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Full Length Research Paper

Analyzing the effects of peak to average power ratio and digital predistortion in orthogonal frequency division multiplexing (OFDM) systems

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Dummy sequence insertion (DSI) and partial transmit sequence (PTS) are two existing distortionless peak to average power ratio (PAPR) reduction techniques that have been proposed for orthogonal frequency division multiplexing (OFDM) systems. Both DSI and PTS have drawbacks. In DSI, increasing the number of dummy sequence decreases the transmission efficiency (TE) and in PTS, the complexity increases when the number of subblock increases. The DSI-PTS scheme has less complexity while the PAPR reduction is even better than PTS and DSI. Simulation and results are presented for IEEE 802.16-2004 standard. The Saleh model power amplifier is applied to show the effects of output spectrum in OFDM systems.

Key words: Dummy sequence insertion (DSI), partial transmit sequence (PTS), orthogonal frequency division multiplexing (OFDM), worldwide interoperability for microwave access (WiMAX), peak to average power ratio (PAPR).

INTRODCUTION

An orthogonal frequency division multiplexing (OFDM) system has been proposed as a standard for the mobile communication systems. Despite the advantages of OFDM signals like high spectral efficiency and robustness against ISI, the OFDM signals have some disadvantages which the main one is the high peak to average power ratio (PAPR) (Han and Lee, 2005; Jiang and Wu, 2008; Higanishaka et al., 2009). The reason of high PAPR is that in the time domain, the OFDM signal is actually sum of many narrowband signals. At some time instances, the sum of these narrowband signals may be large and at the other time may be small, which means that the peak of the signal is much larger than the average value. This high PAPR signal when transmitted through a nonlinear power amplifier creates spectral broadening and also an increase in the dynamic range of the digital to analog converter (DAC). The result will be an increase in the cost of the system and reduction in efficiency. Hence, the technique to overcome this problem in OFDM systems is necessary. In this paper, a new scheme is introduced to enhance the PAPR performance in OFDM systems. In simulations, fixed WiMAX (Worldwide Interoperability for Microwave Access) signal based on IEEE 802.16-2004 standard is applied for demonstrating the effectiveness of the proposed scheme.

RELATED WORKS

To overcome the PAPR problem of OFDM systems, several techniques for reducing the PAPR have been proposed. Some of the most important techniques are selected mapping (SLM) (Buml et al., 1996; Li et al., 2010; Wen et al., 2009) and DSI (Ryu et al., 2004) which are in frequency domain and PTS (Müller and Huber, 1997; Park and Song, 2007; Chen, 2010; Ku et al., 2010; Hou et al., 2010) which is in the time domain. Here the

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PAPR scheme called DSI-PTS that is the combination of DSI and PTS is proposed (Varahram et al., 2010). This scheme is called based on the order of the implementation in the system. PTS technique use iterative routine similar to the trial-and-error method for finding the optimum phase factors that leads to lower PAPR. It is distortionless but is time-consuming, and needs large number of computations (Ku et al., 2010; Hou et al., 2010). In DSI, the main issue is the transmission efficiency which reduces when the number of dummy signal increases and the processing time is high. In this paper, by applying the DSI-PTS scheme, not only the PAPR is reduced but also the complexity and processing time are decreased. The DSI-PTS scheme is further combined with the digital predistortion (DPD) to enhance the efficiency of the system (Mohammady et al., 2010; Varahram et al., 2009).

CONVENTIONAL OFDM SCHEME

In OFDM systems, initially the input data samples are mapped onto phase shift keying (PSK) or quadrature amplitude modulation (QAM), and then using IFFT at the transmitter side and FFT at receiver, they will be converted to time domain and frequency domain, respectively. IFFT is used to produce orthogonal data subcarriers. The N point IFFT can be defined as (Han and Lee, 2005):

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi \frac{n}{N} k}, \quad n = 0,1,2,.......,N-1 \tag{1}$$

where x_n is the n-th signal component in OFDM output symbol, X_k is the k-th data modulated symbol in OFDM frequency domain, and N is the number of subcarriers.

The PAPR (in dB) of the transmitted OFDM signal can be defined as (Jiang and Wu, 2008):

$$PAPR = \frac{(\max(|x_n|^2)}{E\left[|x_n|^2\right]} \tag{2}$$

where $E[.]$ is the expected value operator. The theoretical maximum of the PAPR for N number of subcarriers is as follows:

$$PAPR_{\max} = 10\log(N) \ \ dB \tag{3}$$

In this paper, the memoryless nonlinear power amplifier, Saleh model (Kenington, 2000) is applied. The AM/AM and AM/PM characteristics of the Saleh model are defined as:

$$Z[a(t)] = Z^2{}_{sat} \frac{a(t)}{a(t)^2 + Z^2{}_{sat}} \tag{4}$$

$$\phi[a(t)] = \frac{\pi}{6} \frac{a(t)}{a(t)^2 + Z^2{}_{sat}} \tag{5}$$

where a(t) is the absolute of the input signal, Z_{sat} represents the amplifier input saturation voltage and Z(a) and $\phi(a)$ are AM/AM and AM/PM of the power amplifier, respectively.

The method called digital predistortion (DPD) (Varahram et al., 2009) can be applied to further compensate the nonlinearity of the power amplifier and enhance the efficiency of the system.

PROPOSED DSI-PTS SCHEME

In Figure 1, the block diagram of the proposed scheme for PAPR reduction in OFDM system is shown. From this figure, the complex valued dummy signals are first generated and then added to the vector of data subcarriers. The new vector in the frequency domain is then constructed from K-data and L-dummy subcarriers, respectively. L can be any number less than K. The new vector S is given by:

$$S = \left[X_k, W_L\right] \tag{6}$$

where $X_k = [X_{k,0}, X_{k,1},..., X_{k,N-L-1}], k = 1,2,...,K$ is the data subcarrier vector and $W_l = [W_{l,0}, W_{l,1},..., W_{l,L-1}], l = 1,2,...,L$ is the dummy signals vector.

After the generation of the optimum OFDM signal, the PAPR will be checked with the pre-defined threshold. If the PAPR value is less than the threshold then the OFDM signal will be transmitted otherwise the dummy sequence is generated again which is shown with the feedback in Figure 1. The whole process is one iteration. The number of iterations can be increased to achieve the desired PAPR ($PAPR_{th}$) reduction but the processing time will also increase.

For explaining the DSI-PTS scheme, consider L as the dummy sequence length which $L \leq 55$ and N is the IFFT length that is 256 in the case of fixed WiMAX (Worldwide Interoperability for Microwave Access) which includes 192 data carriers, 8 pilots and 55 zero padding and 1 dc subcarrier.

From the block diagram in Figure 1, X is the input signal with length N. After that, dummy sequence is added. The dummy sequence can be replaced with zeros

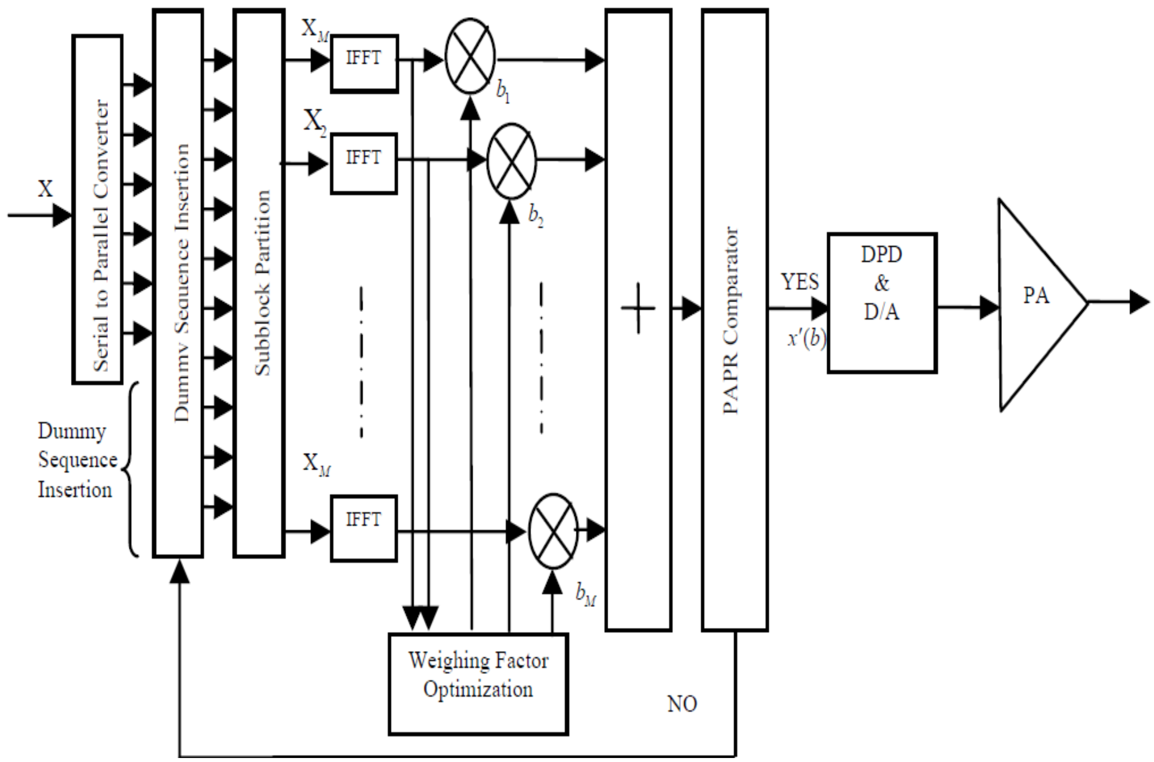

Figure 1. Block diagram of the DSI-PTS scheme with PA.

in the WiMAX (Worldwide Interoperability for Microwave Access) signal samples. Now the signal is partitioned into M disjoint block $S_m = [S_1, S_2, ..., S_M]$ such that $\sum_{m=1}^{M} S_m = S$ and then these subblocks should be combined to minimize the PAPR in the time domain. After doing the IFFT, the phase factors $b_m = e^{j\phi_m}, m = 1, 2, ..., M$ are then used for optimizing the S_m.

In the time domain, the OFDM signal can be expressed as:

$$s'(b) = \sum_{m=1}^{M} b_m s_m \quad (7)$$

where $s'(b) = [s'_0(b), s'_1(b), ...s'_{N-1}(b)]^T$.

The objective is to find the optimum signal $s'(b)$ with the lowest PAPR. We should note that here $N = K + L$ which means that there is no change in the length of input signal after the addition of dummy sequence.

Then, the process is performed by choosing the optimization parameter $\tilde{b}$ with the following condition:

$$\tilde{b} = \arg\min\left(\max_{0 \le k \le NF-1} \left| \sum_{m=1}^{M} b_m s_{m,k} \right| \right) \quad (8)$$

After finding the optimum, $\tilde{b}$, the optimum signal $s'(b)$ is then transmitted to the next block. In (8), F is the oversampling factor which normally has the value of four. Now the PAPR of $s'(b)$ is checked whether it is in the range of the threshold PAPR ($PAPR_{th}$). After this additional task, the signal is transmitted otherwise it is returned to the DSI block to generate the dummy sequence again. This process will continue until the PAPR is less than the $PAPR_{th}$.

RESULTS AND DISCUSSIONS

To evaluate and compare the performance of the DSI-PTS with the conventional PTS and DSI, Matlab simulation has been performed where the OFDM signal is WiMAX based on IEEE 802.16-2004 standards with QPSK modulation and oversampling factor $F = 4$. To obtain the complementary cumulative distribution function (CCDF), 10^4 random OFDM symbols are generated. The oversampling factor is assumed to be 4 because of the calculation of the accurate PAPR. The main parameters

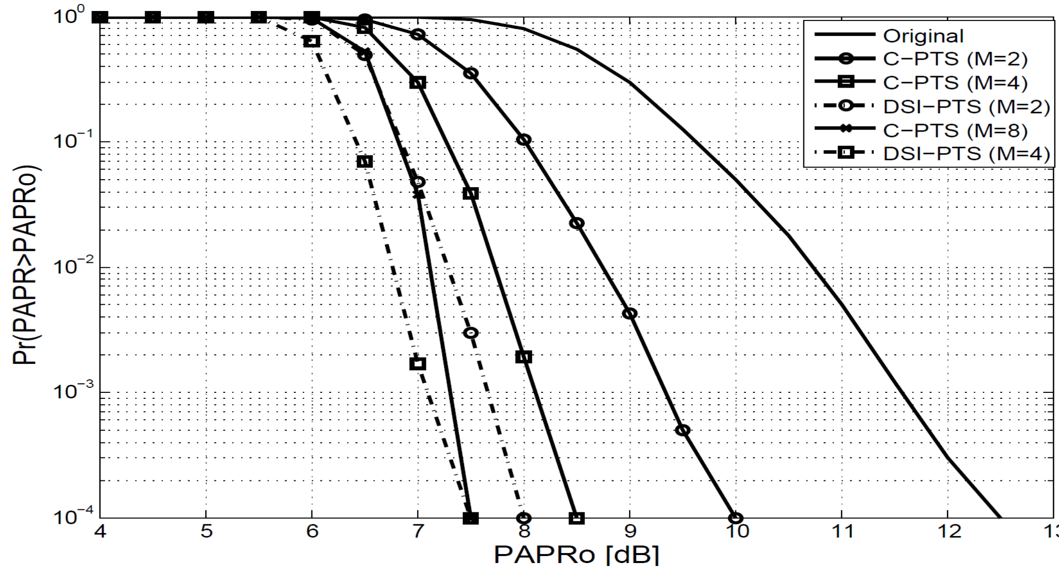

Figure 2. CCDF of the PAPR of conventional PTS and DSI-PTS technique when the number of DSI is 55 and the number of iteration is 10.

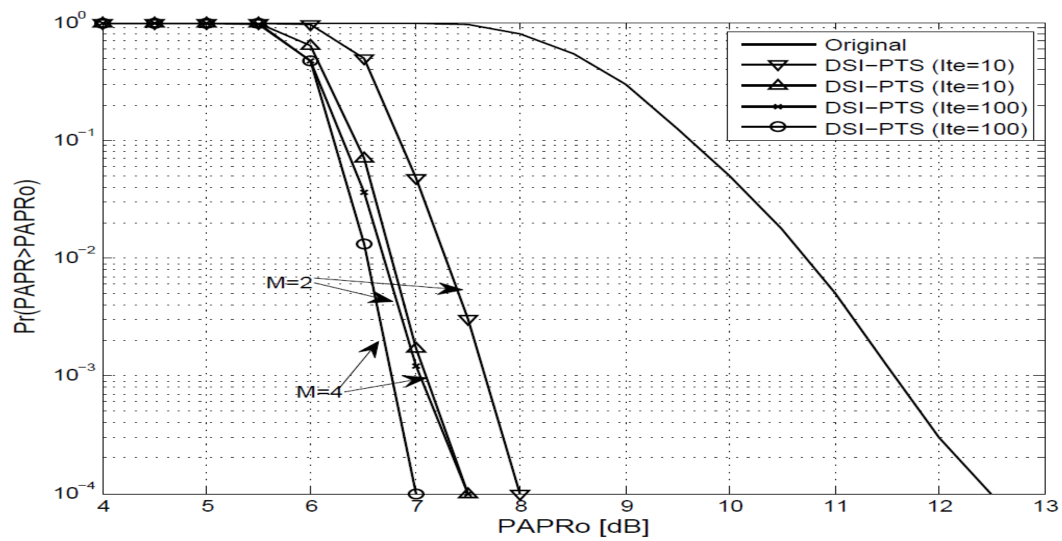

Figure 3. CCDF of PAPR of DSI-PTS technique for different number of iteration when number of dummy sequence is 55.

that should be optimized in the simulations are number of dummy signals, iteration numbers and number of subblocks partitioning.

Figure 2 shows the CCDF of conventional PTS and DSI-PTS scheme. It is assumed here that the number of dummy sequence insertion ($NDSI$) is 55 which has no significant effect on the transmission efficiency ($\mathrm{TE} = 100\%$). The result of this figure is for 10 iterations in DSI loop. The number of iteration is flexible and there is a trade off between the data rate loss and PAPR performance. While the higher number of iterations increase the PAPR performance but as the same time cause the data rate loss. Hence here we choose the number of iterations to be 10 which can create the good PAPR performance. According to this figure, the PAPR when DSI-PTS scheme is applied is 7.5 dB when $M = 4$ and this value is 8 dB when $M = 2$ at $\mathrm{CCDF} = 0.01\%$. It can be observed that the PAPR reduction for our proposed PTS scheme outperforms the conventional PTS scheme with an improvement of 2 and 1 dB at $\mathrm{CCDF} = 0.01\%$, when $M = 2,4$ respectively.

Figure 3 shows the effect of different iteration number on the PAPR performance. From this figure, the maximum PAPR reduction is achieved which is 7 dB at

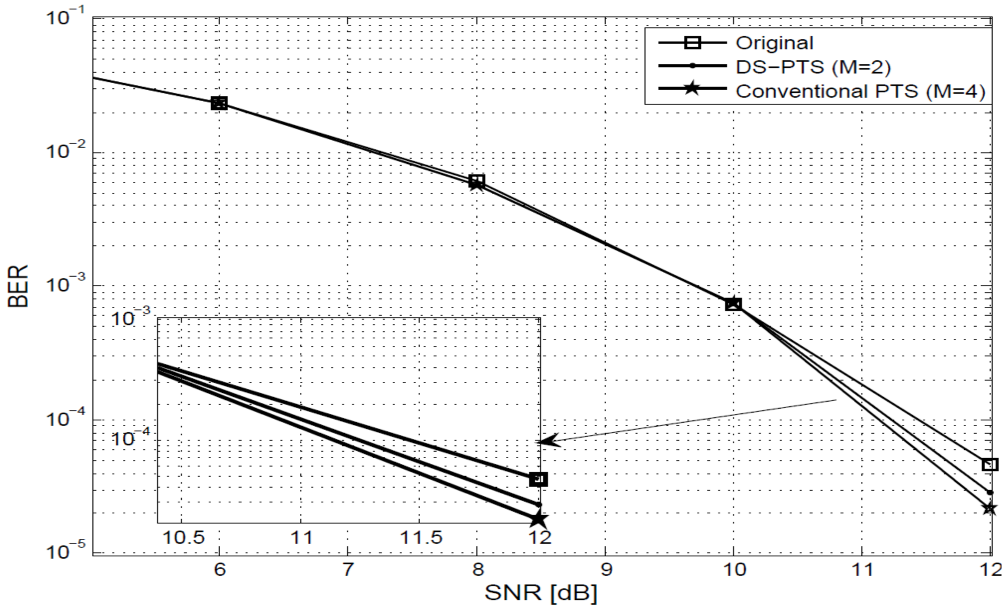

Figure 4. Comparison of BER performance of the conventional PTS and DSI-PTS technique in AWGN channels.

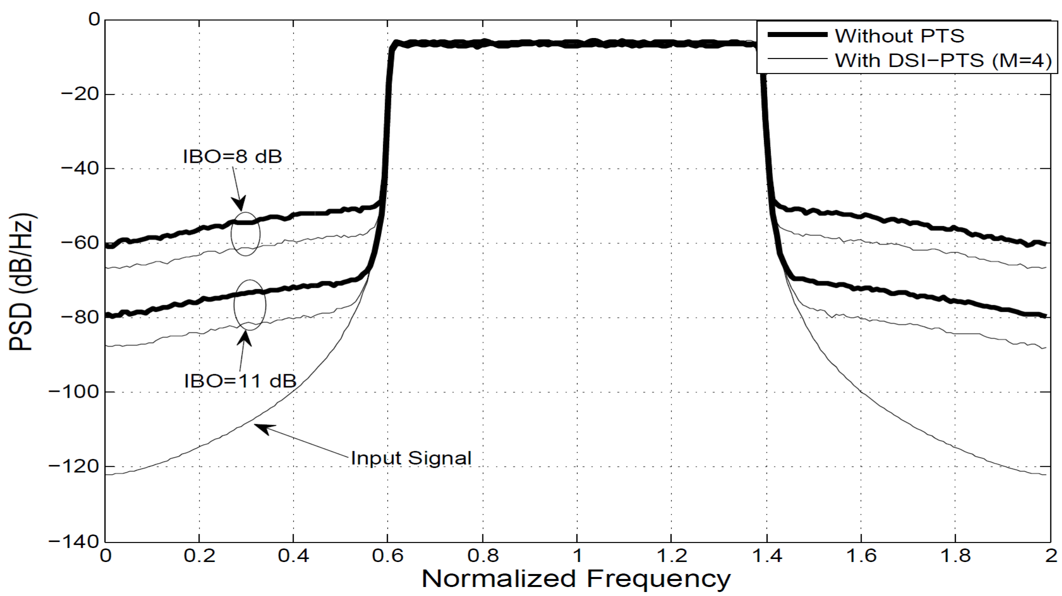

Figure 5. PSD of the Saleh model power amplifier with DSI-PTS for different (IBO)

$\text{CCDF} = 0.01\%$, when 100 iteration is applied with $\text{NDSI} = 55$ and $M = 4$, But increasing the number of iterations will decrease the processing time. There is about 0.5 dB improvement when the number of iteration is 100 compared to 10 iteration for both cases of $M = 2, 4$ as it is shown in this Figure 4. The figure shows a comparison of bit error rate (BER) performance of the conventional PTS and the proposed DSI-PTS scheme in additive white Gaussian noise (AWGN) channels. The number of dummy sequence and iterations are 55 and 10, respectively. From this figure, we can see that the BER is slightly increased when DSI-PTS scheme is applied compared to conventional PTS, but PAPR is much improved according to the result of Figure 2. The performance of system shows improvement at the cost of BER.

Figure 5 shows the power spectral density (PSD) of the Saleh model power amplifier which is considered as memoryless. The PSD is shown for different input back off (IBO). The distortion in output spectrum is more when the IBO has less value, because the PA works in the nonlinearity region close to the saturation point. By considering the IBO = 8 dB, the signal with PAPR reduction is applied to the PA.

Conclusion

A new group of distortionless PAPR reduction method based on a combination of DSI and PTS has been proposed in this paper. In this scheme, the dummy sequences are added to the OFDM signal and after that, the PTS will be performed. By applying the DSI-PTS scheme, the number of division and hence the number of IFFT will be reduced which results in less complexity compared to conventional PTS while better PAPR reduction is achieved. The application of the proposed DSI-PTS scheme will be useful in WiMAX applications.

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