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Performance analysis of Optimal Orthogonal Spreading Codes for wireless CDMA system

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Abstract: *Spreading codes plays a vital role in wireless communication system .It is used in code division multiple access system (CDMA) to serve more number of users with different spreading codes like orthogonal and non orthogonal spreading codes. Here our objective is to found a proposed algorithm for generation of "New orthogonal spreading code" which provides a large no of spreading codes by simultaneously reducing the effect of multiple access interference (MAI) and intersymbol interference (ISI) by maintaining minimum correlation in CDMA system and also the bit error rate (BER) performance of proposed code by using AWGN channel is evaluated. Also the performance comparison between proposed code and the existing code like Walsh code, orthogonal gold code, PN sequence and orthogonal Kasami code takes place. Finally the best result has been established by the proposed code over the existing code.*

Keywords - *AWGN, CDMA, BER, ISI, MAI*

I. Introduction

In Code Division Multiple Access (CDMA) technique, all the users transmit their information simultaneously over the same available channel bandwidth. Thus, they are neither time nor frequency division multiplexed and rather code division multiplexed. Each user is assigned a distinct spreading code, which is used as a signature code for that particular user. In order to serve more and more users, the number of distinct codes should be high enough. Also, we have to ensure that the cross-correlation between any pair of distinct codes must be as minimum as possible so as to allow a very little inter-code interference, thus improving the performance of the system in multiuser scenario. Since bandwidth is a limited resource, one of the primary objectives is to minimize the required transmission bandwidth. Code division multiple access (CDMA) is a center of attention of academic researchers from several years .The advantages' of this system is in comparison to other multiple access system like TDMA and FDMA is frequency reuse and multiuser detection .In CDMA system the entire band width is made available to each user and it is many times larger than the band width required to transmit information and such type of system is called spread spectrum system (SS). Spread spectrum employ a transmission bandwidth that is several orders of magnitude greater than the minimum required signal bandwidth. While this system is very bandwidth inefficient for a single user, the advantage of spread spectrum is that many users can simultaneously use the same bandwidth without significantly interfering with one another. In a multiple-user, multiple access interference (MAI) environment, spread spectrum systems become very bandwidth efficient .so in order to utilize the total bandwidth we use large number of users. In this paper [1] he has giving a new approach towards spread spectrum modulation and CDMA concept. It presents several design considerations including the formation of the spreading signal. Coding is a useful method and sometimes crucial for the control of interference in spread spectrum communication system which has been proposed in [2].Different type of spreading codes are used for giving a high-quality communication system which increases the system capacity. In [3] Deepak Kedia et al. have been proposed a CDMA system whose performance is based upon characteristics of user specific spreading codes. The objective of this paper is to emphasize the different factors disturbing the selection of these spreading codes and gives a performance evaluation of correlation properties of Orthogonal Gold codes, Orthogonal Golay complementary sequences and Walsh-Hadamard codes. In [4] Intersymbol Interference (ISI) always occurs when the communication channel is a multi-path channel .Many methods are used to reduce the effect of ISI. In this paper the autocorrelation property of the spreading codes which minimizing the ISI effect is consider. Here we obtain the spreading codes with minimum autocorrelation property. The results of comparing the average autocorrelation of the obtained codes with that of the well known Walsh codes gives a great improvement in the performance. Amayreh, A. I., & Farraj [5] proposed multiple access interference (MAI) appears in Code Division Multiple Access (CDMA) systems when the communication channel maintain more number of users at a time and the spreading codes are non-orthogonal. In this paper the cross correlation property of the spreading codes is consider, so we propose a method to find spreading codes with minimum magnitude of cross correlation. Using these codes the resultant MAI in the CDMA system is reduced; hence it will increase the system capacity. A vast progress is shown by comparing the cross correlation property of proposed spreading code with existing spreading code is found. In [6], minimum correlation spreading codes are presented in order to minimize the magnitude of auto correlation and cross correlation between spreading codes other than zero-shift. In this paper [7], we propose the generation of the orthogonal sets of codes which are able to maintain the properties of complete complementary codes. The proposed methods can be useful to any sequence with ideal two-level cross-correlation. The characteristics of CDMA codes for next Generation wireless CDMA systems contain availability of large number of codes, impulsive auto-correlation function, zero cross-correlation value and support for variable data rates. The properties of Gold sequence, Kasami Sequences, Pseudo Noise Sequences have been evaluated for CDMA based wireless systems. To reduce the Multiple Access Interference (MAI) in a synchronous system like the downlink mobile radio communication channel, the spreading sequences, or codes, are selected to be orthogonal. From the Spread Spectrum Characteristics of CDMA we observe that it has low power spectral density, privacy is more, and overall good performance. In [8] the author tells Walsh codes are error correcting orthogonal codes and PN sequences are generated sequences with random noises used in error free communication. This paper shows properties of Walsh codes and PN sequences and its implementation in software and hardware. Walsh codes encode n bit messages into 2n bit orthogonal code words. Original message can be recovered after one-fourth of the bits have been corrupted. PN Sequence is statistically random sequences with low correlation property. In paper [9] the cross correlation parameters and their properties of such sequences are as important as autocorrelation properties, and the system performance depends upon the aperiodic correlation in addition to the periodic correlation. This paper presents a survey of recent results and provides several new results on the periodic and aperiodic cross correlation functions for pairs of m-sequences and for pairs of related (but not maximal-length) binary shift register sequences These sequences are widely used in communication and cryptography. In paper [10] a novel approach towards orthogonal spreading codes is consider. Here in this paper we describe the performances of spreading codes when large number of user access the communication system at a time. The performance analysis based upon generation of large number of spreading code, minimum correlation properties of spreading codes and bit error rate performances in comparison to other existing spreading codes.

II. Numerical Background And Analysis

2.1. Walsh Code

A Walsh matrix is a specific square matrix, with dimensions a power of 2, the entries of which are +1 or −1, and the property that the dot product of any two distinct rows (or columns) is zero. Walsh codes are orthogonal codes. Walsh codes are generated using the Hadamard matrix. From the corresponding Hadamard matrix, the Walsh codes are given by the rows. We usually map the binary data to polar form so we can use real number arithmetic when computing correlations. So 0s are mapped to 1s and 1s are mapped to -1s.

$$W(0, 2) = \{1, 1\}$$
$$W(1, 2) = \{1,-1\}$$

Computing the orthogonality, we get:

$$(1 \times 1) + (1 \times -1) = 0 \quad W_1 = [0], \quad W_2 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \quad W_4 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix} \quad \text{and} \quad W_{2N} = \begin{bmatrix} W_N & W_N \\ W_N & \overline{W_N} \end{bmatrix}$$

The Walsh code for each string of length n having a hamming distance of 2^{n-1}. The Distance between any two Walsh codes is 2^{n-1}.

2.2. Gold Codes

A Gold code, also known as Gold sequence, is a type of binary sequence, used in telecommunication (CDMA). Gold codes have bounded small cross-correlations within a set. Gold codes are constructed from a modulo-2 addition of two maximum length sequences. The code sequences are added chip by chip by synchronous clocking. Because the m-sequences are of the same length, the two code generators maintain the same phase relationship, and the codes generated are of the same length as the two base codes, which are added together. Every change in phase position between two generated m-sequences causes a new sequence to be generated. In addition to their advantage in generating large numbers of codes, the Gold codes may be selected so that over a set of codes available from a given -generator the autocorrelation and cross-correlation between the codes is uniform and bounded. When specially selected m-sequences, called preferred m-sequences are used.

2.3. Autocorrelation Property

Auto Correlation Function (ACF) is a measure of the similarity between a spreading code $\{a_n\}$ and its time shifted replica. For a code sequence $\{a_n\}$, it is mathematically expressed as:

$$A(k) = \sum_{n=1}^{k} a_n a_{n+k} \quad (1)$$

Autocorrelation function should be impulsive type i.e. peak value at zero time shifts and zero values at all other shifts. This is required at receiver side to differentiate the desired user from other users producing ISI.

Numerical analysis for minimum autocorrelation:

Let us take a known spreading code C of length N and T is the transpose of the matrix S which is represented as:

$$C = [Y_1, Y_2, \dots Y_{N-1}, Y_N]^T \quad (2)$$

Hence we get C after dispreading operation for autocorrelation as

$$\begin{bmatrix} Y_1 & Y_2 & \cdots & Y_N \\ & Y_1 & \cdots & Y_{N-1} \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & Y_1 \end{bmatrix} * \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_N \end{bmatrix} = \begin{bmatrix} 1 \\ \min_1 \\ \vdots \\ \min_{N-1} \end{bmatrix} \quad (3)$$

Here N-1zero Eigen values are getting and in order to minimize G the convex optimization method in LPP is used i.e. Minimize $G=| C^T \cdot F^T \cdot C |$ (3), Such that $C^T . C=1$

'F' is the matrix with elements as zeros and ones. To obtain the minimum value of auto correlation, we need to minimize the Eigen values for the Eigen vectors of 'F' which is zero or minimum.

2.4. Cross-Correlation:

Cross-correlation is the degree of agreement between two different spreading code sequences $\{a_n\}$ and $\{c_n\}$ mathematically it is expressed as:

$$\backslash C(k) = \sum_{n=1}^{k} a_n c_{n+k} \quad (4)$$

Hence cross correlation reduces the effect of MAI at the receiver; the cross-correlation value must be zero for all time shifts.

Numerical analysis for minimum cross correlation**:**

Similarly like autocorrelation, mathematical analysis of cross correlation property is generally used to reduce MAI in the channel and the cross correlation there are two codes to be taken. Let us take a known spreading code C of length N which is represented as:

$$C = [X_1, X_2, \dots X_{N-1}, X_N]^T \quad (5)$$

Where T is the transpose of the matrix C and another spreading code minimizes the total magnitude of cross correlation with all shift of Y.

Hence we get C_2 & C after dispreading operation and multiplication for cross correlation as

$$\begin{bmatrix} Y_1 & Y_2 & \cdots & Y_N \\ & Y_1 & \cdots & Y_{N-1} \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & Y_1 \end{bmatrix} * \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_N \end{bmatrix} = \begin{bmatrix} 0 \\ \min_1 \\ \vdots \\ \min_{N-1} \end{bmatrix}$$

In order to minimize G the convex optimization method in LPP is used i.e.

$$\text{Minimize } G=| C_2 . F^T \cdot C | \quad (6)$$

Such that $C^T . C=1$

Numerical analysis of minimum correlation: Where G the convex function can written in to a single minimization function H. min H= minG(autocorrelation)+ minG(cross correlation).Finally, it has been found that the eigenvector of a symmetric matrix has one positive Eigen value and N-1 zero Eigen values which provides the minimum correlation spreading sequence. Any spreading code of length N can provide N-1 number of minimum correlation spreading codes. Here, the generated N-1 numbers of codes which are eigenvectors of zero Eigen-value of the matrix are orthogonal to each other.

2.5. Algorithm for proposed code:

The proposed algorithm for generation of orthogonal code for CDMA system has been described below:

STEP 1:

Take any two random PN sequences as input of length (N-1) as $\{a_i\}$ $_{\text{and}}$ $\{b_i\}$.

STEP 2:

Shift $\{a_i\}$ by 'k'- chips one-by-one where k = 0, 1 2, 3…..
N-1.The obtained set of sequences is represented as $T^k\{a_i\}$
STEP 3:
Shift $\{b_i\}$ by 'k'- chips one-by-one where k = 0, 1, 2, 3…… N-1.The obtained set of sequences is represented as $T^k\{b_i\}$.
STEP 4:
Multiplication of sequences.
a_i (zero shift) × each sequence of the set $T^k\{b_i\}$ = (N-1) sequences
a_i (shift for k=1) × each sequence of the set $T^k\{b_i\}$ = (N-1) sequences
a_i (shift for k=2) × each sequence of the set $T^k\{b_i\}$ = (N-1) sequences
a_i (shift for k=N-1) × each sequence of the set $T^k\{b_i\}$ = (N-1) sequences
Similarly, perform element by element multiplication of b_i (shift for k=0, 1, 2, 3, N-2) with each sequence of the set $T^k\{a_i\}$.
So in total we get the number of sequences, $u = 2N^2 – 5N + 3$.
This set of sequences is represented as $u^{\{k\}}$.

III. Simulation And Results

The proposed method of generation of spreading codes for CDMA system is simulated using MATLAB simulating tool. The generated codes are compared with the existing codes on the basis of the number or of codes generation, correlation and BER values

3.1. Performance based on Number of Codes Generation

The number of codes generated by the proposed algorithm has been listed in Table 1 In this perspective, some of the existing codes have also been included in Table 1 given below. This table shows that the proposed algorithm is capable of generating a large number of codes in comparison with existing codes like Walsh code and orthogonal small set Kasami code(Orthogonal small Set Kasami code) for a fixed length. More precisely, for a given code length of *N*, the proposed algorithm generates $2N^2 – 5N + 3$ number of distinct codes whereas Walsh code gives N, and Osmall Set Kasami code generates $\sqrt{N}\times(N-1)$ number of distinct codes.

Table 1: Comparison among Different Spreading Codes on the Basis of Number of Codes

Length of code	NO. of distinct code generated			
	Walsh code	Gold code	Orthogonal Kasami code	Proposed code
4	4	12	6	15
8	8	56	16	91
16	16	240	60	435

3.2. Performance based on Correlation

The average magnitude of auto correlation of proposed code Set of Sequences and existing codes are shown in figure-1. The proposed spreading code gives zero cross correlation value which is a symptom of maintaining orthogonality by the code.

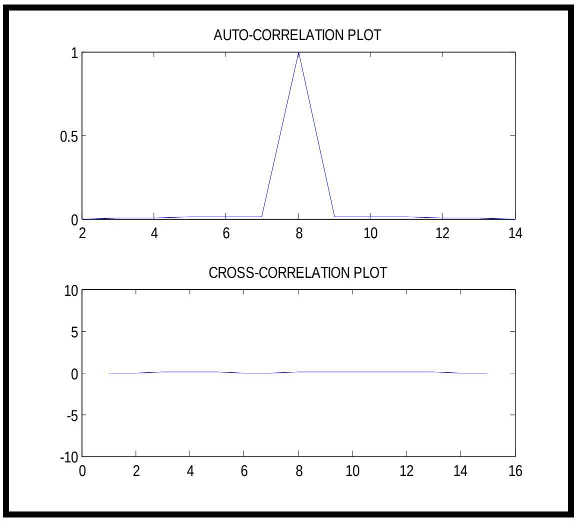

Figure 1: Plot of average auto correlation and cross correlation of proposed code

Then the performance of autocorrelation of proposed code is compared with other known spreading codes like Walsh code, PN sequence, orthogonal Gold code, small set kasami code as shown in fig-2. The average magnitude of autocorrelation vs. number of shift gives an impulsive peak at zero time shift i.e. maximum value at zero and side lobs give minimum as compared to others i.e. zero. Hence from the figure-2 the autocorrelation of proposed code gives good result then other existing spreading codes.

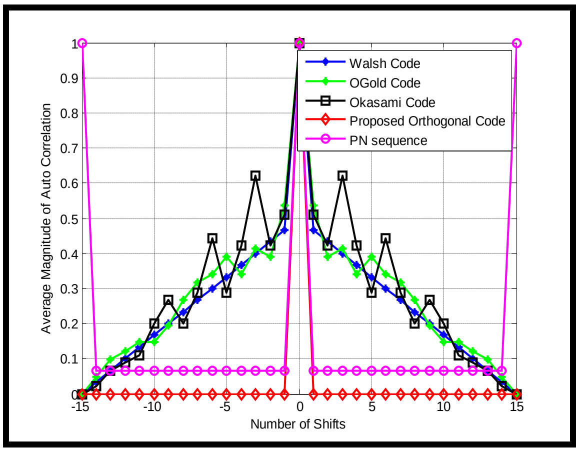

Figure 2: Comparison of average magnitude of autocorrelation of proposed code with other existing code

The average magnitudes of cross-correlation of the proposed code along with other existing codes have been presented in Figure-3 for code of length 16. It is observed that the proposed spreading code not only gives zero cross correlation value at zero time shifts (an indication of maintaining orthogonality by the code) but also provides approximately zero cross correlation value in other shifts. In contrast, other codes offer quite high magnitude of cross-correlation as compared to the proposed Gold Constructed Set of Sequences.

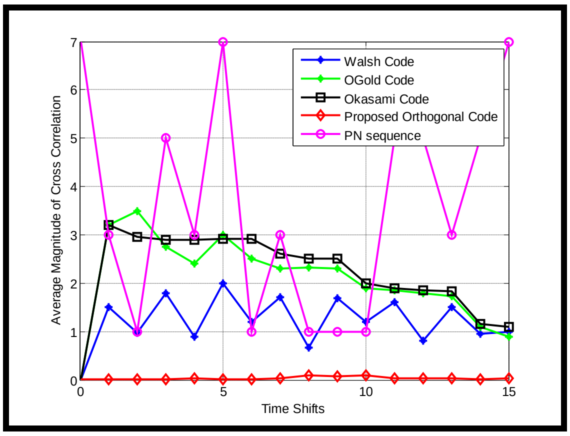

Figure-3: Plot of the average magnitudes of cross-correlation of the proposed code along with other existing codes

Critical analysis of the above figure reveals the fact that at zero time shifts only the PN sequence has non zero magnitude and hence it is more prone to MAI. Both Orthogonal Gold codes and Orthogonal Kasami code show less cross correlation value than PN sequences, whereas Walsh code outperforms the others in this respect. Finally it can be concluded that the proposed code can handle the effect of MAI in a better way than the other codes as it offers the lowest value of cross-correlation amongst the all.

3.3. Performance based on BER values

BER performance evaluation of proposed code Set of Sequences has been carried out using Additive White Gaussian Noise (AWGN) channel. For this purpose, SIMULINK-based downlink CDMA system model has been used and the BER value of such system was also measured. A result of two user model is shown below in table-2 and fig-4.

Table 2: E_b/N_0 (dB) and BER Values for a Two User System

SL.NO.	E_b/N_0 (dB)	BER
1	0	0.0766
2	1	0.0551
3	2	0.0364
4	3	0.0217
5	4	0.0117
6	5	0.0066
7	6	0.0029
8	7	0.0011
9	8	0.0001

Table -2 is given after simulation for two user of code length 16 through two user model of CDMA system & BER tool.

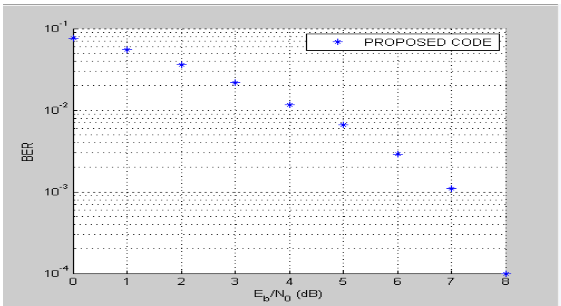

Figure 4: Plot of E_b/N_0 (dB)and BER Values for a Two User System

Simulation analysis of six users in fig 5 uses six code sequences by Montacarlo method in the system simultaneously and gives smallest values of BER at highest value of SNR.

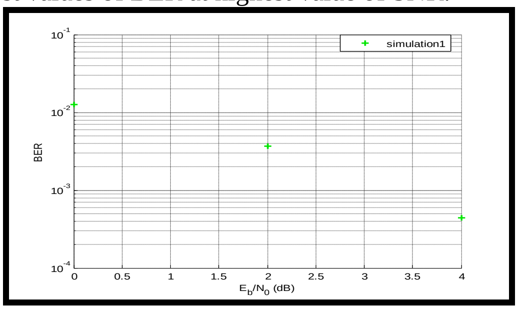

Figure 5: Plot of E_b/N_0 (dB) and BER Values for a Six User System

Comparisons based on proposed code with other existing code by different users: In fig.6,7 & 8 the bit error rate of proposed code is compared with Walsh code, orthogonal small set Kasami code & orthogonal Gold code which is a function of signal to noise ratio for 8 user,10 &12 user case. Here from the figure the proposed code have better BER performance then the other existing codes. Hence CDMA system capacity increases.

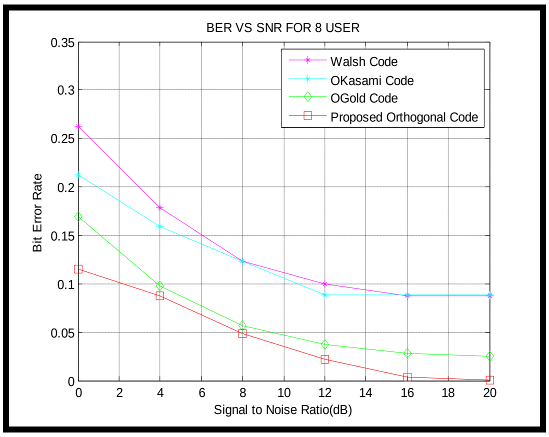

Figure-6

In fig -6 from the graph the proposed code has better BER performance in comparison to other existing codes uses eight users simultaneously through the channel. Orthogonal Gold code has improved BER performance then others but worst then proposed code. Hence Walsh code has less BER performance than other existing codes.

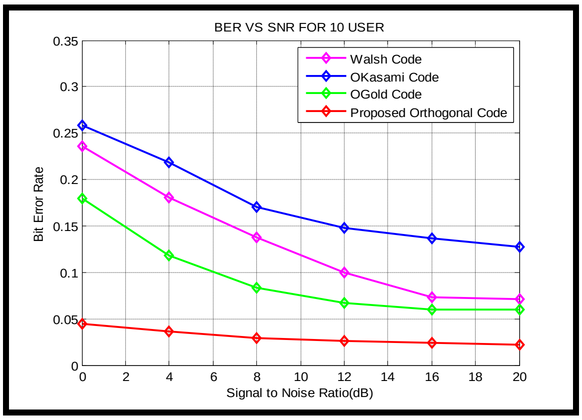

Figure-7

In fig-7 & 8 BER performance of orthogonal Kasami code is worst than other codes. Orthogonal GOLD code and Walsh code has approximately same BER performancein fig-8 but in fig-7 orthogonal Gold code has better result then Walsh code and the proposed code gives better performance than other existing codes. Hence as the number of user's increases the BER performance also enhanced more and more hence the system capacity increases rapidly.

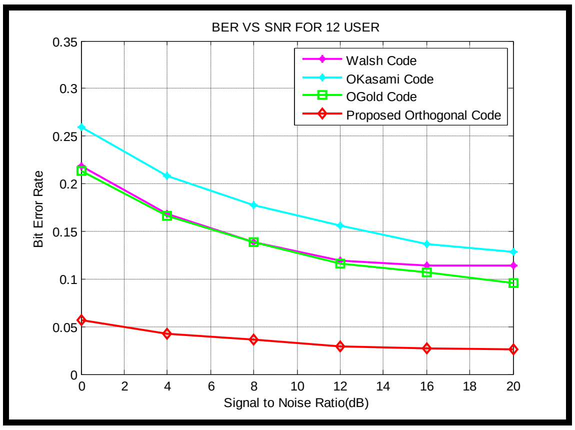

Figure-8

IV. Conclusion

In a CDMA communication system availability of more number of codes, minimum magnitude of cross correlation, impulsive peak auto correlation and BER performance play a major role. To meet all these criteria, an orthogonal gold constructed set of sequences has been proposed in this paper. From above discussion it is clear that the proposed Gold Constructed Set of Sequences gives low cross correlation value, impulsive auto correlation and better BER performance without sacrificing the number of codes. Less correlation value and better BER performances makes the system less prone to MAI effect. Hence it can be concluded that proposed Gold Constructed Set of Sequences outperforms other existing codes and provides an optimum solution for future CDMA communication system.

The present work is based on generating spreading codes for CDMA system satisfying the properties of auto correlation and cross correlation maintaining orthogonality between the codes. Also the BER value is analyzed for a two user system. The future work includes implementation of this method in asynchronous CDMA system by considering the effect of peak average power ratio (PAPR).Then it can be extended to variable length spreading code. Also a comparative study can be done for investigating the best spreading code among all in terms of BER values.

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