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Peak-to-Average Power Ratio Reduction using ABC & PTS Algorithm in Wavelet Packet Modulation: A survey

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***Abstract*— Multicarrier modulation (MCM) technique is considered as the key element in realizing high-speed wireless and wireline digital communications. Wavelet Packet Modulation (WPM) is a new scheme of modulation scheme for transmission of multicarrier signal over wireless channel which provide help in orthogonal wavelet base to replace sine functions. Large Peak to Average Power Ratio (PAPR) of transmitted signal is the major drawbacks of the wavelet packet modulation (WPM) scheme. Adapting the advantage of concentrating the energy to certain subspaces of the discrete wavelet transform, the performance of three methods to reduce PAPR in WPM is detected. In general, the partial transmit sequence (PTS) technique is used to reduce PAPR. This paper investigates the PAPR of WPDM for high-speed digital communications system and uses three methods to reduce peak power of WPDM system. Selected mapping (SLM) technique and partial transmit sequence (PTS) are two methods, employed just in the transmitter side. Also in another design, WPDM signals are clipped to an acceptable peak level and an equaliDltion method used at receiver to eliminate the effect of clipping. Many schemes are compared with data. The accomplishment of the artificial bee colony (ABC) algorithm for Daubechies wavelets was compared with the primary WPM for different Daubechies wavelets, arbitrary search PTS for Daubechies wavelets and optimum PTS by computer simulations.**

***Index Terms*— Artificial bee colony (ABC) algorithm, partial transmit sequence (PTS), peak-to-average power ratio (PAPR), wavelet packet modulation, particle swarm optimization (PSO).**

I. INTRODUCTION

The explosive growth of mobile wireless communications produces the demand for high speed, efficient, and reliable communication over the hostile wireless medium. As a modulation scheme for such applications, Orthogonal Frequency Division Multiplexing (OFDM) possesses several desirable attributes, such as high immunity to inter-symbol interference, robustness with respect to multi-path fading and ability for high data rates.

In the recent years, wavelets have been introduced to the telecommunication society as an orthogonal base for MCM, and have been attracted lots of attentions of experts engaged in this field [1], some of which think that wavelets can be a much better choice compared with Fourier base as an orthogonal modulation scheme.

The Wavelet Packet Modulation (WPM) or Wavelet Packet Division Multiplexing (WPDM) is a viable multicarrier modulation technique with high bandwidth efficiency and flexibility in adaptive channel coding schemes [2]. The WPM has the time and the frequency resolution in transmission packets, so multiplexing of data can be carried out in both the time and the frequency domain. WPDM shares all the benefits of OFDM and exhibits further benefits such as higher efficiency due to elimination of guard interval (01). This benefit is a direct consequence of using wavelet, which is localized in the time domain, so that 01 insertion in every super symbol is not needed.

The characteristics of a multicarrier modulated signal are directly dependent on the set of waveforms of which it makes use. Hence, the sensitivity to multi-path channel distortion, synchronization error or nonlinear amplifiers might present better values than a corresponding OFDM signal. Moreover, the major advantage of WPDM is its flexibility. This feature makes it eminently suitable for future generation of communication systems [2].

However, one of the major problems posed by MCM is its high Peak-to-Average-Power Ratio (PAPR), which seriously limits the power efficiency of the transmitter's High Power Amplifier (HPA). This is because PAPR forces the HPA to operate beyond its linear range with the consequence of nonlinear distortion in the transmitted signal. Clever signal processing techniques are necessary to deal with this problem [3]. There are various PAPR reduction techniques available for OFDM [4] and only few ofthem may be applicable to WPDM, e.g. clipping. In this paper, we investigated three schemes, two powerful and distortionless peak power reduction schemes for WPDM, selected mapping (SLM) and phase rotated partial transmit sequences (PTS). Another scheme is decision aided equalization (DAE) to reduce the PAPR ofthe WPDM signal.

The organization of this paper is as follows: In Section 2, the PAPR problem is reviewed and wavelet packet is presented. Afterward, WPDM system is described in Section 3. In Section 4, three PAPR reduction techniques including SLM, PTS and DAE are described.

II. PAPR PROBLEM AND WAVELET PACKETS

2.1. Peak-to-Average Power Ratio

An OFDM signal on *N* sub-carriers can be represented as:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \, e^{j2\pi f_k t}$$

Where, *N* is the total number of sub-carriers andX_k, k = (0, 1….N-1*)* block of input bits (symbols), f_k=*k* Δ *f*, where *f=1/(NT), T*=original symbol period. Also, the discrete form of OFDM signal x (n) is given by-

$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \, e^{j2\pi\frac{k_n}{N}} for$ n=0,1,2……N-1

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The PAPR of the continuous time baseband OFDM transmitted signal x(t) is the ratio of the maximum instantaneous power and the average power.

$$\text{PAPR} = \frac{max[x(t)]^2}{E\{|x(t)|^2\}} for\ 0 \leq t \leq \text{NT}$$

Where, N is the total number of sub-carriers and E $\{|x(t)|^2\}$ is average power of $x(n)$. Practically, oversampling is needed in discrete OFDM signal. Oversampling is done by padding (L-1) N zeros in frequency domain which corresponds to the oversampling in time domain where LN points IFFT is computed. Oversampling is done to prevent aliasing.

Nonlinear distortion in HPA occurs in the analog domain, but most of the signal processing for PAPR reduction occurs in the digital domain.

The PAPR of digital domain is not necessarily the same as the PAPR in the analog domain. However, in the literature [6], it has been shown that one can closely approximate PAPR in the analog domain by oversampling the signal in the digital domain. Usually, an oversampling factor 4 is sufficient to satisfactorily approximate the PAPR in the analog domain. We work with x[n}, the discrete time samples of x(t), provided that an oversampling factor of at least 4 is used. PAPR is then expressed as [7]:

$$PAPR = \frac{max[x(n)]^2}{E\{|x(n)|^2\}}$$

Where E{} denotes ensemble average calculated over the duration of the OFDM or WPDM symbol.

2.2. The CCDF of the PAPR

The Cumulative Distribution Function (CDF) is one of the most regularly used parameters to measure the efficiency of any PAPR technique. Normally, the Complementary Cumulative Distribution Function (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.

The CCDF of the PAPR denotes the probability that the PAPR of a data block exceeds a given threshold and is expressed as follows [4]:

$$CCDF(PAPR_0) = P_r(PAPR > PAPR_0)$$

In this paper, the performance of the investigated PAPR reduction schemes is demonstrated through the complementary cumulative distribution function (CCDF) of PAPR, which is a performance metric independent of the transmitter amplifier.

2.3. Wavelet Packets

Wavelet transform is a kind of technology derived from Fourier transform. The most interesting dissimilarity between these two kinds of transforms is that individual wavelet functions are localized in space, while Fourier sine and cosine functions are not. This localization feature, along with wavelets localization of frequency, makes wavelet much more popular in some applications, such as, to perform better in impulse interference scenarios, to be active in fast fading transmission channels, to utilize in the transmission of the multi-rate service, etc [8].

Wavelet packets are constructed using quadrature mirror filter (QMF) pairs l(n) and h(n) satisfying the following conditions [1],[9]:

$$\sum_{n=-\infty}^{\infty} l(n) = 2$$

$$\sum_{n=-\infty}^{\infty} l(n)l(n-2k) = 2\,\delta(k)$$

$$h(n) = (-1)^n \mathrm{l}(\mathrm{L}-\mathrm{n}-1)$$

Where usually *l(n)* and *h(n)* are low and high-pass filters, respectively and L is the span of the filter. The QMFs *l(n)* and *h(n)* are recursively used to define the sequence of basis functions $\Phi_n(t)$, called wavelet packets as follows:

$$\Phi_{2n}(t) = \sum_{k\in Z} l(k)\Phi_n(2t-k)$$

$$\Phi_{2n+1}(t) = \sum_{k\in Z} h(k)\Phi_n(2t-k)$$

The function $\Phi_n(t)$, identifies the scaling function Φ , and $\Phi_1(t)$, is the wavelet function ψ. $\{\Phi_n(t)\}$ are called the wavelet packets determined by the scaling function Φ . The sequence *l(k)* and *h(k)* correspond to the discrete impulse response of the low-pass and high-pass filters of a QMF bank with perfect reconstruction. The wavelet packets have two useful properties [5]:

$$< \Phi_n(t-j), \Phi_n(t-k) >= \delta(j-k)$$

$$< \Phi_{2n}(t-j), \Phi_{2n+1}(t-k) >= 0$$

Where (< >) is the inner product of functions and $\delta(.)$ is the delta Dirac function. The first property indicates each individual wavelet packet function is orthogonal with all its nonzero translation. It is the property that will be utilized to eliminate lSI; the second one means the pair of packets coming from the same parent are orthogonal at all translations. Two pairs of dual operators L L^{-1}, H and H^{-1} are defined as [9]:

$$L\{x\}(2n) = \sum_{k\in Z} x(k)l(l-2n)$$

$$H\{x\}(2n) = \sum_{k\in Z} x(k)h(l-2n)$$

$$L^{-1}\{x\}(2n) = \sum_{k\in Z} x(k)l(n-2k)$$

$$H^{-1}\{x\}(2n) = \sum_{k\in Z} x(k)h(n-2k)$$

Where *x(k)* is the input sequence. Based on *l(n)* and *h(n)* and the corresponding reversed filters *l(-n)* and *h(-n)* four operators L^{-1}, H^{-1}, L, H are defined that can be used to construct a wavelet packet tree. L and H are the downsampling convolution operators L^{-1} and H^{-1} are upsampling deconvolution operators [5]. Fig.l gives the decomposition and reconstruction process of wavelet packet.

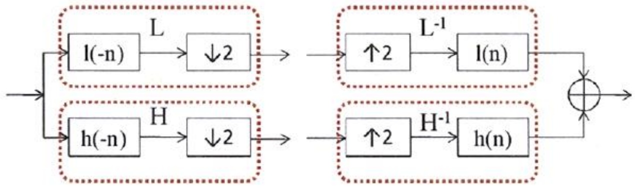
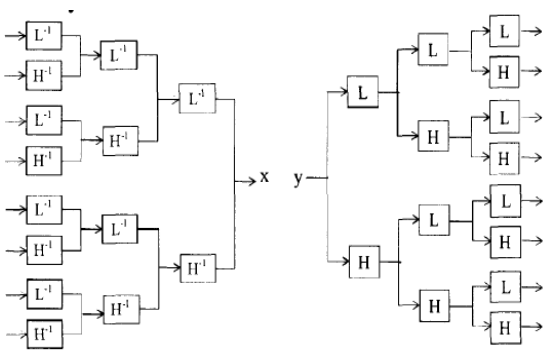


Figure 1: The decomposition and reconstruction of wavelet packet function

Each decomposition *(L)* or *(H)* step results in two coefficient vectors each half the length of the input vector keeping the total length of data unchanged. This decomposition process using *L* and *H* is called Discrete Wavelet Packet Transform (DWPT). The decomposition is a reversible process and the Inverse Discrete Wavelet Packet Transform (IDWPT) can be used to reconstruct the original input vector from the coefficients vectors.

The IDWPT is a series of upsampling filtering processes defined by the operators *(L^{-1})* and *(H^{-1})* [5]. Fig. 2 shows a full IDWPT and DWPT trees which are used in the WPDM system for modulation and demodulation, respectively



(a)IDWPT (b) DWPT

Figure.2: Wavelet packet trees: (a) IDWPT and (b) DPWT

III. WAVELET PACKET DIVISION MULTIPLEXING

Recently, a new class of multicarrier system based on wavelet transform has been proposed [10]. It is considering on wavelet waveforms which are well localized both in time and frequency domain, while sinusoid waveforms, are only localized in frequency but not in time domain. Thus time domain diversity of sinusoid waveform within one symbol period is difficult to achieve. A block diagram of the WPDM system is shown in Fig3.

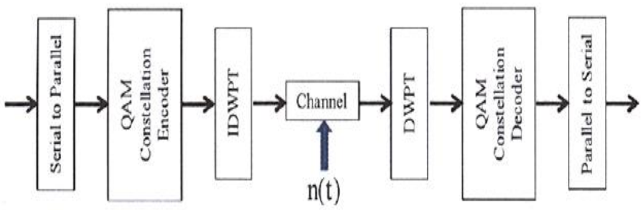


Figure 3: Wavelet packet division multiplexing block diagram

In the transmitter of an OFDM system, the binary information sequence is first encoded by a digital modulation constellation, such as BPSK, QPSK and QAM, and then IFFT operation is performed to convert the encoded data into the time domain signals called OFDM symbols.

Similar to the OFDM system, at the transmitter of a WPDM system, an IDWPT block is used in the place of the inverse fast Fourier transform (IFFT) block, while at the receiver a DWPT block is used in the place of the fast Fourier transform (FFT) block.

The IDWPT works in a similar fashion to an IFFT block. It takes as the input QAM symbols and outputs them in parallel time-frequencies "subcarriers". In the WPDM, *x[n]* is constructed as the sum of M waveforms *[k]* individually modulated with the QAM symbols as follows [2]:

$$x[n] = \sum_{s} \sum_{m=0}^{M-1} a_{s,m} \varphi[n - sM]$$

Where $a_{s,m}$ is a intent encoded s^{th} data symbol regulate m^{th} the waveform T is denoting the sampling period, $\varphi_m[k]$ is non-null only in the interval [0, LT − 1] for any m{0..M − 1}. In an AWGN channel, the waveforms $\varphi_m[k]$ should be cooperatively orthogonal to accomplish the lowest probability of defective symbol accommodation i.e. = δ[m − n] where represents a convolution operation and δ[j] = 1 if j = 0, and 0 otherwise.

The DWPT at the receiver recovers the transmitted symbols through the analysis formula exploiting orthogonality properties of DWPT. In the digital communication terminology, the usage of IDWPT and DWPT in WPDM is equivalent to transmit and matched filtering respectively.

3.1. PAPR in WPDM

The PAPR of the base band transmitted signal x(t) is defined as the ratio of maximum power of the transmitted signal over the average power. The PAPR of MC-CDMA signal in analog domain can be represented as [5]:

$$PAPR = \frac{max_{0 \le tT_s} |X(t)|^2}{E(|X(t)|^2)}$$

Non-aligned distortion in HPA occurs in the analog domain, but the most of the signal processing operation for PAPR reduction occur in the digital domain. The PAPR of discrete time signal is given as [6]:

$$PAPR = \frac{max_n(|x(n)|^2)}{E(|x(n)|^2)}$$

Where, E (.) denotes ensemble average calculated over the duration of WPDM symbols. The Complementary Cumulative Distribution Function (CCDF) of the PAPR is one of the most frequently used performance measures for PAPR reduction techniques. The CCDF of the PAPR denotes the probability that the PAPR of data block exceeds a given certain value, and is expressed as follows [2]:

$$CCDF\ (PAPR0) = \Pr\{PAPR > PAPR0\}$$

From the central limit theorem it follows that for a large value of subcarriers N, the real and imaginary component of the multicarrier signal are modeled as a zero mean Gaussian distribution random variable with varianceσ^2. The amplitude of the MC-CDMA signal therefore has a Rayleigh distribution and its power distribution becomes a central chi-square distribution with two degrees of freedom and zero mean [6]. The CCDF of the PAPR can be calculated as:

$$\Pr(PAPR \leq PAPR0) = 1 - (1 - e^{-PAPR0})^{N}$$

The distribution obtained by the conventional analysis, however, does not fit those of the PAPR of the MC-CDMA signals obtained by computer simulations, even for very large N. In [8], Van Nee and Prasad gave an empirical approximation:

$$CCDF(PAPR0) = 1 - (1 - e^{-PAPR0})^{\alpha N}$$

IV. PAPR REDUCTION TECHNIQUES

4.1. Partial Transmit Sequences (PTS)

In this section, we show two representative of PTS techniques, the original PTS technique and Cimini and Sollenberger's iterative flipping technique.

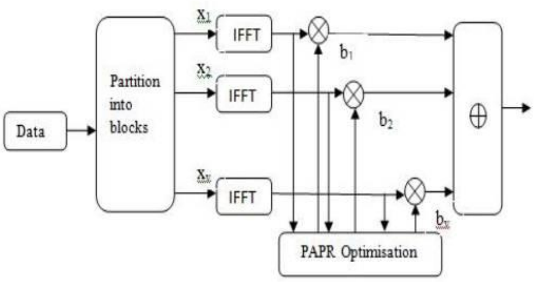


Figure.4: Block diagram of the PTS technique

PTS is one of the PAPR reduction techniques. The main structure of this scheme is the data block and data block is divided into non-overlapping sub block with independent rotation factor. Before applying the phase transformations, the technique divides the frequency vector transmitter signal into smaller blocks. Here phases are randomly generated and the generated phases are multiplied. Thus, by modifying the data by using the phase manipulations, the PAPR value will be reduced. If there is more PAPR value, high power amplifiers are required. So, by reducing the PAPR by using this technique, low power amplifiers are sufficient to design the system which results in decreasing the cost of the design. In PTS method, the frequency vector is divided into smaller blocks before applying the phase transformation and the main advantage of PTS technique is it has lower PAPR and less redundancy. In this technique, the original OFDM sequence is divided into a number of sub-sequences and each sub-sequence is multiplied by different weights until an optimum value is chosen.
The block diagram of the PTS technique is shown in Fig.4. The subcarrier vector is partitioned into disjoint sub-blocks which can be represented as:

$$Xm\ [Xm,o,\ Xm,I,\ ...,Xm,N\_I]^{T}, \quad m\ 1,2,\ ...,M$$

All the subcarrier positions which are presented in another block must be zero so that the sum of all the subblocks constitute the original signal, i.e,

$$\sum_{m=1}^{M} X(m) = X$$

Each sub-block is converted through IDWPT into a WDPM signal X_m with oversampling, which can be represented as:

$$X\ m=[Xm,o,Xm,l,\ ...,Xm,LN\_l]T,m=1,2,...,M$$

Where L is the oversampling factor. After that, each subblock is multiplied by a different phase factor b_m to reduce PAPR of the WPDM signal. The phase set can be represented as:

$$P = \{e^{j2\pi w/W} \mid w = 0,1,\ldots,W-1\}$$

The choice *bm={ ±j }* is very interesting since actually no multiplication is performed to rotate the phase. The peak value optimization block in Fig.4 iteratively searches the optimum phase sequence which shows minimum PAPR [3-41. After finding the optimum phase sequence which minimize PAPR of the WPOM signal, all the sub-blocks are summed as in the last block of Fig.4 with multiplication of the optimum phase sequence. Then, the transmit sequence can be represented as:

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

Information, about which particular data vector was used to generate the reduced PAPR signal, must be transmitted to the receiver using additional carriers as side information.

4.2. Selected Mapping (SLM)

Selected mapping is well-known technique for peak power reduction in OFDM. In the SLM approach, statistically independent sequences are first generated from the same data sequence and then the one with the lowest PAPR is selected for transmission. A block diagram of the SLM technique is shown in Fig. 5.

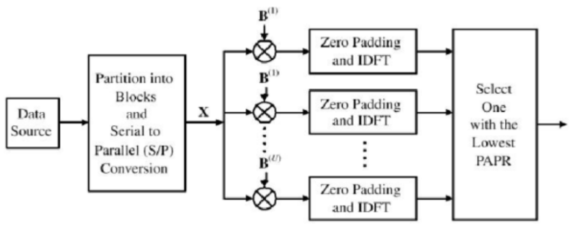


Figure.5: Block diagrams of the SLM technique

In selected mapping method, M independent data blocks
Sm= [Sm,0, Sm, 1,…,Sm, N-1] T, m=1, 2,….,M represent the same information are obtained by multiplying the original sequence with M uncorrelated sequence Pm. These are then forwarded into IFFT operation simultaneously. And then the PAPR is calculated for each vector separately. The sequence with the smallest PAPR is selected for final transmission. The receiver is required to have information about selected phase vector sequence and ensure that the vector sequence is received correctly. This can degrade the spectral efficiency of the system.

4.3. Decision Aided Equalization

The simplest technique for PAPR reduction is to clip the high amplitude peaks [1], which leads to a significant distortion of the desired signal and an increase in the bit error rate. Clipping is a method which is applied in the transmitter in order to reduce the PAPR ofMCM signals. This operation can be implemented on the discrete samples prior to the DAC or by designing the DAC and/or amplifiers with saturation levels that are lower than the signal dynamic range. This clipping approach is widely used, although it is known to degrade the receiver symbol error rate (SER) and increase the out-of-band radiation [12].

We applied an iterative ML receiver, named Decision Aided Equalization (OAE), to overcome this effect. The PAPR of the multicarrier signal can be reduced at the transmitter by using a simple clipper and the nonlinearly distorted signal can be recovered with very low degradation using the proposed iterative ML algorithm. DAE is a method which is applied in the receiver in order to improve the system performance and decrease the errors due to clipping the signal.

If the nonlinear characteristic of the transmitter is known, the nonlinear distortion is a deterministic function of the data that can be corrected at the receiver.

In [13], a method to iteratively reconstruct the signal before clipping and in [14], iterative estimation and cancellation of clipping noise is proposed. In this paper, the dangerous effect of clipper on system performance is reduced by using decision aided equalization. The block diagram of modified WPDM Receiver is shown in Fig.6. In this method, first in transmitter, signal level is clipped to an acceptable peak level and then, nonlinear distortion will be equalized to be removed at receiver. In transmitter, a clipper is used to prevent from transmitting of high PAPR signal which is the source of nonlinearity and distorts the signal. A memoryless Cartesian clipper can be formulated as:

$$g(x)=\begin{cases} A & x>A \\ x & -A\le x\le A \\ -A & x<-A \end{cases}$$

where A is the clipping level and x denotes either the real part or the imaginary part of the WPDM signal. The input back-off (ibo) is defined as the ratio of the maximum allowable input power to the average input power, which is described as:

$$ibo=\frac{A^2}{E\{x^2\}}$$

Clipping produces severe distortion in the signal which should be eliminating at the receiver.

It was shown that in most typical applications, the receiver can accurately estimate the transmitted vector from the distorted, filtered, and noisy received vector by performing a simplified ML detection. Alternatively, the receiver can compute an estimate of the distortion, from the received vector, if the receiver knows the transmission nonlinear function g(.) and has an estimation of the transmitted QAM vector. Although the estimates may degrade from errors, the receiver can use these estimates to reduce the nonlinear distortion term in an iterative fashion.

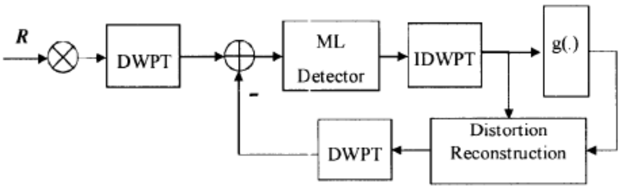


Figure.6: Diagram of modified WPDM Receiver

4.4 PSO-PTS

PSO as an optimizer is used to solve the phase factor problem, which is shown as PSO process block in Fig 3 below. In PSO algorithm solution space of the problem is called particles, which is φ_k in the PTS based PSO scheme [17]. By moving the particles around in the search-space, the optimal solution of the phase problem will be reached. During the movement of the particles, each particle is characterized by two parameters: position and velocity [18]. The PSO algorithm evaluates particles with fitness value, which is PAPR the objective function. A solution space is randomly generated, which is a matrix of size S×K where S is the number of particles and K is the number of disjoint sub-block [19]. In other words, the solution space is a matrix its rows are $\varphi_1, \varphi_2, \ldots\ldots, \varphi_k$.
Since the PSO is an iterative algorithm, in the i[th] iteration each particle can be described by its position vector $Y_{SK}^t = y_{S1}^t, y_{S2}^t, \ldots\ldots, y_{SK}^t$ and velocity vector is given as, $V_{SK}^t = v_{S1}^t, v_{S2}^t, \ldots\ldots, v_{SK}^t$ where $S\epsilon[1,S]$ and $Y_{SK}^t \epsilon R$ where R denotes the domain of the objective function. The PSO algorithm searches the solution space for the optimum solution by using iteration process. Each particle updates itself in every iteration by tracking two best positions. These are called the local best position, which is the best solution this particle achieved $p_{sk} = p_{s1}, p_{s2}, p_{s3}, \ldots . p_{sk}$ and the global best position can be given as

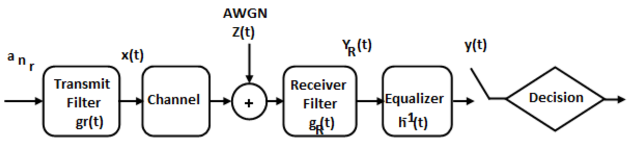


Figure 7: PAPR reduction techniques by using PSO based PTS weighing factor

$p_{sk}^g = p_{s1}^g, p_{s2}^g, p_{s3}^g, \ldots\ldots, p_{sk}^g$ which the best position is obtained so far by any particle in the whole swarm. The updating process of the position and velocity of each particle can be expressed as

$$V_{SK}^{t+1} = wV_{SK}^t + C_1 r_1 (p_{sk}^t - Y_{SK}^t) + c_1 r_1 ((p_{sk}^t)^g - Y_{SK}^t)$$
$$Y_{SK}^{t+1} = Y_{SK}^t + V_{SK}^t$$

Where, c_1 and c_2 are the acceleration terms [20]. The constant r_1 and r_2 are uniform distribution random numbers in the range of [0, 1]; w is the inertia factor.

4.5 ABC ALGORITHM FOR PTS

The artificial bee colony (ABC) algorithm, which simulates the foraging behavior of honey bee colonies, was recently proposed by Karaboga [37]. In the ABC algorithm, employed bees, onlooker bees, and scout bees are tasked with finding optimum food sources, and first the food source positions are generated randomly. If the PAPR reduction problem arises, then a food source position and phase vector $b_i = [b_{i1}, b_{i2}, \dots, b_{i(v-1)}], i = 1, \dots, SN$, both are equivalent, where SN denotes the size of population, which is composed of the employed bees or the onlooker bees. The employed bees look for a new food source within the neighborhood of the previous source. If the nectar amount of the new source is higher than the previous one, the new source is memorized as a possible optimum solution. In the ABC-PTS, the new phase vector (the new food source) is expressed by

$$b_i' = b_i + \emptyset_i(b_i - b_k)$$

Where, b_k is a solution within the neighborhood of b_i, and $\emptyset_i$ is a random number in the range of [−1, 1]. The nectar amount of the food source determines the quality or fitness of the solution. The fitness of a solution is expressed as

$$fit(b_i) = f(x) = \begin{cases} \frac{1}{1+f(b_i)}, & iff(b_i) \geq 0 \\ 1 + abs(f(b_i)), & if\ f(b_i) < 0 \end{cases}$$

Where, f (bi) represents the PAPR value of the signal and is desired to be at a minimum. Employed bees share the fitness of the food sources with onlooker bees in the hive. The onlooker bees then move to a food source depending on its fitness value. The probability of an onlooker bee selecting a food source is calculated as

$$p_i = \frac{fit(b_i)}{\sum_{i=1}^{sn} fit(b_i)}$$

After an onlooker bee reaches a food source, it looks for a new source within the neighborhood of the previous one and memorizes the food sources according to their fitness. After the employed bees and onlooker bees complete their searches, if the fitness values of the food sources do not improve with a number of iterations that is called the “limit” value, employed bees become the scout bees. The scout bees look for new food sources randomly by

$$b_i = \min(b_i) + rand(0,1) * (\max(b_i) - \min(b_i)) \quad (4)$$

Where, min (b_i) and max (b_i) are the lower and upper bounds of the phase vector.

The above steps are repeated within in a cycle, called the maximum number of cycles (MCN). In a cycle, possible SN solutions are produced. In the ABC-PTS algorithm, MCN * SN possible solutions are produced to find the optimum phase vector.

V. CONCLUSION

We have considered a WPDM scheme as an example and investigate the PAPR of WPDM for high-speed digital communications system. In this paper, many methods used to reduce PAPR of WPDM system. Two powerful and distortion less peak power reduction schemes for WPDM are compared, one investigated technique is selected mapping (SLM) and the second utilizes partial transmit sequences (PTS) along with ABC scheme that are employed just in transmitter side. In the third, WPDM signals are clipped to an acceptable peak level and an equalization method is used at receiver to eliminate the effect of clipping. Two previous methods, are complicated but, this one, has less complexity. The ML decoder often has an exponential complexity. In order to avoid this extremely large complexity, we described a simple algorithm that iteratively estimates the nonlinear distortion and reduces the complexity. Simulation results that have shown the BER performance of decision aided equalization (DAE) method are in close proximity of the ideal case while the PAPR is reduced to acceptable level.

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