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POWER ENVELOPE VARIATION IMPROVEMENT OF DOWNLINK LTE SYSTEM USING COMPLEX NUMBER MANIPULATION APPROACH

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ABSTRACT: - Today the world is witnessing very significant developments in the world of digital communications. For that, the subscribers are demanding for quality and speed for the available services. To achieve these objectives, must be accurate and low impurity communication devices available.

The orthogonal frequency division multiplexing (OFDM) scheme, is the downlink modulation scheme utilized in the long term evolution (LTE) system. Because of the coherent addition of the subcarriers, the output power variation will show high peaks compared with the average, known as Crest factor, thus, the amplification gain is degraded and intermodulation distortion will appears.

Different sorts of schemes have been introduced to mitigate these problems, but either on the expense of complexity or the bit error rate (BER) performance degradation. In this paper, a novel simple to implement algorithm suggested by the authors to mitigate the high Crest factor.

The suggested approach is based on complex numbers manipulation, by exchanging the real and imaginary parts, to destroy the coherence order of the OFDM subcarriers, leading to lower crest factor. Results show that the computational complexity and the reduction gain are improved significantly.

Keywords: PAPR, Crest Factor, non-linearity distortion mitigation, OFDM, power envelope fluctuation, SLM.

1. INTRODUCTION

The current era of wireless communication systems promises the subscribers to deliver to them wide range of services. Thus, fourth generation (4G), which is represented by Long Term Evolution (LTE) system, has been adopted by the Third Generation Partnership Project (3GPP) community. However, LTE indeed can provide high throughput data transmission, using frequency multiplexing. Different schemes of frequency multiplexing are available such as; Frequency Division Multiplexing (FDM), Orthogonal Frequency Division Multiplexing (OFDM). The theoretical principle of operation of the FDM needs wide range of spectrum bandwidth, but it cannot use this wide bandwidth efficiently, due to the too much guard bands, to avoid the intercarrier interference. The OFDM technique can use the spectrum very efficiently by overlapping the subcarreirs, if the subcarreirs are orthogonal to each other, without intercarrier interference. That is, more than 50% of the spectrum will be free, which can be used for other functions of the system. Hence, LTE has adopted the OFDM as a modulation technique for the downlink transmission.

OFDM modulation scheme has drawn much attention of researchers. Therefore, huge effort paid to enhance the limitations of this modulation method. One of the most and familiar problems of the OFDM system is the large variation of the power envelope. The reason behind the power envelope large variation is the coherence addition of the in-phase subchanels, this coherency leads to large power peaks compared with the average power, this phenomenon is called Crest Factor (CF)(1). Various methodologies are found in the literature to overcome the CF problem. Two categories are the divisions of the literature for the CF enhancement methods; frequency-domain, and Time-domain. Selected Mapping (SLM)(2-6), Partial Transmit Sequences (PTS)(7-9), Active Constellation Extension (ACE)(10), and Random Variable Constellation Mapping (RVCM)(11) are all belong to the Frequency-domain category.

Amplitude clipping (12, 13), Side Information Supported Amplitude Clipping (14), companding transform (15), and the Post IFFT-Modified SLM (16) are all belong to the time-domain category. In this paper, we focus on the frequency-domain, where distortion-less methods can be founded easily. SLM will be used in this work, where the principle of its operation is to change the phases of the samples in frequency domain. SLM needs to represents the OFDM data vector multiple times, thus, the block of Inverse Discrete Fourier Transform (IDFT) will be repeated many times as shown in Figure (1), therefore, the computational complexity will be increased dramatically. Taher et al proposed a new fashion for the SLM-scheme called Sliding the SLM (SSLM) to decrease the computational complexity of the original scheme (17). In this paper, the authors suggested changing the data vector element's orders, such that, the required number of IDFT blocks of the SLM can be reduced, consequently, the computational complexity will be reduced significantly. The suggested order changing is by exchanging the real with the imaginary parts of the data vector, in the frequency domain, and then the traditional SLM can be used with reduced number of IDFT blocks.

The rest of this paper is organized as follows: section 2 shows the OFDM system, Crest Factor, and the SLM method for CF reduction. In section 3, the development of the suggested method will be given. The results and discussion of the new algorithm will be shown in section 4. Last but not least, section 5 explores the conclusions of whole the work.

2. OFDM CREST FACTOR AND SLM-SCHEME

The IDFT is the mathematical formulation of the OFDM modulation scheme, it is formulated as (11),

$$g(k) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} G(n) e^{j2\pi\frac{nk}{N}}, n, k = 0, 1 \ldots N-1 \tag{1}$$

Where G are randomly drawn from multi-level quadrature amplitude modulation (M-QAM) or multi-phase shift keying (M-PSK), n and k are the frequency and time domain indices, respectively, and N stands for the number of subcarriers. However, due to the coherence combination of the subcarriers, the power envelope will fluctuate with high peaks with respect to the average. This phenomenon can be determined mathematically, which is called Crest Factor (CF).

$$\mathrm{CF} = \frac{\max|g(k)|}{\sqrt{E[|g(k)|^2]}} \tag{2}$$

Where E[·] is the expectation or the mathematical mean value operation, in other words, CF is the ratio of the maximum peak to the average mean square value of the signal power's envelope. To reduce the CF value, SLM-algorithm is one of the efficient approaches that reduces the CF effectively (17). Although the SLM-scheme is a probabilistic methodology, which doesn’t degrade the BER performance (2, 17), the computational complexity is very high, because of the multiple signal representation methodology of the SLM-scheme.

The theory behind the SLM-algorithm is by coping the data vector, at frequency-domain, Q-times, each copy will be multiplied component-wise by its dedicated rotating vector, $\mathbf{V}_q$ where q = 1, 2…Q, the rotated branches will be fed to the IDFT blocks, at this step, a comparison, to find the branch with lowest CF, produces the OFDM time domain symbols with low CF. Furthermore, another output, which is the index of the branch of the low CF, will be sent with the OFDM signal as side information, as shown in Figure (1). According to the aforementioned algorithm, the number of multiplications operations can be determined [17]

$$\Pi_{SLM} = 2QN\log_2 N \tag{3}$$

And the number of additions operations will be(17)

$$\Lambda_{SLM} = 4QN\log_2 N \tag{4}$$

Where Q in both of the last two expressions stands for the number of IDFT blocks. In the next section, the proposed algorithm will be explained. It will be shown that the computations of Equations (3 and 4) will be reduced significantly.

3. NOVEL ALGORITHM

To introduce the suggested scheme in superior way, Equation (1) should be re-formatted in matrix format,

$$\mathbf{g} = \mathbf{F}^{-1}\mathbf{G} \tag{5}$$

Where $\mathbf{F}$ is the Discrete Fourier Transform (DFT) matrix. Assuming the real part of vector $\mathbf{G}$ can be extracted as,

$$\mathbf{G}_r = \mathrm{Real}(\mathbf{G}) \tag{6}$$

And the imaginary part can be extracted as,

$$\mathbf{G}_i = \mathrm{Imag}(\mathbf{G}) \tag{7}$$

Then, $\mathbf{G}$ can be expressed as,

$$\mathbf{G} = \mathbf{G}_r + j\mathbf{G}_i \tag{8}$$

That is, Equation (5) can be re-expressed as,

$$\mathbf{g} = \mathbf{F}^{-1}[\mathbf{G}_r + j\mathbf{G}_i] \tag{9}$$

Our suggested method consists of two steps; the first step is to exchange the real and the imaginary parts of $\mathbf{G}$, hence

$$\widetilde{\mathbf{G}} = \mathbf{G}_i + j\mathbf{G}_r \tag{10}$$

Consequently, by substituting the last expression in Equation (9) yields,

$$\begin{aligned}\mathbf{g} &= \mathbf{F}^{-1}\widetilde{\mathbf{G}} \\ &= \mathbf{F}^{-1}[\mathbf{G}_i + j\mathbf{G}_r]\end{aligned} \tag{11}$$

The last equation represents the first part of our new algorithm. The second part is to utilize the SLM based CF reduction technique. Let the rotating vector, which conceive lowermost value of CF be $\mathbf{V}_q$, then Equation (11) will take the following form,

$$\mathbf{g}_q = \mathbf{F}^{-1}\mathbf{V}_q[\mathbf{G}_i + j\mathbf{G}_r] \tag{12}$$

Where the subscript q stands for the index of the rotating vector, which enhances the CF. The rotating vector can be drawn from Hadamard matrix's rows

$$H = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ 1 & -1 & \cdots & -1 \\ \vdots & \vdots & \ddots & 1 \\ 1 & -1 & \cdots & -1 \end{bmatrix} \tag{13}$$

The conventional SLM-scheme uses at least $Q = 16$(17) to make the system practically accepted. However, because of the first part manipulation of our approach, which will destroy the coherency of the data vector in the frequency-domain, the required number of rotating vectors can be reduced without fear about the CF reduction gain, with respect to SLM-scheme. This will be seen better in the subsequent sections.

Accordingly, the computational complexity will be reduced dramatically. The new complexity can be decided according to the deducted number of rotating vectors. Assuming the new number of rotating vectors is R, then the number of multiplications operations can be calculated as,

$$\Pi_{RSLM} = 2RN\log_2 N \tag{14}$$

While the number of additions operations can be seen as,

$$\Lambda_{RSLM} = 4RN \log_2 N \qquad (15)$$

Where $R < Q$. By comparing Equations (14 and 15) with Equations (3 and 4), the Computational Complexity Reduction Factor ($CCRF$) can be determined

$$CCRF = \left(1 - \frac{R}{Q}\right) \times 100\% \qquad (16)$$

For instance, if $Q = 16$ and $R = 6$, the $CCRF = 62.5\%$. Thus, the computational complexity can be reduced 62.5% compared with the traditional SLM-scheme.

4. RESULTS AND DISCUSSION

The suggested algorithm has been interpreted utterly. It can be explored totally by Equation (12) in the previous section. In this section, the results of the traditional SLM method and the suggested scheme will be shown, both compared with a non-CF reduced OFDM signals. However, for an LTE applications, the size of the OFDM symbol, N, will be 256 subcarriers with 16-QAM mapping. The number of rotating vectors are 16 and 6 for the traditional and proposed approaches, respectively.

Figure (2) shows the CF comparison results of the conventional SLM-algorithm, with respect to the proposed algorithm as well as the original OFDM signals. It is obvious that the SLM based scheme has reduced the CF by 1 dB compared with the original signal. The utilized number of rotating vectors, Q, was 16. The proposed algorithm employed only 6-rotating vectors, $R = 6$, where the CF was enhanced by 1.3 dB, with respect to the original OFDM signals.

In other words, the suggested method superior the traditional SLM-scheme by 0.3 dB. Although the enhancement, with respect to the conventional SLM-method, was not high, but the computational complexity was improved dramatically, where according to Equation (16) the computational complexity of the mathematical multiplications operations was reduced by 62.5%. Moreover, the number of additions operations was reduced as well by 62.5%, compared with the traditional SLM-scheme. Thus, the proposed algorithm superior the conventional SLM-scheme in both the computational complexity and the CF-reduction gain.

5. CONCLUSIONS

In this paper, a simple complex number manipulation was proposed, in order to reduce the computational complexity of the traditional SLM-scheme. The following points were concluded:

1. The suggested method has improved the CF as well as the computational complexity of the conventional SLM.
2. Thus, the LTE system can gain reduced system's complexity.
3. Hence, it is recommended to adopt our proposed method to be utilized by the LTE systems.

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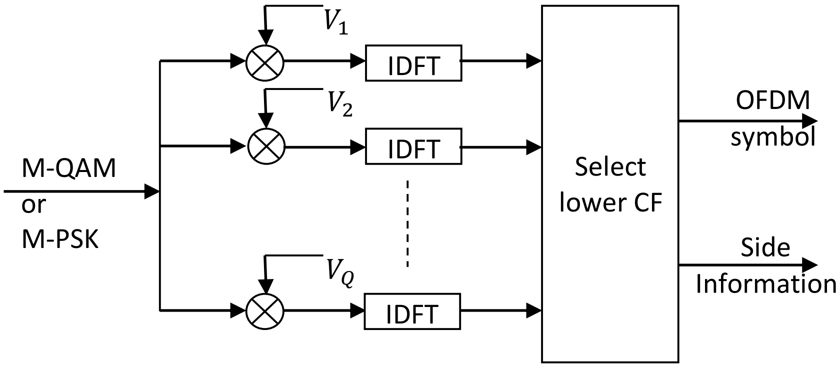

Figure (1): OFDM system with traditional SLM-scheme

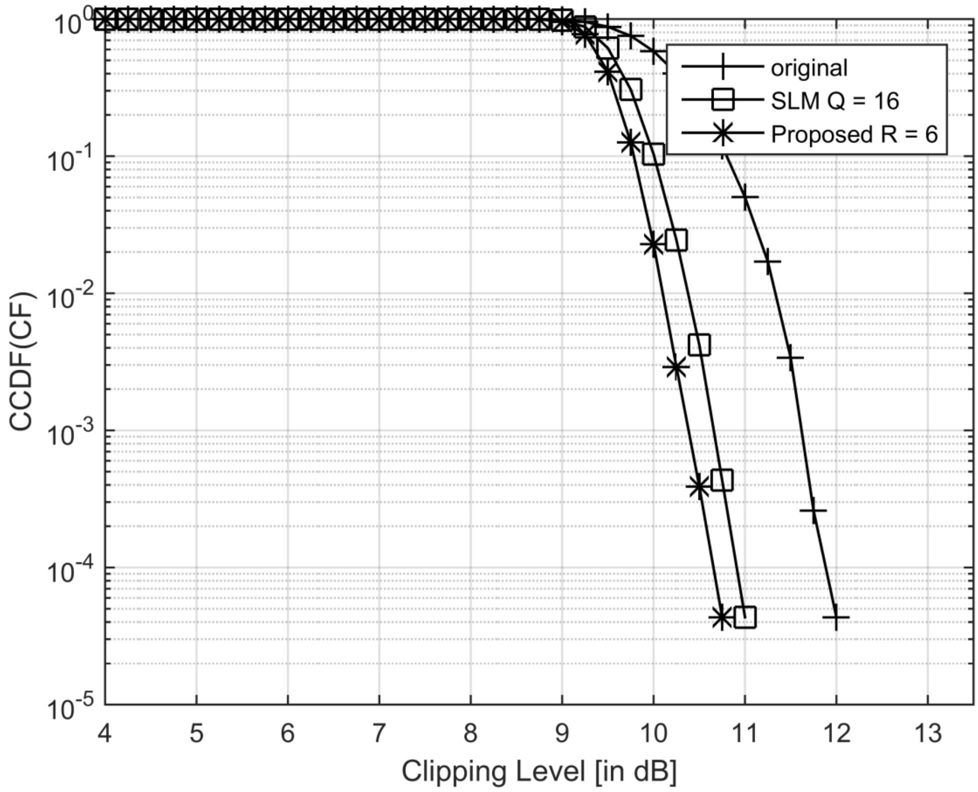

Figure (2): Crest Factor results-comparison of the traditional SLM-scheme, the proposed algorithm, and the original OFDM signals