PERFORMANCE EVALUATION OF CI-VOFDM FOR PAPR REDUCING

ĐÁNH GIÁ HIỆU NĂNG HỆ THỐNG CI-VOFDM ĐỂ GIẢM TỶ SỐ CÔNG SUẤT ĐỈNH TRUNG BÌNH

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ABSTRACT

High Pick to Average Power Ratio (PAPR) contributes to increasing in complexity of the Analog to Digital Converter (ADC) and the Digital to Analog Converter (DAC), as a result, it reduced efficiency of the High Power Amplifier (HPA) and degradation of orthogonal frequency division multiplexing (OFDM) system performance. In this paper, the carrier interferometry (CI) spreading code in Vector OFDM (V-OFDM) to reduce the PAPR value is proposed. The simulation shows that the PAPR value decreases in CI-V OFDM systems compare to the conventional OFDM system.

***Keywords**: Pick to Average Power Ratio (PAPR), Carrier Interferometry (CI), Orthogonal Frequency Division Multiplexing (OFDM).*

TÓM TẮT

Tỷ lệ công suất đỉnh trung bình cao (PAPR) là nguyên nhân làm tăng độ phức tạp của bộ chuyển đổi tương tự số (ADC) và chuyển đổi số sang tương tự (DAC), làm giảm hiệu quả của bộ khuếch đại phát (HPA) và giảm hiệu suất của hệ thống ghép đa tần trực giao theo tần số OFDM. Bài báo này đề cập đến giải pháp mã lan truyền chéo (CI) trong VOFDM nhằm giảm giá trị công suất đỉnh trung bình. Kết quả mô phỏng cho thấy giá trị của PAPR trong hệ thống CI-VOFDM giảm so với hệ thống OFDM thông thường.

***Từ khóa**: Tỷ lệ công suất đỉnh trung bình cao, mã lan truyền chéo, ghép đa tần trực giao theo tần số.*

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1. INTRODUCTION

The OFDM system divides the high data rate sequence into parallel low data rate sequence, where the low data rate symbols are simultaneously transmitted through the orthogonal subcarriers. The transmission of each symbol on its unique carrier leads to the potential for high peak power because there is a possibility of all in phase bits on subcarriers to add up coherently. When signals with high peak power pass through an HPA, high Out of Band (OOB) distortions may occur [1]. To prevent saturation and clipping of OFDM signal peaks, the power amplifier must not be driven to saturation, i.e., the amplifier operates with sufficient Back-Off (BO) that will increase with the PAPR.

The power fluctuations can be measured by Peak to Average Power Ratio (PAPR), Crest Factor (CF), and Power Ratio (PR). High PAPR causes drawbacks like an increased complexity of Analog to Digital Converter (ADC) and Digital to Analog Converter (DAC), a reduced efficiency of the HPA and degradation of system performance.

High PAPR demands the DAC/ADC with enough dynamic range to accommodate the high peaks of the OFDM signals High PAPR requires a high precision DAC with a reasonable amount of quantization noise which might be very expensive for a given sampling rate of the system [2].

Also high PAPR will require an HPA with wide dynamic range to operate in linear region, i.e., HPA needs a back-off to make sure it remain linear over an amplitude range that include the high peak amplitudes. The expansion of the linear region increases the cost of the power amplifier. Nonlinearity characteristics cause spectral widening of transmitting signal resulting in ISI and Inter-Channel Interference (ICI) which degrades the system performance.

Diminishing the PAPR value has been proposed by several methods, which basically can be classified into three types. First, the signal distortion techniques reduce the peak amplitudes by nonlinearly distorting the OFDM signal at or around the peaks. This category includes the clipping, peak windowing and peak cancellation techniques. Second, the coding techniques use a special forward error correcting code to exclude OFDM symbols with large PAPR value. Third, scrambling techniques scrambles each OFDM symbol with different scrambling sequences and selecting the sequence that provides the lowest PAPR value.

This paper proposed the carrier interferometry (CI) spreading code to be introduced in the precoded/vector OFDM to combat the high PAPR. The CI code lies under the second category of reducing PAPR in OFDM systems.

2. BRIEF REVIEW OF PEAK TO AVERAGE POWER RATIO (PAPR)

Apart from the advantage of Precoded-OFDM and Vector-OFDM (VOFDM) of being robust to ISI channel spectral nulls and the reduction of cyclic prefix transmission data rate, respectively, there PAPR value is not convincible in comparison with the conventional OFDM system. In case of Carrier Interferometry OFDM (CI/OFDM), the PAPR value is lower compared to the conventional OFDM system. This brought an idea of combining the Precoded-OFDM/VOFDM and CI/OFDM is resulting in the CI - VOFDM system. The PAPR of the transmitted OFDM signal $\overline{x}(n)$ is the ratio between the peak power value per OFDM symbol and its average power value per OFDM symbol.

The PAPR of OFDM signal $\overline{x}(n)$ is the ratio of the maximum power and its average power [8], mathematically given by

$$\mathrm{PAPR}\left(\overline{x}(n)\right)=\frac{\max\limits_{0\le n\le N-1}\left[\left|\overline{x}(n)\right|^2\right]}{E\left\{\left|\overline{x}(n)\right|^2\right\}} \quad (1)$$

Where the numerator of equation (1) expresses the maximum power and the denominator is the average power of the transmitted signal, $E\{\cdot\}$ denotes the expectation. The power of OFDM signal is defined as:

$$\begin{aligned}\left|\overline{x}^2(n)\right| &= \sum_{k=0}^{N-1}\sum_{k'=0}^{N-1} x_k x_{k'}^* e^{j2\pi n\left(k-k'\right)/N}\\ &= \sum_{k=0}^{N-1}\left|x_k\right|^2+\sum_{k=0}^{N-1}\sum_{k\neq k'} x_k x_{k'}^* e^{j2\pi n\left(k-k'\right)/N}\end{aligned} \quad (2)$$

The peak power of OFDM signal is defined as

$$\begin{aligned}\max_{0\le n\le N-1}\left|\overline{x}(n)\right|^2 &= \max_{0\le n\le N-1}\left[\sum_{k=0}^{N-1}\left|x_k\right|^2+\sum_{k=0}^{N-1}\sum_{k\neq k'} x_k x_{k'}^* e^{j2\pi n\left(k-k'\right)/N}\right]\\ &\le N^2\max_k\left|x_k\right|^2\end{aligned} \quad (3)$$

The relation between time and frequency domain average power is

$$\frac{1}{N}\sum_{n=0}^{N-1}\left|\overline{x}(n)\right|^2=\left(\frac{1}{N}\sum_{n=0}^{N-1}\left|x(n)\right|^2\right)\cdot N \quad (4)$$

Substituting equation (3) and (4) into (1), the PAPR equation becomes

$$PAPR\left(\overline{x}\right)\le\frac{N^2\max\limits_{0\le k\le N-1}\left|x_k\right|^2}{N\cdot\left(\frac{1}{N}\sum_{n=0}^{N-1}\left|x_k\right|^2\right)}\le N\cdot\frac{\max\limits_{0\le k\le N-1}\left|x_k\right|^2}{\frac{1}{N}\sum_{n=0}^{N-1}\left|x_k\right|^2} \quad (5)$$

The inequality in the PAPR will turn to equality only if the value of all x_k's is maximal. The maximum PAPR which is the worst case is denoted by

$$\mathrm{PAPR}_{max}=N\cdot\frac{\max\limits_{0\le k\le N-1}\left|x_k\right|^2}{\frac{1}{N}\sum_{n=0}^{N-1}\left|x_k\right|^2} \quad (6)$$

In phase modulation schemes, the peak power and average power have the same value and the PAPR is equal to N.

The distribution function of PAPR is most commonly used to evaluate the performance of PAPR reduction methods [3,4]. For large values of N typically greater or equal to 64, real and imaginary parts of the transmitted signal approach the Gaussian distribution with a zero mean and a common variant $\sigma_{\overline{x}}^2$. However, it is better to consider the distribution of the OFDM signal envelope because the PAPR depends on the signal envelope and the power has a central chi-square distribution with two degrees of freedom, the envelope is Rayleigh distributed. The Cumulative Distribution Function (CDF) is given by

$$\begin{aligned}F_X(x) &= \int_0^x \frac{u}{\sigma_{\overline{x}}^2}\exp\left(-u^2/2\sigma_{\overline{x}}^2\right)du\\ &= 1-\exp\left(-x^2/2\sigma_{\overline{x}}^2\right), \qquad x\ge 0\end{aligned} \quad (7)$$

The probability that the $\mathrm{PAPR}\left(\overline{x}\right)=\frac{x^2}{2\sigma_{\overline{x}}^2}$ is less than or equal to a given threshold PAPR_0 for N subcarriers is

$$\begin{aligned}P\left(\mathrm{PAPR}\le\mathrm{PAPR}_0\right) &= \left(\mathrm{CDF}\right)^N\\ &= \left(1-\exp\left(-\mathrm{PAPR}_0\right)\right)^N\end{aligned} \quad (8)$$

The probability that the PAPR is greater than PAPR_0 is defined as

$$\begin{aligned}P\left(\mathrm{PAPR}>\mathrm{PAPR}_0\right) &= 1-\left(\mathrm{CDF}\right)^N\\ &= 1-\left(1-\exp\left(-\mathrm{PAPR}_0\right)\right)^N\end{aligned} \quad (9)$$

Equation (8) and (9) defines the Complementary Cumulative Distribution Function (CCDF), the statistical method that provides the amount of time a signal spends above any given power level. It can be seen that the (P(PAPR > PAPR_0) increases as the number of subcarriers increases at any level.

3. PAPR REDUCTION METHODS

CI was proposed in [5] to eliminate the large power peaks and, hence, reduce the PAPR in OFDM system without raising the system complexity. The evaluation of system performance of MIMO STBC OFDM and MIMO STBC CI/OFDM was introduced in [6,7]. The theoretical analysis was studied when there is an existence of HPA nonlinearity and the introduction of CI codes brought a big improvement in the system.

A combination of CI spreading code and peak-windowing with clipping/filtering of a single iteration was proposed in [8-10]. The spreading was followed by peak-windowing and clipping before transmission of the OFDM signal. The definition of efficient PAPR was defined as the PAPR with minimum total degradation (TD), TD is the sum of signal to noise ratio of SSPA (SNR_{SSPA}) and the OBO of SSPA (OBO_{SSPA}) in dB. There was an improvement in the reduction of PAPR and no spectrum broadening due to the clipping process.

The rotated precoder [11] was proposed to reduce PAPR in the precoded-OFDM system with zero padding half of the information symbols for N-point FFT. Description of rotated precoder based OFDM was mentioned in chapter two. The wavelet transformation was proposed as the precoder to perform decomposition over the vector information symbols from the binary phase shift keying (BPSK) modulator. The half of the information symbols are $\sqrt{2}$ or $-\sqrt{2}$ and the remaining half of the information symbols are zeros [12,13].

In CI-VOFDM, each vector sequence is transmitted simultaneously over all carriers and the phase offset makes symbols separable at the receiver. Also the phase offset makes the symbols not to add coherently at the same time, i.e. when one symbol's add coherently, the others do not. The peak power of CI-VOFDM is lower than that of OFDM (sum of peak carrier powers), since when the power of one symbol $\tilde{s}_l$ reaches the peak power, symbol $\tilde{s}_b$ is at minimum power. The average power of CI-VOFDM is equal to OFDM average power. The PAPR of CI-VOFDM in the worst case is given by:

$$PAPR_{worstcase} = \frac{\left(\frac{1}{2}\max_{0<n<N-1}\left|\tilde{s}^v(n)\right|\right)^2}{\frac{1}{N}\sum_{n=0}^{N-1}\left|\tilde{s}^v(n)\right|^2} << N \qquad (10)$$

4. SIMULATUON RESULTS

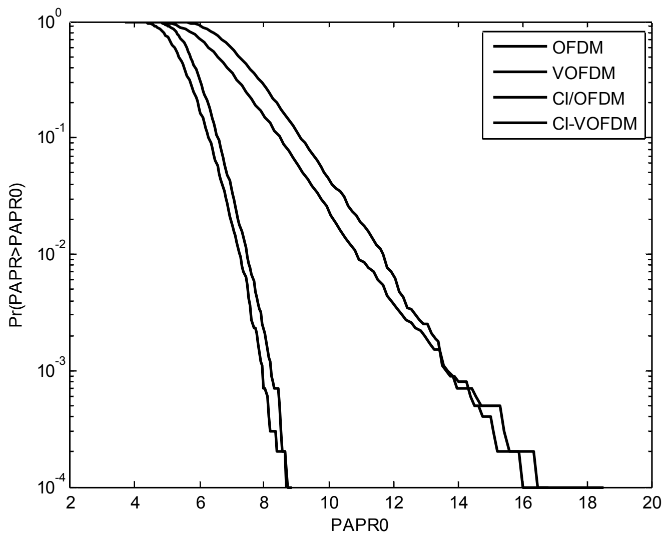


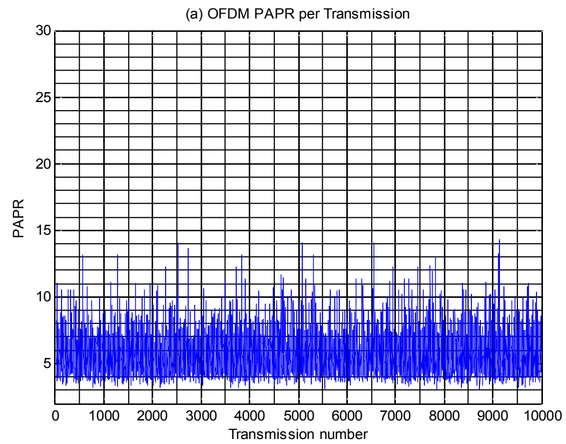
Figure 1. Complementary Cumulative distribution functions for conventional OFDM, VOFDM, CI/OFDM, and CI- VOFDM systems

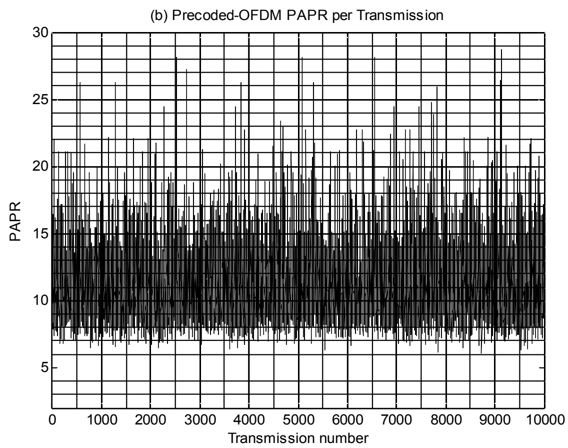
Assuming that the modulation and demodulation are ideal QPSK. The comparison of rotated precoder based OFDM and CI-VOFDM complementary cumulative distribution function (CCDF) and PAPR level is demonstrated in this section.

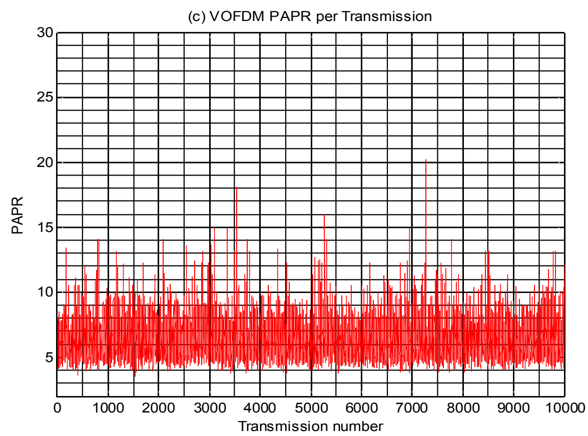
Using N = 1024, V = M = 2, and QPSK modulation figure 1 shows the CCDF of conventional OFDM, VOFDM, CI/OFDM, and CI-VOFDM systems, 10 000 data symbols are generated.

From figure 1, CI-OFDM described the gain of about 8 dB compared to VOFDM and it is comparable to that of the CI/OFDM system.

With N = 256 carriers across 10000 transmissions under the conventional OFDM, precoded-OFDM, VOFDM, CI/OFDM and CI-VOFDM system, we have the following results:







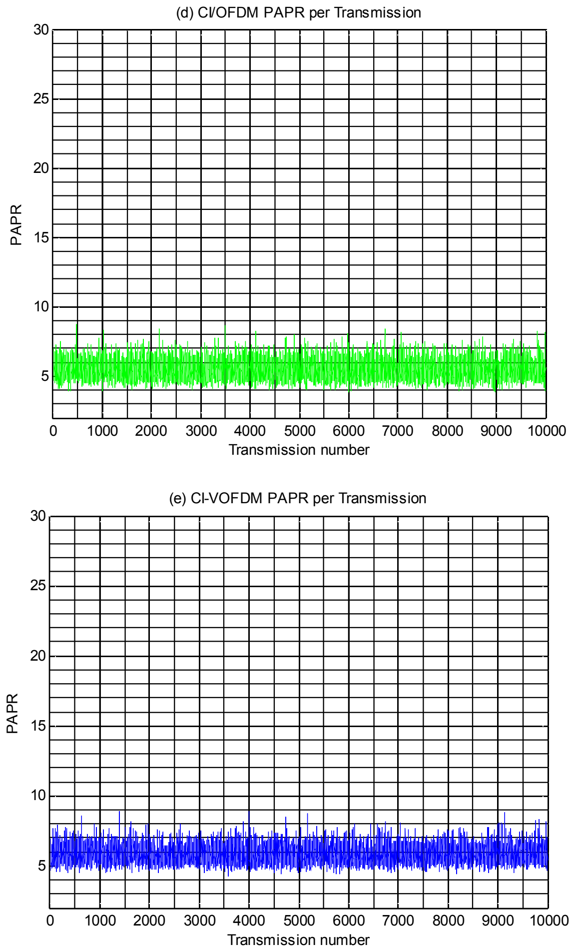


Figure 2. PAPR level per transmission for OFDM, Precoded-OFDM, VOFDM, CI/OFDM, and CI-VOFDM systems

Figure 2 shows the PAPR of (a) the conventional OFDM, (b) precoded-OFDM, (c) VOFDM, (d) CI/OFDM and (e) CI-VOFDM across 10,000 transmissions with N = 256 carriers. Precoded-OFDM displays higher PAPR value which exceeds 25, followed by VOFDM where there are spurious peaks with PAPR greater than 15, OFDM has peaks that exceed 10, CI-VOFDM there is no peak greater than 9, and CI/OFDM displays the lower one with peaks less than 8.5

5. CONCLUSION

In this paper, the CI spreading code in vector OFDM to reduce the PAPR value has been proposed. The simulations show that CI-OFDM described the gain of about 8 dB compared to VOFDM and it is comparable to that of the CI/OFDM system. PAPR value in CI-VOFDM is nearly smallest, where the mission was being accomplished since there is a big difference between the VOFDM and CI-VOFDM PAPR.

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