Performance Comparison of ASC and PTS to Reduce PAPR in OFDM WLAN Systems

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Abstract

The main objective of this paper is to implement a post-Inverse Fast Fourier Transform (IFFT) Peak to Average Power Ratio (PAPR) reduction method based on time domain linear symbol combining to minimize the PAPR at the transmitter. High PAPR is a particular disadvantage of Orthogonal Frequency Division Multiplexing (OFDM) systems and can significantly degrade the power efficiency at the transmitter. The Adjacent Symbol Combining (ASC) method has a relatively low complexity with very less side information bits per symbol and does not require external randomization sequences. This paper will also investigate the impact of the ASC method on the Wireless Local Area Network (WLAN) system Bit Error Rate (BER) performance. It is shown that the BER degradation is relatively small with the forward error correction coding technique. In this paper, the PAPR reduction, complexity and system performance of the ASC technique is compared with the well known Partial Transmit Sequence (PTS), due to the similarities shared between these PTS and the ASC. The ASC technique is similar in principle to PTS techniques in producing multiple time-domain signal representations per OFDM symbol.

Key Words : Orthogonal Frequency-Division Multiplexing (OFDM), Peak-To-Average-Power Ratio (PAPR) Reduction, Adjacent Symbol Combining (ASC), Partial Transmit Sequence (PTS), SeLective Mapping (SLM), Complementary Cumulative Distribution Function (CCDF).

I. Introduction

Multicarrier transmission, also known as Orthogonal Frequency-Division Multiplexing (OFDM) or Discrete MultiTone (DMT), is a technique that has seen rising popularity in wireless and wireline applications mainly due to the recent advances in digital signal processing technology [1,2,7]. For wireless applications, an OFDM-based system is of interest because it provides greater immunity to multipath fading and impulse noise, and eliminates the need for equalizers, while efficient hardware implementation is realized using Fast Fourier Transform (FFT) techniques. However, such a transmission technique has a major drawback related to its high Peak to Average Power Ratio (PAPR) and is caused by the large envelope fluctuations of the time-domain signal[10]. High PAPR values lead to serious problems such as severe power penalty at the transmitter, which is not affordable in portable wireless systems where terminals are powered by battery.

Several PAPR reduction techniques have been discussed in the literature[9] including Amplitude Clipping (AC),

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Sequence Coding (SC), Tone Reservation (TR), and Multiple Signal Representation (MSR) techniques such as the SeLective Mapping (SLM)[3-5] and Partial Transmit Sequence (PTS) techniques[8,11]. The simplest of PAPR reduction is the AC technique, and is found to cause both in-band and out-of-band distortion. On the other hand, the SC technique could offer excellent performance on PAPR reduction, the cost in complexity and data rate loss makes it unpopular. The TR technique is popular in wired systems due to its low computational complexity, but the increase in the transmit signal power and associated degradation in bandwidth efficiency, makes it undesirable in wireless systems. In the case of the SLM technique, it can achieve excellent PAPR reduction with a high signal processing complexity due to the use of multiple Inverse Fast Fourier Transform (IFFT) operations per OFDM block. Similar to the SLM technique, the PTS technique requires several IFFT operations per OFDM symbol and it produces superior PAPR performance to the SLM technique, it also has a higher complexity requirement and requires more side information bits. Both the SLM and PTS techniques is of intense interest to many researchers who have proposed modifications with the aim to reduce the complexity and improve the performance of these techniques [6,14,15].

To optimize both complexity and PAPR reduction ability with less side information bits per symbol, a PAPR reduction technique is implemented that operates on multiple time-domain OFDM symbols. Similar to the PTS technique, the principal idea of the Adjacent Symbol Combining (ASC) technique is to create several different time-domain representations for each OFDM symbol and transmit the one with the lowest PAPR. However, unlike the PTS technique in which the OFDM symbol is partitioned into several subsets and then each subset is individually IFFT-processed before performing the combinations in the time domain to form multiple time-domain representations, the ASC technique creates various representations by forming linear combinations among adjacent time-domain OFDM symbols. Thus, the ASC technique does not require more than one IFFT process per OFDM symbol while the PTS technique requires U IFFT operations per OFDM symbol, where U is the number of subsets used per OFDM block.

II. System Description

In this section, a brief description of the OFDM scheme as well as a definition of the PAPR problem is presented. At the OFDM transmitter, the information bit stream is first mapped to the symbols according to a certain modulation such as M-ary Phase-Shift Keying (M-PSK) or M-ary Quadrature Amplitude Modulation (M-QAM), to create a vector of complex-valued symbols represented as $X = [X_0, X_1, \ldots, X_{N-1}]$. Each complex symbol then modulates one orthogonal subcarrier and an OFDM signal is formed by summing all the N-modulated independent subcarriers that are of equal bandwidth and have a fixed frequency separation of $\Delta f = 1/NT$, where NT denotes the useful data block period. The mathematical representation of an OFDM time-domain signal, assuming a rectangular time-domain window, is given as

$$x(t) = \sum_{n=0}^{N-1} X_n e^{j2\pi n \Delta f t}, \quad 0 \le t \le NT \qquad (1)$$

The PAPR is computed for the time-domain signal samples [12] as,

$$PAPR(x(t)) = \frac{\max_{0 \le t \le T} |x(t)|^2}{\frac{1}{T} E\left\{ \int_0^T |x(t)|^2 \, dt \right\}} \qquad (2)$$

where x(t) represents the OFDM symbol in time domain, and T is the symbol duration

The Asc Technique

Similar to the SLM and PTS techniques, the ASC technique is also based on a probabilistic approach, and generates different representations for each OFDM symbol and transmits the one with the least PAPR. Unlike the PTS and SLM techniques, the ASC technique only requires one IFFT operation per OFDM block. To generate different representations for each OFDM symbol, the ASC technique exploits the variations between different time-domain OFDM symbols. This is achieved by linearly combining two different time-domain symbols together using various mathematical operations, which include addition, subtraction, and complex-conjugate operations. The ASC mode works on two adjacent time-domain OFDM symbols and their complex conjugates. To clarify the operation of this approach, for two time-domain OFDM symbols, each parent set has four members (symbols or combination of symbols) as shown in Table I. Any two members, the ones which have the lowest PAPR, and are separable at the receiver, are selected for transmission. The parent sets consisting of [x(1)* x(2)*] and [x(1)* x(2)] are not taken into consideration because their members have the same PAPR as those in [x(1) x(2)] and [x(1) x(2)*] respectively. Similarly, not all possible members need to be included in the parent sets when they have the same PAPR as other members already present in the parent set[13].

TABLE I : PARENT SETS AND MEMBER COMBINATIONS

P(1)=[x(1) x(2)]	P(2)=[x(1) x(2)*]
x(1)	x(1)
x(2)	x(2)*
√(1/2)(x(1)+x(2))	√(1/2)(x(1)+x(2)*)
√(1/2)(x(1)-x(2))	√(1/2)(x(1)-x(2)*)

$$PAPR\big(x(t)\big) = \frac{max_{0\le t<T}|x(t)|^2}{\frac{1}{T}E\{\int_0^T |x(t)|^2 dt\}} \qquad (2)$$

Transmitter Structure

Fig.1 shows the block diagram for the ASC based OFDM system [13]. The members of each parent set are viewed as simultaneous equations that are resolved at the receiver using the substitution or elimination methods. However, a more common technique is to use a matrix representation for the combining process. In this case, the combinations are produced using a matrix multiplication between each parent set and a set of combining matrices. Such a way of producing the linear combinations is to make it easier to both encode the side information bits associated with the combinations, which are necessary at the receiver to recover the original symbols, and perform the reverse combining process at the receiver. The members x(1) + x(2) and x(1) are selected, the generation of these members are represented using (3)

$$\left[\sqrt{\frac{1}{2}}(x(1)+x(2))x(1)\right] = [x(1)\ \ x(2)]h(1) \qquad (3)$$

where the combining matrix h(1) can be either as in (4) or (5).

$$h(1) = \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 \\ \frac{1}{\sqrt{2}} & 0 \end{bmatrix} \qquad (4)$$

$$h(1) = \begin{bmatrix} \frac{1}{\sqrt{2}} & 0 \\ \frac{1}{\sqrt{2}} & 1 \end{bmatrix} \qquad (5)$$

Similarly, each possible set of combinations is represented in the form of a matrix multiplication. Each matrix is associated with a unique combination that is represented by the side information bits. It is essential to ensure that only combinations having an invertible combining matrix are considered in the search for the best PAPR signal representations to enable the receiver to reverse the combining process.

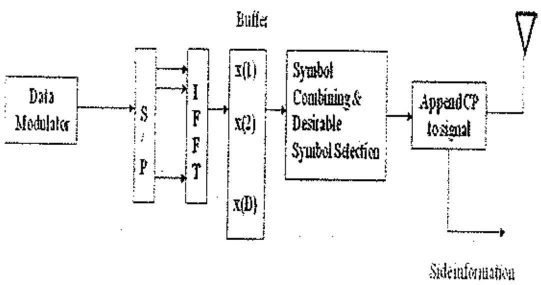

Fig.1. Transmitter Block Diagram with the ASC technique

Receiver Structure

A simpliûed block diagram for the receiver of the ASC approach [13] is shown in Fig. 2. In the case when the selected members belong to parent-sets which contain complex-conjugated OFDM symbols it is necessary to perform the reverse-combining process in the time-domain, but after channel equalization which is usually implemented in the frequency domain. Therefore, after equalizing the received symbols, these symbols are transformed back into time domain in order to recover the original OFDM symbols using the inverse of the same combining matrix applied at the transmitter as identiûed by the Side Information bits. The resolved signals are then transformed back to the frequency domain to complete the detection.

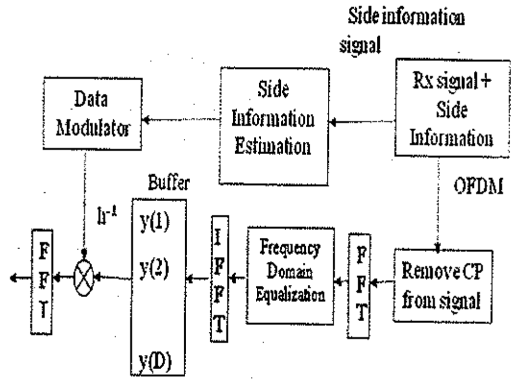

Fig.2. Receiver Block Diagram with the ASC technique

CONVOLUTIONAL ENCODER

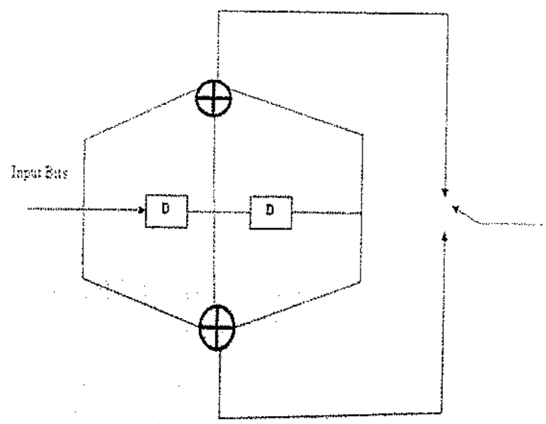

Fig.3. Convolutional Encoder with rate 1/2

Convolutional encoder of rate ½ shown in Fig.3 is used as the channel encoder to encode the generated random bits and a viterbi algorithm is used in the receiver side to decode the received bits.

III. Simulation Results And Discussions

Simulation Parameters

WLAN Specifications

64 Subcarriers

BPSK Modulation

Convolutional Encoder of rate ½,

AWGN Channel

CCDF PLOT

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 a data block exceeds a given threshold. where x(k) is the time domain OFDM symbol and x' represents the threshold value of PAPR.The CCDF plot is plotted using histogram function. The formula for calculating the CCDF is given by (6),

$$CCDF(PAPR(x(k)) = P((PAPR(x(k)) > PAPR_0) \quad (6)$$

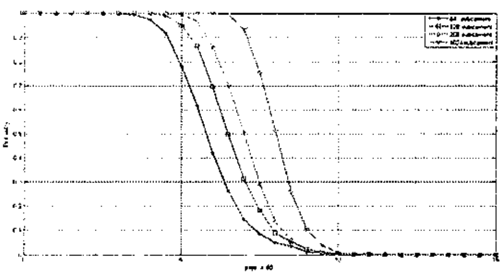

Fig.4. CCDF plot for BPSK-OFDM with different number of subcarriers

The simulated result in Fig.4 shows the CCDF plot for BPSK-OFDM with different number of subcarriers N=64, 128, 256 and 1024. Here the curve shifts towards the right as the number of subcarriers increases. The number of subcarriers varies depending on the application. Hence the PAPR reduction is necessary for any kind of OFDM based application.

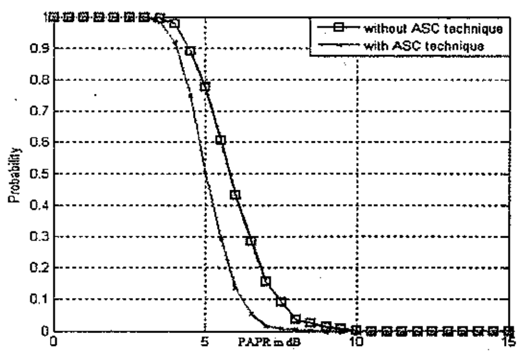

Fig. 5. CCDF plot for OFDM using BPSK Modulation with and without ASC

The simulated result in Fig.5 shows that nearly 2.5 dB reduction in PAPR value is achieved using the ASC technique with much reduced complexity and 3 bits of side information for two adjacent symbols.

The simulated result in Fig.6 shows the reduction in PAPR using the Partial Transmit Sequence technique.

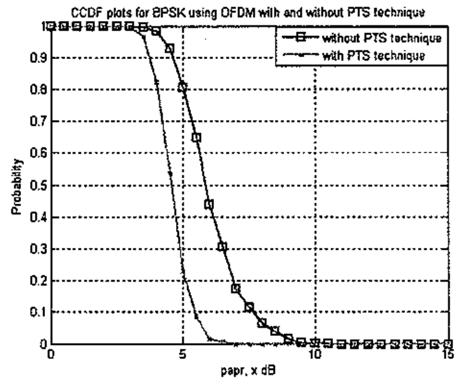

Figure 6 : CCDF plots for OFDM using BPSK Modulation with and without PTS

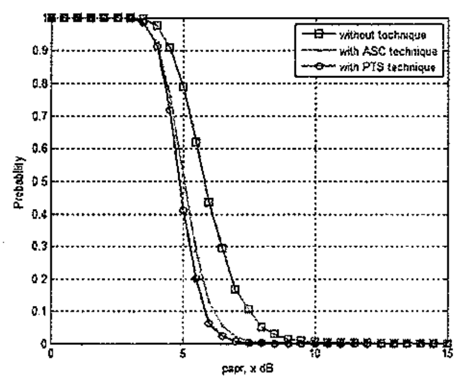

Figure 7 : CCDF Comparison between PTS and ASC technique

From the simulated results in Fig.7, it is concluded that almost same amount of reduction in PAPR value is achieved in both the techniques. But the number of side information bits and complexity is more in the case of PTS technique due to more number of IFFT operations.

Ber Plot For Asc Ofdm Bpsksystem Without Convolutional Encoder

The theoretical BER is calculated using the complementary error function. The simulation results are having a wide variation from the theoretical values for ASC OFDM BPSK modulated signal without convolutional encoder as shown in Fig.8.

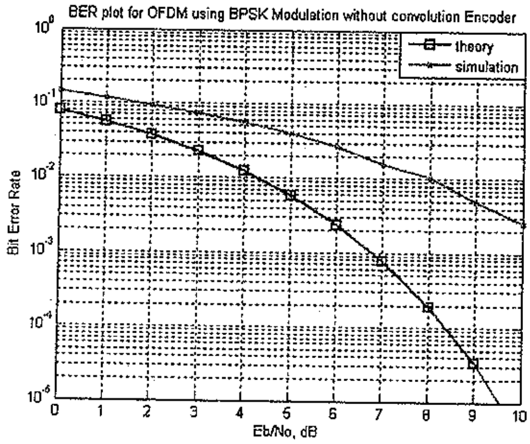

Figure 8 : BER plot for ASC OFDM using BPSK Modulation without Convolutional Encoder

Ber Plot For Asc Ofdm Bpsk System With Convolutional Encoder

The Bit Error Rate of is plotted with the convolution encoder of rate ½. After including the channel encoder, the BER of ASC OFDM BPSK modulated signal with Convolutional encoder is more or less approaching the theoretical value as simulated in Fig.9.

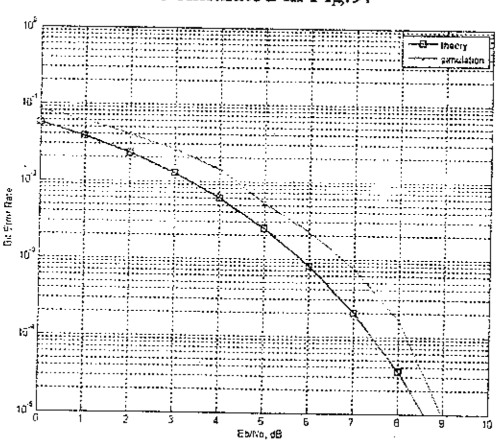

Fig. 9. BER plot for ASC OFDM BPSK Modulation with Convolutional encoder

The power spectral density of the OFDM signal is estimated using the Welch's averaged modified periodogram method of spectral estimation.

The simulated results in Fig.10 shows that the spectrum does not have any inband or out of band radiation in ASC OFDM BPSK system.

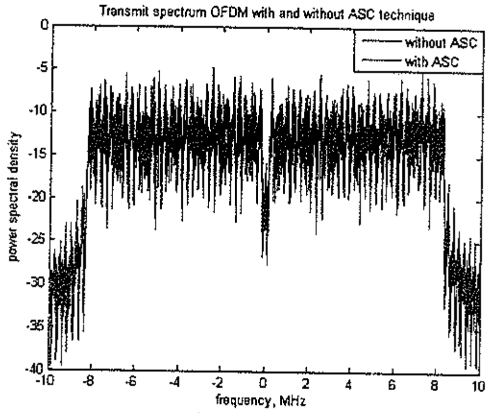

Figure 10 : Transmit spectrum of OFDM with and without ASC technique.

IV. Conclusion

The time-domain symbol combining PAPR reduction technique for Wireless LAN environment implemented in this paper is shown to provide excellent PAPR reductions and at lower complexities, especially in terms of the number of multiplications, when compared to the powerful PTS technique. Similar to the conventional SLM and PTS techniques, the correct detection of the received data blocks is dependent on correctly estimating the side information bits necessary for reversing the randomization process. This drawback is overcome by protecting the side information bits through the use of FEC coding such that the BER of these bits is extremely small. But in this technique only three bits of side information is required for two adjacent symbols. Also, similar to the SLM and PTS techniques, the ASC technique requires processing at the receiver side. While the SLM and PTS techniques require to reverse the randomization process take place at the transmitter and it requires an extra IFFT process to reverse the combining process. Finally, unlike the SLM, PTS, and TR techniques, the ASC technique entails some latency at the receiver due to requiring the availability of all symbols involved to reverse the combining process. Such latency is not a problem for communication systems, which use interleaving. The results provided by the PSDF, BER, and PAPR CCDF figures are used collectively as a guide to provide the best operational parameters for ASC depending on the application under consideration.

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