Efficient use of null subcarriers to reduce PAPR in OFDM System

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Abstract-The peak-to-average power ratio (PAPR) of multi-carrier transmission can be reduced by exploiting null subcarriers which are already mandated in most OFDM wireless standards. This new approach requires no channel side information, can be compatible with existing standards, imposes no rate hit, is distortionless, has low computational complexity, and can complement most other PAPR-reduction methods (such as active constellation extension, partial transmit sequences, selective mapping, tone injection, tone reservation).

Keywords— Bit error rate (BER), Multicarrier, Orthogonal frequency division multiplexing (OFDM), Peak to average power ratio (PAPR), Null subcarriers.

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a multicarrier modulation scheme. It is one of the most attractive candidates for fourth generation (4G) wireless communication. It effectively combats the multipath fading channel and improves the bandwidth efficiency. At the same time, it also increases system capacity so as to provide a reliable transmission [1]. OFDM offers high spectral efficiency, low inter-symbol interference (ISI), immune to the multipath delay, immunity to frequency selective fading and high power efficiency. Due to these merits, 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) [8]. Fig.1 shows the OFDM block diagram.

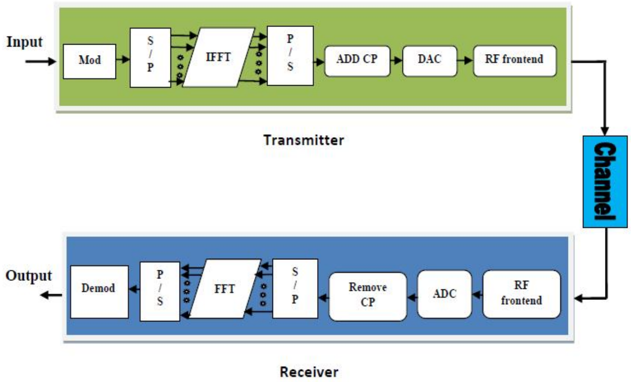

Fig.1: OFDM block diagram.

However OFDM system suffers from serious problem of high PAPR. 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 [1]-[4]. Therefore, reducing the PAPR is of practical interest. Many PAPR reduction methods have been proposed. Some methods are designed based on employing redundancy, such as coding [4], [5], selective mapping with explicit or implicit side information [6], [3], [5], or tone reservation. An apparent effect of using redundancy for PAPR reduction is the reduced transmission rate. PAPR reduction may also be achieved by using extended signal constellation, such as tone injection. Nonetheless, these schemes 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 CSI.

In this paper, null subcarriers are exposed to reduce the PAPR of OFDM system. A null subcarrier is also known as an unused subcarrier without carrying transmit energy[8]. In IEEE 802.11a/g, 6 nullsubcarriers at the low-frequency end and 5 null-subcarriers at the high-frequency end serve as guard-band.

It is considered tolerable to use some of these null subcarriers for other purposes because the spectral mask as shown in figure 2 has its transition-band over those null subcarriers and thereby passing a good portion of the energy[8].

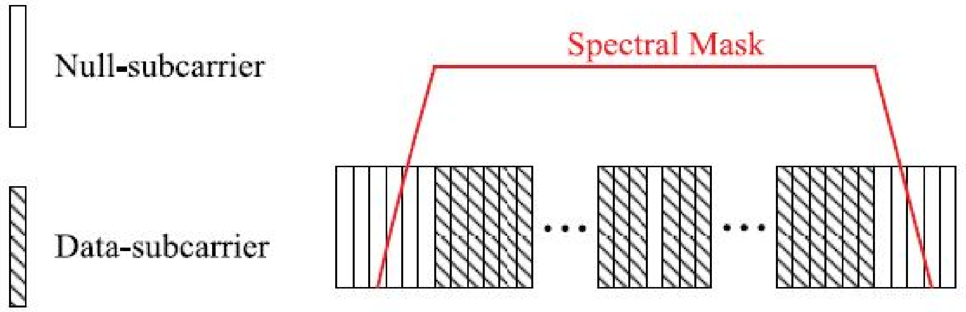

Fig. 2: Spectral Mask

The remainder of this paper is organized as follows. In section II, some basics about PAPR problem in OFDM is given. Section III describes different PAPR reduction techniques which are using null subcarriers. Section IV contains the comparison of different PAPR reduction techniques. Section V contains the conclusion.

II. 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 [7]. 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 [5]. 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 [5]. 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,

$$\text{PAPR} = \frac{\text{Ppeak}}{\text{Paverage}} = 10log10 = \frac{\max[|xn|^2|]}{E[|xn|^2]}$$

Where $Ppeak$ represents peak output power, $Paverage$ means average output power. $E\cdot$ 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 [2]. 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.

III. 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. Figure 3 and 4 below explains the basic flow of those two methods.

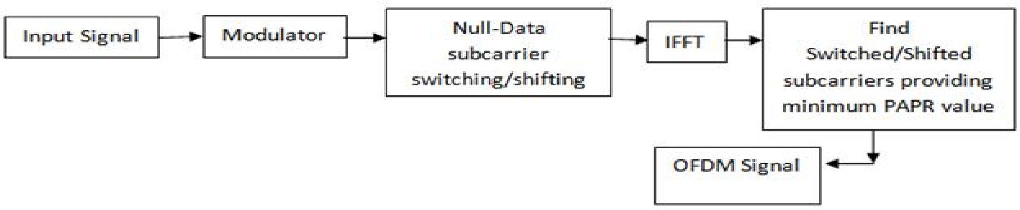

Fig. 3: OFMD Transmitter with switching/shifting method

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At transmitter side, some operation is performed on null subcarriers to reduce the PAPR and at the receiver side; those operations are reverted to back to its original state.

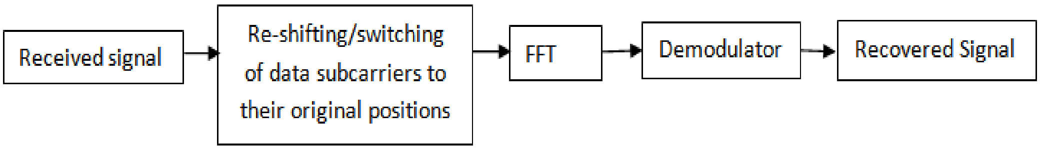

Fig. 4: OFMD Receiver with switching/shifting method

- Switching Null Subcarriers:

This scheme switches one or more null-carriers with to-be-identified data-subcarrier(s). This will change the input to the IFFT operator, and thus the IFFT operator's output and its PAPR. Therefore, PAPR will be different for each switching operation of null subcarriers. Main idea here is to use that switching combination which will provide lowest PAPR value [8].

Consider an OFDM transmission with L subcarriers at the frequencies $\{f_\ell, \ell = 1...L\}$ listed ascending and indexed by $S = \{\ell = 1...L\}$. Of these, N are null subcarriers, with indices drawn from the ascending set $N = \{g_n, n = 1...N\} \subset S$, respectively occupying the ascending frequencies $\{fg_n, n = 1...N\}$.

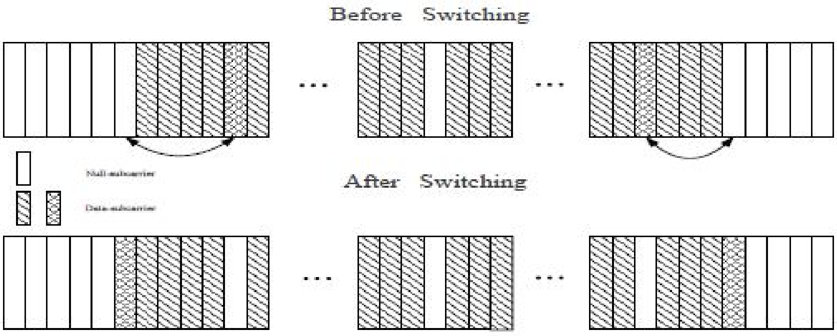

Fig. 5: Switching Null subcarriers

The remaining L - N subcarriers serve as data-subcarriers, with indices from the ascending set $D = \{h_d, d = 1...L - N\} \subset S$, respectively occupying the ascending frequencies $\{fh_d, d = 1...L - N\}$. Obviously, $N \cup D = S$, and $fg_n \neq fh_d$, $\forall$ n, d. Assigned to the data-subcarriers at $\{fh_d, 1 \leq d \leq L - N\}$ are, respectively, the M-ary data symbols $\{X_d, d = 1...L - N\}$, taken from any phase-modulated and/or amplitude-modulated constellation.

Without modifying L or N specified in a given OFDM standard, the method switches P number of null subcarriers (i.e. $\{g_p, p= 1, ..., P\} \subset N =\{g_n, n = 1, ..., N\}$) with P number of data-subcarriers (i.e. P members of $\{h_p, p = 1, ..., P\} \subset D = \{h_d, d = 1, ..., L - N\}$), such that if $fh_p < fh_{p+1}$, then $fg_p < fg_{p+1}$.

The above constraint (i.e. if $fh_p < fh_{p+1}$ then $fg_p < fg_{p+1}$) allows no channel side information to be transmitted, because:

- The receiver has a priori knowledge of D;
- The received data allow the identification of $\{h_p, p = 1, ..., P\}$ on account of their low power-levels; and
- The permutation of the P switched data-subcarriers remains unchanged after the switching. Hence, the receivers can 'un-switch' correctly, even with no channel side information.

The task is to identify the $\{h_p, p = 1...P\}$ (from $\{h_d, d = 1...L - N\}$) that minimizes the peak-to-average power ratio (PAPR) z, of the discrete-time OFDM signal. With L, N, P specified, there exist altogether

$$\binom{L-N}{P} = \frac{(L-N)!}{P!(L-N-P)!}$$

number of different 'switching' possibilities, for each of which the transmitter is to evaluate the corresponding PAPR z. To be chosen will be the one 'switching' possibility that offers the least PAPR z. As per 802.11a specification, Number of data subcarriers (L-N) =48, if P=2 is considered then 1128 numbers of iterative searching are required.

This means 1128 times IFFT needs to be performed for every single OFDM symbol. The number becomes 194580 if P = 4 is considered. This implies that the computational time and associated energy cost can be a hindrance for delay sensitive services or power constrained hand-held devices.

To verify the this PAPR reduction technique, herein the IEEE 802.11a standard is used as an example, even though this method could be implemented in any multi-carrier system with null-subcarriers. From figure 6, it can be seen that PAPR of OFDM system with switching algorithm is low as compared to OFDM system without switching algorithm.

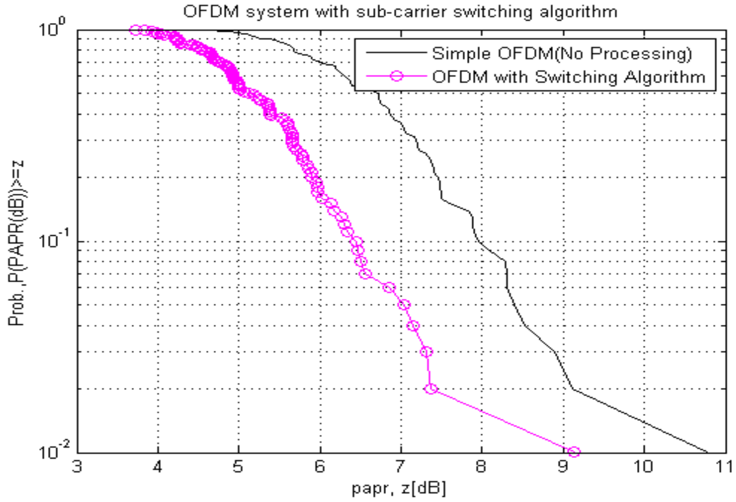

Fig. 6: PAPR reduction using switching method

- Shifting Null Subcarriers:

This method reduces the PAPR of OFDM system using same concept as null-data subcarrier switching method. This method shifts one or more null-carriers with to-be-identified data-subcarrier(s) [9].

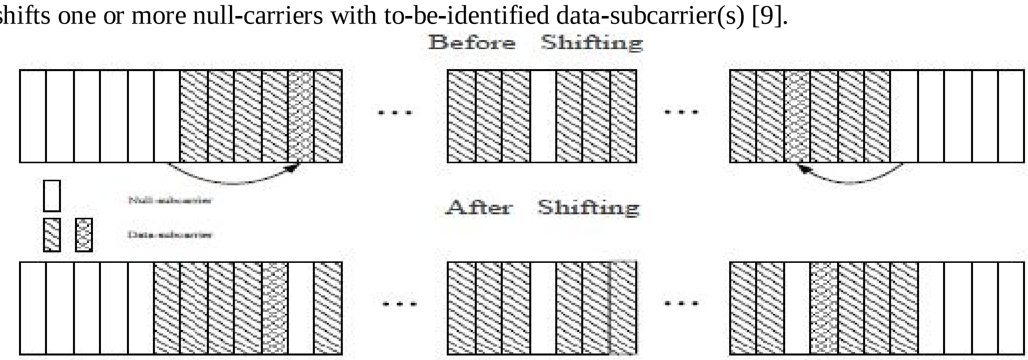

Fig. 7: Shifting Null subcarriers

This changes the input to the IFFT operator, and thus the IFFT operator's output and it's PAPR. Therefore, PAPR will be different for each shifting operation of null subcarriers. Main idea here is to use that shifting combination which will provide lowest PAPR value. This method requires lower computational complexity as compared to switching of null subcarriers method.

To verify the this PAPR reduction technique, herein the IEEE 802.11a standard is used as an example, even though this method could be implemented in any multi-carrier system with null-subcarriers. From figure 8, it can be seen that PAPR of OFDM system with shifting algorithm is low as compared to OFDM system without shifting algorithm.

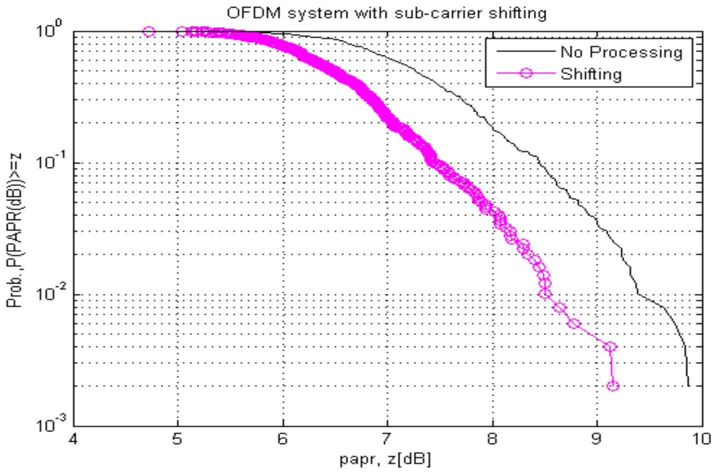

Fig. 8: PAPR reduction using shifting method

IV. COMPARISON WITH OTHER TECHNIQUES

Table 4.1 shows the comparison of different PAPR reduction techniques with switching/shifting null data subcarrier method.

TABLE 4.1
COMPARISON WITH OTHER TECHNIQUES

Name of Schemes	Name of parameters		
	Distortion less	Power increases	Data rate loss
Clipping and Filtering	No	No	No
Partial Transmit Sequence(PTS)	Yes	No	Yes
Selective Mapping (SLM)	Yes	No	Yes
Interleaving	Yes	No	Yes
Tone Reservation (TR)	Yes	Yes	Yes
Switching/Shifting Method	Yes	No	No

V. 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. These techniques are CSI-free pre-processing algorithms, which can be compatible with most existing OFDM standards, and which can complement many other PAPR-reduction algorithms.

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