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Bandwidth Efficient Diversity Scheme Using STTC Concatenated With STBC: MIMO Systems

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Abstract**----**Multiple-input multiple-output (MIMO) systems are widely in use to improve quality, reliability of wireless transmission and increase the spectral efficiency. However in MIMO systems, multiple copies of data are received after experiencing various channel effects. The limitations on account of complexity due to number of antennas in case of conventional decoding techniques have been looked into. Accordingly we propose a modified sphere decoder (MSD-1) algorithm with lower complexity and give rise to system with high spectral efficiency. With the aim to increase signal diversity we apply rotated quadrature amplitude modulation (QAM) constellation in multi dimensional space. Finally, we propose a new architecture involving space time trellis code (STTC) concatenated with space time block code (STBC) using MSD-1 at the receiver for improving system performance. The system gains have been verified with channel state information (CSI) errors.

Keywords**----**Channel State Information , Diversity, Multi-Antenna, Rotated Constellation, Space Time Codes.

I. INTRODUCTION

THE field of multi-antenna processing and space-time coding has attracted large interest in the communication community due to the huge capacity of the multi-antenna environment. Generally MIMO techniques /algorithms aims at data rate maximization or diversity maximization, looking for performance enhancement[1].Space time coding, a new coding paradigm, aims at extracting the total available spatial diversity in the MIMO channel . Space time block coding (STBC) achieving with full diversity and full rate were introduced in [2] with two transmitters, and were generalized for any number of transmitters [3].The STBC does not provide coding gain and in view of this it is worthwhile to consider a joint design of error control coding, modulation, transmit and receive diversity to develop an effective signaling scheme called space time trellis code (STTC) [4], which combats the effect of fading. STTC became extremely popular as it can simultaneously offer coding gain with spectral efficiency and full diversity over fading channels. The received data can be decoded using various techniques.

The maximum likelihood (ML) technique is certainly an optimum decoding technique but with the increase in the number of transmit and receive antennas along with a complex constellation adds to the computational complexity of the decode mechanism [5]-[7].Many very efficient algorithms are available for ML decoding some well known are root lattices [8]. Several Leech lattice decoders have been proposed with an ever improving efficiency, a review of these decoders can be found in [9]. They do not take full advantage of the lattice structure which is useful for large bit rate applications. Because of the lattice based structure, sphere decoding can be employed to reduce the complexity of M L decoding [10].The sphere decoder algorithm is a suboptimal decoding technique that is computationally efficient achieving a symbol error rate that is dependent on the initial radius of the sphere. Considerable research has gone into sphere decoding in the last decade. This has resulted in the emergence of quite a few decoders with various variants to facilitate the decoding process. In [11] authors have presented a pulse position amplitude modulation (PPAM) space time trellis codes for ultra wide band MIMO communications, though at the cost of higher receiver complexity.

In this paper, we propose an efficient decoding algorithm which is an improvement over the existing decoding algorithms and provides decrease in complexity at the receiver. The complexity is determined by the FLOPS (Floating point operations per second). We further propose a new architecture involving STTC concatenated with STBC using the MSD-1 at the receiver to improve system performance and reliability in multi antenna environment. The essential part of the most of the MIMO space time architecture is the need for the channel state information (CSI) at the receiver, so is the case with the architecture that has been presented in this paper.

This paper is organized and summarized as follows. In section 2, we briefly describe the system model. Section 3, presents the algorithm of the modified sphere decoder along with different variants. In section 4, a new architecture involving STTC concatenated with STBC using the MSD-1 at the receiver has been proposed. Simulation results and performance analysis are presented. In section 5**,** performance of the architecture with CSI errors has been evaluated. Finally section 6, provides a brief conclusion of the subjects discussed in the previous sections.

II. DESCRIPTION OF THE SYSTEM MODEL

Consider a baseband transmission multiple antenna system as shown in Fig.1 with M transmit and N receive antennas over the Rayleigh fading channel. An n-dimensional QAM constellation is obtained as th**e** Cartesian product of two-dimensional QAM signal sets.

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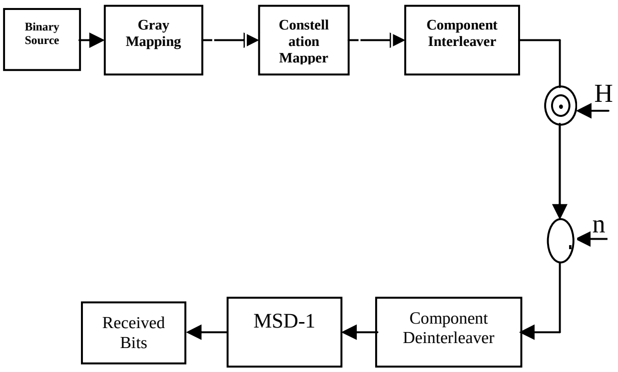

Fig. 1 System Model

The information bits are grouped into blocks and each block of m bits is mapped onto the constellation by applying the Gray mapping in each dimension.Each group of $m=n$ bits uniquely identifies one of the n components of the multidimensional QAM constellation vector $u= (u_1,\dots, u_n)$, where $u_i = 1, \pm 3,\dots$. So, vector u is the integer component vector to which the information is easily mapped. The point x of a rotated constellation is obtained by applying the rotation matrix M to u. The set of all lattice points $\{x = uM,\ u \in Z^n\}$ belongs to the n-dimensional cubic lattice with generator matrix M and diversity L. The baseband signal vector transmitted during each symbol period is given by $\tilde{x} = [\tilde{x}_1, \tilde{x}_2, \dots\dots \tilde{x}_n]^T$, where each component of the vector is independently drawn from a complex constellation such as QAM. The channel is modeled as an independent Rayleigh fading channel, separately operating on each component. We assume perfect channel state information at the receiver. The received signal at each instant is given by

$$\tilde{y} = \tilde{H}\tilde{x} + \tilde{n} \tag{1}$$

where n is a Nx1 complex vector AWGN component wise independent with a variance σ^2 per dimension. Moreover, $\tilde{H}$ is an MxN transfer function of the channel with entries $\tilde{h}_{nm}$ where $\tilde{h}_{nm}$ is the complex function between transmitter m and receiver n. The channel is assumed to be estimated accurately using training symbols embedded in each burst; thus, we assume in the sequel M=N. To get a lattice representation of this multiple antenna system, the complex matrix equation is transformed into the real matrix equation.

III. MODIFIED SPHERE DECODING (MSD-1) ALGORITHM

In this paper we employ a decoder with a lower complexity by incorporating suitable changes in the existing decoder algorithm in such a way that whenever a valid lattice point is found within the sphere, in addiction to reducing the current squared radius d^2 so that the newly discovered lattice point lies on the surface of the sphere, the algorithm recomputes all the lower and upper bounds according to the new value. When a vector inside the sphere is found, the square distance between this vector and the receive vector is given by :

$$\hat{d}^2 = T_n - T_1^2 + q_{11}(M_1 - u_k)^2 \tag{2}$$

This value is compared to the minimum square distance d^2 found so far in the search. The algorithm is modified in such a way so that the initial radius of the sphere is not an important factor and we intend to increase the decreasing rate of the radius. In the algorithm, whenever a point is found inside the sphere, the new radius is selected as

$$d^2 = k * \hat{d}^2 \tag{3}$$

where d is the new radius , $\hat{d}^2$ is the squared distance of the previous founded point to the center and the scale parameter k is bounded by $0 \leq k \leq 1$ increases the rate of decreasing of the sphere decoder.We apply a function to obtain optimal value of scaling factor so that BER is not degraded to much extent at reduced complexity. The function that gets these desired properties is given by [12]

$$k(t) = \exp\left[-\left(\frac{1}{\alpha}t\right)^{\beta}\right] \tag{4}$$

where t is the number of points in the n^{th} dimension of lattice and α, β are the parameters that control this function. A flowchart of this algorithm is present in Fig. 2.

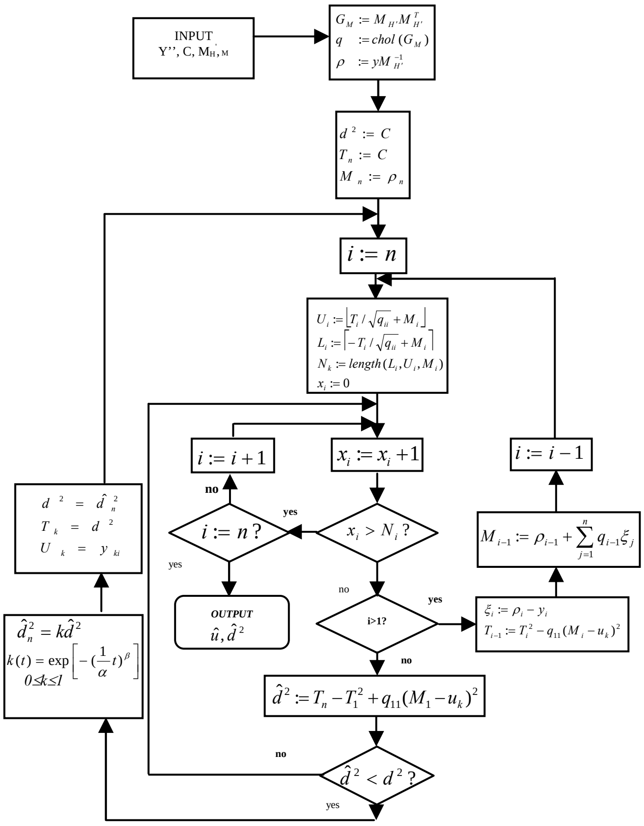

Fig. 2 Flowchart of Modified Sphere Decoder (MSD-1)

A. Results and Discussion

We compare the performance and complexity of MSD-1 algorithm to other decoding algorithms. FLOPS in each following simulations are calculated using FLOPS function in MATLAB, which counts the approximated floating point operations that algorithm needed to complete decoding one block of transmitted codewords.

Simulations have been done by drawing a random independent sequence of channel parameters, in accordance with the distribution of these parameters. In this section we present simulation results which compare the performance of the MSD-1 with MLSE with 2x2 rotation matrix for 16, 64 QAM constellations. For each set of drawn parameters the BER is evaluated and after a sufficiently large number of parameter states the estimate of the BER distribution is constructed. We restrict ourselves to the signal to noise ratio interval E_b/N_o=[0,10dB] for 16-QAM and E_b/N_o=[0,12dB] for 64-QAM.

In the Fig. 3 & 4, we present simulations taken with the MSD-1 namely using 2x2 rotation matrix simulation for 16, 64-QAM. From the figures , we could observe that for the 16-QAM simulations after 4 dB and for the 64-QAM simulations after 7 dB that the performance of MSD-1 is almost same as that of MLSE detection algorithm. This is due to taking into account only some of the valid symbols i.e. only 4.1% & 8.4% for 16-QAM & for 64-QAM simulations with 2x2 rotation matrix.

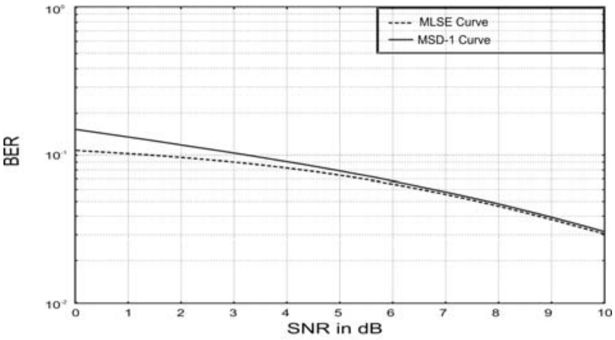

Fig. 3 2x2 Rotation matrix simulation for 16 QAM

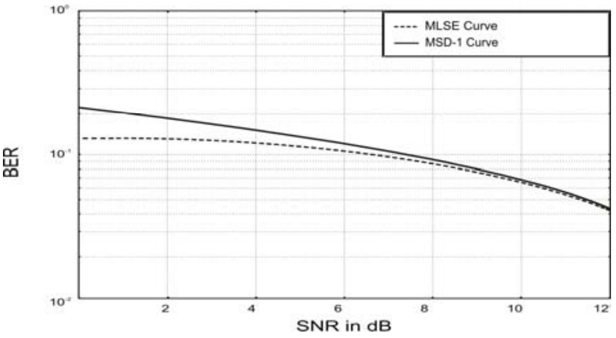

Fig. 4 2x2 Rotation matrix simulation for 64 QAM

The performance of the MSD-1 is also compared with the alamouti code scheme using exhaustive MLSE algorithm. We can see from the Fig. 5 that there is a considerable improvement in the BER, when the initial radius of the sphere increases. From the graphs for the scaling factor, we can observe that the performance of the sphere decoder degrades as the scaling factor is reduced from 1 for a radius of $\sqrt{10}$. Also there has been no significant improvement in BER for a radius $\sqrt{30}$, as what is obtained for a radius $\sqrt{10}$.

The complexity analysis for these curves can be examined in Fig. 6. It can be observed that ML decoding has the highest complexity. The FLOPS per symbol is significantly higher than that of the other techniques. The reduction in scaling factor to 0.4 reduces the computational complexity of the existing sphere decoder. The computational complexity of the modified sphere decoder algorithm is lower when compared to the other decoding techniques for a given radius. Thus, Alamouti code has a BER that improves with increasing radius.

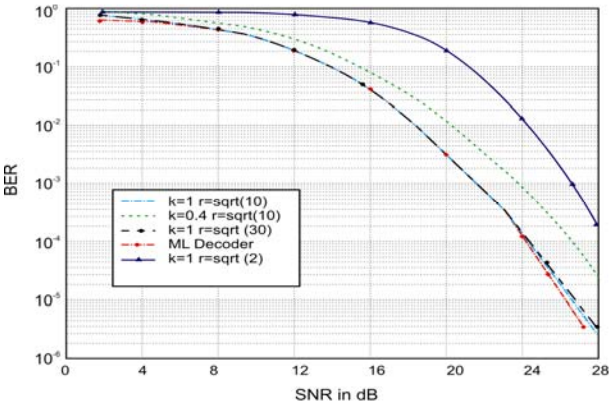

Fig. 5 Performance for STBC using different decoding algorithms

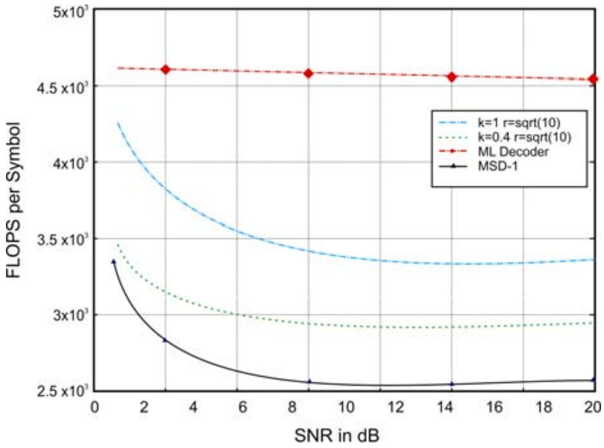

Fig. 6 Computing complexity for STBC using different decoding algorithms

IV. DIVERSITY SCHEME ALONG WITH ERROR CORRECTION

The constellation rotation although has improved the performance but the additive channel noise in the presence of deep fade is expected to further degrade the performance of decoder by enhancing the BER. Utilization of error control coding at the signaling stage of the constellation is apparently an alternative to improve the performance. The MSD-1 error may turn out to be significantly high as compared to the error correcting power of the coder-decoder if such a stage is not incorporated. Therefore, there is a need to explore error correcting coding stage at the input of the Space – Timer coder.

A. Proposed System Architecture

A new scheme has been proposed involving the concept of STTC concatenated with STBC using MSD-1 at the receiver to improve performance and reliability for multi antenna system. Fig. 7 shows the block diagram of the proposed architecture. The data bits are encoded by STTC and then fed to STBC encoder without changing transmission rate.The outputs of STTC are linearly arranged according to the Almouti scheme. The channel is the Rayleigh fading channel and at the receiver there are two antennas which feed the received signals to the MSD-1. The output of the MSD-1 is sent to the classical viterbi decoder.

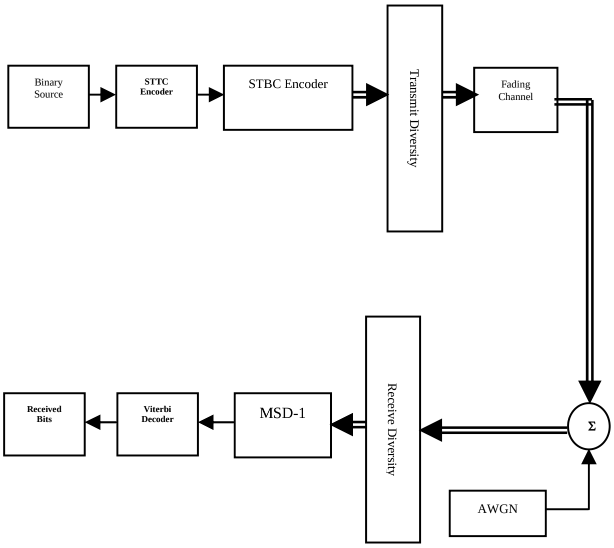

Fig.7 The proposed system architecture

B. Simulation Results and Performance Analysis

The proposed architecture was simulated in MATLAB environment and the performance was studied. The channel matrix H is assumed to be available at the receiver. The fading components of the matrix are modeled as complex Gaussain noise with variance of 0.5 per dimension; this gives rise to the Rayleigh fading channel. 10,00,000 input bits have been considered as input to the proposed architecture. Complex AWGN noise, i.e. the W matrix is added at the receiver so that the noise variance per dimension is given by $10^{-SNR/10}$. The curves in Fig. 8 represent the average bit error rate as a function of the SNR at the receiver. The performance of the proposed scheme having STTC concatenated with STBC shows an improvement of 3.5 to 4 dB over the system with only STBC. In Fig. 9 the performance of the proposed architecture has also been checked for unrotated constellation. Lowering of BER suitably compensates the loss in capacity.

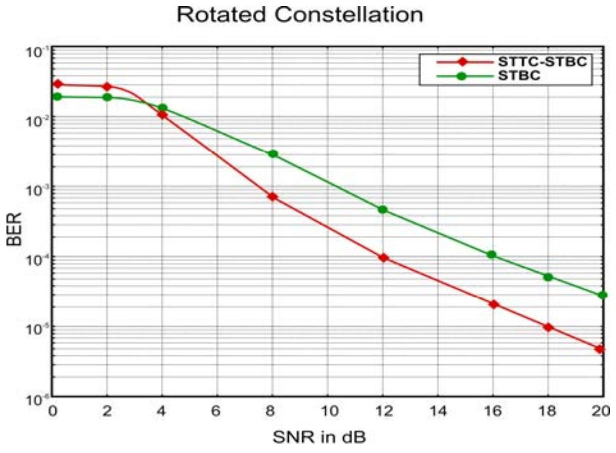

Fig. 8 Performance of the architecture with and without STTC

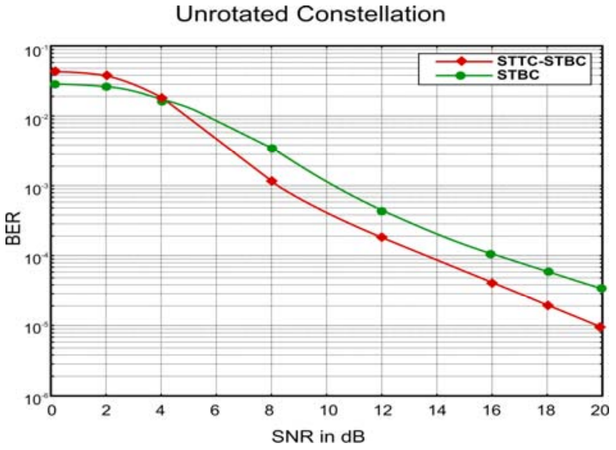

Fig. 9 Performance of unrotated architecture with and without STTC

V. PERFORMANCE OF THE ARCHITECTURE WITH CSI ERRORS

The essential part of most of the MIMO ST architectures is the need for the CSI at the receiver, so is the case with the architecture that has been presented in section IV. There are estimation techniques [13] available to estimate the channel state at the receiver. This scheme works on pilot symbols being transmitted from the transmitter. However, it is always possible that the CSI estimates do have errors inherently and, this necessitates the study of any MIMO architecture under errors in CSI. In this paper the proposed system architecture is evaluated with errors in the estimated CSI. However, the channel estimation is not perfectly available in most of the cases in its exact form. Therefore in low SNR case, the constellation rotation may be expected to improve the performance by increasing noise.

When looking at the proposed system with CSI errors, we can model the errors in various ways, either as the errors dependent on the SNR or independent of the SNR. We have adopted the way of introducing errors in CSI independent of SNR. The errors in the 2x2 channel CSI, $\begin{pmatrix} \in_{11} & \in_{12} \\ \in_{21} & \in_{22} \end{pmatrix}$ are modeled here as zero mean complex Gaussian variables with variance of 0.01.

Hence the overall CSI available at the receiver is

$$\begin{pmatrix} h_{11}+\in_{11} & h_{12}+\in_{12} \\ h_{11}+\in_{21} & h_{12}+\in_{22} \end{pmatrix}. \qquad (5)$$

That is, errors have been incorporated in all the four channels. Incorporating this error model in the receiver part of the system and carrying out the rest of the simulation as before, the performance plots were obtained. This was done for both the cases of rotated constellation as well as unrotated constellation. The results are in Fig. 10 and Fig. 11 respectively.

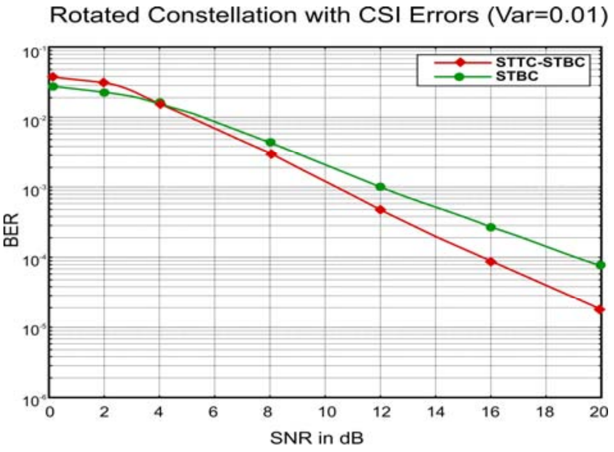

Fig. 10 Performance of proposed architecture with CSI errors

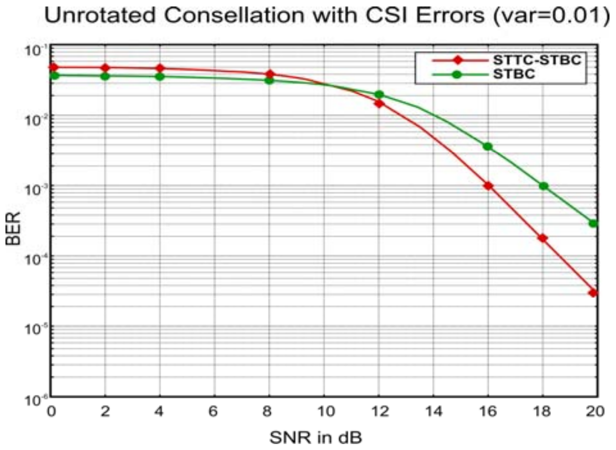

Fig. 11 Performance of unrotated architecture with CSI errors

VI. CONCLUSION

With the aim of increasing the 'diversity order' of the signal set, the rotation matrix scheme was introduced. Performance and complexity of MSD-1 is compared with different decoding algorithms for STBC and found that this algorithm have a significant saving in computational complexity, give rise to system with high spectral efficiency and does not depend on constellation size.

Further, we construct an architecture for the MIMO channel for a specific case of two antennas using two time slots. The need for error stage was introduced , the decoding control coding was felt due to the rotated constellation still being prone to AWGN. Hence, a new combined architecture involving the concept of STTC concatenated with STBC using the MSD-1 at the receiver has shown 3.5 to 4 dB improvement in the BER performance to the case when there is only STBC in the system for both rotated & unrotated constellation. The simulation studies have revealed that this architecture does provide a good performance improvement and better bandwidth efficiency (4 symbols PCU) as well.

We have also introduced the problem of CSI estimation errors and analyzed the proposed architecture. The results have shown interesting trends justifying the use of rotated architecture with STBC based STTC. Also, when the receiver is simulated to have errors in CSI, the performance degradation is marginal in comparison with the case of the performance of the proposed architecture with CSI.

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