International Journal of Research in Engineering, Science and Management
Volume-1, Issue-12, December-2018
www.ijresm.com | ISSN (Online): 2581-5792

Reduction of MIMO-PAPR by Residue Number System

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***Abstract*: The PAPR stands for peak to average power .In a multi-input-multi-output (MIMO) communication system there is a necessity to limit the power that the output antenna amplifiers can deliver. Their signal is a combination of many independent channels, so the demanded amplitude can peak to many times the average value. The orthogonal frequency division multiplexing (OFDM) system causes high peak signals to occur because many subcarrier components are added by an inverse discrete Fourier transformation process at the base station. This causes out-of-band spectral re growth. If simple clipping of the input signal is used, there will be in-band distortions in the transmitted signals and the bit error rate will increase substantially. This work presents a novel technique that reduces the peak-to-average power ratio (PAPR). It is a combination of two main stages, a variable clipping level and an Adaptive Optimizer that takes advantage of the channel state information sent from all users in the cell. Simulation results show that the proposed method achieves a better overall system performance than that of conventional peak reduction systems in terms of the symbol error rate. As a result, the linear output of the power amplifiers can be minimized with a great saving in cost.**

***Keywords*: MIMO, PAPR, residue number**

1. Introduction

This project addresses the problems that result from high peak-to-average power ratio (PAPR) levels in a multi-antenna communication system by devising a signal shaping method. Large-scale multi-input-multi-output (MIMO) systems are likely to be adopted as the technology for the fifth-generation wireless systems (5G). Such systems are also called massive MIMO, very large MIMO, hyper-MIMO, or full-dimension MIMO. The 5G system must be devised to accommodate the dramatic growth of mobile phones, tablets, laptop computers, smart watches, and other wireless devices. Having many advantages such as high communication reliability, high energy efficiency, and simple signal processing, large-scale MIMO is popular as a topic for research and exploitation. In Figure 1.1, orthogonal frequency-division multiplexing (OFDM) together with MIMO has been adopted by present and future wireless local area network (WLAN) standards such as IEEE 802.11a/g, IEEE 802.11n, and IEEE 802.11ac. It is a powerful multi-carrier modulation technique for gaining the bandwidth efficiency of the wireless communication systems. Moreover, one of the main reasons to use OFDM is to increase the robustness to withstand frequency selective fading and narrowband interference. As a result, the advantages of OFDM make this technology a promising alternative for digital broadcasting and communications.

The main disadvantage of an OFDM system is the large value of the high PAPR that results from the superposition of all subcarrier signals by an inverse discrete Fourier transformation (IDFT) process. High PAPR then causes waveform distortion because of any nonlinear amplifier characteristics, in particular the constrained output power. To resolve this problem, the transmitter would need to employ an expensive amplifier in each transmitting antenna.

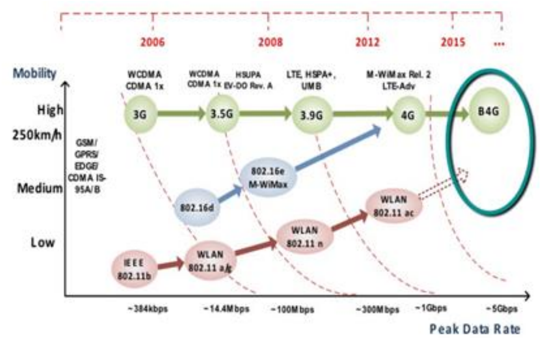


Fig. 1. Evolution of wireless standards in the last decade

A. *High power consumption*

The greatest power consumption in the OFDM systems is in the power amplifiers as shown in Table 1. They typically consume about 80% of the power budget of a base station (BS).

Table 1
Conventional BS average power consumption distribution

Appliances	**Estimated standard power (%)**
Power amplifier	80
Air conditioning	10
Signal processing	5
Power supply	5

Out of concern for the transmitting power, we wish to reduce the output signal to a small proportion of the maximum output power of the amplifiers. A small reduction of an individual transmitted power maps to a huge power reduction when a very large number of antennas are involved. Reducing that power is a key focus of this research. On the other hand, the signal processing's proportion of the power budget is only around 5%.

B. High cost of the amplifiers in the systems

Even though high values of PAPR have long been a problem in a single antenna of the OFDM transmission, the costs of the amplifiers are increased in proportion to the number of antennas in massive antenna systems. The use of expensive RF amplifier components is an undesirable way to solve this problem in the future. In consequence, many researchers have presented a variety of digital processing methods for reducing PAPR, both to tackle the high power consumption and the high price of the amplifiers of a large number of antenna systems.

2. Background

PAPR problems resulting from OFDM have long been known. Although there are remedies for single antenna systems, they become especially serious when an OFDM system is applied in multiple antenna systems. This problem negatively affects the high-power amplifiers (HPAs) at the front end of each antenna. To keep the desired information from the original signal in each HPA, the system should be designed to use as much of its dynamic range as possible. But when the uncorrelated multi-channel input signals combine to produce a peak amplitude, this would take the high power amplifiers into a nonlinear region. This will cause many negative effects causing nonlinear distortions, both out-of-band spectral and in band distortions. The out-of-band spectral affects other operators operating in the adjacent frequency bands whereas; the in-band distortion degrades the symbol error rate (SER) performance.

In the past, there have been many efforts to deal with the PAPR problems on a large-scale MIMO-OFDM system, resulting in numerous articles. In the integration between a multiuser (MU) pre coding, an OFDM modulation and a PAPR reduction (or a PMP scheme) was presented, where its aim was to reduce the large PAPR.

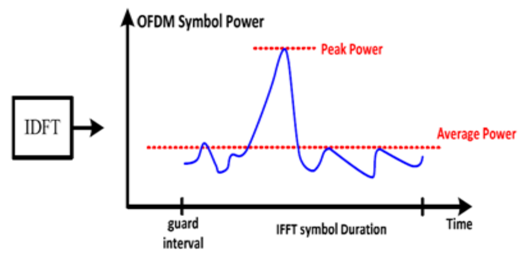
The fast iterative truncation algorithm (FITRA) was devised by Studer et.al. For shrinking the high level of PAPR. By using a constant envelope pre coding, the transmit power and hence the high PAPR of the large antenna of the BS is reduced efficiently. In, the weakest Eigen channels are employed for decreasing PAPR. It is utilized with least squares iterative for estimation the high peak level of the transmitted signal.

Lastly, in antenna reservation is used for clipped signals to compensate by transmitting correction signals on a set of reserved antennas.

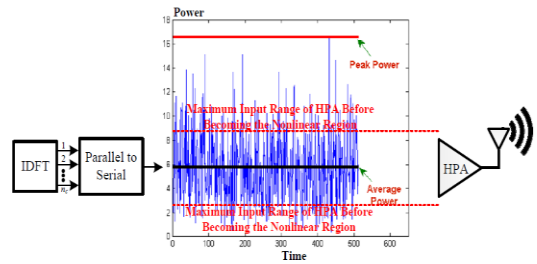
A method that is frequently used to address large PAPR is a fixed level clipping technique. As shown in Fig. 2, it is located after the IDFT and before the power amplifiers. This leads to in-band distortion in the form of inter modulation terms and spectral re growth into the adjacent channel.

This project focuses on decreasing the effects of both in-band and out-of-band distortions from the existing PAPR reduction methods for the large-scale MIMO-OFDM systems, along with a generalised transmission scheme and theoretical studies.

The research outcome of this project is able to be further implementation to enhance the wireless network throughput and SER performance of the next generation in wireless communication systems.

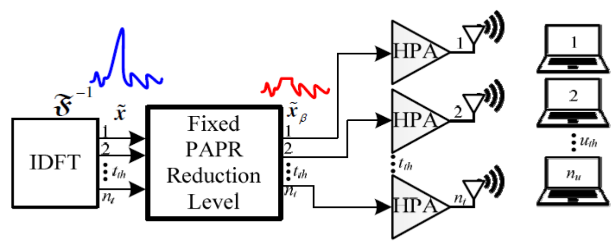


(a) The high peak power of PAPR signal in one subcarrier on OFDM system

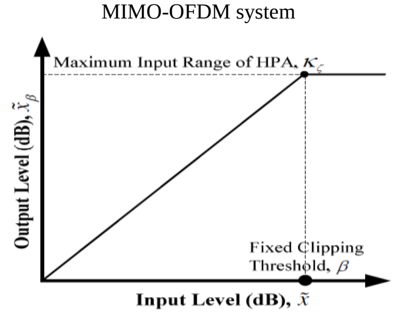


(b) The high peak power of PAPR signal in the multiple carriers on OFDM systems

Fig. 2. High dynamic ranges in OFDM symbols taken from

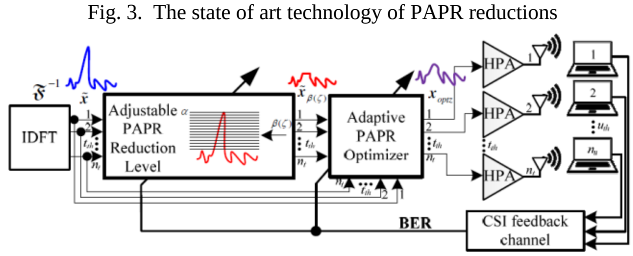


(a)The area of the conventional PAPR reductions in the downlink large-scale MIMO-OFDM system

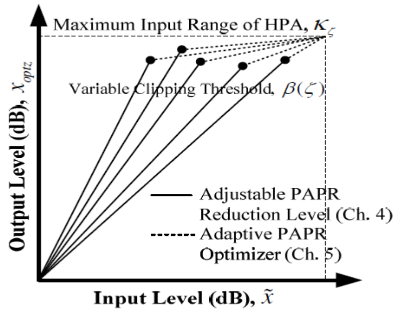


(b) The fixed PAPR reduction's input/output characteristic.

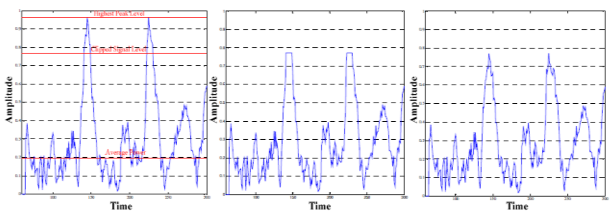
Fig. 3. The state of art technology of PAPR reductions



(a) The area of the proposed technique on the downlink large-scale MIMO-OFDM system



(b) The proposed technique's input/output characteristics
Fig. 4. The proposed technique of the adjustable PAPR reductions



(a) The original signal (b) The clipped signal (c) The expected signal
Fig. 5. An APO retains the transmitted signal before sending

3. Motivation and goals

Even though the negative effects of PAPR on OFDM system and the PAPR reductions are well understood, the literature on the similar analysis for equalizing the clipped signal is low. Practically, there is no existing material to optimize the clipped signal for PAPR reduction methods. In doing this, it is necessary to know if any of the PAPR reduction methods available for OFDM could be applied for the proposed technique and if so what are the modifications required. Furthermore, what are the negative impacts of the proposed scheme? How could it be improved by other techniques? These questions need to find answers to achieve the goals to mitigate the PAPR problems of the large-scale MIMO-OFDM systems.

In this project, a study is conducting on the negative effects of PAPR. It also seeks to find the new technique to relieve them. The main goals of this thesis are:

1. To establish a simulation setup in MATLAB to analyse PAPR reductions on the large-scale MIMO-OFDM system;
2. To analyse the negative effects of PAPR in the large-scale MIMO-OFDM system;
3. To invent a new method to relieve the PAPR problems;
4. To design an assistant tool for PAPR reduction to equalise the clipped signal; and
5. To propose and analyse the new versions of both a clipping scheme (CP) and a PMP.

4. Orthogonal frequency division multiplexing

OFDM is a kind of the frequency division multiplexing modulation. It is utilized as a digital multi-carrier modulation method. A large number of orthogonal subcarriers, *c n*, are employed to transport the pre coded data, x . This pre coded data is then divided into many several parallel streams by using a serial-to-parallel converter to each c n subcarrier. Each subcarrier is 2orthogonal to each other (or they are totally independent of one anther). Finally, the data stream is converted to frequency domain by employing an inverse discrete Fourier transform (IDFT). In this stage, each IDFT creates the high peak amplitude of PAPR into the data stream after reverting into a single data stream.

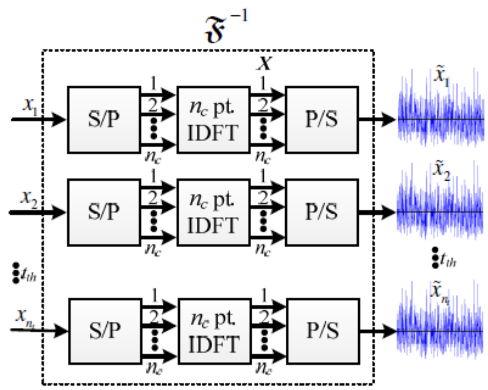


Fig. 6. Block diagram of an OFDM system for *t n* antennas

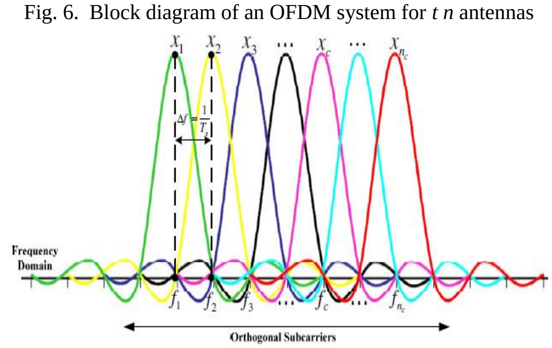


Fig. 7. The OFDM spectrum

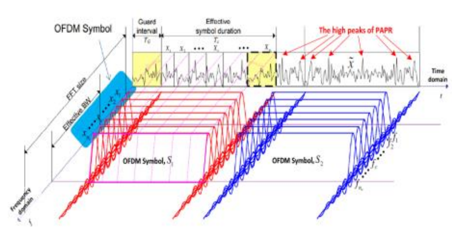


Fig. 8. Time/frequency-domain description of OFDM symbols

The main advantages of OFDM system can be listed:

1. More efficient assistance in multipath environments: the high-speed serial data will be transmitted by dividing up into many much lower-speed serial data signals. This technique makes the bit or symbol periods longer, therefore multipath time delays have less of an impact. In order to resist the multipath effects, the system needs to add more subcarriers over a wider bandwidth. It means that the higher frequencies can be used with fewer multipath effects.
2. Low-complexity processing: By the benefits of the

advances in a digital signal processing, the low-complexity processing can be used with a simple and efficient implementation.
3. Low-complexity at receivers: for the above reason, it can reduce the physical size of the terminals. Furthermore, it can decrease the power consumption on the wireless devices.
4. A variety of the modulation techniques: for a given chunk of spectrum space, the many modulation techniques are used for widely varying maximum data rates. Simple digital modulations can be employed on OFDM such as amplitude shift keying (ASK), frequency shift keying (FSK), binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), and Quadrature amplitude modulation (QAM).

On the other hand, the disadvantages can also be listed as:
1. *Doppler shifts:* a special form of multicarrier modulation by OFDM systems is more sensitive to Doppler spreads than the single-carrier schemes. They influence the carrier frequency offsets, affecting in intercarrier interference (ICI).
2. *Synchronisation accuracy:* another problem of OFDM is the inaccurate synchronisation. Even though the effective OFDM synchronisation enables the data error rates to be kept to a minimum, error rates are exponentially increased by this problem.
3. *Noise sensitiveness:* OFDM is sensitive to high amplitude impulsive noise because the noise energy spreads among all OFDM subcarriers increasing bit error rate (BER) in the overall systems.
4. *The high amount of PAPR*: the main drawback of an OFDM signal is a high peak of PAPR. Subsequently, the transmitted signal needs to gain itself with the expensive power amplifiers. That means the greater efficiency in the radio frequency (RF) power amplifiers, the higher cost and the more power consumption in the systems.

5. PAPR of MIMO-OFDM

The PAPR of output signals at each antenna is defined as the ratio between the maximum peak power and the average power,

$$PAPR_{n_t} = 10\log\frac{\max\{|s_{n,k}|^2\}}{E\{|s_{n,k}|^2\}} \quad (1)$$

$$(n_t = 1,2,\ldots,N_T; k = 0,1,2,\ldots.,N-1)$$

In MIMO-OFDM, the PAPR of all T N transmit signals should be simultaneously as small as possible, which is defined as,

$$PAPR = \max\{PAPR_1, PAPR_2, \ldots, PAPR_{N_r}\} \quad (2)$$

$$P\{PAPR > z\} = 1 - \{PAPR \le z\} = 1 - (1 - e^{-z})^N \quad (3)$$

In MIMO-OFDM, since the NT number of antennas, the CCDF is presented,

$$P\{PAPR > z\} = 1 - \{PAPR \le z\} = 1 - (1 - e^{-z})^{N_T N} \quad (4)$$

It can be seen from (3) and (4) that the PAPR performance of MIMO-OFDM systems is even worse than that of OFDM.

A. *Partial transmit sequence in MIMO-OFDM*

The block diagram of partial transmit sequence (PTS) scheme in MIMO-OFDM is shown in Fig. 9. In each antenna channel it is a single antenna PTS-OFDM. It partitions an input data block of N symbols into M disjoint sub-blocks as follows:

$$X = [X^0, X^1, \ldots., X^{M-1}]^T \quad (5)$$

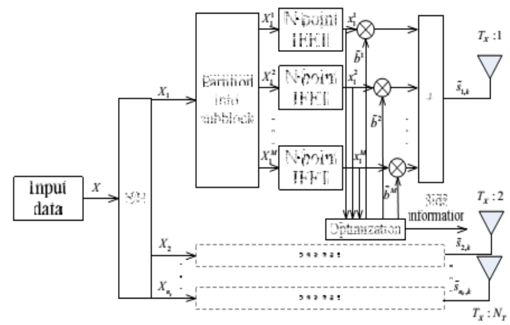


Fig. 9. The block diagram of PTS scheme in MIMO-OFDM

Then each partitioned sub-block is multiplied by a complex phase factor $b^\mu = e^{j\phi\mu}, \mu = 1, 2, \ldots, M$, subsequently taking its IFFT to yield

$$x = IFFT\{\sum b^\mu X^\mu\} = \sum b^\mu x^\mu \quad (6)$$

After the PAPR comparisons among the candidate sequences, the optimal phase factor b^μ can be got. And the corresponding signal in the n_t antenna with the lowest PAPR can be expressed as

$$\bar{s}_{n,k} = \sum \bar{b}^\mu x^\mu, 0 \le k \le N-1, \; 1 \le n_t \le N_T \quad (7)$$

B. *RNS-based PAPR reduction*

An RNS is defined by the relative prime modulus set$m_v(v = 1,2,\ldots V)$. Any integer R can be represented in RNS by residue sequence$\{r_1, r_2, \ldots, r_v\}$.

$$r_v = R(mod\ m_v) \quad (8)$$

The number r_v is said to be the residue of R with respect to m_v, and we shall usually denote this by $r_v = <R>_{m_v}$. In this sense, a big integer can be converted into the small residues in RNS, and these residues are always smaller than the corresponding modulus. The integers in the range of $[0, M_I)$ can be represented in this RNS uniquely and unambiguously, where $M_I = \pi_{i=1}^{V} m_v$ is referred to as the information dynamic range, i.e., the legitimate range of the information symbol.

The information symbols can be uniquely recovered by residue sequence through CRT, which is one of the fundamental theorems of RNS. The relationship between the information symbols R and its residues is as follows

$$R = \left(\sum S_v < \frac{1}{S_v} >_{m_v} r_v\right) mod M_I \quad (9)$$

International Journal of Research in Engineering, Science and Management
Volume-1, Issue-12, December-2018
www.ijresm.com | ISSN (Online): 2581-5792

where $<\frac{1}{S_v}>_{m_v}$ called as multiplicative inverse of s_v, $S_v = \frac{M_I}{m_v}$ and $\left(S_v <\frac{1}{S_v}>_{m_v}\right) mod\ m_v = 1$.

The definition of signed number in RNS is similar to that in TCS (Two's Complement System). An integer R in the legitimate range $[0, M_I)$ can be represented as a signed number, $\bar{R}$ .Then if $0 \le R \le \left[\frac{M_I}{2}\right]$ or $\left[\frac{M_I}{2}\right] \le R \le M_I$, $\bar{R}$ is positive and negative respectively, where $[x]$ denotes the smallest integer larger than x .

The basic diagram of RNS-based PAPR reduction scheme in MIMO-OFDM is given in Fig. 10.

The number of modulus $\{m_1, m_2, \dots, m_V\}$ is V, and the input are converted into V residues by the corresponding modulus set, and the number of transmit antennas equals the number of residue sub-channels. These residue signals are preformed OFDM modulation in the corresponding residue channels. In the each of the V parallel residue sub-channels one IFFT of length N is employed.

The function of mapping module, if the input is positive, it can be sent into B/R (binary to residue) module directly; otherwise the input adds the legitimate M_I before B/R.

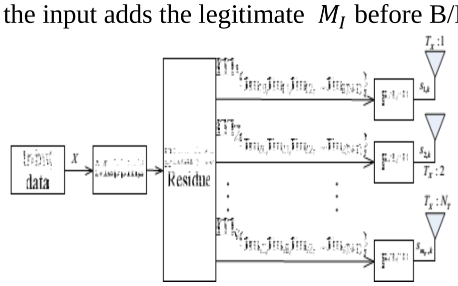


Fig. 10. The basic diagram of RNS-based scheme in MIMO-OFDM

Through B/R conversion, the serial data streams are divided into V parallel residue sub-channels transmitting signals.

In each residue sub-channel, the residue sequences $\{r_{m,0}, r_{m,1}, \dots, r_{m_v(N-1)}\}$ which correspond to the modulus r_v residue sub-channel are transmitted into IFFT module respectively. The output corresponding to the modulus v m residue sub-channel after IFFT is represented as follows.

$$s_{m_v k} = s\left(\frac{kT}{n}\right) = \sum r_{m,i} \exp\left(j\frac{2\pi ik}{N}\right) \quad (0 \le k \le N-1, 0 \le i \le N-1) \tag{10}$$

6. Simulation results

In this section, some simulations are employed to demonstrate PAPR reduction performance and computational complexity comparison between the proposed scheme and the original PTS scheme. The OFDM symbol of each antenna channel contains 2048 subcarriers, and for simplicity, we expect all N sub-carriers to be active.

A. Complexity analysis

In this part, the overall computational complexity of RNS scheme in MIMO-OFDM will be discussed. A complex complication takes 4 real multiplications and 2 real additions, and a complex addition requires 2 real additions. Furthermore, it can be assumed that the complexity of a real multiplication equal the complexity of 4 real additions. In the RNS scheme according to (10), it needs the number of modulus V N-pointed IFFT operations. Considered the input as the complex signal, a modular addition would take 6 real additions in the most complexity situation and a modular multiplication would take 30 real additions. $|s_{n,k}|^2$ is calculated to determine the PAPR, which requires 2VN real multiplications and VN real additions.

As to computational complexity, compared with PTS, the RNS-based PAPR reduction scheme in MIMO-OFDM can result in 42.2% and 93.9% reduction in equivalent real additions for M=3 and M=8, respectively.

Note that in PTS scheme the complexity of searching increases exponentially with the number of sub-blocks. In the comparison, the implementation of RNS-based PAPR reduction scheme is supposed in the most complex way. However, the binary phase factors of {1,-1} are used, i.e. W=2, the computational complexity of the rotation of each sub-block for the PTS scheme is reduced.

The proposed scheme has the potential to reduce the computational complexity compared with PTS-MIMO-OFDM scheme.

B. PAPR reduction

The performance of PAPR reduction is evaluated by CCDF. To compare with the original PTS scheme in MIMO-OFDM, we assume the antenna number of two schemes and the subcarrier number in each sub-channel are the same. Each OFDM symbol contains N = 2048 subcarriers throughout, where the number of input symbols is 1000. The parameter used for simulation is shown in Table 2.

Table 2
Parameter used for simulation of PAPR

Parameters	**Value**
Subcarrier number N	2048
The number of input symbols	1000
Antenna number, N_T	3
Modulation format	64QAM/4QAM
Module number of RNS, V	3
Module set of RNS	{128, 127, 63}
PTS Sub-block number, M	3/8
PTS phrase factor	{1, -1}

7. Conclusion

An RNS-based PAPR reduction scheme in MIMO-OFDM is presented in this paper, which utilize the properties of RNS and characteristic of RNS modular operation to effectively reduce the PAPR without side information. Theoretical analysis and simulation results demonstrate the proposed scheme outperforms the PTS scheme in the PAPR reduction performance and the computational complexity.

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