PAPR Reduction in NC-OFDM/OQAM System using Nonlinear Companding Transform

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Since the inherent higher Peak-to-Average Power Ratio (PAPR) in Non-Continuous Orthogonal Frequency Division Multiplexing with Offset Quadrature Amplitude Modulation (NC-OFDM/OQAM) is higher than that of conventional NC-OFDM systems, a novel continuous and differentiable nonlinear companding scheme is investigated and analyzed when employing the conventional companding transforms. By making full use of the characteristic of the Gaussian-distributed original signals and employing a truncation to the distribution function of the original signals, the companded signals can be restricted in a specific region which consistent with the distribution of original signals. Therefore, the companded signals cannot only achieve an improved PAPR and Bit Error Ratio (BER) performance but also maintain the statistical characteristics of the original signals. Theoretical analysis and simulation results demonstrate that the proposed scheme substantially outperforms the conventional nonlinear companding schemes.

Keywords: NC-OFDM/OQAM system, Peak-to-Average Power Ratio (PAPR), Bit Error Rate (BER)

Introduction

Orthogonal Frequency Division Multiplexing with Offset Quadrature Amplitude modulation (OFDM/OQAM) has drawn significant attention recently, because of its low, narrow band interference, sidelobe, and high spectrum efficiency. The wireless transmission based on NC-OFDM/OQAM is a viable technology for Cognitive Radio (CR) transceivers operating in Dynamic Spectrum Access (DSA) networks. However, in spite of many advantages, NC-OFDM/OQAM based CR system still suffers from the problem of the high PAPR of the transmitted NC-OFDM/OQAM signals of the Secondary User (SU) frequency band. As the signal structure of NC-OFDM/OQAM system entirely differs from OFDM/OQAM system, therefore the classical PAPR reduction algorithms cannot be directly applied to the NC-OFDM/OQAM system. At present, the PAPR techniques in Multicarrier systems can be divided into 2 categories, the transform method in frequency domain and time domain transformation. Time-domain transform method after the FFT processing is of typical clipping, and filtering. Compressing transform has broad applicability, but because of its improved system loss of BER performance often accompanies PAPR, it is shown how to efficiently reduce the PAPR system while maintaining a lower bit error rate becomes a severe problem of nonlinear companding transform. Aiming at the above problem, in this paper a new PAPR suppression using nonlinear companding algorithm is proposed for NC-OFDM/OQAM signals.

NC-OFDM/OQAM system model and PAPR problem

The NC-OFDM/OQAM system transmits the data symbols on a plurality of parallel orthogonal subchannels, but unlike conventional NC-OFDM/OQAM and pulse forming OFDM/OQAM, the transmission time of symbols on each subchannel is not entirely symmetrical. In general, the transmission of symbols on the subchannel will be shifted by one symbol period and Figure 1 shows a typical NC-OFDM/OQAM system principle. From the equivalent baseband signal containing N subcarrier, the corresponding NC-OFDM/OQAM signal can be achieved through the FFT, and then the output of the NC-OFDM/OQAM signal can be expressed as

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Where \( N \) is the number of subchannels and \( M \) is the symbol period. The spectrum utilization of the system is the forming filter with length \( L_g \), \( X_{k,i} \) is the data to be transmitted.

In this work, the complementary cumulative distribution function (CCDF) is used to describe the statistical distribution characteristics of the PAPR of the system. It indicates that the peak-to-average ratio of the signal exceeds the probability of a specific threshold which is given as \( \text{PAPR}_0 \).

Accordingly the expression for computing the PAPR is given as

\[
x(n) = \sum_{k=0}^{N/2-1} \sum_{l=0}^{L_g-1} \frac{\varphi_{\alpha}(n-kM)}{\alpha} \varphi_{\alpha}(n-kM)
\]

\[
+ \sum_{k=0}^{N/2-1} \sum_{l=0}^{L_g-1} \frac{\varphi_{\alpha}(n-(k+1/2)M)}{\alpha} \varphi_{\alpha}(n-(k+1/2)M)
\]

... (1)

Where \( N \) is the number of subchannels and \( M \) is the symbol period. The spectrum utilization of the system is \( \rho = \frac{N}{M} \), \( \varphi(n), n \in [0, L_g - 1] \) the forming filter with length \( L_g \), \( X_{k,i} \) is the data to be transmitted.

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\[
PAPR = 10 \log_{10} \frac{\max_{n} \left| \frac{E[x_{n}]^2}{E[|x_{n}|^2]} \right|}{\left| \frac{E[|x_{n}|^2]}{E[|x_{n}|^2]} \right|} \text{dB}
\]

Where \( | \cdot | \) represents the amplitude of the signal, \( E[\cdot] \) indicates the expected, \( L \) is the Oversampling factor.

The Algorithm design

Let \( h(\cdot) \) denote the basic companding transform function, which only changes the amplitude of the input signal without changing its phase value. \( x_n \) is the original NC-OFDM/OQAM signal, \( y_n \) is the signal which is given as \( h(x_n) \).

In order to maintain the average power of the signal before and after the companding transformation, the adjusted scalar function \( h(x) \) is

\[
h(x) = sgn(x)\alpha F^{-1}_{|x|}(F_{|x|}(x))
\]

... (2)

Here \( F \) is the compression function and \( F^{-1} \) is the decompression function. Where \( \alpha \) is the power compensation co-efficient.

\[
\alpha = \frac{E[|x_n|^2]}{E[|x_n|^2]} \left[ -\ln \left( 1 - \frac{1}{\beta} \left[ 1 - \exp \left( -\frac{x_n^2}{\sigma^2} \right) \right] \right) \right]^{1/2}
\]

... (3)

It can be seen from the analysis, \( \alpha \) is a fixed parameter.

Performance analysis and simulation experiments

In the simulation process, the number of subcarriers in the system is \( N=64 \), and each simulation uses independent data symbols. The modulation mode is QAM, simulated with AWGN channel model. For ease of analysis, the system signal is not encoded. In the simulation process, the spectrum utilization of the system is considered as \( \rho = 0.8 \), and the oversampling factor is taken as \( L=4 \). In addition, several typical nonlinear companding algorithms are compared in the simulation, which are: \( \mu \)-law \( (\mu=3) \), EC (companding depth \( d=1 \)), and the PC \( (c=0.25, k_2 =0.45) \). In the simulation process several typical values of the companding parameters are given, i.e., 1.4, 1.6, 1.8 and 2.2. Here, mainly the performance of the system is analyzed and compared. All the simulations are performed using MATLAB 2012 ® on Intel i3 processor. Figure 2 shows the PAPR suppression performance of different companding algorithms with QAM modulation for the system. It can be seen from Figure 2 that, as mentioned earlier, the probability distribution of the proposed algorithm
is more close to that of EC, PC and the original signal, for larger values of parameter $\lambda$. The distribution of signal is more consistent, when the value of $\lambda$ is small, the distribution of the signal after companding is more concentrated than EC and PC. Figure 3 shows the BER performance comparison curves of different companding algorithms using 16QAM in AWGN channel. Here, taking into account the power expansion at the cost of BER loss, so the PAPR and BER performance is usually considered to be more appropriate. It can be seen from Figure 2 that the PAPR performance of this algorithm is better than EC by 0.5 dB under the condition of $10^{-3}$ CCDF. As can be seen from Figure 3 use of 16QAM modulation when the advantages of this algorithm is still obvious. It can be seen that the PAPR and BER performance of the algorithm proposed in this paper are superior to other companding algorithms in AWGN channel condition and different modulation mode. Since companding transform often amplifies interference signal, the receiver can obtain better performance even though decompression is not possible and is given by simulations. It can be seen from the figure 3 that when the decompression is carried out, the algorithm is better than other algorithms. The error performance of the system is not improved when the receiving end is not decompressed, and the error performance advantage of the algorithm is still obvious.

**Conclusion**

In this paper, we mainly study and analyze a new second-order smooth continuous derivative nonlinear expansion and compression algorithm. The algorithm is based on the progressive Gaussian distribution of the original signal, and the amplitude distribution function is truncated. Under the basic condition of guaranteeing the average power of the signal, the amplified signal is limited to the original signal distribution within a specific range, to effectively reduce the system PAPR, but also as much as possible to maintain the distribution of the original signal characteristics with reduced system error rate. Theoretical analysis and simulation experiments verify the effectiveness of the proposed algorithm. Also, this method not only to the PAPR problem of NC-OFDM/OQAM system but can also solve problem for general NC-OFDM and other non-continuous multi-carrier transmission system.

**References**