Performance Analysis using Adaptive Decision for Parallel Interference Cancellation Receiver in Asynchronous Multicarrier DS-CDMA Systems

R.Gomathi, A.K.Gnanasekar, V.Nagarajan

Abstract –**In this paper, we present and analyze the performance of asynchronous multicarrier direct-sequence code division multiple-access (DS-CDMA) system using adaptive decision at the receiver. In addition to that parallel interference cancellation (PIC) scheme is presented at the receiver. The PIC scheme offers better interference suppression capability. At the last stage, the interference cancelled outputs from all the subcarriers are maximal ratio combined (MRC) and feeds viterbi decoder. Convolutionally coded multicarrier DS-CDMA system compares BER from the decision which helps in further improvement.**

Keywords - Interference cancellation, Multiple access Interference.

I.INTRODUCTION

Multicarrier CDMA schemes are categorized mainly into two groups. One spreads the original data stream using a given spreading code, and then modulates a different subcarrier with each chip (in a sense, the spreading operation in the frequency domain), and other spreads the serial-to-parallel (S/P) converted data streams using a given spreading code, and then modulates a different subcarrier with each of the data stream (the spreading operation in the time domain). Direct Sequence Code-Division Multiple Access (DS CDMA) has become a popular multiple-access signaling methodology due, in part, to its robustness against fading, anti-interference capability, and multiple-access capacity. The large spreading bandwidths employed typically exceed the coherence bandwidth of the channel, so that the fading tends to be frequency selective. In such a situation, a RAKE receiver can be used to exploit path diversity and effectively combat the performance degradation due to multipath [2]. The anti-interference capability in a direct-sequence (DS) system is achieved by correlating the received signal with the predetermined spreading sequence, thus then allowing the inherent processing gain of the system to attenuate the interference[2].Multicarrier (MC) approach offers several advantages including robustness in fading and interference, operation at the lower chip rates and non-contiguous bandwidth operation. Several studies have analyzed the performance of multicarrier DS-CDMA systems.

The available bandwidth is decomposed into a set of disjoint equi-width frequency sub-bands of bandwidth approximately equal to the coherence bandwidth of the channel. Each sub-band of the channel is assumed to fade non-selectively and independently. In short, path diversity is exchanged for frequency diversity, wherein forward error correction may be employed. The current literature on multicarrier modulation (MCM) as applied to DS-CDMA may be classified into two general areas, depending upon whether time-domain or frequency-domain spreading is employed. These classes of DS-CDMA systems are discussed and surveyed .

In fact, multicarrier DS systems techniques can be categorized into two types, a combination of orthogonal frequency division multiplexing (OFDM) and CDMA or a parallel transmission scheme of narrowband DS waveforms in the frequency domain .In the former system, a spreading sequence is serial-to-parallel converted, and each chip modulates a different carrier frequency. This implies that the number of carriers should be equal to the processing gain, and each carrier conveys a narrowband waveform, rather than a DS waveform. In other words, the resulting signal has a PN coded structure in the frequency domain. In the latter system, the available frequency spectrum is divided into M equi-width frequency bands, where M is the number of carriers, typically much less than the processing gain, and each frequency band is used to transmit a narrowband DS waveform. In fact, both systems show a similar fading mitigation effect over a frequency selective channel. However, the latter system requires only M adaptive gain amplifiers in the maximal ratio combiner, which may simplify the receiver.

Our contribution in this paper is that we propose and analyze a PIC scheme which directly uses the soft output of the MFs for cancellation and makes decision. In the proposed PIC scheme, at

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each cancellation stage, on each subcarrier, a weighted sum of the soft outputs of the other users in the current stage is subtracted from the soft output of the desired user to form the input to the next stage. At the last stage, the interference cancelled outputs from all the subcarriers are maximal ratio combined (MRC) to form the decision statistic. We derive analytical expressions for the bit error rate (BER) for the first and second stages in the proposed PIC scheme on Rayleigh fading channels. Analytical results are found to agree well with the simulation results. The proposed PIC scheme is shown to offer better performance than the conventional MF receiver.

II. SYSTEM MODEL

Fig. l(a) shows a bandlimited single-carrier wideband DS waveform in the frequency domain, where the bandwidth is given by

$$W_{sc}= (1+ \beta)(1/T_{c}) \tag{1}$$

In (1), $0 < \beta < 1$, and T_c, is the chip duration of the single carrier system.

In the multicarrier system proposed, we divide W_{sc} into MR equi-width disjoint frequency sub-bands, as shown in Fig. 1(b). Note that while the multicarrier system is depicted as using a contiguous spectrum, this need not be the case, in general. The ability to make use of a noncontiguous spectrum to achieve a given total bandwidth represents an advantage over the single-carrier approach (which requires a contiguous spectrum). The bandwidth of each frequency sub-band W_{Mc} is given by

$$W_{Mc} = (W_{sc} / MR) \tag{2}$$

Note that MRT_C is the chip duration of the multicarrier system, and MR is the total number of subcarriers. The parameter M will specify the number of convolutionally coded symbols per input data symbol, and R will specify the number of frequency diversity branches per coded symbol. The orthogonal MC DS-CDMA transmitter spreads the S/P converted data streams using a given spreading code in the time domain so that the resulting spectrum of each subcarrier can satisfy the orthogonality condition with the minimum frequency separation. This scheme was originally proposed for an uplink communication system because the characteristics of the orthogonal MC DS-CDMA are effective for establishing a quasi-synchronous channel.

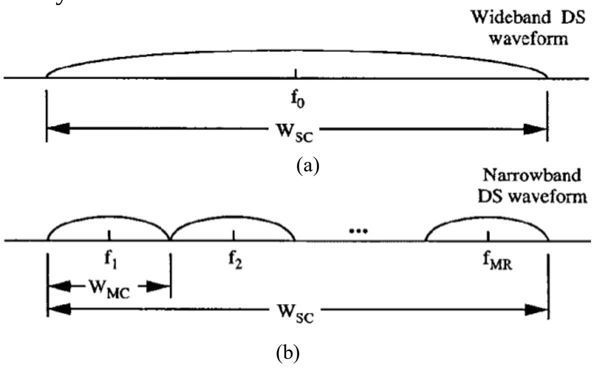

Fig. 1. Power spectral density of a (a) single-carrier DS waveform and (b) multicarrier DS waveform.

PIC appears to be more attractive in the case when high speed detection is preferred, since the cancelation of the interference is performed in parallel. However, the potential gain from PIC depends on the precise estimate of the MAI. A partial PIC is proposed in [8] to mitigate the effect of unreliable MAI estimation.

A . Transmitter

Across each of the MR carrier frequencies, we transmit DS-CDMA signal, such that distinct binary symbols may be transmitted at a given carrier frequency. The transmitter for the desired user is shown in Fig. 2(a). The binary data sequence is given as input to a convolutional encoder. The output code symbols are interleaved and serial-to-parallel converted such that parallel code symbols may be transmitted simultaneously. Each of the code symbols, in turn, is replicated via a rate repetition code. The code symbols are then mapped to DS-CDMA modulators such that each of the convolutionally coded symbols is transmitted over independent frequency diversity branches. The code symbols are mapped to subcarriers so as to maximize the separation in frequency between repetition code symbols for each respective convolutional code symbol.

B. Receiver

The demodulator for the desired subcarrier of the *k*th user, shown in Fig. 2(b), receives two *distinct* binary code symbols which are multiplied by a pseudorandom spreading sequence
such that there are chips per code symbol, and each user has a unique spreading sequence. The resulting sequence modulates an impulse train, where the energy per chip is and the period of the impulse train is MRTC. After passing through a chip wave-shaping filter, the baseband DS-CDMA waveform is upconverted to subcarrier frequency and multiplexed with the other subcarrier signals, then the parallel interference cancellation technique is used. Assume that there are K asynchronous CDMA users in the system, where all of them use the same MR subcarriers, the average power received from the user at the base station is also assumed to be the same, implying perfect power control. The channel is assumed to be a slow-varying frequency-selective fading channel with a delay spread of T_m. We constrain M and R to satisfy the following conditions:

- Each sub-band of a multicarrier system has no selectivity,

  i.e., $T_m/(MRT_C) \leq 1$.

- All the sub-bands are subject to independent fading, i.e.,

  $W_{MC} \geq (\Delta f)_c$, where $(\Delta f)_c \approx 1/T_m$.

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These two conditions are satisfied if

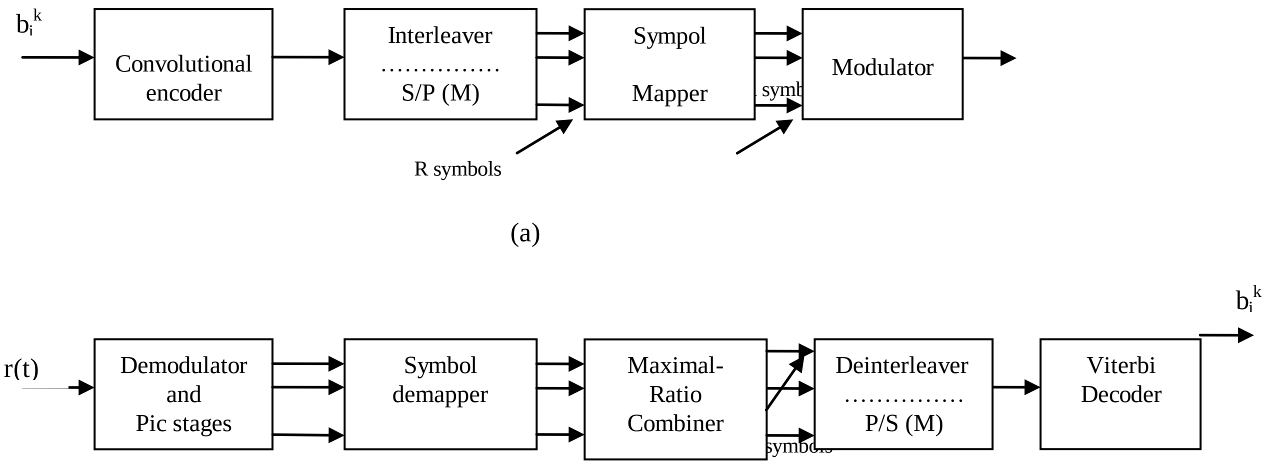
$$T_m/T_C \leq MR \leq (1+\beta)T_m/T_C \,. \qquad (3)$$

The received signal is then given by

$$r(t) = \sum_{k=1}^{K} \{\sqrt{2Ec}\, \sum_{n=-\infty}^{\infty} C_n^{(k)}\, h(t - nMRT_C - \tau_k)$$

$$.\ \sum_{V=1}^{MR} \alpha_{K,V} [\, a_{v,n/N} \cos(2\pi f_v t + \theta_{k,v}) + n_w(t) \qquad (4)$$

Where h(t) is the impulse response of the chip wave shaping filter, the $\{\tau_k\}$ are asynchronous delays assumed to be i.i.d



(b)

Fig.2 (a) transmitter block diagram (b) receiver block diagram

Uniform random variables over $[0,MRT_c)$, $\theta_{k,v}=\psi_{k,v}+\beta k,v$ and $n_w(t)$ is AWGN with two sided power spectral density of $\eta_0/2$. The receiver of the desired user is shown in Fig. 3(a). Each correlator consists of a bandpass matched filter operation, followed by coherent demodulation, sampling, despreading, and summing.The MR receiver test statistics are then demapped into M partitions of R terms in accordance with the mapping rule. Each partition is input to a maximal-ratio combiner producing a diversity combined test statistic corresponding to each of the M convolutional code symbols. The resulting M diversity combined outputs are deinterleaved and ultimately feed metric calculations in the soft-decision Viterbi decoder.We assume that the chip wave-shaping filter satisfies the Nyquist criterion and is of unit energy. We further define

$$X(t) \Leftrightarrow X(f) \equiv |H(f)|^2 \qquad (5)$$

and assume that X(f) is bandlimited to W'.This implies that the DS waveforms do not overlap in frequency, and thus, adjacent channel interference may be ignored. Since X(f) satisfies the Nyquist criterion, we may ignore interchip interference as well.

III. ANALYSIS

We evaluate the performance of the first user (K=1), assuming perfect carrier, code, and bit synchronization. Then the output, prior to sampling, from the correlator branches at the desired subcarrier frequency, $y_v(t)$, are given by

$$y_v(t) = Sy_v(t) + Iy_v(t) + Ny_v(t) \qquad (6)$$

where

$$Sy_v(t) = \sqrt{2Ec}\, \alpha_{1,v} \sum_{n=-\infty}^{\infty} a^{(1)}_{v,\lfloor n/N \rfloor} C_n\, x(t - nMRT_C)$$

$$Ny_v(t) = Lp\{n_{wv}(t)\sqrt{2}\, \cos(2\pi f_v t + \theta_{1,v}\}$$

represent components due to the desired signal S and additive white Gaussian noise N, respectively. In the above equations, we have assumed, without loss of generality, that $\tau_1=0$. The term $n_w(t)$ represents the band-limited process obtained by convolving the additive white Gaussian noise with the impulse response of the desired bandpass chip filter. Finally,Lp{.} denotes a low-pass filter operation to remove double-frequency terms. The interference component is given by

$$Iy_v(t) = \sum_{k=2}^{K} \{\, \sqrt{Ec}\, \alpha_{k,v} \sum_{n=-\infty}^{\infty} a^{(k)}_{v,\lfloor \frac{n}{N} \rfloor} \cos(\varphi_{k,v})$$

$$C_n^{(k)}\, x(t - nMRT_C - \tau_k)\ \} \qquad (7)$$

where $\varphi_{k,v} = \theta_{k,v} - \theta_{1,v}$. To characterize the interference, we assume the spreading sequences of the multiple-access interferers to be statistically independent, random binary sequences, whereupon the product of those sequences with the code symbols are random binary sequences. We may thus drop the code symbols from (18) and define $\mathcal{E}_{k,v} \triangleq \cos(\varphi_{k,v})$ It can be shown, based on the statistics of the $\{\alpha_{K,V}\}$ and $\{\varphi_{k,v}\}$ that the $\{\mathcal{E}_{k,v}\}$ are i.i.d. zero-mean Gaussian random variables with variance equal to unity. Equation (7), therefore, is essentially equivalent to

$$I_{yv}(t) = \sum_{k=2}^{K} \{\sqrt{Ec}\ \mathcal{E}_{k,v} \sum_{n=-\infty}^{\infty} C_n^{(k)} x(t-nMRT_C-\tau_k)\ \} \quad (8)$$

Now, we can evaluate the statistics of the signal out of the desired correlators, and which can be written as

$$Z_v = S_{zv} + I_{zv} + N_{zv} \quad (9)$$

Where

$$S_{zv} = \sum_{n'=0}^{N-1} C_{n'}^{(1)} S_{yv}(n'MRT_C)$$

$$I_{zv} = \sum_{n'=0}^{N-1} C_{n'}^{(1)} I_{yv}(n'MRT_C)$$

$$N_{zv} = \sum_{n'=0}^{N-1} C_{n'}^{(1)} N_{yv}(n'MRT_C)$$

Note that while we assume the $\{C_n^{(k)}, k = 2,\ldots K\}$ to be independent random binary sequences, then we take the spreadingsequence for the desired user $C_n^{(1)}$ to be deterministic.

Under some conditions for number of subcarriers and resolvable paths of the system we can assume that each subcarrier experiences frequency nonselective fading , the received signal at the base station can be expressed as

$$r(t) = \sum_{k=1}^{K} \sum_{i=1}^{M} \sum_{j=1}^{R} \sqrt{\frac{2R}{M}}\ \alpha_{ij}^{k}\ b_i^{k}(t-\tau_k) \cos(2\pi f_{ij}t + \varphi_{ij}^{k}) + n(t) \quad (10)$$

where τ_k represents the time mismatch in the context of the k[th] user, with respect to the reference user, α_{ij}^{k} is the channel fading coefficient, $\varphi_{ij}^{k} = \varphi_{ij}^{k} - \psi_{ij}^{k} - 2\pi f_{ij}\tau_k$, which is assumed to be an i.i.d random variable having a uniform distribution in $[0,2\pi)$, ψ_{ij}^{k} is due to the transmission channel, while n(t) represents the AWGN with zero mean and double sided PSD of variance $N_0/2$.

Assuming that the first user k=1 is the reference user, the receiver provides a correlator for each subcarrier ,finally a p/s converter is employed to recover the serial data stream. For detecting b_u ,

$$Z_{uv} = S_{uv} + N_{uv} + \sum_{K=2}^{K} I_1^{(k)} + \sum_{k=2}^{K}\sum_{i=1}^{M}\sum_{j=1}^{R} I_2^{(k)}(i,j) \quad (11)$$

$$S_{uv} = \sqrt{\frac{2R}{M}}\ (g_{uv}^{2}/2)\ b_u T_s$$

While the noise term can be expressed as [8]

The interference term $I_1^{(k)}$ can be viewed as the interference by the same carrier but from other users. $I_2^{(k)}$ can be viewed as the interference due to other k^{th} users from the other subcarriers.

In this scheme the interfering users are weighted before subtracting from the reference signal r_{uv} , which implies the technique of interference cancellation. The reference signal can be expressed as [8],

$$r_{uv} = \sqrt{\frac{2R}{M}}\ [\ \sum_{k=1}^{K} b_u^{k}(t-\tau_k)(\alpha_{uv}^{k}/2) \cos(\varphi_{uv}^{k})\ c_k(t-\tau_k) + \sum_{k=2}^{K}\sum_{i=1}^{M}\sum_{j=1}^{R} \alpha_{ij}^{k}\ b_i^{k}(t-\tau_k)\ c_k(t-\tau_k) \cos(2\pi f_{ij}t + \varphi_{ij}^{k}) \cos(2\pi f_{uv}t)dt] + \eta_n(t) \quad (12)$$

here i=u and j≠then the signal has to be reconstructed for both the subcarrier

$$\hat{I}_1^{(k)} = \sqrt{\frac{2R}{M}}\ (g_{uv}^{k}/2) \cos(\varphi_{uv}^{k})\ \hat{b}_u^{k}(t-\tau_k)\ c_k(t-\tau_k) \quad (13)$$

$$\hat{I}_2^{(k)} = \sqrt{\frac{2R}{M}}\ (g_{ij}^{k}/2)\ \hat{b}_i^{k}(t-\tau_k)\ c_k(t-\tau_k) \cos[2\pi(f_{ij} - f_{uv})t + \varphi_{ij}^{k})] \quad (14)$$

where the estimate of the transmitted u^{th} bit for the k[th] user is expressed as $\hat{b}_u^{k}$. For the first user,

$$\hat{Z}_{uv}^{1} = \int_0^{Ts}\{r_{uv}(t) - [\sum_{k=2}^{K} \hat{I}_1^{(k)} + \sum_{k=2}^{K}\sum_{i=1}^{M}\sum_{j=1}^{R} \hat{I}_2^{(k)}]\}c(t)g_{uv}^{1}\}\ dt \quad (15)$$

At the first stage the output consisits of reference signal component , interference component and noise component. Then at the second stage, the interference components are subtracted from the reference signal and as it is adaptive the interfering users are weighted before subtracting from the reference signal. At the third stage,for compensating the imperfect estimate of the interfering term has to be added. The cancellation stages can be carried over large number of stages.

$$z_{uv} = r_{uv} - \sum_{k=2}^{K} \hat{I}_1^{(k)} w_{uv}^{(k)} - \sum_{k=2}^{K}\sum_{i=1}^{M}\sum_{j=1}^{R} \hat{I}_2^{(k)} w_{ij}^{(k)} \quad (16)$$

$$Z_{uv} = r_{uv} - \sum_{k=2}^{K} I_1^{(k)} - \sum_{k=2}^{K}\sum_{i=1}^{M}\sum_{j=1}^{R} I_2^{(k)} + \hat{I}_1^{(1)} \quad (17)$$

The obtained output is then made to pass through the symbol demapper where the output from the subcarriers which carry the same code symbol are

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combined followed by the maximal ratio combiner, then by the interleaver and feeds into Viterbi decoder.

With sufficient interleaving of coded symbols output from the convolutional encoder, we assume that the vector of deinterleaved maximal-ratio combined receiver outputs, at time index l , $\bar{Z}_{l,}$ represent uncorrelated (and therefore independent), conditionally, jointly Gaussian random variables. Then, the branch metric for the rth path through the decoder trellis at time index l is given by

$$\mu_l^{(r)} = \log P(\bar{Z}_l \mid \bar{B}_l^{(r)}) \qquad (18)$$

where $\bar{B}_l^{(r)}$ represents the vector of M convolutionally coded symbols at time index corresponding to the rth path. The rth path metric can be defined as

$$U^{(r)} = \sum_{l=1}^{B} \mu_l^{(r)} \qquad (19)$$

The probability of bit error rate can be defined as

$$P_e < \left.\frac{\partial T(D1,D2,\ldots\ldots DM,B)}{\partial B}\right|_{B=1,\ Di = Pi,\ i=1,2,\ldots\ldots M} \qquad (20)$$

Where

$$P_i \triangleq \prod_{j=1}^{R} \frac{1}{1+\bar{\gamma}_{i,j}}$$

Hard decision can be taken from the output of the soft decision . For example when rate of the encoder is about ½ and K=3, the soft decision as three digit combination where one digit corresponds to hard decision and two other digits indicate the number of quantization level (above or below basic threshold), i.e. the area where the peak of the pulse was found.

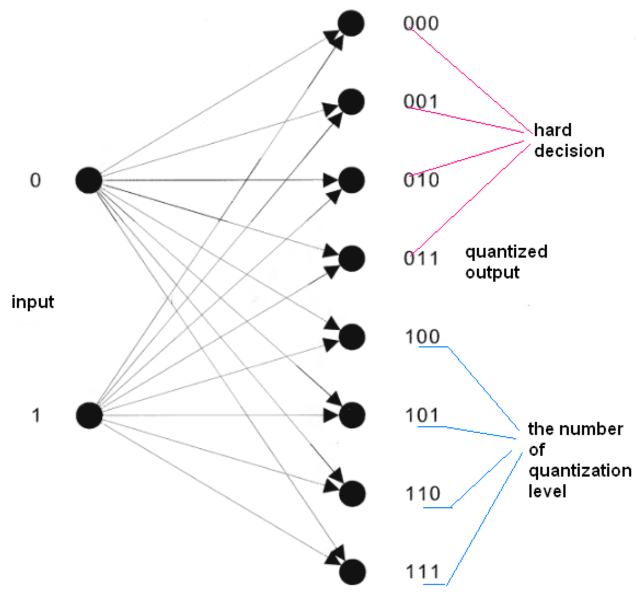

Fig.3 Determining hard decision from soft decision.

IV. PERFORMANCE RESULTS

In this section we present the performance of the system which involves parallel interference cancellation by making adaptive decision in asynchronous system. The hard decision is taken when the rate of the encoder is ½. Increasing the parameter M will yield the lower rate codes allowing the system to better combat MAI and fading. On increasing the parameter R will primarily increase the extent to which the system can combat multipath fading, through diversity. The improvement in performance due to increasing in any one parameter is offset by degradation in performance as a result of decreasing the other parameters.

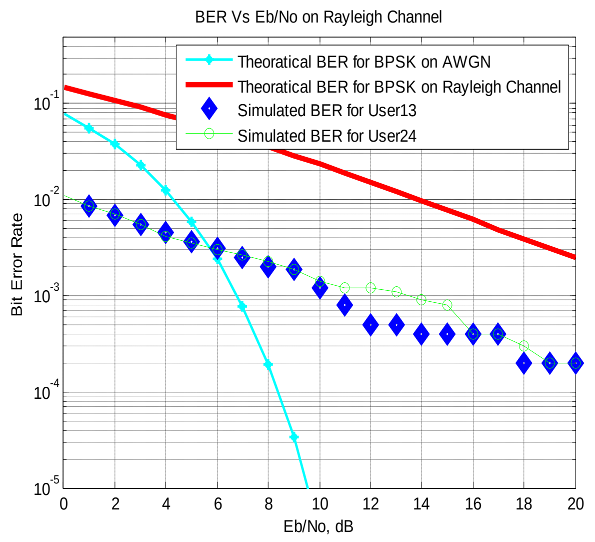

Fig. Bit error rate versus E_b/N_0 for adaptive decision

V. CONCLUSION

In this paper, we analyzed the performance of parallel interference cancellation for an asynchronous MC DS-CDMA system . This proposed system provides coded performance and it includes the decisiom making process which seems to be adaptive. The PIC scheme effectively cancels the MAI and significantly helps in improving the bit error rate.

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