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The Comparative Study of Peak-to-Average Power Ratio Reduction Techniques for LTE OFDM system & its Effect

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Abstract

Orthogonal frequency division multiplexing (OFDM) is a multicarrier modulation technique which uses orthogonal subcarriers to convey information. Orthogonal frequency division multiplexing (OFDM) has been adopted as a standard for various high data rate wireless communication systems due to the high spectral bandwidth efficiency, robustness to frequency selective fading channels, well suited for mimo technology, Facilitate frequency-domain scheduling supports flexible bandwidth deployment etc. However, implementation of the OFDM system entails several difficulties. One of the major drawbacks is the high peak-to-average power ratio (PAPR) problem in multicarrier transmission system which leads to power inefficiency in RF section of the transmitter, inter carrier interference, high out-of-band radiation, and bit error rate performance degradation. It is preferred to have a minimum PAPR, as it will allow a higher average power to be transmitted for a fixed peak power; and thus, improving the overall signal to noise ratio at the receiver. This paper reviews the various techniques proposed for PAPR reduction schemes and their modifications for achieving the low computational complexity required for practical implementation in wireless communication systems.

Index Terms: - OFDM PAPR, 3GPP, LTE BER, ICI, TR. , PTS

I. INTRODUCTION

3GPP LTE uses orthogonal frequency division multiplexing access (OFDMA) for downlink transmission. Orthogonal frequency division multiplexing (OFDM) technology is one of the most attractive technologies for fourth generation (4G) wireless communication. Due to various advantages like robustness to multipath fading, high spectral efficiency, immunity to impulse interferences, flexibility and easy equalization over single carriers communication systems. OFDM uses the principles of Frequency Division Multiplexing (FDM) but in much more controlled manner, allowing an improved spectral efficiency. The basic principle of OFDM is to split a high-rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers. Orthogonal frequency division multiplexing (OFDM)has been widely used in several digital transmissions. , because of its ability to combat with the frequency selective fading of sideband communication with reasonable complexity transmission. However, OFDM faces several challenges,. The key challenges are ISI due to multipath-use guard interval, large peak to average ratio due to non linearity's of amplifier; phase noise problems of oscillator, need frequency offset correction in the receiver. one major problem for OFDM applied system is its time-domain transmitted signal with a high PAPR especially for a large number of subcarriers. in addition, when a high PAPR signal passes through a power amplifier (PA), the PA may be pushed to a saturation region and, then, both in-band and out-of-band distortions are occurred to degrade the system performance. . Large peak-to-average power (PAP) ratio which distorts the signal. If the transmitter contains nonlinear components such as power amplifiers (PAs).). The nonlinear 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. As one of characteristics of the PAPR, the distribution of PAPR, which bears stochastic characteristics in OFDM systems, often can be expressed in terms of complementary Cumulative Distribution Function (CCDF).

II. OFDM SYSTEM MODEL & CHARACTERISTICS OF OFDM SIGNALS.

The development of OFDM systems can be divided into three parts. This comprises of Frequency Division Multiplexing, Multicarrier communication and Orthogonal Frequency Division Multiplexing. Orthogonal Frequency Division, The orthogonality of the carriers means that each carrier has an integer number of cycles over a symbol period. They are totally independent of one another. This is achieved by placing the carrier exactly at the nulls in the modulation spectra of each other. The sub-carriers in an OFDM system are precisely orthogonal to one another Thus, they are able to Overlap without interfering. As a result, OFDM systems are able to maximize spectral efficiency without causing adjacent channel interference. .

Multicarrier Transmission Technique

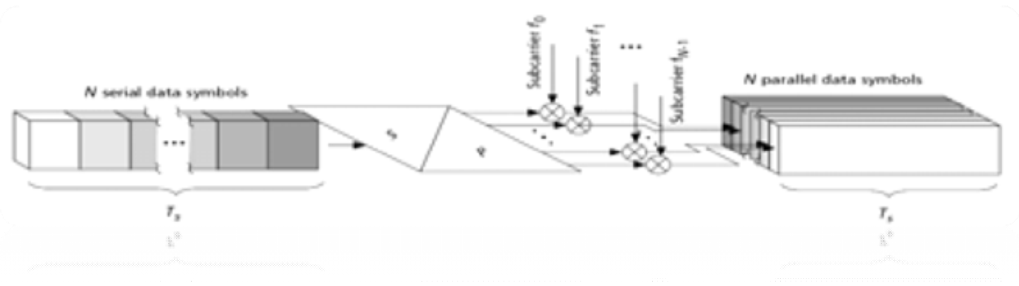

Fig. 1

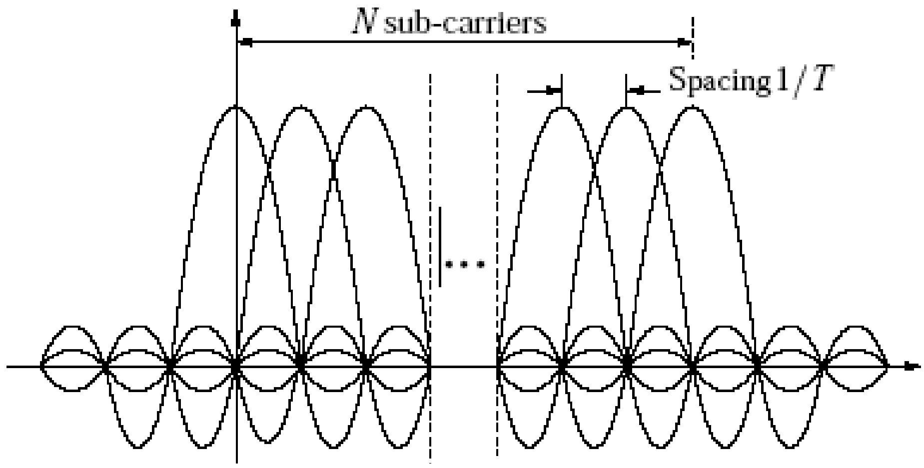

Fig. 2

OFDM Orthogonality

Two periodic signals are orthogonal when the integral of their product over one period is equal to zero. For the case of continuous time:

$$\int_0^T \cos(2\pi nft)\cos(2\pi mft)\,dt = 0 \qquad \text{(i)}$$

For the case of discrete time

$$\sum_{k=0}^{N-1} \cos\left(\frac{2\pi kn}{N}\right)\cos\left(\frac{2\pi km}{N}\right)\,dt = 0 \qquad \text{(ii)}$$

where $m \neq n$ in both cases.

Let $Y = [Y_0, Y_1 \_\_\_\_\_\_\_\_\_\_ Y_{N-1}]^T$ denote an input symbol vector in the frequency domain, where y_k represent the complex data of k the subcarrier and N is the number of subcarriers also called the input subcarriers. The input symbol vector is also called the input symbol sequence. The OFDM signal is generated by summing all the N modulated subcarriers each of which is separated by $1/Nt_s$ in the frequency domain, where t_s is the sampling period. Then a continuous time baseband OFDM signal is defined as:

$$y_t = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} Y_k \, e^{j2\pi \frac{k}{Nt_s} t}, \qquad 0 \le t < Nt_s$$

Suppose that the input data streams is staisticaly independent and identically distributed i. e the real part $\Re\{y(t)\}$& imaginary part $\Im$m $y\{(t)\}$are correlated and orthogonal. Therefore, based on central limit theorem, when N is considerably Large, the distribution of both real & imaginary approaches Gaussian distribution with zero mean and variance.

$$\sigma^2 = E[\Re_e\{y_t\}^2] + [\Im_m\{y_t\}^2]/2 \qquad \text{(v)}$$

Where E(Y) is the expected value of y. In other words OFDM signal with large N, become Gaussian PDF as

$$P_r\{y(t)\} = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{[y(t)]^2}{2\sigma^2}} \qquad \text{(vi)}$$

Moreover, the Rayleigh nature of original OFDM signals amplitude can be gotten and its PDF can be expressed as

$$P_r(r) = 2re^{-r^2}$$

Where r is the amplitude of OFDM signal.

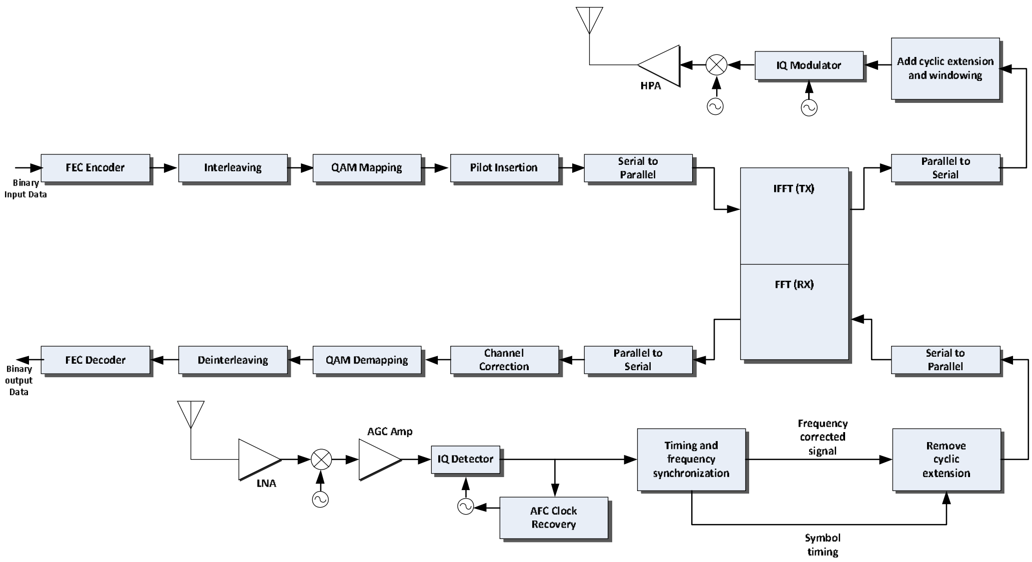

Fig. 3 Block diagram of OFDM transceiver

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 o f 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).

The Fast Fourier Transform (FFT) transforms acyclic 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.

III. PAPR PROBLEM IN OFDM

(a). DEFINITION OF PAPR SYSTEM:

The PAPR ratio is a measure of the dynamic range in OFDM signals. Thus high PAPR induces a high dynamic range which describes high variability in the signal range For an OFDM system with N sub-carriers, the peak power of received signals is N times the average power when phase values are the same. At each instant they are different with respect to each other at different phase values. When all the points achieve the maximum values simultaneously; this will cause the output envelope to suddenly shoot up which causes a 'peak' in the output envelope. . This ratio of the peak to average power value is termed as Peak-to-Average Power Ratio Mathematically defined as

$$PAPR = \frac{max[|y(t)|]}{E[|y(t)|^2]} \qquad \text{(vii)}$$

where E{. } denotes expectation operator. .

The PAPR of baseband signal will reach its theoretical maximum at $PAPR\ (dB)$ =10log N. Another commonly used parameter is the Crest Factor (CF), which is defined as the ratio between maximum amplitude of OFDM signal $s(t)$ and root-mean-square (RMS) of the waveform. The CF is defined as

$$CF[y(t)] = \frac{max[|y(t)|]}{E[|y(t)|^2]} = \sqrt{PAPR} \qquad \text{(viii)}$$

(b). PAPR REDUCTION TECHNIQUES

Several PAPR reduction techniques have been proposed to reduce PAPR in OFDM system which is one of the major drawbacks in multicarrier systems. These techniques are divided into two groups. These are signal scrambling techniques and signal distortion techniques, these techniques again split into various part as shown in fig. (4)

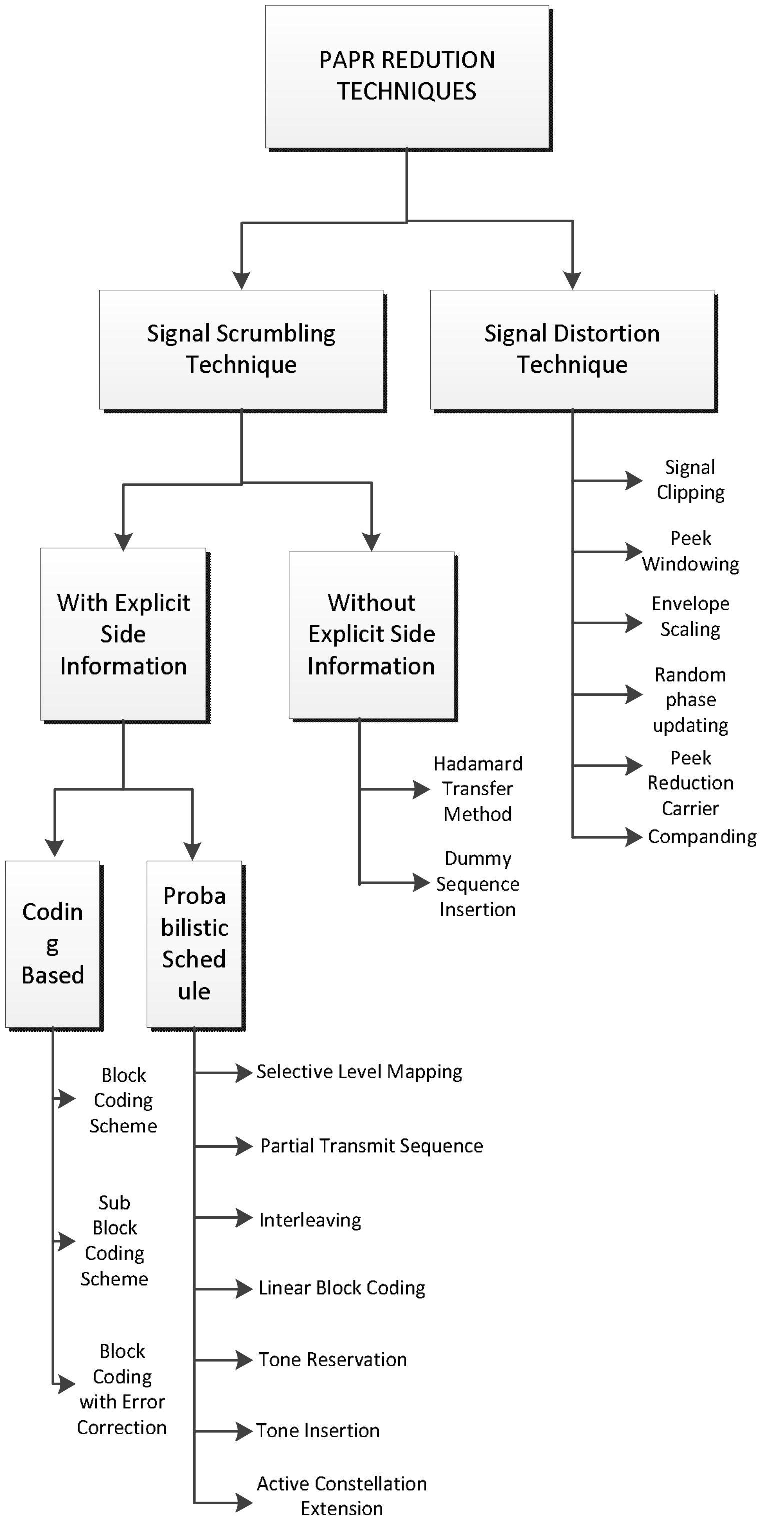
PAPR REDUTION TECHNIQUES
Signal Scrumbling Technique
Signal Distortion Technique
With Explicit Side Information
Without Explicit Side Information
Signal Clipping
Peek Windowing
Envelope Scaling
Random phase updating
Peek Reduction Carrier
Companding
Hadamard Transfer Method
Dummy Sequence Insertion
Codin g Based
Proba bilistic Sched ule
Block Coding Scheme
Sub Block Coding Scheme
Block Coding with Error Correction
Selective Level Mapping
Partial Transmit Sequence
Interleaving
Linear Block Coding
Tone Reservation
Tone Insertion
Active Constellation Extension

Fig. (4)

A ; SIGNAL SCRAMBLING TECHNIQUES:

(i). Block coding Technique:.

This is simple and appropriate for short codes. This Technique is used for the reduction of the peak to mean envelope power ratio (PAPR) of multicarrier transmission systems by selecting the various sets of code words. Three areas are identified to make code practical. Section of suitable code words is for any number of carriers, any coding rate, and any M-ary phase modulation scheme. -Selection of code words to enable efficient implementation of the encoding /decoding. -Selection of code words to offer error deduction and correction. The most trivial brute force approach is sequential searching for all possible code words for a given length of a given number of carriers.

$$s(t) = \sum_{k=1}^{k=N} d_k(t) e^{j(2\pi f_k t + \varphi_k)} \ldots\ldots\ldots\ldots \quad \text{(xi)}$$

$$y(t) = \sum_{k=1}^{k=\frac{N}{2}} [d_k(t) e^{+f(2k-1)\pi f_k t} + d_{-k}(t) e^{-f(2k-1)\pi f_k t}] \ldots\ldots\ldots\ldots \quad \text{(x)}$$

This form gives a term in the summation as two carriers that are equidistant from and on either side of the centre frequency of the complex envelope representation.

***(ii) Sub Block Coding Technique*:**

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 known as systematic odd parity checking coding (SOPC). But this coding is only possible in with small frame size. In case of large frames, the long information sequence is divided in to several Sub-blocks, and each sub-block encoded with SOPC, the reduction of PAPR will be larger. The insertion of an odd parity checking bits into each frame reduces PAPR. The idea is developed to optimize the positions of the odd parity checking bits for further PAPR reduction at the cost of the introduction of side information to inform the receiver of the positions of odd parity checking bits.

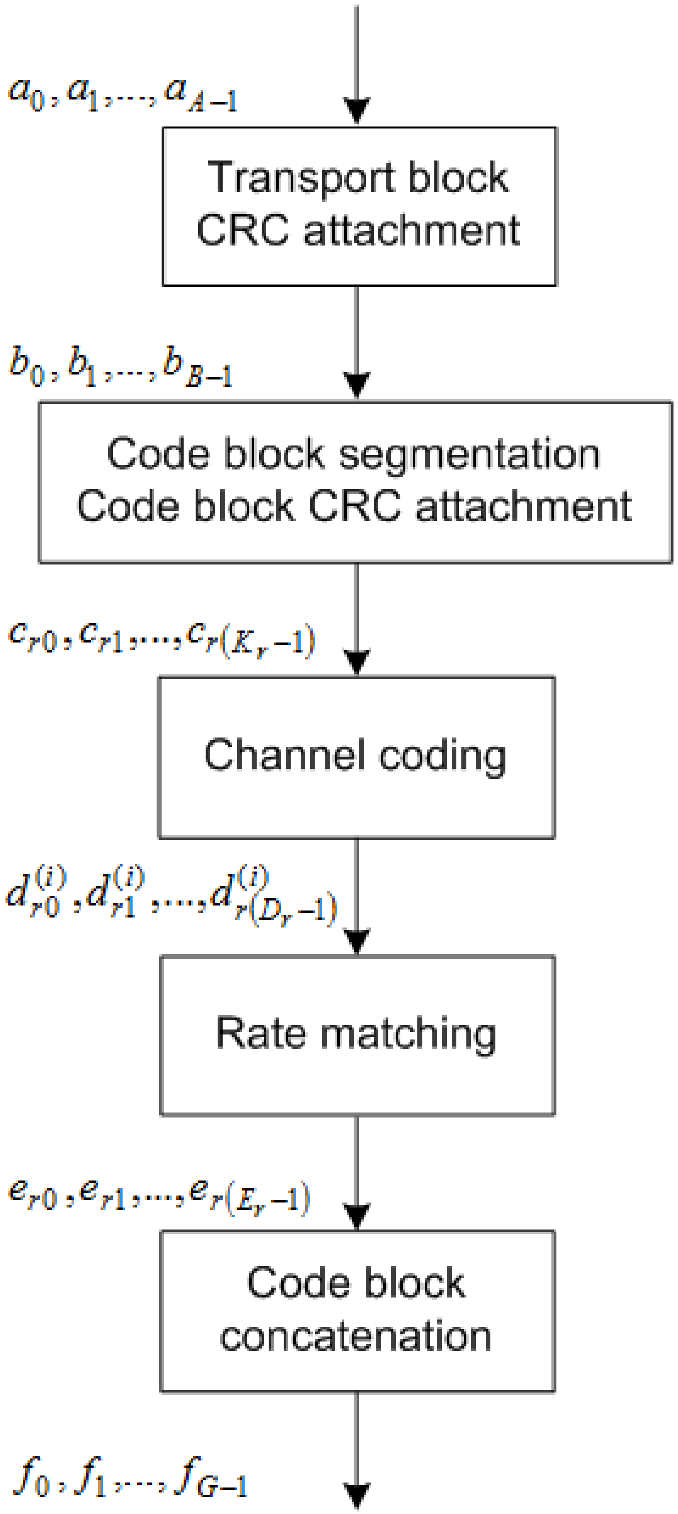

Fig. 5 (Flow chart for Coding Technique)

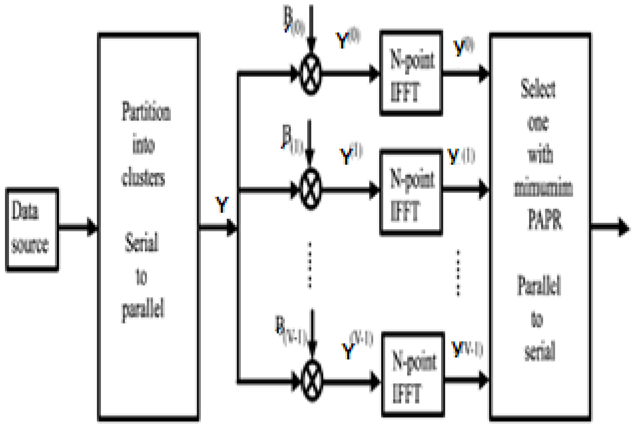

Fig. 6. (Block Diagram of SLM)

(iii)Selected Mapping Technique (SLM):

SLM scheme is one of the initial probabilistic approaches with a goal of making occurrence of the peaks less frequent, not to eliminate the peaks. In selected mapping (SLM) method a whole set of signals is generated representing the same information, and then the most favourable signal with low PAPR is chosen and transmitted. The frequency domain constellation points are multiplied with a set of randomly generated phase vectors which is available at both the transmitter and the receiver. Then, the block with the least PAPR is sent to the IFFT to create the time-domain signal to be transmitted. The index of the phase matrix which gives the minimum PAPR signal is also sent as side channel information (CSI). At the receiver, the received time domain signal is multiplied with the conjugate phase vector (using the CSI) and sent through the FFT to retrieve the original signal. This scheme is very reliable but main drawback that is side information must be transmitted along with chosen signal.

Each data block is multiplied v by different phase factors, each of length$\boldsymbol{N}$, $\boldsymbol{B^V} = [\boldsymbol{b_{V,0}}, \boldsymbol{b_{V,1}} \dots\dots \boldsymbol{b_{V,N-1}}]^T$ Where v=0, 1…. . V-1, and $\boldsymbol{b_{k,v}} = \boldsymbol{e^{j\varphi_{k,v}}}$ known as the weighting factor and $\boldsymbol{\varphi_{k,v}} \in$ is uniformly distributed in$(\boldsymbol{0}, \boldsymbol{2\pi})$. Component wise vector multiplication is

$$Y_k^V = Y^V b_{k,V}$$

$$0 < k \le N-1$$

The resultant signal is after taking its IFFT the sequence generated is

$$\boldsymbol{y}^{v(t)} = [y_0 b_{v,0}, y_1 b_{v,1} ----- y_{N-1} b_{v,N-1}]^{\wedge T} \qquad \text{(xi)}$$

among which $\tilde{y} = y^{\tilde{v}}$with lowest PAPR is selected for transmission.

$$\tilde{v} = \underset{v=1,2,\dots V}{\operatorname{argmin}}\left(max\left|y_{v,k}\right|\right)$$

It should be noted that there is a saturation effect, that is, the additional PAPR reduction gain decreases as *V* increase

The transmitted OFDM signal is given by

$$y(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} Y_k b_{v,k} \exp\ (j2\pi k\Delta f t)$$

Here $\Delta f = \frac{1}{NT}$; NT=Duration of D (xii)

For implementation of SLMOFDM systems, the SLM technique needs V IFFT operation and the number of required bits as side information is log_2^V for each data block.

(vi). Partial Transmit Sequence (PTS):

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 perform better than SLM schemes. When differential modulation is used in each sub block, no side information needs to be transmitted to the receiver.

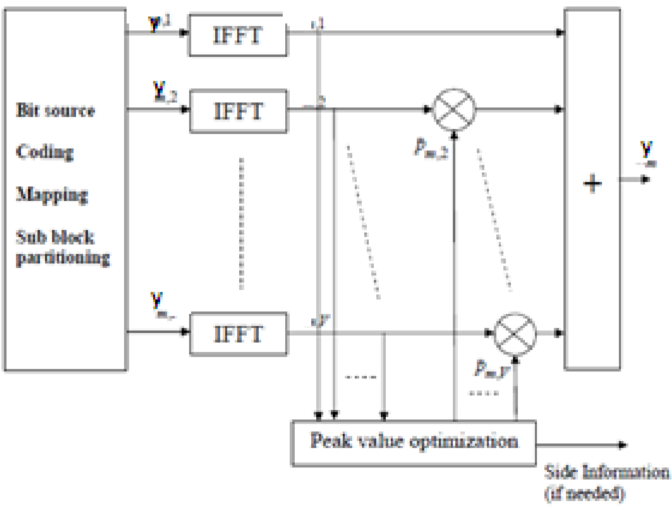

Fig. 7. (Block Diagram of PTS)

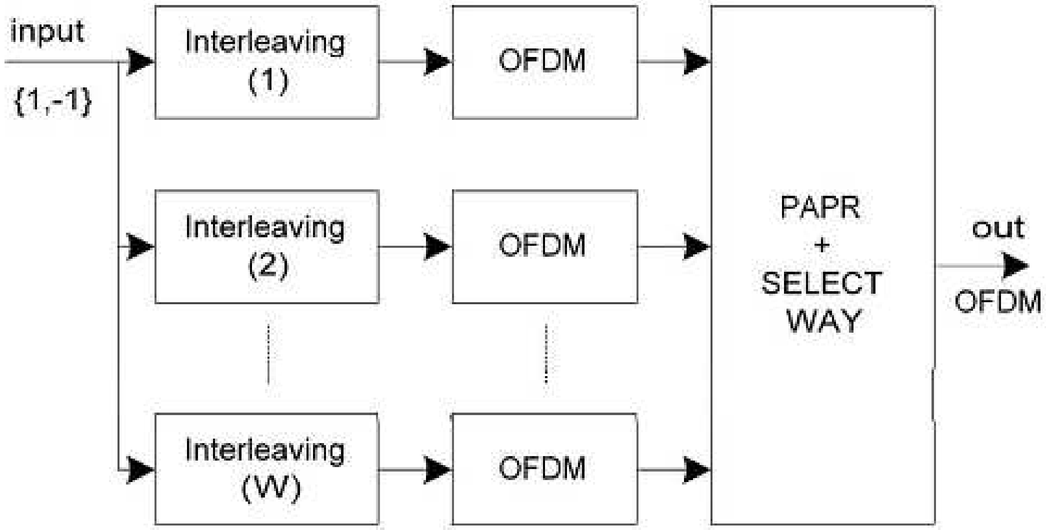

Fig 8. (Block Diagram of Interleaving)

The original signal is given as

$$y_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} Y_k \, e^{j2\pi \frac{k}{N} n}, n = 0, 1, \ldots, N-1 \qquad \text{(xiii)}$$

The signal to be transmitted is broken into several blocks, $Y_{m,k}$ of length N/V (where N is number of subcarriers and V is number of sub blocks). All subcarrier positions which are occupied in another block are set to 0, i. e.

$Y_m = \sum_{k=1}^{V} Y_{m,k}$Next a constant phase rotation, $p_{m,k} = e^{+\varphi_{m,k}}, \varphi_{m,k} \in (0, 2\pi)$ 1<k<V is

Performed on each sub blocks except for the first one is kept constant, giving

$$\bar{Y}_m = \sum_{k=1}^{V} p_{m,k} Y_{m,k} \qquad \text{(xiv)}$$

the information in is$\bar{Y}_m$ same as $Y_m$but with an added phase rotation, which must be known at the receiver. An IFFT is performed on each sub block which are then all summed together to create a possible transit symbol,

$$y_m = \sum_{k=1}^{V} p_{m,k} \, IFFT \, \{Y_{m,k}\} = \sum_{k=1}^{V} p_{m,k} \, y_{m,k} \qquad \text{(xv)}$$

The process is repeated again with a different phase rotation $p_{m,k}$ to produce another alternative transmit signal. The optimum parameters for transmit signal are

$$\{\tilde{p}_{m,1} \ldots \ldots \tilde{p}_{m,V} = arg \min_{\tilde{p}_{m,1} \ldots \tilde{p}_{m,V}} \left(\max_{0 \le n < N-1} \left| \sum_{k=1}^{V} p_{m,k} \, y_{m,k} \right| \right) \qquad \text{(xvi)}$$

The optimum phase angle $\tilde{p}_{m,k}$is the one where PAPR is minimized. Therefore, the actual transmit signal is given as

$$\tilde{y}_m = \sum_{k=1}^{V} \tilde{p}_{m,k} \, y_{m,k} \qquad \text{(xvii)}$$

(v) Interleaving:

This method is also termed as Adaptive Symbol Selection Method. Multiple OFDM symbols are created by bit interleaving of input sequences. The basic Idea is to use W interleaving ways and selecting one with the lowest PAPR. The basic idea in adaptive interleaving is to set up an initial terminating threshold. PAPR value goes below the threshold rather than seeking each interleaved sequences. The minimal threshold will compel the adaptive interleaving (AL) to look for all the interleaved sequences, whereas for the large threshold value, AIL will search only a fraction of the interleaved sequences. The main important of the scheme is that it is less complex than the PTS technique but obtains comparable result. This method does not give the assurance result for PAPR reduction.

(vi)Tone Reservation (TR):

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.

Tone reservation method is based on adding a data block and time domain signal. A data block is dependent time domain signal to the original multicarrier signal to minimize the high peak. This time domain signal can be calculated simply at the transmitter of system and stripped off at the receiver. The amount of PAPR reduction depends on some factors such as number of reserved tones, location of the reserved tones, amount of complexity and allowed power on reserved tones This method explains an additive scheme for minimizing PAPR in the multicarrier communication system. It shows that reserving a small fraction of tones leads to large minimization in PAPR ever using with simple algorithm at the transmitter of the system without any additional complexity at the receiver end.

The advantage of TR method is that it is less complex, no side information and also no additional operation is required at the receiver of the system. This time domain signal can be easily computed at the transmitter and stripped off at the receiver.

(vii)Tone Injection (TI):

Tone Injection uses a set of equivalent constellation points for an original constellation points to reduce PAPR.

The main idea behind this method is to increase the constellation size. Then, each point in the original basic constellation can be mapped into several equivalent points in the extended constellation, since all information elements can be mapped into several equivalent constellation points. These additional amounts of freedom can be utilized 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. The drawbacks of this method are; need to side information for decoding signal at the receiver side, and cause extra IFFT operation which is more complex.

B: Signal Distortion Technique.

(viii)Peak Windowing:

Peak Windowing technique provides better PAPR reduction with better spectral properties than clipping. Peak windowing can achieve PAPR around 4dB for 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. With windowing method, PAPR can be reduced down to about 4dB, independent of the number of sub carriers.

***(ix)Envelope Scaling**:*

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 scheme seems only suitable to PSK schemes, where all the envelope of all subcarriers input are equal.

(x)Random Phase updating:

In the random phase updating algorithm, a random phase 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.

***(xi)Companding*:**

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 occurring frequently. 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. 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.

(xii)Clipping and Filtering:

One of the simple and effective PAPR reduction techniques is clipping, which cancels the signal components that exceed some unchanging amplitude called clip level. However, clipping yields distortion power, which called clipping noise, and expands the transmitted signal spectrum, which causes interfering. Clipping is nonlinear process and causes in-band noise distortion, which causes degradation in the performance of bit BER and out-of-band noise, which decreases the spectral efficiency. Clipping and filtering technique is effective in removing components of the expanded spectrum. Although filtering can decrease the spectrum growth, filtering after clipping can reduce the out-of-band radiation, but may also cause some peak re-growth, which the peak signal exceeds in the clip level. The PAPR is reduced at the cost of small increase in the total in band distortion.

IV. CONCLUSIONS

OFDM is a very striking technique for wireless communications due to its spectrum efficiency and channel robustness One of the serious drawbacks of OFDM systems is that the composite transmit signal can exhibit a very high PAPR when the input sequences are highly correlated. In this paper,. we described several important aspects, as well as provide a mathematical analysis.

A study of the complexity issues of the PAPR reduction technique is required especially looking at ways of further reducing the complexity of the sphere decoder. Although many PAPR reduction schemes have been developed, none of them satisfies commercial requirements or has been adopted as a standard for wireless communication systems. But, the modified PAPR reduction schemes with low computational complexity can be applied to high data rate OFDM systems. Upcoming studies on PAPR reduction may include a combination of different schemes.

OVERALL ANALYSIS OF DIFFERENT TECHNIQUES

Signal Distortion Technique				
Peak Windowing	No	Yes	No	No
Envelope Scaling	No	Yes	No	No
Random Phase updating		Yes	No	Yes
Peak Reduction Carrier		Yes	Yes	No
Companding	No	Yes	No	Yes
Clipping and Filtering	No	No	No	No

Reduction Technique	Parameters			
Signal Scrambling Technique	Decrease Distortion	Power Raise	Complexity	Defeat Data Rate
Coding Schemes	Yes	No	No	Yes
Selected Mapping Technique	Yes	No	Yes	No
PTS	Yes	No	Yes	Yes
Interleaving	Yes	No	No	Yes
Tone Reservation	Yes	Yes	No	Yes
Tone Injection	Yes	Yes	No	No

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