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NON-LINEARITY DISTORTION MITIGATION OF DOWNLINK-LTE SYSTEM USING MODIFIED AMPLITUDE CLIPPING AND FREQUENCY DOMAIN RANDOMIZATION

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ABSTRACT: - Wireless telecommunication systems are almost the most dominant field of the communication systems context nowadays especially the long-term evolution (LTE) system. Orthogonal frequency division multiplexing (OFDM), has become the base for current and future communication systems, because of its capability to combat multipath and fading channels and its competency for high data rate transmissions. However, coherent combination of subcarriers leads to large power peaks with respect to the average power level; this is the so-called peak power ratio (PPR). Various methodologies are available in the literature, the simple approach is the amplitude clipping.

However, amplitude clipping causes in-band distortion and out-of-band-radiation, thus, the bit error rate (BER) performance will degrades dramatically. Taher et al (2014) suggested a new amplitude-clipping algorithm, where the core-clipping function was replaced with a non-distorting function, but the proficiency of reducing the PPR was not in the good extent. In this paper, the new clipping function will be supported by frequency-domain randomization operation, such that the coherent combination of the OFDM subcarriers will not stay in the same order, leading to lower PPR at the output of the power amplifier. Results show that the hybrid combination of the randomization process with the new clipping function produces lower values of PPRs. Thus, the proposed approach has gotten 1.5 dB more reduction magnitude in the PPR with respect to Taher et al scheme. The complementary cumulative distribution function (CCDF) was the tool to monitor the PPR performance behavior.

Keywords: Amplitude Clipping, CCDF, non-linearity distortion, OFDM, PPR

1. INTRODUCTION

An important event has been started; it is the mobile fast data rate revolution. It cannot stop, since millions of subscribers demand the services of the mobile data. Nowadays, the internet becomes an important factor in our life. Using the internet, users can follow their preferred news, movies, even they communicates with each other using the social soft-wares such as; skype, viber, whatsup and others, more than using the voice telephony. Thus, high data throughputs becomes essential. High throughputs and wideband networks with very high quality are substantial design factors for the current and next mobile data era. The third generation partnership project (3GPP) has developed different wireless standards, its last standard was the Long Term Evolution (LTE), as fourth generation (4G) of wireless communication system.

However, LTE should provide some necessary factors to be accepted by the subscribers, such as; improved capacity, wide coverage area, high throughputs, low services costs, could support the multiple-input-multiple-output (MIMO) system, and high flexibility in the operating bandwidth. Thus, according to 3GPP standards, the Orthogonal-Frequency-Division-Multiplexing (OFDM) was the best fit, as a modulation scheme for the LTE system, to provide all of the aforementioned required design factors in the LTE system. By adopting OFDM, LTE can deliver data to subscribers with data rate up to 1Gbps[1]. Thus, the most important factors, in other words, that made OFDM best choice are: the capability to combat multipath and fading channels, excellent spectrum usage, implementation significantly low complexity, administer flexible bandwidth, further, it accommodates frequency selectivity scheduling with MIMO ability.

Among these competences, on the other hand, OFDM modulation has a part of inadequacy such as the power fluctuation. In fact, OFDM is a multicarrier modulation methodology, thus, agreement of phases will be added together constructively, leading to tremendous peaks of power with respect to the variance of the output power, and this is the so-called, peak-power-ratio (PPR). Oodles of schemes were originated in the literature, to defeat the PPR problem[2], such as the tone reservation (TR)[3], tone injection (TI)[4], active constellation extension (ACE)[5], selected mapping (SLM)[6], partial transmit sequences (PTS)[7], and the amplitude clipping (AC)[8]. Among these approaches, AC-method represents the easiest scheme from the implementation point of view, because it requires lowest number of mathematical operations of multiplications. That is, the most important reasons that made AC-scheme the simplest approach is that it works in the time-domain, where multiple signal representation, which will increase the complexity hardly, is not needed. The rule fundamental this fashion involves clipping the unwanted peaks after the operations of the inverse Fourier transform, which represented by the Inverse Discrete Fourier Transform (IDFT). A soft envelop limiter is the core function of the AC-scheme [9-12].

Cutting high peaks is, in general, a non-linear operation, where discontinuities will appear, hence, un-infinite bandwidth, theoretically, is required, therefore, a low-pass-filter (LPF) have to be employed, which will add more complexity to the system, to remove the out-of-band (OOB) radiation. However, another problem will arise, the internal-band amplitude will grow again, which causes degradation in the BER of the system, thus, a treatment is necessary at this step[9-14]. Taher et al (2014)[15] have introduced a new clipping function, such that, the LPF is not necessary, even the in-band re-growth will not appear.

However, the PPR reduction gain can be improved more than the scheme in[15], by including a frequency-domain randomization process, to change the arrangement order of the OFDM samples, before the IDFT operations. Thus, more PPR reduction gain can be achieved using our proposed algorithm. The rest of this paper is organized as; an introduction to the OFDM system, amplitude clipping, and the PPR will be shown in section 2, section 3 draws the novel scheme of our work, where the clipping operation of Taher et al (2014) will be shown with our contribution. Section 4 shows the results and our discussions, while section 5 summarizes the work of this paper.

2. OFDM AND PPR PROBLEM

OFDM signals can be generated using orthogonal subcarriers, these subcarriers can be found in the IDFT expression [15]

$$s_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} S_n e^{j2\pi\frac{nk}{N}} \qquad (1)$$

Where n and k stand for the frequency- and time-domains indices, respectively. While S_n represents the frequency-domain samples. Thus, there are N orthogonal subcarriers will be utilized for the modulation process. However, S_n will be drawn randomly from either of the baseband modulation families; Multiple-quadrature amplitude modulation (M-QAM) or multiple-Phase shift keying (M-PSK). Because of the orthogonalality nature of the OFDM, some of the modulated subcarriers will be added together constructively, consequently, there will be a high peaks of power, if compared with their average, accordingly, the PPR will be significantly large, leading to BER performance degradation of the system. This PPR can be expressed mathematically as [15]

$$\text{PPR} = \frac{\max(|x_1|, \dots |x_N|)}{E\{|x_n|^2\}} \quad (2)$$

Where $E\{\cdot\}$ corresponds to the expectation operation or the mean value. The Complementary Cumulative Distribution Function (CCDF) of the PPR can be then determined [15],

$$\text{CCDF(PPR)} = \Pr(\text{PPR} > \mu) \quad (3)$$

In the last expression, μ represents the required clipping threshold. However, to better evaluation of the CCDF function, the OFDM samples must be oversampled by 4[16], to make the discrete signal properties similar to the continuous signal properties. On the other hand, the AC-algorithm could reduce the PPR to an acceptable level, but at the cost of BER-performance. Thus, in mathematical formulation, AC-method can be described as[15],

$$f(s_k) = \begin{cases} s_k & if\ |s_k| \le x \\ x & if\ |s_k| > x \end{cases} \quad (4)$$

Where x is the amplitude clipping level, it can be calculated from the following equation [15]:

$$x = \sqrt{E\{|x_n|^2\}} \times \beta \quad (5)$$

Where β stands for the clipping ratio, which must be less than one, β <1[15], in other words, as long as β approaches zero, the clipped portion will be higher, and if β more than one towards infinite, there will be no clipped portion.

3. PROPOSED ALGORITHM

As described in the last section, AC-scheme cuts-off, blindly, the top-parts of the higher peaks, therefore, the signal will undergo a distortion, which produces OOB radiation and in-band distortion. Taher et al (2014) suggested to change the clipping function of Equation (4) by another, that don't needs a LPF as,

$$\hat{s}_k = \begin{cases} s_k & if\ |s_k| \le x \\ \frac{\sqrt{|s_k|}}{B} & if\ |s_k| > x \end{cases} \quad (6)$$

Where B is a constant integer. In the last expression, the clipped parts can be recovered at the receiver, if the clipped samples are known at the receiver, as side information. Thus, the clipping function of the last expression should be defined at both transmitter and receiver. The clipping sample's indices will be the side information, to be sent to the receiving end, which is out of the scope of this paper.

It can be shown that the PPR can be enhanced more by including another distortion-less function in the frequency-domain, i.e., before the feeding to the IDFT operations. However, the function is an operation that randomizes the order of the OFDM samples. The randomization operation is necessary, where the samples of the same phase will located in different locations, then, there will be no coherency in the addition operation of the IDFT function, which reduces, consequently, the PPR significantly. To explain this function, let us express Equation (1) using matrix notation,

$$\mathbf{s} = \mathbf{F^{-1}} \times \mathbf{S} \quad (7)$$

Where $\mathbf{F^{-1}}$ is the IDFT-matrix. Thus, assuming that the randomization elements are all ones of negating signs,

$$R = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & -1 & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \cdots & -1 \end{bmatrix} \quad (8)$$

Where size of R is $N \times N$, then, multiplying the OFDM frequency domain vector by R, before the IDFT function, yields,

$$\tilde{\mathbf{s}} = \mathbf{F^{-1}} \times \mathbf{R} \times \mathbf{S} \quad (9)$$

Where **R** is the matrix notation form of *R*. That is, the phase sequences of the original vector **s** will be changed according to (9), leading to a different order of samples; therefore, the PPR will be reduced, as will be shown in the results in the next section.

4. RESULTS

The novel method has been explored mathematically in the last section. The new method of Taher et al [15] has also been reviewed. In this section, the results of the proposed scheme will be shown compared with Taher et al [15] approach. However, the simulation parameter setting are chosen according to the LTE standards, where N = 256 subchannels and 16-level QAM as mapping family. The clipping ratio was 0.28 for both Taher et al[15] and our suggested algorithm. Furthermore, the number of the randomly generated OFDM symbols was 50,000. Figure 1 shows the PPR comparison for three cases; the original without clipping signal, Taher et al [15] results, and the proposed method. It is shown that for OFDM signals of size 256-subchannels of 16-QAM mapping, the PPR was reduced by 2.6 dB and 1.1 dB for the suggested and Taher et al methods, respectively. Thus, the proposed approach has gotten 1.5 dB more reduction magnitude in the PPR with respect to Taher et al scheme [15].

Hence, the suggested method in this work could enhance the capability of the PPR reduction gain. However, the randomization process is a probabilistic method, therefore, the BER-performance should be not degrades. Hence and as shown in Figure 2, the BER-performance did not suffers degradation. It is shown in Figure 2 that the BER-curves of the suggested approach and Taher et al algorithm have identical behavior. In other words, the BER-performance of the suggested method is similar to that of Taher et al, because the randomization function did not add any degradation in the BER-performance.

5. CONCLUSIONS

One of the most important limitations of the OFDM scheme is the high PPR, which is a result of its nature modulation operations. In this work, a novel method, to overcome the PPR problem, has been suggested. We showed that the proposed method can reduce the PPR more than that of Taher et al. Moreover, the suggested fashion did neither increase the computational complexity of whole the system nor degrades the BER-performance. Furthermore, the order of the baseband modulation is not limited in our approach, as well as the baseband mapping family is not a matter in the suggested method. Therefore, our new approach can be recommended to be a useful algorithm for PPR reduction in the modern multicarrier based communications systems.

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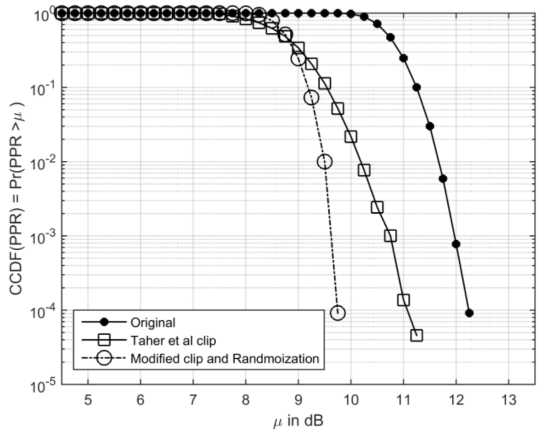

Figure (1): PPR comparisons for the original, Taher et al and the suggested approaches.

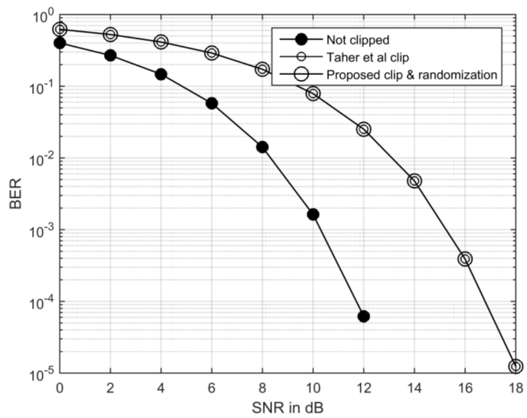

Figure (2): BER comparisons for the original, Taher et al and the suggested approaches.