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Highly Computational Efficient PAPR Reduction Technique by Shifting Null Subcarriers within the Data Subcarriers for Transmission in an OFDM System

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ABSTRACT

To minimize the PAPR of multi-carrier transmission, we propose an advanced scheme by rearranging the null-subcarriers and data-subcarriers. This new method shifts the "innermost" null subcarriers among different data-subcarriers to minimize the PAPR. Considering the practicability for implementation, we propose the "Simplified" version, which degrades the computational load by applying proposed shifting scheme only to the subblock with the largest PAPR. The proposed method is distortionless, does not affect the constellation at the data-subcarriers, maintains better PAPR reduction and reduces BER while keeping low computational complexity, needs less CSI, also can be concatenate with almost all other PAPR-reduction methods and is compatible with existing standards.

KEYWORDS- Intersymbol interference, Non-linear distortion, Null subcarriers, Orthogonal frequency division multiplexing, peak-to-average power ratio (PAPR)

1. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a most effective multicarrier modulation scheme used in wireless and wire line communications. It is a special case of high-data-rate multicarrier transmission technology, where a single data stream is transmitted over a number of lower rate subcarriers instead of single carrier system. The available spectrum is divided into several sub-bands and one subcarrier is used in each sub-band. These subcarriers are orthogonal to each other. Information bit stream is transmitted in parallel on these sub-bands.

The main reason to use OFDM is its robustness against the selective fading or narrowband interference, high spectral efficiency and easy implementation. Hence, due to these favorable features, it is widely used in modern broadband communication systems. OFDM provides greater bandwidth efficiency, immunity to multi-path fading and impulse noise, resistance to frequency selective fading, and exemption from the need of complex equalizers and digital signal-processor hardware implementation. It has been widely adopted in the international standards, such as IEEE 802.11, IEEE 802.15, IEEE 802.16, IEEE 802.20, European Telecommunications Standards Institute (ETSI), Broadcast Radio Access Network (BRAN) committees and 3G Long Term Revolution (LTE) [1].

However OFDM system suffers from serious problem of high instantaneous Peak-to-Average Power Ratio (PAPR) of transmitted OFDM signals. In OFDM system, output is superposition of multiple sub-carriers. In this case, some instantaneous power output might increase greatly and become far higher than the mean power of system. To transmit signals with such high PAPR, it requires power amplifiers with very high power scope. These kinds of amplifiers are very expensive and have low efficiency. If the peak power is too high, it could be out of the scope of the linear power amplifier. This gives rise to non-linear distortion which changes the superposition of the signal spectrum resulting in performance degradation. If no measure is taken to reduce the

high PAPR, MIMO-OFDM system could face serious restriction for practical applications [2]-[5]. Therefore, reducing the PAPR is of practical interest.

The peak amplitude of the OFDM signal could be 'N' times that of a single-carrier system, where 'N' denotes the number of carriers. When the peak amplitudes of the OFDM signals with high PAPR reach or exceed the saturation region of power amplifier at the transmitter and/or receiver, the OFDM signals will suffer from nonlinear distortion, spectrum spreading, in-band distortion and inter modulation interference across the OFDM subcarriers. All these impacts demote the bit-error-rate (BER) at the receiver. One simple solution is to use expensive power-amplifiers with a large saturation region. However, as high peak amplitudes occur irregularly, this High Power Amplifier (HPA) would be inefficient. Besides, high peaks are also constrained by design-factors such as cost and battery power of electronics [1]. Large PAPR also demands the Digital-to-Analog Converter (DAC) with enough dynamic range to accommodate the large peak of the OFDM signals. High PAPR becomes huge obstruction to harvest all the features of OFDM system for the implementation of high speed broadband communication systems.

2. PROPOSED METHODS

A number of approaches have been proposed to deal with the PAPR problem, along with various schemes and design dimensions for PAPR reduction [8]. These techniques include amplitude clipping, clipping and filtering, coding, tone reservation, tone injection, active constellation extension and multiple signal representation techniques such as partial transmit sequence (PTS) [12], selected mapping (SLM) [11], and interleaving. These techniques achieve PAPR reduction possibly at serious expenses, such as signal transmission power increase, BER increase, data-rate loss, computational complexity increase, and exclusive requirement of Channel Side Information (CSI). No specific PAPR reduction technique is the best solution for all multicarrier transmission systems. Nonetheless, it should be carefully chosen according to various system requirements [5]. In section III, some basics about PAPR problem in OFDM is given. Section IV describes different PAPR reduction techniques which are using null subcarriers. Section V contains the conclusion. In this paper, null subcarriers are exposed to reduce the PAPR of OFDM system [9].

One of the design dimensions is to explore null subcarriers. A null subcarrier is also known as unused subcarrier without carrying transmit energy. The aim is to introduce an improved version of approach called 'Null-Switching' for PAPR reduction with low computational overhead [10]. In a nutshell, the null switching method is to interchange data-subcarriers with some innermost null subcarriers in the guard-band, in order to change the frequencies of some terms input to the IFFT operator. This switching null subcarriers scheme switches one or more null-carriers with to-be-identified data-subcarriers. This changes the input to the IFFT operator, and thus the IFFT operator's output and it's PAPR. The guard-bands of many multi-carrier standards (e.g. IEEE 802.11a's) have null-subcarriers in the transition-band of the transmit spectrum mask (i.e. the band-pass filter matched to the desired user's data-subcarriers). Hence, such a null-subcarrier frequency (now switched to carry data) can pass a good portion of any energy therein onto the receiver. For the above switching, the transmitter is to search for the data-subcarrier that (when switched with a null-subcarrier) would achieve the greatest PAPR reduction [1]. The new method of shifting null subcarriers among data subcarriers is characterized by better BER performance and very low computation complexity.

3. SOME BASICS ABOUT PAPR PROBLEM IN OFDM

OFDM signal exhibits a very high PAPR, which is due to the summation of sine waves and non-constant envelope. Therefore, RF power amplifiers have to be operated in a very large linear region [6]. Otherwise, the signal peaks get into non-linear region causing signal distortion. This signal distortion introduces inter modulation among the subcarriers and out-of-band radiation [7]. PAPR is a very important situation in the communication system because it has big effects on the transmitted signal. Low PAPR makes the transmit power amplifier works efficiently, on the other hand, the high PAPR makes the signal peaks move into the non-linear region of the RF power amplifier which reduces the efficiency of the RF power amplifier. In addition, high PAPR requires a high-resolution DAC at the transmitter, high-resolution analog to digital

converter (ADC) at the receiver [7]. Any non-linearity in the signal will cause distortion such as inter-carrier interference (ICI) and inter symbol interference (ISI).

PAPR of OFDM signal is given by:

PAPR = *Ppeak/Pavg.* = $10\log(\max[|xn|^2]/E[|xn|^2])$ (1)

Where,

Ppeak represents peak output power,

Pavg. means average output power,

'E' denotes the expected value,

'xn' represents the transmitted OFDM signals.

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. The PAPR of baseband signal will reach its theoretical maximum at (*dB*) =10log N.

The Cumulative Distribution Function (CDF) is used to measure the efficiency of any PAPR reduction 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 [3]. By implementing the Central Limit Theorem for a Multicarrier signal with a large number of sub-carriers, the real and imaginary part of the time domain signals have a mean of zero and a variance of 0.5 and thus follow a Gaussian distribution. So Rayleigh distribution is followed for the amplitude of the multicarrier signal, where as a central chi-square distribution with two degrees of freedom is followed for the power distribution of the system.

4. PAPR REDUCTION USING NULL SUBCARRIERS

There are two techniques which reduces the PAPR value of OFDM system using null subcarriers. Those techniques are switching null subcarriers and shifting null subcarriers. Fig. 1 below explains the basic flow of those two methods.

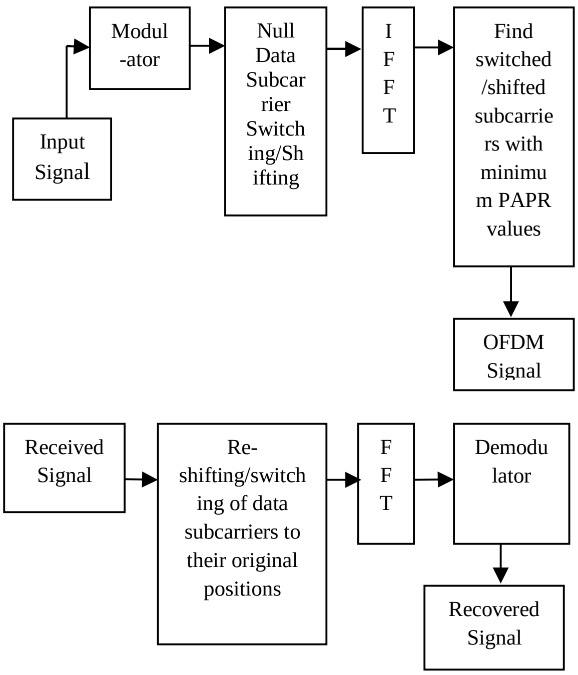

Fig.1 OFDM Transreceiver with Switching/Shifting Method for Null Subcarriers.

4.1. Full Version of Proposed Method

Consider OFDM transmission with L subcarriers at ascending frequencies set $\{fl, l = 1, \cdots, L\}$, and indexed by $S = \{l = 1, \cdots, L\}$. Of these, N where N less-equal L are null-subcarriers, with distinct indices drawn from the ascending set $N = \{gn, n = 1, \cdots, N\} \subset S$. These N null-subcarriers respectively occupy the increasing frequencies $\{fgn, n = 1, \cdots, N\}$, while the remaining L-N subcarriers serve as data-subcarriers, with distinct indices from the ascending set $D = \{hd, d = 1, \cdots, L - N\} \subset S$.

These L-N data-subcarriers respectively occupy the increasing frequencies $\{fhd, d = 1, \cdots, L-N\}$. Moreover, $N \cup D = S$, and $fgn \neq fhd$, $\forall n, d$. Assigned to the data-subcarriers at $\{fhd, 1 \le d \le L - N\}$ are, respectively, the M-ary data symbols $\{\overline{xd}, d = 1, \cdots, L - N\}$, taken from a quadrature amplitude modulation (QAM) or quadrature phase-shift keying (QPSK) constellation.

Without modifying L, N, D, the proposed method shifts P elements $\{\tilde{g}p, p = 1, \cdots, P\}$ of the null-subcarrier set $N = \{gn, n = 1, \cdots, N\}$ at the frequency $\{f\tilde{}lp, p = 1, \cdots, P\}$corresponding to P elements $\{\tilde{}lp, p = 1, \cdots, P\}$ of the subcarrier set S, such that if $f\tilde{}lp < f\tilde{}lp+1$, then $f\tilde{}gp < f\tilde{}gp+1$. The transmitter is to search for the most advantageous frequencies for the P "innermost" null subcarrier(s) to shift to, for the greatest PAPR reduction. The optimization problem is to identify $\{f\tilde{}lp, p = 1, \cdots, P\}$ to minimize the PAPR. There are altogether $\binom{L-N}{P} = \frac{(L-N)!}{P!(L-N-P)!}$ different "shifting" possibilities.

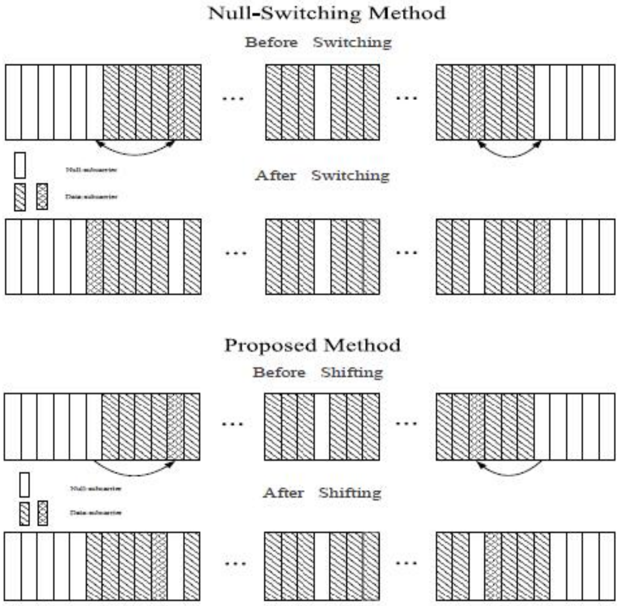

Fig.2 Comparison of Proposed method with Null-Switching method

For the IEEE 802.11a/g standard, the number of null subcarriers as guard-bands at low-frequency end is one more than that at high-frequency edge, if P is even; the number of null-subcarriers as guard-bands at low-frequency end equals to that at high-frequency edge, if P is odd [1].

4.2. Simplified Version for Practical Implementation

Considering the practicability for implementation, the "Simplified" version, which degrades the computational load by applying the basic idea only to the sub-block with the largest PAPR.

Specifically, the OFDM symbols $\bar{x}$ are partitioned into V disjoint sub-blocks:

$\bar{x}^{(v)} \triangleq [\bar{x}_0^{(v)} \ldots \bar{x}_{L/V-1}^{(v)}]$ with $\bar{x}_k^{(v)} = \bar{x}d$ or 0, $0 \le v \le V - 1$,

such that :

$$\bar{x} = \sum_{v=0}^{V-1} \bar{x}(v) \qquad (2)$$

Only the sub-block with the largest PAPR will undergo the basic scheme in "Full" version. Thus, the number of "shifting" possibilities is reduced significantly. With the increasing of *V*, the computational complexity is reduced dramatically [1].

5. SIMULATIONS

The IEEE 802.11a standard ensures appropriate candidate which has minimum PAPR after shifting of null subcarrier. An 802.11a OFDM carrier signal is the sum of one or more OFDM symbols each comprised of 52 orthogonal subcarriers with baseband data on each subcarrier being independently modulated using Quadrature amplitude modulation (QAM). This composite baseband signal is used to modulate a main RF carrier. To begin the OFDM signal creation process, the input bit stream is encoded with convolution coding and interleaving. Each data stream is divided into group of 4 bits because here we are using 16-QAM and then converts into complex numbers (I+JQ) representing the mapped constellation point. 52 bits of the IFFT block are loaded. Out of these 48 bits contains constellation points which are mapped into frequency offset indexes ranging from 0 to 64, skipping the 4 pilot and zero bits. There are 4 pilot subcarrier inserted into frequency offset index location 5, 26, 40 and 54. The zero bit is the Null or DC subcarrier (contains 0 value i.e. 0+0j) and is not used. When the IFFT block is completely loaded, the IFFT computed, giving a set of complex time domain samples representing the combined OFDM subcarrier waveform. In between each OFDM symbols preamble is used for synchronization and concatenated together, in this way OFDM burst is transmitted.

The Fig.3 shows the PAPR analysis using CCDF plot. For p=1 where 'p' is the number of null subcarriers, the PAPR at 0.2% probability is 9.5 dB approx. For p=2, it is further reduced to 8.7 dB approx. and for shifting sub-block, it comes around 9.5 dB.

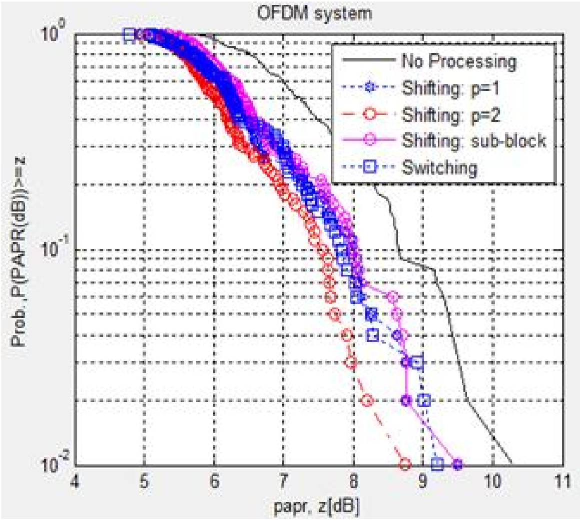

Fig.3 Performance of OFDM system by applying Shifting scheme for reducing PAPR

TABLE 1 Different Schemes for PAPR reduction with simulation PAPR values

Different Schemes for PAPR reduction	PAPR z[dB] at 0.01 Prob.
No Processing	10.35
Shifting at p=1	9.5
Shifting at p=2	8.75
Shifting using sub-block	9.5
Switching	9.25

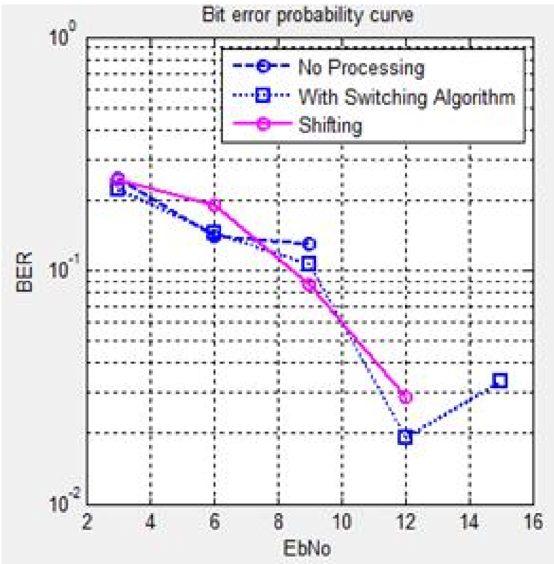

Fig.4 BER Performance of Shifting Algorithm

6. CONCLUSION

The PAPR of OFDM system can be reduced by reordering the null-subcarriers and data-subcarriers. These techniques switch/shifts the “innermost” null subcarriers among different data-subcarriers to minimize the PAPR. For computational overhead reduction, sub-blocks of data carriers are transmitted to reduce the overall time. The simulation results have demonstrated the effectiveness of the approach for a 16-QAM modulation scheme and had been evaluated in terms of BER versus SNR. The results clearly depict the efficiency of our proposed algorithm, as well as ability to achieve large reduction in PAPR. These techniques are CSI-free, which can be compatible with most existing OFDM standards, and which can complement many other PAPR-reduction algorithms.

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