PAPR MINIMIZATION IN SC-FDMA AND OFDM FOR LTE UPLINK AND DOWNLINK

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Abstract : Long term evaluation (LTE) and LTE advanced (LTE-A) systems should have spectral efficiency, high data rate transmission capability, both inter symbol interference (ISI) and multipath fading free transmission to accommodate more users and applications. Hence, in LTE uplink, a single carrier frequency division multiple access (SC-FDMA) and in downlink, orthogonal frequency division multiplexing (OFDM) are preferred. In this paper, a low complexity selective mapping (LC-SLM) in which both the computational complexity and length of the side information (overhead) is reduced along with the PAPR. The SC-FDMA is a low PAPR version of the OFDM. The PAPR reduction performance of the LC-SLM and SC-FDMA for various modulation schemes and number of subcarriers in OFDM is analyzed.

IndexTerms - ***OFDM, SC-FDMA, PAPR, SLM, LTE-Advanced.***

I. INTRODUCTION

The main requirements of modern wireless communication systems are to i) support high-data-rate transmission, ii) optimum utilization of the spectrum, iii) both fading and inter-symbol interference-free transmission in order to accommodate more users and applications. In general, single carrier frequency division multiple access (SC-FDMA) and orthogonal frequency division multiplexing (OFDM) systems fulfil the fore mentioned requirements [1]. The SC-FDMA is a single carrier FDMA scheme and deals with the multiple users and utilizes discrete Fourier transform (DFT) spread OFDM. Hence, the SC-FDMA is a modified form of OFDM with similar throughput performance and complexity [2]. The SC-FDMA is viewed as DFT-coded OFDM in which data symbols are transformed from time-domain into frequency-domain by the DFT prior to OFDM modulation. The one of the principal applications of SC-FDMA is LTE uplink [3]. The Peak to average power ratio (PAPR) of SC-FDMA is inherently low compared to the OFDMA and reduces the base station (BS) power amplifier back-off in both SISO and MIMO systems. Moreover, the bit error rate (BER) of SC-FDMA is better at the user end compare to OFDMA [4, 5].

The OFDM, not only mitigates both the inter symbol interference (ISI) and multipath fading, but also supports higher data rate transmission. Moreover, due to its capability of spectral overlapping, the OFDM is spectral efficient. Because of its numerous advantages, the OFDM has been preferred in several applications such as digital audio broadcasting, high definition television, Wireless LAN, WiMax , IEEE 802.20, long-term evolution (LTE) and the LTE-Advanced (LTE-A) systems. However, due to coherent addition of sub carriers, the peak power of the OFDM signal is very high and leads to high PAPR. [6]. High PAPR requires a large dynamic range in ADC, creates in-band distortion and out of band radiation. Several techniques have been proposed for PAPR reduction such as signal clipping, clipping - recursive filtering, coding, tone injection (TI), tone reservation (TR), active constellation extension (ACE), partial transmit sequence (PTS), and selective mapping (SLM) so on and so forth. The SLM is one of the best methods for PAPR reduction in OFDM systems [7]. However, the computational complexity (CC) is the main drawback in traditional SLM. Modified SLM greatly reduces the CC by generating more candidate blocks with less number of IFFTs [8].

II. SC-FDMA Modulation

The SC-FDMA transmitter system is shown in fig 1 in which the modulation symbols are grouped into symbols with length of N. Then, the input symbols are converted into the frequency domain by using M-point DFT and these symbols are mapped to the N (N>M) orthogonal subcarriers. For minimizing the ISI, some portion of the present symbol (tail of the symbol) is appended to the header of the next symbol and is termed as cyclic prefix (CP) and then linear convolution becomes circular convolution and array multiplication of the DFT samples indicates the frequency domain of the data.

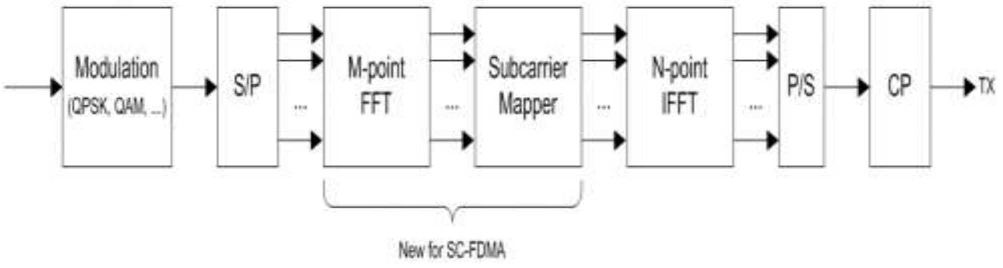

Figure.I.1: Block diagram of SC-FDMA

III. OFDM SYSTEM

In an OFDM, M information bits are grouped into N symbols (X_k) and the symbols are modulated on N mutually orthogonal subcarriers. Each subcarrier bandwidth is equal to total bandwidth (W) of the system over the N. The value of N should be selected such that, the subcarrier bandwidth (W/N) should be less than the coherence bandwidth (B_c). This process increases the symbol duration by N times and frequency selective fading channel becomes flat fading channel. OFDM signal can be represented as

$$x(t) = \frac{1}{\sqrt{N}}\sum_{K=0}^{N-1} X_k e^{j2\pi f_k t}, \qquad 0 \le t \le NT \qquad (1)$$

where $j = \sqrt{-1}$.

3.1 PAPR problem in OFDM:

Before the IFFT process in an OFDM, the input sequence average power is the maximum value of autocorrelation. The IFFT operation is the multiplication of exponential function to the input, summation and sampling the results. Due to high correlation property of IFFT input, resulting a large amplitude. Thus, in an OFDM signal, the peak power is far greater than the average power and leads to high PAPR. High PAPR moves the operation of OFDM signal into the saturation region of power amplifier and creates signal distortion and radiation. The PAPR of OFDM signal x(t) can be defined as

$$PAPR[x(t)] = \frac{P_{peak}}{P_{average}} = 10log_{10}\frac{max[|X(n)|^2]}{E[|X_n|^2]} \qquad (2)$$

where E[ ] denotes expected value. Increase in N, increases the peak of an OFDM signal due to its Rayleigh distribution and its probability exceeds a threshold

$$\left(P_0 = {\sigma_0}^2 / {\sigma_n}^2\right).$$

$$P(PAPR \ge P_0) = 1 - (1 - e^{-P_0})^N \qquad (3)$$

Let there are N Gaussian iid random Variables x_n; $0 \le n \le N-1$ with zero mean and unit power. Average power $E_n = (x[n])^2$ is

$$E\left[\frac{1}{\sqrt{N}}(|X_0 + X_1 + X_2 + \cdots + X_{N-1}|)^2\right]$$

$$\frac{1}{N}E(|X_0 + X_1 + X_2 + \cdots + X_{N-1}|)^2$$

$$\frac{E|x_0|^2}{N} + \frac{E|x_1|^2}{N} + \cdots + \frac{E|x_{N-1}|^2}{N} = 1$$

For N coherent subcarriers, the maximum expected value is

$$Max\left[\frac{1}{\sqrt{N}}(|X_0 + X_1 + X_2 + \cdots + X_{N-1}|)\right]^2$$

$$= [\left|\frac{N}{\sqrt{N}}\right|]^2 = \left|\sqrt{N}\right|^2 = N$$

Hence, for an OFDM with N subcarriers, the PAPR is N times the single carrier signal. Lot many schemes are existed to reduce PAPR and from the literature, it is found that the SLM is one of the best PAPR reduction schemes.

3.2 CONVENTIONAL SLM

In an SLM scheme, initially M independent sequences of same information are array multiplied with phase sequence, and then, the resulting M statistically independent data blocks $S_m = \left[S_{m,1}, S_{m,2}, \ldots\ldots, S_{m,N}\right]^T$, $m = 1,2,3 \ldots\ldots, M$ are applied to IFFT. The PAPR of M vectors are calculated and the sequence with minimum PAPR is selected for transmission as shown in Fig.1. Several phase sequences such as Hadamard, Riemann, Shapiro Rudin, Chue, Chaotic, Pseudorandom and so on forth can be used in SLM for PAPR reduction [9]. Due to its unity variance and simplicity, the Hadamard phase sequence [10] is considered for PAPR reduction in SLM OFDM system. The elements of phase sequence $P1$ are set to 1 to produce the original signal. The symbols in branch can be expressed as

$$S_m = \left[X_1 V_{m,1,} X_2 V_{m,2,} \ldots\ldots, X_N V_{m,N}\right]^T \qquad (4)$$

and then transfer M OFDM frames from frequency domain to time domain by performing IFFT operation. The entire process is given by

$$x_m(t) = \frac{1}{\sqrt{N}} \sum_0^{N-1} X_n V_{m,n} \,.\, e^{j2\pi n \triangle f t} \qquad 0 \leq \mathrm{t} \leq \mathrm{NT},\ m = 1,2,3 \ldots . M \quad (5)$$

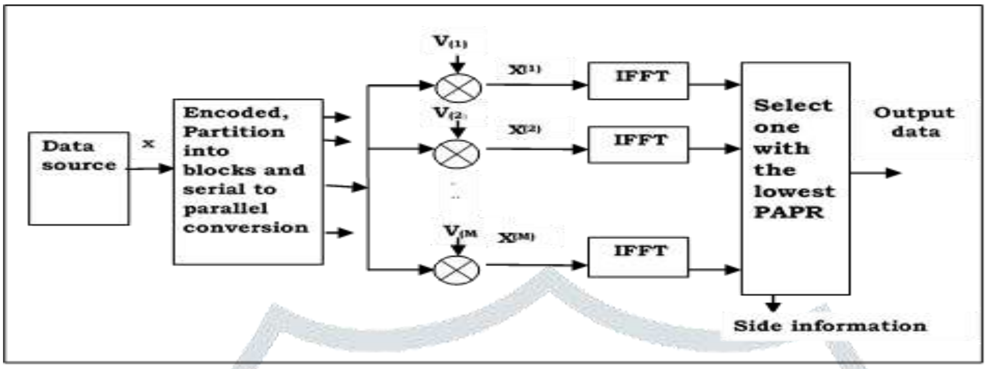

Figure 1. Block Diagram of Selective Level Mapping

The sequence with minimum PAPR is selected for transmission and can be modelled as

$$x_d = argmin_{1 \leq \mathrm{m} \leq \mathrm{M}}\left(PAPR(x_m)\right) \qquad (6)$$

3.3 Low complexity SLM

Low complexity SLM (LC-SLM) in which more number of candidate blocks with less number of IFFTs are generated. As the performance of PAPR reduction depends on number of candidate blocks, LC-SLM greatly reduces computational complexity at the marginal cost of PAPR reduction. In LC-SLM, outputs of IFFTs and complex conjugates of IFFT outputs are linearly combined as shown in Figure3 and explained in [8].

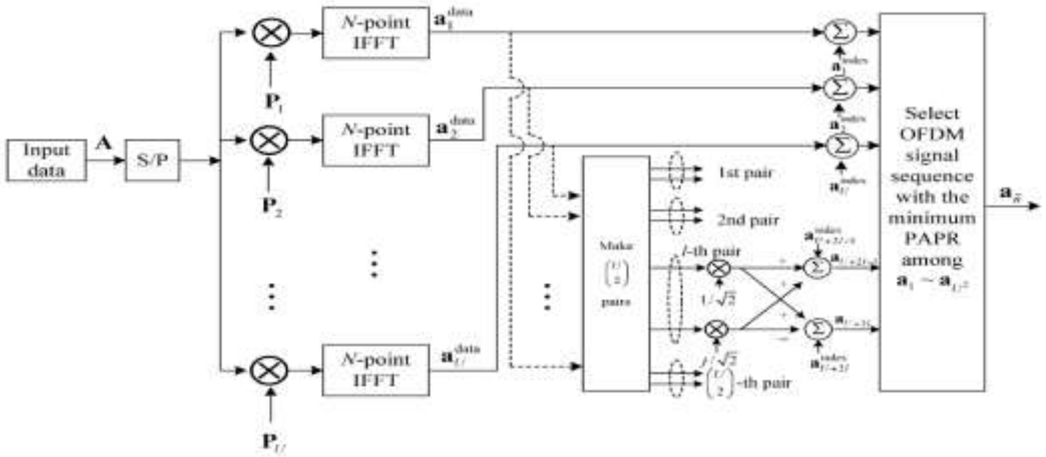

Figure.2: block diagram of Low Complexity SLM scheme

IV. RESULTS AND DISCUSSION

In this work, SC-FDMA and SLM-OFDM systems which are suitable for LTE uplink and downlink respectively are implemented. In SC-FDMA, the PAPR performance is analyzed by varying the size of the IFFT and FFT. Figure 3 shows the lower PAPR of SC-FDMA compared to conventional OFDM. The variation of PAPR performance for different orders of QAM (4QAM, 8QAM and 16QAM) is shown in figure 4. Figure 4 shows an improved PAPR performance with increase in order of modulation. Figure 5 and figure 6 show the PAPR performance variation with change in size of IFFTs and FFTs. 16 IFFT and 128 FFT show superior PAPR reduction performance over the lower order IIFTs. Figure 7 compares the PAPR reduction performance of conventional SLM and low complexity SLM. The PAPR reduction performance for different candidate blocks is observed in figure 8. Better PAPR reduction is achieved with increase in number of candidate blocks at the marginal cost of side information length which is used for recover of data at the receiver.

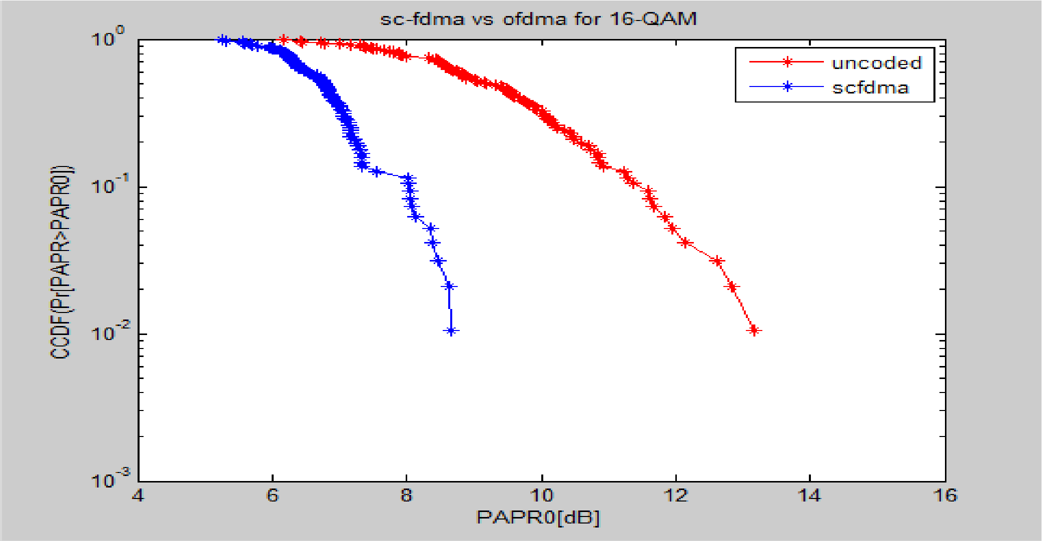

Figure 3: PAPR comparison of SLM and SC-FDMA systems.

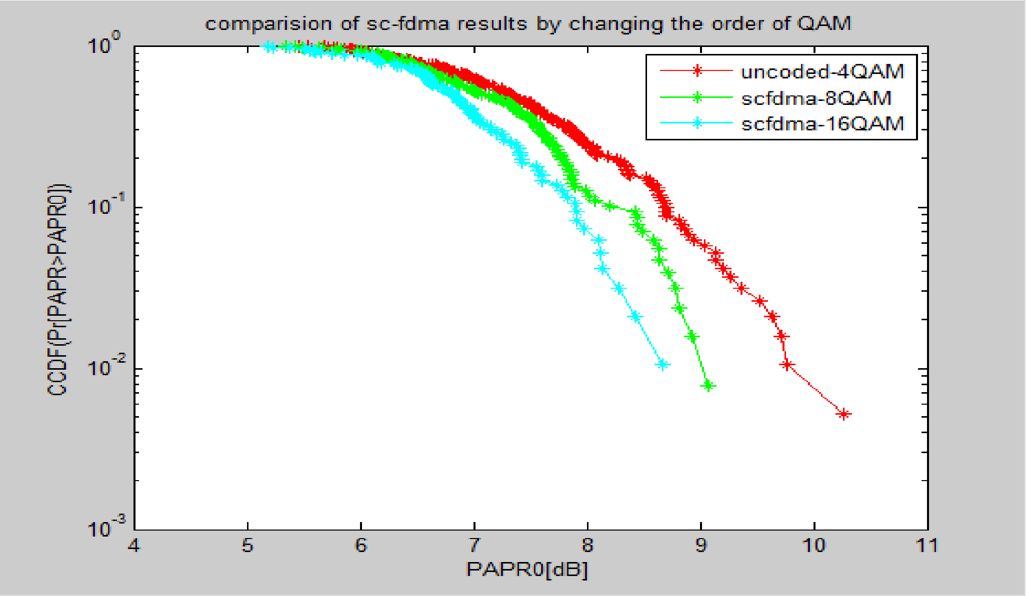

Figure 4: PAPR variation for different orders of QAM.

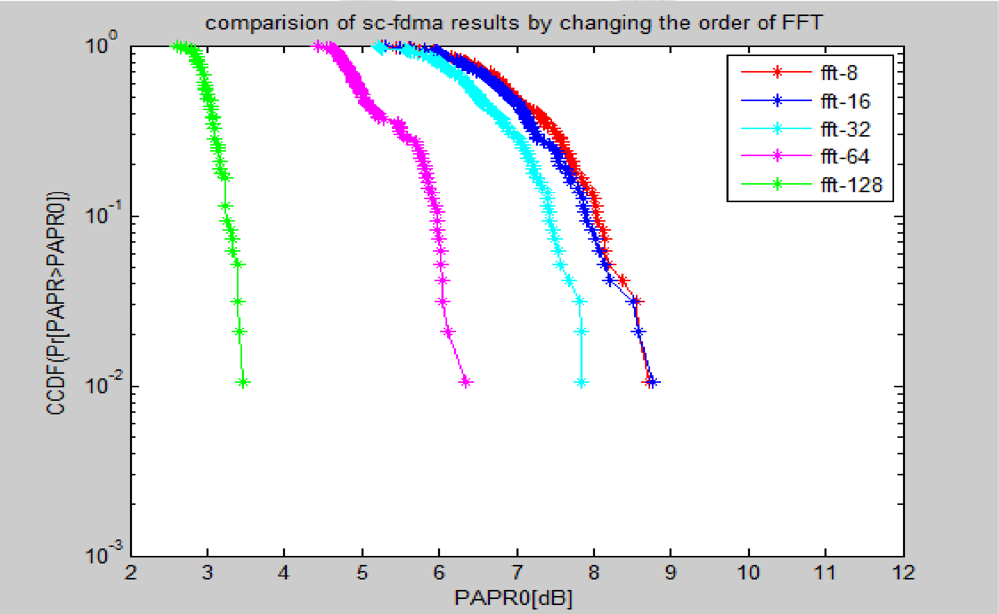

Figure 5: PAPR variation with change in order of FFTs.

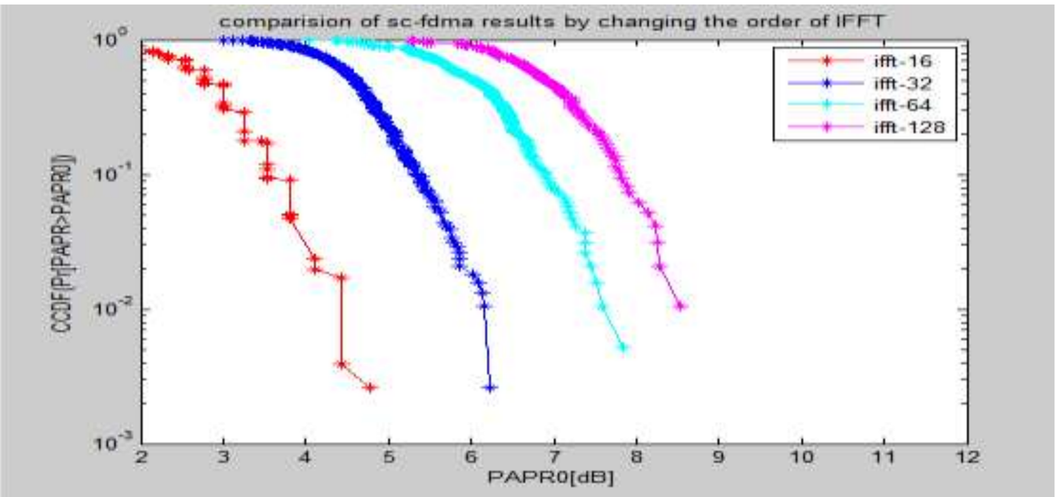

Figure 6: PAPR performance comparison in SC-FDMA system with change in order of IFFTs.

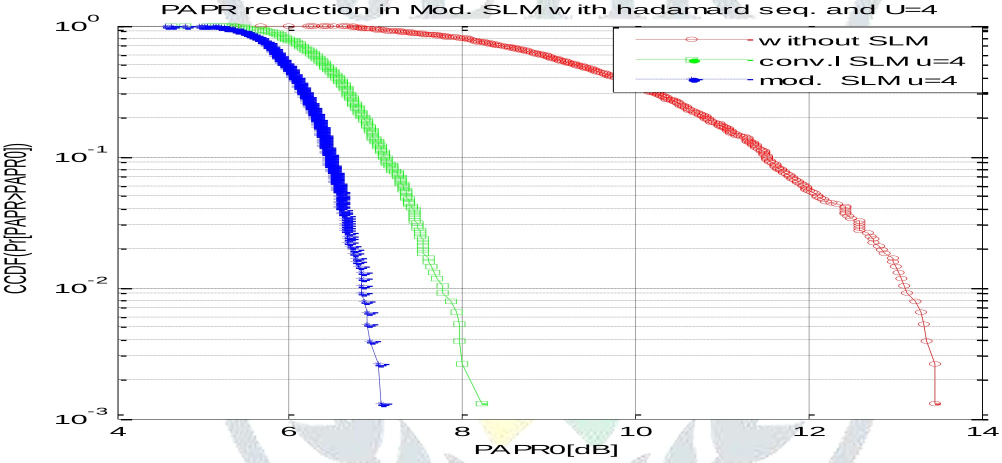

Figure 7 PAPR improvement in conventional and modified SLM over SLM free OFDM system.

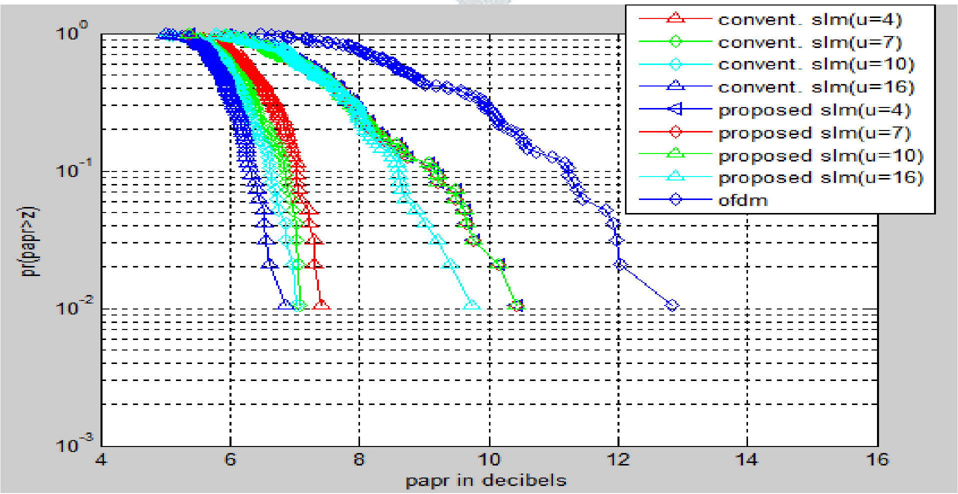

Figure 8: PAPR improvement of conventional and modified SLM for different number of candidate blocks.

IV. CONCLUSIONS

In this paper, SC-FDMA, SLM-OFDM are implemented and their PAPR reduction performance for various modulation schemes, number of subcarriers, and number of candidate blocks is analyzed. From the simulation results, it is concluded that PAPR reduction performance improves with increase in size of FFT whereas the PAPR reduction decreases with increase in size of IFFT in SC-FDMA system and the PAPR reduction performance improves with increase in candidate blocks in both SLM and LC-SLM. LC-SLM scheme greatly reduces the computational complexity of SLM at marginal cost of PAPR in OFDM systems.

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