Investigation of PAPR Reduction Technique Using TRC-SLM Integration

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***Abstract* - Orthogonal division multiplexing system is an appealing technique for a high information rate communication system. It has been largely adopted in modern communication systems because it provides high bit rates, robustness to delay spread and frequency spectral efficiency. On the other hand, OFDM has a major drawback which is high peak to average power ratio (PAPR) of the signal of OFDM transmitter. This value limits OFDM performance in various wireless systems. In this paper, a new method is proposed to reduce PAPR of the OFDM system by combining two PAPR lessening methods which are Tone Reservation Clipping (TRC) and Selective Mapping (SLM) methods. The OFDM signal is firstly applied with TRC method, and then applied with the SLM method to decrease the PAPR value. The proposed method is compared with different PAPR reduction methods such as TRC, SLM, and Partial Transmit Sequence (PTS) methods. The simulation results show that the proposed approaches outperform the TRC and SLM algorithms individually as well as PTS algorithm. MATLAB program has been used for all conducted simulations.**

Keywords - Digital Transmission, OFDM, PAPR, TRC, SLM, PTS and TRC-SLM Integration.

I. INTRODUCTION

Innovative approaches for digital transmission were developed which can be used in both wired and wireless schemes to support the increasing request for maximum capacity in communication systems. Therefore, an efficient modulation scheme is used to achieve the required high data rates and spectral efficiency. To this end, a telecommunication field has applied in popular way of a powerful modulation technique which is Orthogonal Frequency Division Multiplexing (OFDM). OFDM stands for Multi-Carrier Modulation method where a one high bits stream is organized into many low bits stream and is modulated by applying sub-carriers that have been orthogonal to each other. OFDM is an effective way for high capacity digital communications. The considered data which tend to be sent is distributed over many orthogonal carriers. The carriers are modulated independently at a low level of a low rate. The orthogonality is created by selecting the proper frequency spacing between them. In fact, modulation and multiplexing technologies are widely employed in the OFDM system which is, in turn, used aggressively in the field of communication systems. Accordingly, OFDM is adopted as the best candidate for wireless systems which require high transmission rates and spectral efficiency due to its benefit in responding to multipath phenomena, high bit rates, and bandwidth efficiency. Also, the major feature for the OFDM system is extreme spectral efficiency, immune to channel fading and impulse interferences, and ease of equalization. On the other hand, OFDM has many defects which are high Peak to Average Power Ratio (PAPR), frequency error, and subcarrier interference [1].

PAPR can be defined as the ratio of the highest powers of the OFDM signal and the average power of this OFDM signal. PAPR arises from many sub-carriers in a multi-carrier system that is out of phase. Sub-carriers with matchless phases will be different from each other. If all these points with high value, envelop will be produced at the output port and the peak has occurred immediately which results in PAPR [2].

Since various subcarriers in the OFDM system are added with an IFFT process, the transmit signals can possess maximum peak values in the time domain. Accordingly, PAPR is a popular case in OFDM systems as compared to single-carrier systems. In reality, high PAPR is responsible for SQNR (Signal-to-Quantization Noise Ratio) of ADC (Analog-to-Digital Converter) and DAC (Digital-to-Analog Converter), but decreases power amplifier efficiency in the transmitter. Since the power amplifier efficiency in the uplink is a challenge because of the limited battery power in the mobile device, the uplink is affected by the case of PAPR. Generally speaking, a nonlinear distortion on the outputs of linear amplifiers has happened. Actually, this is caused by saturation characteristics due to an ingress is higher than its normal value [3]. Thus, RF power amplifiers would be run in a wide linear region. Else, maximum value of the signal will be in a non- linear area of the power amplifier system and the amplifier will distort the signal. The intermodulation between the subcarriers and out of band radiation will occur. Therefore, the power amplifiers must be run with a high value of power back-offs which means low quality of amplifier and uneconomic transmitter. Accordingly, it is important to decrease the value of PAPR [1]. Therefore, there are many methods to minimize the effect of PAPR effect in OFDM system which can be classified into three major classes: signal distortion methods which include Clipping and Filtering, Peak Windowing, and Commanding Transforms. The second technique is Multiple Signaling and Probabilistic Methods which are categorized as Selective Mapping (SLM), Partial Transmit Sequence (PTS), Interleaved OFDM, Tone Injection (TI), Tone Reservation (TR), and Active Constellation Extension. The third method reduction is Coding Techniques which are Linear Block Coding, Golay Complementary Sequences, Turbo Coding, Bose Chaudhari Hochquenghem (BCH), and Low-Density Parity Check (LDPC) [4].

In [5], an Improved Subblock Successive Transform (ISST) algorithm was proposed. They use both the spatial domain and frequency domain to permute the subblocks while the conventional one uses space domain only. PAPR reduction technique is submitted by [6] to maintain a behavior of linear precoding by Block Diagonalization (BD) for multiuser OFDM systems based on Multiple Input Multiple Output (MIMO) schemes. They propose BD transmission selecting mapping (BD-SLM) to decrease PAPR and achieve BD effect at the same time. In [7], PTS to minimize PAPR effect in MIMO OFDM has been introduced. A new algorithm to decrease PAPR in MIMO device is provided by [8]. The copy theory based combined with the customary SLM technique has been utilized by them, which means that a new type of MIMO OFDM system decreases the SLM PAPR in the related results. In [9], various reduction techniques for PAPR issue in MIMO-OFDM system have been presented. They propose a novel complexity PAPR lessening technique for space frequency block coding of MIMO-OFDM. A combination of higher order partitioned PTS in conjunction with Bose Chaudhuri Hocquenghem Code (BCH) has suggested to minimize the PAPR largely by selecting the signal which has the low value of PAPR between the other signals [10]. The results applied for OFDM communication system has depicted and shown the various techniques that decrease the value of PAPR effect in communication system [11]. A Vandermonde matrix as a unique phase sequence for the swapped selected mapping S-SLM method in OFDM systems is submitted by [12] by employing an inter-leaver to increase the performance regarding PAPR minimization and complication.

In this study, the OFDM signal is initially applied with TRC method, and then employed with SLM method to decrease the PAPR value using MATLAB simulator. The proposed method is compared with diverse PAPR reduction approaches as in TRC, SLM, and Partial Transmit Sequence (PTS) methods. The simulation results depict that the anticipated approach outdo the TRC and SLM and PTS algorithms.

II. SELECTIVE MAPPING (SLM) TECHNIQUE

In selective mapping, information symbols will have different random phase rotations, and the set of phases of fewer PAPR results will be used for transmission as in Figure 1.

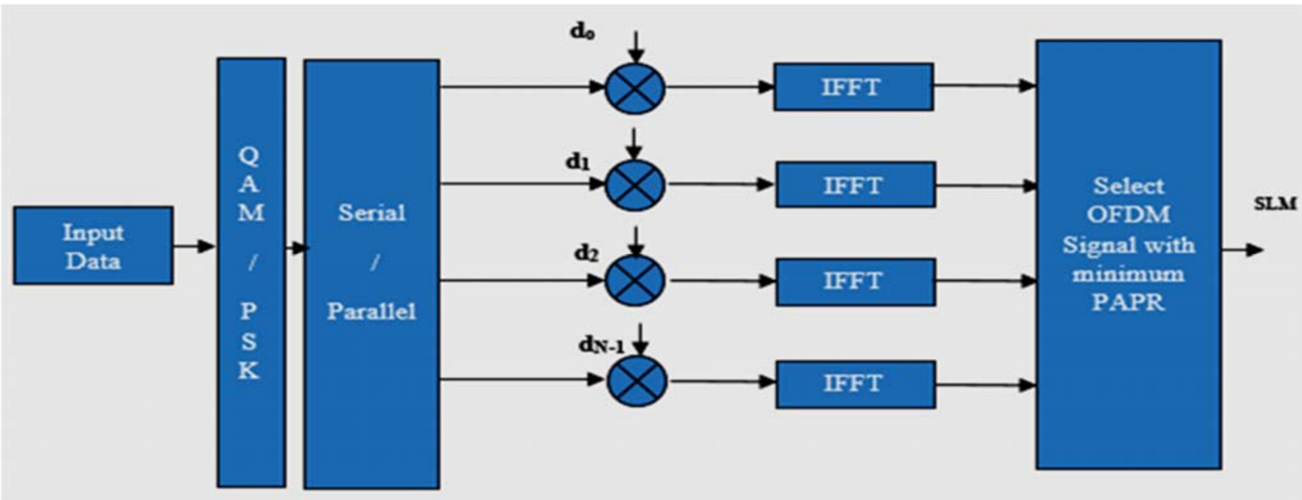

Figure 1. SLM Technique block diagram

The input data sequence X is given as X = [Xo, X1, X2, XN-1] multiplied by the phase vector d = exp(j2πφ). Where φ is the phase sequence that can be written as:

$$\Phi= [\Phi o, \Phi 1, \Phi 2, \ \ldots\ldots \ , \Phi N\text{-}1] \quad \Phi \in [\ 0, \Omega\ ] \tag{1}$$

$$\varphi = [\varphi o, \varphi 1, \varphi 2\ , \ldots\ldots\ \varphi N\text{-}1] \quad \varphi \in [\ 0, \Omega\ ] \tag{2}$$

The input signal after IFFT can be determined by:

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k * d_{n,k}\, e^{j2\pi nk/N} \tag{3}$$

The lowest PAPR can be selected by this equation [13]:

$$\dot{x} = \text{argmin} \quad (\max(|xn|)) \tag{4}$$

where $k = 0,1,2 \dots N-1$ n = 0, 1...N-1

III. CLIPPING-BASED TR (TR-C)

In this method, the x_n signal is clipped to create the clipped signal y_n. The vector of x_n is OFDM signal vector and y_n is achieved by using classical amplitude clipping. The correction signal c_n is created by subtraction of the clipped signal y_n from the original OFDM signal vector x_n as in the following equations [14]:

$$y_n = \begin{cases} x_{n,} & |x_n| \le A_{max} \\ A_{max}e^{j\varphi(x_n),} & |x_n| \ge A_{max} \end{cases} \tag{5}$$

$$c_n^i = x_n^i - y_n^i, \tag{6}$$

where x_n the original OFDM signal, y_n is the clipped signal, A_{max} is the clipping magnitude level and c_n^i is the correction signal. Taking FFT result in:

$$C_k = FFT(c_n^i) \tag{7}$$

Some null will be applied in some positions of the result sequence, and the other values could be set to zero .

$$C_k^{\sim} = \begin{cases} C_k & K \in PRC \\ 0 & K \notin PRC \end{cases} \tag{8}$$

The time-domain signal $c_n^{\sim}$ is gained by taking IFFT for the signal $c_k^{\sim}$. The newly transmitted signal xni can be created by adding the $c_n^{\sim}$ to the original OFDM signal x_n:

$$\text{xni} = x_n + \mu c_n^{\sim} \tag{9}$$

Where μ indicates the value of weight factor. TR-C block diagram can be shown in Figure 2[14].

The absolute signal of sent signal xni can be evaluated by:

$$\text{Absolute Signal} = \text{ABS}(\text{xni}^2) \tag{10}$$

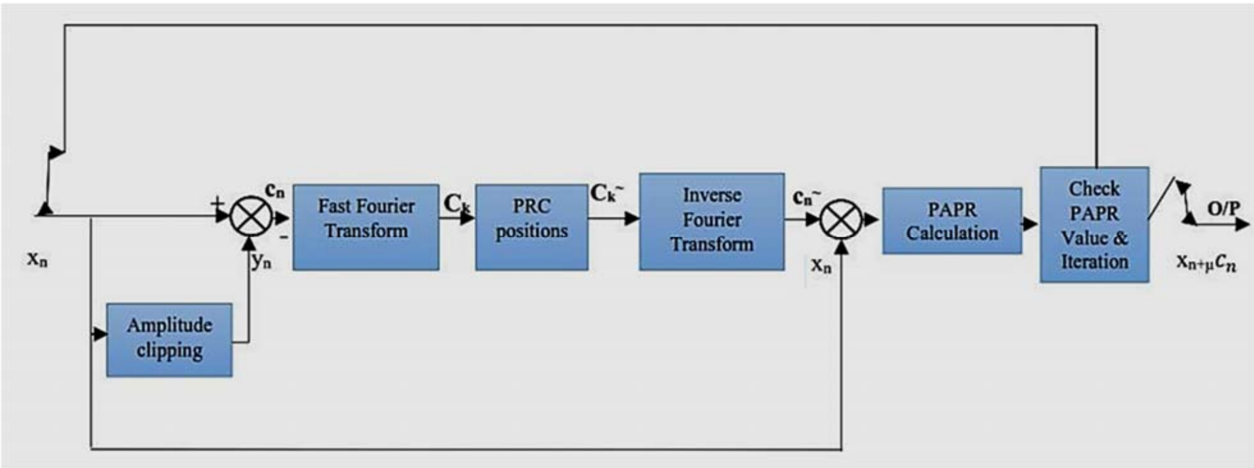

Figure 2. Block diagram of the clipping based TR [14]

IV. THE PROPOSED COMBINED SLM AND TR-C METHOD

In this proposed method, a data of 1024 symbols will be modulated with 4 QAM modulation. This signal is first applied to the TR-C method with a number of Peak Reducing Carriers (PRC) of 10, clipping magnitude with a value of 3, and 5 iterations. The 1024 data stream is first modulated with 4 QAM modulation. Then the modulated signal is applied to IFFT process to get the OFDM signal xn. This signal will be applied to the TR-C method where it will be added to the correction signal resulting from the TR-C method. After some iterations, the peak values will be reduced in the original signal. Then, the resulting signal will be applied to the SLM method in which a set of phases will be created. These random phases will be responsible to drop the peaks in OFDM signal to get the lowest PAPR value as in Figure 3. This absolute signal will be input for the SLM process.

The PAPR of the OFDM signal in single symbol period can be determined by [14].

$$PAPR = 10\ log_{10}(\text{Ppeak} \ |\text{Pav}) \tag{11}$$

where P_{peak} and P_{av} can be computed as:

P_{peak}= max | s (n) $|^2$ and $P_{av} = E[|s(n)|^2]$

Therefore, the PAPR can be computed by:

$$PAPR = 10\, log_{10} \frac{\max | s\ (n)\ |2}{E[|s(n)|^2]} \qquad (12)$$

where $|s(n)|^2$ stands for the peak signal power, P_{av} is average signal power, and E{.} is the expected value operation. Generally, the input and output signal of IFFT always stand for random data.

Complementary Cumulative Distribution Function (CCDF) represents PAPR distribution that indicates the time amount for a signal to spend more than the level of average power of measured signal and can be given by [14]:

$$CCDF = 1 - Pr\ (PAPR\ \leq \text{Dth}) \qquad (13)$$

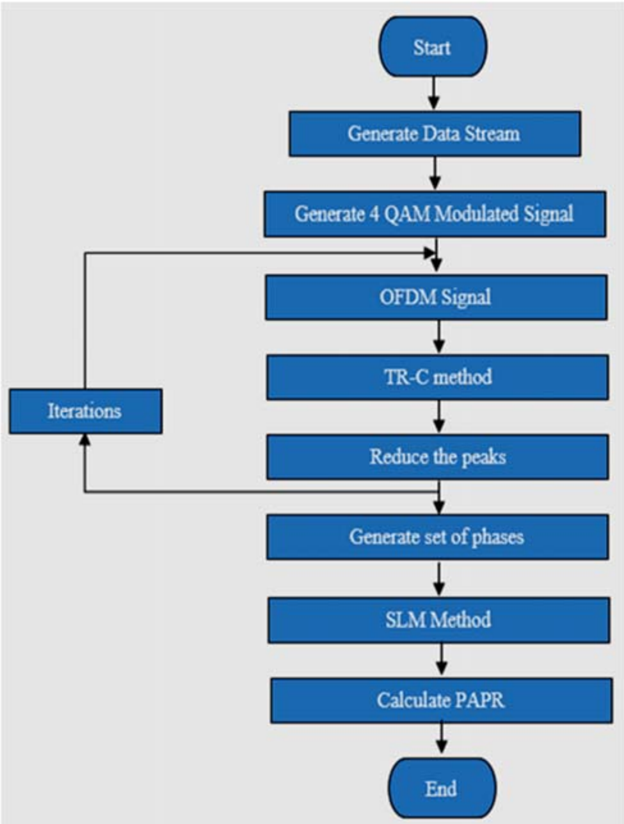

Figure 3. TR-C+SLm flowchart

V. Simulation Results and Discussions

In this section, simulation results of the PAPR reduction using various numbers of subcarriers are considered. The results below depict that the increase in the number of subcarriers results in raising values of PAPR. The CCDF is used to measure the value of PAPR effectiveness in reduction methods.

Figure 4 shows the performance of TRC method for QAM OFDM system with different number of subcarriers. The value for PAPR is 9.1dB for 64 subcarriers, 10.7 for 512 subcarriers, and 10.85 for 1024 subcarriers. Figure 5 depicts SLM method performance for QAM OFDM method where the PAPR is 6.8db for 64 subcarriers, and the PAPR is 8.36dB, and 8.65 dB for N= 512, and 1024 respectively.

The performance results for the combined TRC pulse SLM method for 4 QAM OFDM system are recorded in Figure 6. When the number of subcarriers is 64, the PAPR is 5.8dB while the PAPR value is 7.8dB for N=512 and 8.4dB for N= 1024. It is clear that PAPR is proportional to subcarriers number in all above PAPR reduction methods. Also, the combined technique outperforms the SLM and TRC method since the PAPR values in this method are the lowest.

Figure 7 depicts the PAPR values between original OFDM, TRC, SLM, PTS, and TRC plus SLM technique. It is clear that the proposed technique has a high performance than the performance of the original OFDM, TRC, SLM, and PTS method where the value of PAPR for TRC plus SLM is 8.5 dB, and the value of PAPR is dB, 9.31dB, 11.01dB, 8.62dB, and 11.59 dB for PTS, TRC, SLM, and original OFDM respectively for the 4 QAM OFDM system.

Figure 8 illustrates the proposed TRC plus SLM technique for different modulation schemes which are BPSK, 4 QAM, and 16QAM. The figure shows that the performance of the technique has somewhat slight changed results for these modulations although 4 QAM and 16QAM uses higher bits than BPSK. This, of course, is advantageous outcome since it is well known that PAPR significantly increases as number of modulated bits increases.

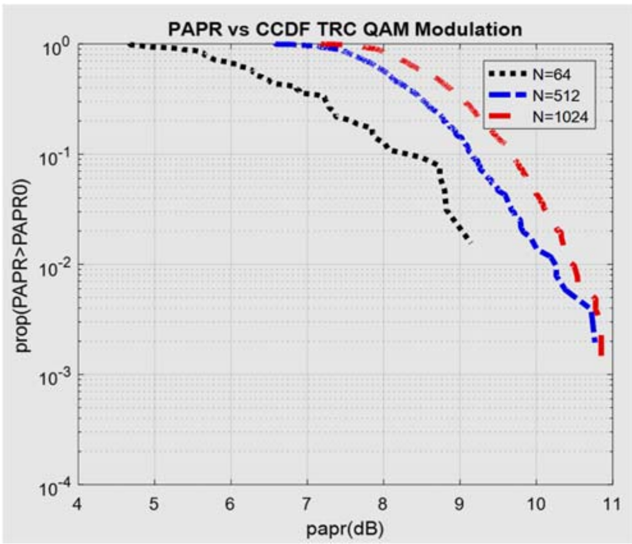

Figure 4. TRC method for QAM OFDM method with different number of subcarriers

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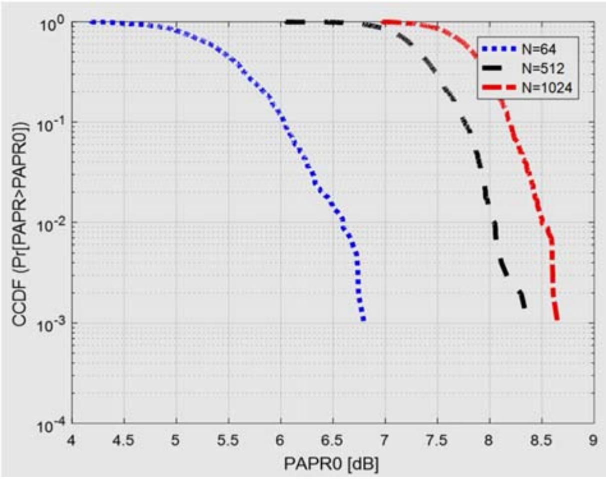

Figure 5. SLM Method for QAM OFDM System with different number of subcarriers

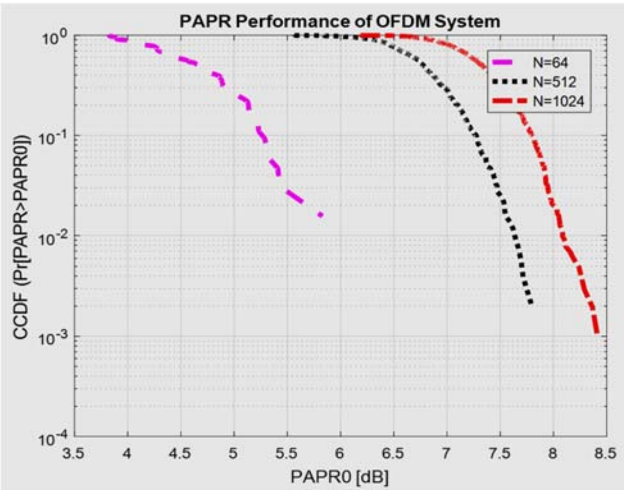

Figure.6. TRC-SLM Combined method for 4QAM OFDM System with different number of subcarriers

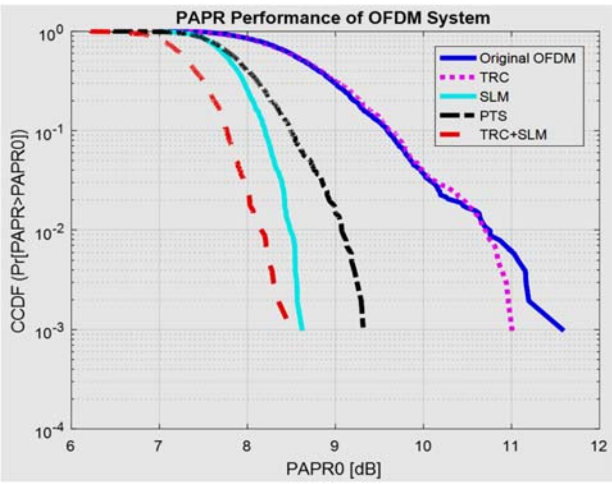

Figure 7. Original OFDM, TRC, SLM, PTS Vs and combined TRC SLM Technique under 4 QAM condition and N=1024

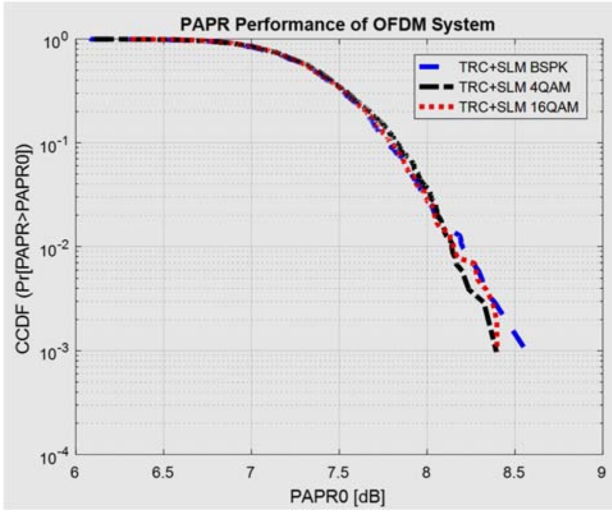

Figure 8. TRC-SLM performance for different modulation schemes

VI. CONCLUSION

This paper has submitted a new PAPR reduction technique by integrating two methods of PAPR reduction which are TRC and SLM algorithms. Firstly an OFDM signal is treated with TRC technique, and after a number of iteration, the resulting signal with reduced PAPR value is processed with the cascaded SLM technique with set of phases. Minimum PAPR value is produced. The simulation result for a different number of carriers (N) and different modulation schemes show that the proposed technique provides a better PAPR reduction value than of TRC and SLM methods separately. In addition to that, it outperforms the PTS method for a different number of carriers and different modulation schemes. Future works are possible by employing higher iterations to get possible lowest PAPR value. Also, optimizing techniques can be adopted to enhance the reduction of PAPR as in Genetic Algorithm and Particle Swarm.

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