t)(n \in Z_+)$ are defined by the following recursive functions:

$$w_{2n}(t) = \sqrt{2}\sum_{k \in Z_+} h(k) w_n(2t-k) \quad (16)$$

$$w_{2n+1}(t) = \sqrt{2}\sum_{k \in Z_+} g(k) w_n(2t-k) \quad (17)$$

where h(k) and $g(k) = (-1)^k h(L-1-k)$ stand for a pair of quadrature mirror filters (QMFs) of length L and Z_+ denotes the non-negative integers.

The discrete wavelet transform (DWT) is a type of batch processing, which analyzes a finite time domain signal by breaking up the initial domain in two parts: the detail and approximation information. The DWT property is only few coefficients of DWT dominates the representation. [25]-[26]

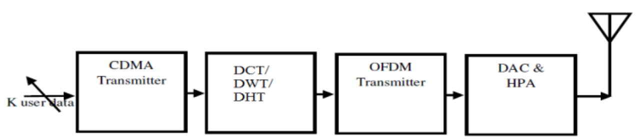

Fig. 10. MC-CDMA system using discrete transform techniques

I. *Discrete Hartley Transform*

The DHT is a linear transform. In DHT N real numbers $x_0,x_1,\ldots,x_{N-1}$ are transformed in to N real numbers $H_0,H_1,\ldots,H_{N-1}$. According to the N point DHT [27], N point DHT can be defined as

$$H_k = \sum_{n=0}^{N-1} x_n \left[\cos\left(\frac{2\pi nk}{N}\right) + \sin\left(\frac{2\pi nk}{N}\right)\right] = \sum_{n=0}^{N-1} x_n cas\left(\frac{2\pi nk}{N}\right) \quad (18)$$

where $cas\theta = \cos\theta + \sin\theta$ and k=0,1,…,N-1

$$a_{m,1} = cas\left(\frac{2\pi mn}{N}\right) \quad (19)$$

The precoding matrix A can be constructed as

$$A = \begin{bmatrix} a_{00} & a_{01} & \ldots & a_{0(L-1)} \\ a_{10} & a_{11} & \cdots & a_{1(L-1)} \\ \vdots & \vdots & \ddots & \vdots \\ a_{(L-1)} & a_{(L-1)} & \cdots & a_{(L-1)(L-1)} \end{bmatrix} \quad (20)$$

A is a precoding matrix of size $L \times L$, m and l are integers from 0 to L-1. The DHT is also invertible transform which allows us to recover the x_n from H_k and inverse can be obtained by simply multiplying DHT of H_k by 1/N. [25]-[28]

IV. Spreading Codes

Various spreading codes exist which can be distinguished with respect to orthogonality, correlation properties, implementation complexity and peak-to- average power ratio (PAPR). The selection of spreading code depends on the scenario. In synchronous downlink, orthogonal spreading codes are of advantage, since they reduce the multiple access interference compared to non-orthogonal sequences. However, in the uplink, the orthogonality between the spreading codes gets lost due to different distortions of the individual codes. Thus, simple PN sequence can be chosen for spreading in uplink. If the transmission is asynchronous, gold codes have good cross-correlation properties.

Here synchronous downlink MC-CDMA system is used. The spreading codes used in MC-CDMA have their length N. the individual element in the code is referred to as chips. Each chip of a code belongs to the set {1, -1}. The property of the codes that is desired is for the codes of different users to be orthogonal, i.e.,

$$\sum_{i=0}^{N-1} c[i]c[i] = N\delta_{l,m} \quad (21)$$

A. *PN Sequences*

The property of a PN sequence is that he sequence appears to be noise-like if the construction is not known at the receiver. They are typically generated by using shift registers. Often used PN sequences are maximum-length shift register sequences, known as *m*-sequences. A sequences has a length of

$$n = 2^m - 1 \quad (22)$$

Bits and is generated by a shift register of length m with linear feedback. The sequence has a period length of n and each period contains 2^{m-1} ones and 2^{m-1}-1 zeros; i.e. t is balanced equation.

B. *Walsh Hadamard codes*

Walsh-Hadamard code is generated from a hadamard matrix whose rows form an orthogonal set of codes. The code sequences in this code set are the individual rows of a Hadamard matrix. Hadamard matrices are square matrices whose entries are either +1 or -1 and whose rows and columns are mutually orthogonal. If N is a non-negative power of 2, the $N \times N$ Hadamard matrix, is defined recursively as follows:

$$H_{2N}^{W} = \begin{bmatrix} H_N & H_N \\ H_N & \overline{H}_N \end{bmatrix} \quad (23)$$

$$H_2 = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix} \quad (24)$$

Walsh-Hadamard codes are important because they form the basis for orthogonal codes with different spreading factors. This property becomes useful when we want signals with different spreading factors to share the same frequency channel.

C. Golay Complementary (CP) codes

In a similar manner, an orthogonal set of golay complementary codes can be recursively obtained by

$$H_{2N}^{C} = \begin{bmatrix} H_N & \overline{H}_N \\ H_N & -\overline{H}_N \end{bmatrix} \quad (25)$$

where $\overline{H}_N$ is composed of H_N of which right half columns are reversed, e.g., if $H_N = [A_N \quad -B_N]$ where A_N and B_N are $N \times \frac{N}{2}$ matrices, then $\overline{H}_N$ □ $[AN \quad -BN]$.

It can readily be shown by induction that

$$H_N^{C} □ H_N^{CT} = I_N \quad (26)$$

where I_N denotes the $N \times N$ identity matrix, hence the matrix given above is orthogonal.

D. Orthogonal Binary User Codes

Orthogonal binary user codes are constructed through performing search operations in the binary sample space that consist of zero mean and linear phase codes. In contrast to WH codes, the OBU codes do not necessitate the condition that there can be only one code in the set for a given number of zero crossings. Again, for WH codes, decimal value of all *n*-bit codes are multiples of either $2^{(n/2)}+1$ or $2^{(n/2)}-1$. OBU do not impose this restriction. Rather, efforts were made to reduce the number of codes that fulfill this criterion in order to avoid the codes that are common to WH codes. For a given code length, more than one OBU code sets can be formulated. In this context one may remember that for a given code length there exist only one set of WH codes. Since shorter code length implies smaller binary sample space, there exist a considerable number of short OBU codes that are common with same length WH codes. But this number reduces as code length becomes higher.

E. Gold codes

PN sequences with better cross-correlation properties than *m*-sequences are part of so-called Gold sequences. A set of *n* Gold sequences is derived from preferred pair of *m*-sequences with n cyclically shifted versions of the second preferred m-sequences. By including the two preferred *m*-sequences, a family of *n*+2 Gold codes is obtained. Gold codes have a three-valued cross-correlation function with values $\{-1, -t(m), t(m)-2\}$, where

$$t(m) = \begin{cases} 2^{(m+1)/2} + 1 & for\, m\, odd \\ 2^{(m+1)/2} + 1 & for\, m\, even \end{cases} \quad (27)$$

V. Criteria For The Selection Of PAPR Reduction Technique

1. *High capability of reducing PAPR:-* It is the first and the most important factor to be considered during the selection of PAPR reduction technique considering the few harmful side effects such as in-band and out-band distortion.
2. *Loss in data rate:-* Some techniques i.e., signal scrambling techniques with explicit side information requires the data rate to be reduced. In the techniques like SLM, PTS, interleaving the data rate is reduced due to side information transmitted to the receiver that gives the information about what has been done at the transmitter side and this side information can be received in error unless some kind of protection in the form of channel coding is employed. Thus when channel coding is used the loss in data rate due to side information is further increased.
3. *Increase in BER at the receiver:* **-** The aim of PAPR reduction is to increase the system performance as well as the BER than that of the original MC-CDMA system. Therefore all methods which have more increase in BER at the receiver should be paid more attention. Moreover, if the side information is received in error at the receiver that may result in error in entire data frame and thus this may also increase the BER at the receiver.
4. *Computational complexity***:-** Computational complexity is an important factor to be considered during the selection of PAPR reduction technique. The technique such as PTS finds the best solution of PAPR reduction of the signal by using much iteration. Also, the PAPR reduction capability of interleaving technique is better for large number of interleavers. Thus, more complex techniques have better PAPR reduction capability in most of the cases.
5. *Without additional power increase:* **-** The design of the system should take into consideration the efficiency of the power. If operation of the technique that reduces the PAPR need more power, it degrades the BER performance when the transmitted signals are normalized back original power signal.
6. *Other consideration*: **-** More attention should be paid to effects of non-linear devices such as digital-to-analog

converter, HPAs and mixers as PAPR reduction mainly avoids non-linear distortion due to these memory-less devices introducing into the communication channels. Also the cost of these non-linear devices should also be considered in designing the PAPR reduction scheme.

VI. Comparative Study Of PAPR Reduction Techniques

TABLE I: Advantages and Disadvantages of Different PAPR Reduction Techniques

S. No.	Technique	Advantages	Disadvantages
1.	Clipping	• No loss in data rate • No side information required	• Distortion (In-band and Out-band) • Increase BER
2.	Companding	• Better power spectral density • Low implementation complexity • No constraint in modulation format and sub-carrier size	• Increases average received power • Out-band distortion
3.	Selected Mapping (SLM)	• No distortion is introduced • Does not require any complex optimization techniques • More effective than PTS for same amount of side information	• Side information needed • Complexity increases with increase in number of phase factors
4.	Partial Transmit Sequence (PTS)	• Less complex than SLM • PAPR reduction in PTS performs better than SLM	• Side information is larger than SLM
5.	Chip Interleaving	• Less complex • No performance degradation • No need of side information	• Multiple iterations needed
6.	Spreading Code based Techniques	• Excellent performance in PAPR degradation	• Cost of complexity is high • Data rate loss
7.	Discrete Cosine Transform (DCT)	• Does not influence BER	• Computational complexity increases
8.	Discrete Wavelet Transform (DWT)	• High spectral efficiency • No loss of data rate • No distortion	• Complexity increases
9.	Discrete Hartley Transform (DHT)	• Shows better PAPR gain when compared with SLM	• Complex

VII. Conclusion

MC-CDMA is an important multiple access candidate for 4G wireless communication system. The transmitted signal of an MC-CDMA system exhibits a very high peak-to-average power ratio (PAPR) when large number of sub-carriers are used. Therefore amplifier should be operated in large linear ranges to avoid non-linear distortion. This leads to very inefficient amplification and very expensive transmission. In this paper we have discussed various PAPR reduction techniques for multicarrier transmission, all which have the potential to reduce PAPR at the cost of loss in data rate, increase in BER, transmit signal power and computational complexity. The PAPR reduction technique should be chosen according to the appropriate system requirements. The comparative study of the PAPR reduction techniques is also discussed in the paper with their advantages and disadvantages.

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