Clipping and Inter-modulation Noise Mitigation Method for OFDM Systems

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ABSTRACT

One of the disadvantages of using OFDM is its larger peak to averaged power ratio (PAPR) as compared with the conventional single carrier transmission method. The OFDM signal with larger PAPR will cause the undesirable spectrum re-growth and the larger degradation of bit error rate performance due to the inter-modulation products occurring in the non-linear amplifier at the transmitter. The clipping method in conjunction with the Decision Aided Reconstruction (DAR) method is well known as one of the solutions to improve the PAPR of OFDM signal and provide the better BER performance. In this paper, we propose the Improved DAR (IDAR) method in which the clipping noise and inter-modulation noise due to the non-linear amplifier are mitigated on the basis of DAR method. The proposed method enables the efficient usage of transmission amplifier with keeping the lower PAPR and better BER performance. This paper presents various computer simulation results to verify the performance of proposed IDAR method in the non-linear channel and multi-path fading channel.

Keywords: PAPR, SSPA, Clipping, DAR and IDAR.

1. INTRODUCTIONS

The OFDM technique has been received a lot of attentions especially in the field of wireless communications because of its efficient usage of frequency bandwidth and robustness to the multi-path fading. From these advantages, the OFDM has already been adopted as the standard transmission technique in the wireless LAN systems and the terrestrial digital broadcasting system [1-3]. The OFDM is also considering as one of the candidate transmission techniques for the next generation of mobile communications systems. One of the disadvantages of using the OFDM signal is that its time domain signal has the larger peak to averaged power ratio (PAPR) as compared with the conventional single carrier modulation method [4]. The larger PAPR would cause the un-desirable spectrum re-growth and the degradation of bit error rate (BER) performance both from the inter-modulation products occurring in the non-linear amplifier at the transmitter. To overcome this problem, a clipping method is often used to improve the PAPR performance of OFDM signal. Although this method can reduce the PAPR performance relatively, the BER performance would be degraded at the receiver due to the clipping noise. To solve this problem, the decision-aided reconstruction (DAR) method was proposed in [5-6]. The DAR method can improve the BER performance considerably by reconstructing the clipping noise from the decision data and subtracting it from the received signal. However the DAR method proposed in [5-6] can only compensate the clipping noise and not for the inter-modulation noise due to the non-linear amplifier.

In this paper, we propose the improved DAR (IDAR) method in which the inter-modulation noise due to the non-linear amplifier as well as the clipping noise is mitigated on the basis of DAR method. The salient feature of proposed method is to enable the efficient usage of non-linear amplifier at the transmitter. In the following of this paper, Section 2 presents the system model of using OFDM technique and Section 3 presents the proposed IDAR method. Section 4 presents the various computer simulation results to verify the performance of proposed method, and we draw some conclusions in Section 5.

2. OFDM SYSTEM MODEL

Fig. 1 shows the structure of transmitter. In the figure, the modulated signal X_n at the n-th sub-carrier frequency is converted to the time domain signal x_k by performing IFFT. The time domain signal is given by the following equation.

\[ x_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j2\pi kn} \]  

where N is the number of IFFT points. The amplitude of time domain signal x_k after adding the guard interval (GI) is clipped by the following operation to reduce the PAPR.

\[ y_k = \begin{cases} x_k & |x_k| \leq A \\ A e^{\frac{|x_k|}{A}} & |x_k| > A \end{cases} \]  

where y_k is the clipped signal and A is the clipping amplitude. In this paper, the clipping level (CL) is defined by the following equation.
where, $Es$ is the averaged power of transmitted signal. Since the clipping is the non-linear operation, the clipping noise would fall both in-band and out-of-band which cause the un-desirable spectrum re-growth and degradation of BER performance, respectively. The out-of-band clipping noise can be reduced by the pre-filter before inputing the non-linear amplifier as shown in Fig.1. The non-linear operation of amplifier can be expressed by the following equation.

$$s_k = F\left[\left|z_k\right|e^{j\left[\arg\left|z_k\right|\Phi\left|z_k\right|\right]}\right] \tag{4}$$

where, $z_k$ is the time domain signal after passing the pre-filter, $F[\ ]$ and $\Phi[\ ]$ represent the AM/AM and AM/PM conversion characteristics of non-linear amplifier. The transmission signal at the output of amplifier includes the clipping noise fallen in-band and the inter-modulation noise due to the non-linear amplifier both of which lead to the degradation of BER performance at the receiver.

The received time domain signal given by Eq.(5) is

$$r_k = s_k \otimes h_k + w_k \tag{5}$$

where, $h_k$ is the channel response of multi-path fading and $w_k$ is the additive white Gaussian noise (AWGN). The received time domain signal given by Eq.(5) is converted to the frequency domain signal by FFT. The frequency domain signal is first equalized by using the estimated channel frequency response. The equalized signal including the clipping noise, inter-modulation noise and AWGN can be expressed by the following equation.

$$R_n = X_n + C_n + P_n + W_n \tag{6}$$

where $X_n$, $C_n$, $P_n$ and $W_n$ are the transmitted signal, clipping noise, inter-modulation noise and AWGN all in the frequency domain, respectively. By using Eq.(6), the decisions for the information data are made for all sub-carriers on the basis of the following equation.

$$\hat{X}_n = \min \left|R_n - X_n\right| \tag{7}$$

The decision data in the frequency domain is converted to the time domain signal $\hat{x}_k$ by IFFT and the same operations of clipping given in Eq.(2) as performed at the transmitter is made for the time domain signal as shown in Fig.2. After this operation, the time domain signal including the clipping noise can be reconstructed by the following equations.

$$\hat{y}_k = \begin{cases} \hat{x}_k, & \left|\hat{x}_k\right| \leq A \\ Ae^{j\arg(\hat{x}_k)}, & \left|\hat{x}_k\right| > A \end{cases} \tag{8}$$

The time domain signal given in Eq.(8) is also processed by the pre-filter of which response is the same as that in Fig.1 and by the same operation of non-linear amplifier given by Eq.(4) as performed at the transmitter. After these operations, the time domain signal including the clipping noise, band-limiting noise of pre-filter and inter-modulation noise can be reconstructed by the following equations.

$$\tilde{s}_k = F\left[\left|z_k\right|e^{j\left[\arg\left|z_k\right|\Phi\left|z_k\right|\right]}\right] \tag{9}$$

where, $\tilde{z}_k$ is the time domain signal after processing the pre-filter. Here, the clipping amplitude $A$, and the AM/AM and AM/PM conversion characteristics given by $F[\ ]$ and $\Phi[\ ]$ all of which are used at the transmitter are assumed to be known at the receiver. By using Eq.(9), the error signal consisting of the clipping noise, band-limiting noise and inter-modulation noise incurred at the transmitter can be estimated by the following equation.

$$\hat{e}_k = \hat{x}_k - \tilde{s}_k \tag{10}$$

The error signal given by Eq.(10) is then converted to the frequency domain signal as given by the following equation.

$$\hat{E}_n = \hat{C}_n + \hat{P}_n + \hat{W}_n \tag{11}$$

By subtracting Eq.(11) from Eq.(6), the frequency domain signal coped with both the clipping noise and inter-modulation noise can be obtained by the following equation.

$$CL(dB) = 10\log\left(\frac{A^2}{E_s}\right) \tag{3}$$


\[
\hat{R}_n = R_n - \hat{E}_n = X_n + (C_n - \tilde{C}_n) + (P_n - \tilde{P}_n) + W_n \quad (12)
\]

The decisions for the information data are made again for Eq.(12) by using Eq.(7). By repeating the above procedures, the better BER performance could be achieved. The required number of iteration to achieve the best BER performance is evaluated in the following section.

The proposed IDAR method on the basis of above procedures could provide the better BER performance with the lower PAPR performance, even when the non-linear amplifier is operated at the near saturation region.

**Fig.2:** Structure of receiver with proposed IDAR method

**3. PERFORMANCE EVALUATION**

This section presents the various computer simulation results to demonstrate the performance of proposed IDAR method in the non-linear channel and multi-path fading channel. Table 1 shows the list of simulation parameters used in the following computer simulations. The modulation method is 16QAM and its demodulation method is the coherent detection with the frequency domain equalization method. Two paths model defined by D/U is used as the multi-path fading. The model of amplifier is assumed by the Solid State Power Amplifier (SSPA) of which input and output characteristics of AM/AM is given by the following equation.

\[
F[p] = \frac{\rho}{[1+(\rho/A)^{2\varphi}]}^{1/2p} \quad (13)
\]

where, \( \rho \) is the amplitude of input signal, \( A \) is the saturated output level, and \( p \) is the parameter to decide the non-linear level.

**Table 1: Simulation parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulation</td>
<td>16QAM</td>
</tr>
<tr>
<td>Demodulation</td>
<td>Coherent</td>
</tr>
<tr>
<td>Allocated bandwidth</td>
<td>5MHz</td>
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<tr>
<td>Type of Pre-Filter</td>
<td>8th order Butterworth</td>
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<td>Pre-Filter 3dB bandwidth</td>
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<tr>
<td>Number of FFT points</td>
<td>512</td>
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<tr>
<td>Number of sub-carriers</td>
<td>128</td>
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<tr>
<td>Symbol duration</td>
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<tr>
<td>Guard interval</td>
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</tr>
<tr>
<td>Non-linear amplifier</td>
<td>SSPA</td>
</tr>
<tr>
<td>2-Path Fading Model</td>
<td>DU=10 dB</td>
</tr>
</tbody>
</table>

**Fig.3:** PAPR performance

**Fig.4:** BER performance vs. iteration numbers under AWGN channel.
Fig. 5 shows the BER performance versus C/N for the conventional DAR and the proposed IDAR methods when the iteration times is 3 and IBO is 2dB. In the figure, BER performances are shown when changing CL is 2dB, 4dB, 6dB and 8dB. From the figure, it can be observed that the proposed IDAR method can achieve much better BER performance than that for the conventional DAR method even when the non-linear amplifier is operated at almost the saturation region of IBO = -2dB.

From the computer simulation results, it can be concluded that the proposed IDAR method can achieve the efficient usage of non-linear amplifier with the better BER performance and lower PAPR.

Fig. 7: BER performance in non-linear channel under multi-path channel.

5. CONCLUSION

This paper proposed the improved DAR method which can improve the BER performance even when the non-linear amplifier is operated at the saturation region. The salient feature of the proposed method is to mitigate both the inter-modulation noise and the clipping noise on the basis of DAR method. This paper presented various computer simulation results on the performance of proposed method and demonstrated that the proposed method enables the efficient usage of non-linear amplifier with the better BER performance and lower PAPR.

6. REFERENCES