BAMUD Features Demonstration by SystemView

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Abstract. *Direct-sequence code-division multiple access (DS-CDMA) is a frequently used wireless technology in DS-CDMA communications. The conventional DS-CDMA detector follows a single-user detection strategy in which each user is detected separately without regard for the other users. The better strategy is multi-user detection (MUD), where information about multiple users is used to improve detection of each individual user. This paper presents an adaptive multi-user detector converging (for any initialization) to the minimum mean square error (MMSE) detector without requiring training sequences. This blind multi-user detector (BAMUD) requires no more knowledge than does the conventional single-user detector. The structure of adaptive blind detector is simulated by the system design tool SystemView. The aim focus is to verify theoretical knowledge of BAMUD structure using hardware-oriented PC-based model in SystemView.*

Keywords

Multi-user detection, CDMA systems, multi-access interference (MAI), suboptimum multi-user receivers, near-far effect, blind adaptive MUD.

1. Introduction

The emerging third-generation (3G) wireless communications will support not only voice communications but also high-speed data and multimedia services. In addition, they will also allow subscribers to access several services at once. This means future wireless communications systems should provide much higher capacity than current systems. Data and multimedia services also have a higher transmission quality requirement. Higher capacity and higher quality requirements pose real challenge for designing of 3G wireless systems [8].

Although, various solutions around the world have been proposed reflecting different requirements, there is one common envision that the wideband CDMA is the most promising technologies for the next-generations of wireless communications. It is well known that the capacity of the CDMA system is limited by multiple access interference (MAI), caused by non-orthogonality of signature waveforms of active users due to diverse phenomena such as asynchronous transmission, multipath propagation or limited bandwidth. Therefore, the MAI rejection is important to facilitate increased capacity in the licensed band that deploys CDMA. The techniques to mitigate the MAI in the CDMA can be divided into single-user detection and multi-user detection (Fig. 1).

By single-user detection, we mean that one user's spreading code and delay is known and utilized at the receiver. The structure of the MAI (such as spreading codes, delays and powers of the other users) is assumed to be unknown. The complexity in single-user detection is generally much smaller than that of MUD, but single-user approach is not applicable in real systems. More about detection schemes can be found e.g. in [1], [2], [4].

In this paper, we have studied BAMUD because of its relative low construction complexity and ability to solve MAI. Steady complexity regardless of the number of transmitting users is particularity of the BAMUD. Hence, it is worthwhile to search into BAMUD properties for more details. Let us consider BAMUD as one of the candidates for future mobile terminal detection technique. Accordingly, suitable simulation and development tool is needed for a design. Matlab is a good mathematical mean to verify detector functionality. But, for the purpose of design tune, tests and troubleshooting, hardware oriented simulation tool is preferable to Matlab. We decided to use graphically oriented dynamic system analysis software SystemView as a simulation tool [12].

In the next Section, we present the most popular MUD receivers. In Section 3, a principle of blind adaptive multi-user (BAMUD) detector designed by Verdu [8] will be presented. Canonical representation of space-time signals which blind detector operate with and minimum output energy (MOE) concept are mentioned in order to gain blind detection realization scheme. The description of simulated transceiver with blind adaptive MUD is depicted in Section 4. Some simulation results are part of Section 5.

2. Multi-User Detection: Review

It is known that optimal, maximum-likelihood decoding of all users has significant performance benefits compared with matched filter alternatives. Unfortunately, the solution also involves a joint Viterbi processor with exponential complexity in the number of users. Suboptimal realization is much easier to construct but system performance is not ideal. The goal of the research is to find a receiver with a relatively low complexity and convergence to ideal. Generally, non-linear detectors exhibit better performance related to linear detectors. It is because non-linear threshold can define decision regions more precisely. On the other hand, they are of more complex construction related to linear detectors.

An adaptive approach appears to be a possible solution of this problem. Less complex linear detector with adaptive approach could be used to solve MAI. Principle fundaments of adaptive techniques consist in detector parameters tuning. Successful suppression of an undesirable interference is the target. It will lead to an increase of signal-to-noise (signal-to-interference) ratio.

Next, a short view of linear detector known characteristics follows. The optimum multi-user detector needs to know following information in order to operate:

1) The signature waveform of the desired user,
2) The signature waveforms of the interfering users,
3) The timing (bit-epoch and carrier phase) of the desired user,
4) The timing (bit-epoch and carrier phase) of each of the interfering users,
5) The received amplitudes of the interfering users (relative to that of the desired user).

The conventional receiver requires only 1) and 3), but it is severely limited by the near-far problem, and even in the presence of perfect power control, its bit-error-rate is orders of magnitude far from optimal. The decorrelating detector shows that linear receiver (modified matched filter orthogonal to the multi-access interference) is sufficient in order to achieve optimum resistance against the near-far problem (for high signal to background noise ratios).

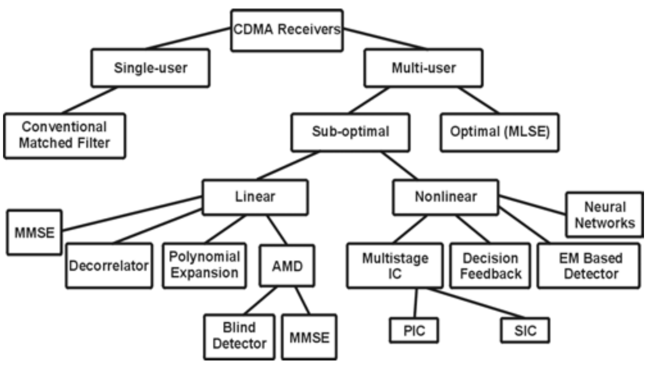

Fig. 1. Hierarchy of CDMA MUD receivers.

Moreover, it does not require knowledge of 5). On the other hand, inverse decorrelation matrix (with a number of users becomes substantial disadvantageous) is needed to compute.

Some attention has been focused recently on adaptive multi-user detection [6] which eliminates the need to know the signature waveforms of the interferers 2), timing 4), and amplitudes 5). Note that even in systems where this knowledge is available (as in the case of a centralized multi-user receiver which demodulates every active user), it is usually computationally intensive to incorporate that knowledge into the receiver parameters, so an adaptive algorithm can be an attractive alternative even in such a situation.

3. Blind Adaptive Multi-User Detection

In the single-user equalization, adaptive algorithms that operate without knowledge of the channel input are called blind. It is used canonical representation to support blind adaptive multi-user detector construction [4], [5]. Received signal manipulation consists of two processes: conventional detection and adaptive subtraction of orthogonal parts to desired signal contained in multi-access signal. Characteristic blind adaptive multi-user detector block model given by Verdu is viewed in Fig. 2 [4].

Let s_k be a linear multi-user detector signature waveform for k-th user. Than MUD output $\hat{b_k}$ depends on the sign of the correlation (represented by $< \bullet >$) between received baseband signal r and c_k:

$$\hat{b}_k = \mathrm{sgn}\left(\langle r, c_k \rangle\right). \tag{1}$$

Canonical representation for c_k is:

$$c_k = s_k + x_k \tag{2}$$

where, x_k and s_k (spreading signature waveform) are uncorrelated and

$$\langle s_k, x_k \rangle = 0. \tag{3}$$

Thanks to the canonical linear transformation, every linear transformation for multi-user detection is characterized by its corresponding orthogonal signal x_k.

The aim of the adaptive process is to minimize the output energy of the detector. Minimum output energy (MOE) can be achieved by x_k adaptation from:

$$\mathbf{MOE}(x_k) = \mathbf{E}\left[\left(\langle r, s_k + x_k \rangle\right)^2\right]. \tag{4}$$

Using (3) and (4), cost function for the constrained optimization problem is given by

$$\mathbf{J}(x_k) = \mathbf{E}\left[\left(\langle r, s_k + x_k \rangle\right)^2\right] + \lambda \langle s_k, x_k \rangle. \tag{5}$$

Solving (5) we get gradient estimate

$$\hat{\nabla}\mathbf{J}(x_k) = 2.\left[\langle r, s_k + x_k \rangle r - \langle r, s_k + x_k \rangle \langle s_k, x_k \rangle s_k\right]. \tag{6}$$

Let us consider the adaptive algorithm updates proceed at the data rate ($1/T$). The observed waveform $r(t)$

is slotted into waveforms of duration T: …, $r[i\text{-}1]$, $r[i]$, $r[i+1]$,… where

$$r[i] = r\left(t \in \langle i.T, (i+1).T\rangle\right) \tag{7}$$

Let us denote the responses of the matched filters for s_k and $s_k+x_k[i\text{-}1]$ by

$$\mathbf{Z}_{\mathbf{MF}}[i] = \langle r[i], s_k \rangle , \tag{8}$$

$$\mathbf{Z}[i] = \langle r[i], s_k + x_k[i-1] \rangle , \tag{9}$$

respectively. Stochastic gradient adaptation rule is then

$$x_k[i] = x_k[i-1] - \mu \mathbf{Z}[i]\left(r[i] - \mathbf{Z}_{\mathbf{MF}}[i] s_k\right), \tag{10}$$

depicted in Fig. 3 [4], [5]. $\mathbf{Z}[i]$ and $\mathbf{Z}_{\mathbf{MF}}[i]$ are represented by constant value slotted signals defined as

$$\left.\begin{aligned} \mathbf{Z}_{\mathbf{MF}}(t) &= \langle r[i], s_k \rangle = \mathbf{Z}_{\mathbf{MF}}[i] \\ \mathbf{Z}(t) &= \langle r[i], s_k + x_k[i-1] \rangle = \mathbf{Z}[i] \end{aligned}\right\} t \in \langle i.T, (i+1).T\rangle \tag{11}$$

in our Verdu's modified model. The orthogonal component at the i-th iteration, $x_k[i]$, depends only on …, $r[i\text{-}1]$, $r[i]$.

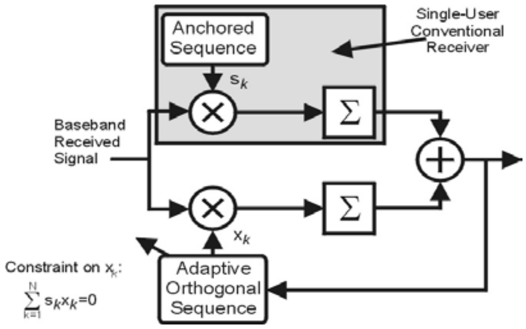

Fig. 2. Block diagram of a BAMUD.

4. BAMUD Design in SystemView

We decided to simulate the mentioned BAMUD presented by (8), (9) and (10) in the system design tool SystemView. This program is intended for simulating communication system conditions as degradation of transmitted signal, MAI, near-far problems by easy way. Specific linear and non-linear functions and many operators (called tokens) are available in systematically organized libraries. User-friendly graphical organization allows focusing on a specific design goal under complex system design conditions [12], [13].

Synchronous multi-user CDMA system is considered in this section. Transmission model consists of a desired user transmitter metasystem, an interfering users transmitters metasystem and a communication channel metasystem. The receiver is represented by BAMUD detector and decision unit metasystems (Fig.4).

A source token with reference to data file represents input information data. Afterwards, the data is spread by Gold generated PN sequence; signal power can be adjusted for the purpose of near-far problem simulation. Other interfering users sides are constructed analogous with own information data source and a different Gold generator set. A trivial transmission channel is done by selected user signals sum and AWGN noise only. It is simple possible to simulate liable real line non-linearity and step response of the communication channel by non-linear functions and filters with impulse response equal to an intended channel. However, this channel simplification promotes to faster blind detector construction.

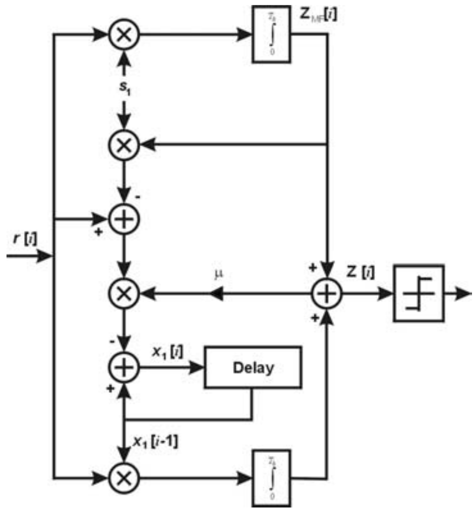

Fig. 3. Blind Adaptive MUD.

The signal continues to flow from a communication channel to BAMUD detector metasystem displayed in Fig. 5. The sum of all users feeds the SS demodulator. The second demodulator input is desired user spreading sequence coming from transmitter directly. The processing according to (10) follows:

- Serial, sample by sample processing (from conventional detector to adaptive process);
- Parallel, block by block processing (remaining adaptive mechanism).

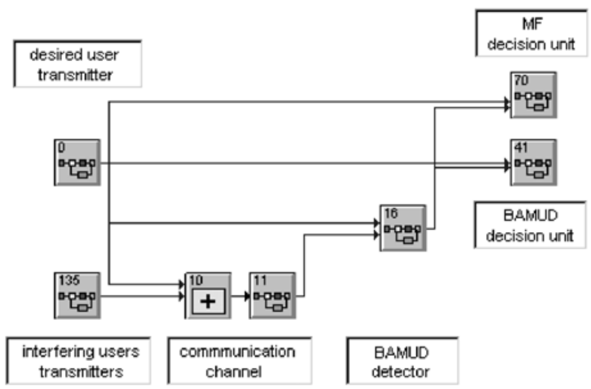

Fig. 4. Synchronous CDMA systems modeled in SystemView.

Serial and parallel design has its advantages and disadvantages. Generally, it is processing rate and design complexity trade-off. Therefore, serial approach has been chosen to bring in transparency to a model. Hence, serial integrator has a relevant output delay (information bit duration delay in our case); it is impossible to provide adaptive process synchronization with feedback.

Parallel fraction consists of:

1) Multiple integrating sample-and-hold function within chip duration (equally to oversampling) gives a PN sequence length block of samples.
2) Next, parallel $x[i]$ block processing succeeds (10).

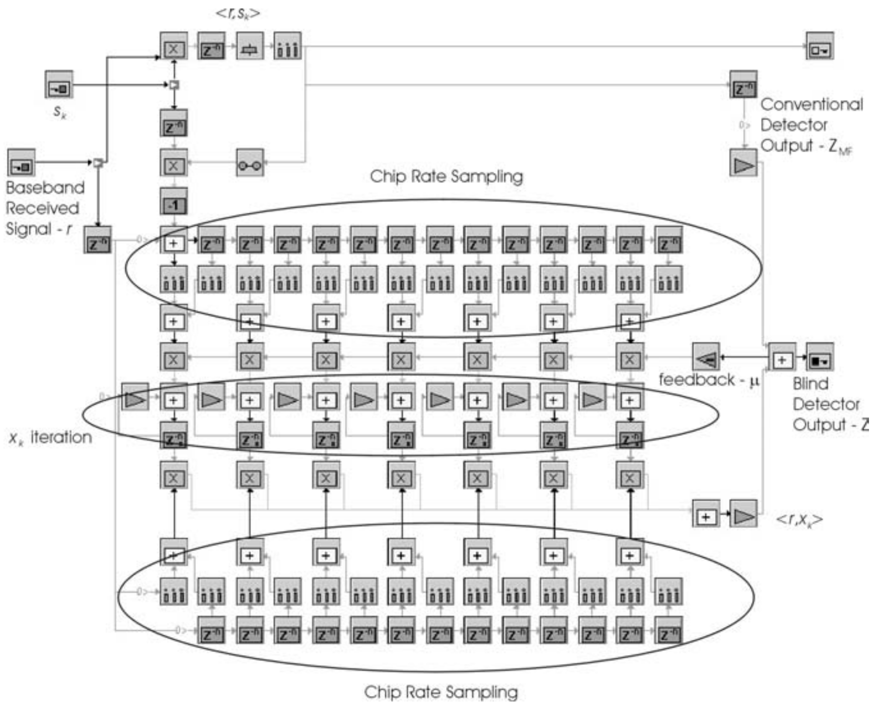

Fig. 5. BAMUD designed in SystemView.

Conventional detector unspread output which is a part of BAMUD enters a decision unit available for BER evaluation. On-coming processing follows an adaptive operation in order to eliminate MAI. BAMUD output enters another decision unit to evaluate BAMUD BER. Decision units are responsible for the desired user data bits estimation under the default threshold level. The estimated output is compared with the data sequence from the transmitter (evidently, shifted of a previous processing system delay). Than, BER is obtained as a ratio of two mentioned signals mismatch time periods related to whole investigated sequence time.

Most of the SystemView parameters are defined globally as some token constants or by default function. This preset brings a transparency into simulation and makes it possible to modify a design easily.

5. Simulation and Results

Due to a synchronous model and a simple channel there are only some fundamental inputs to the simulation we had to set. The information stream length gives BER output precision. The spreading gain determines the receiver ability to solve MAI and so determines a number of simultaneously transmitted users. Background noise is a problem in conventional communication (TDMA, FDMA) systems either in CDMA systems and should be observed carefully. Extra, apt adaptation constant adjustment is important to ensure BAMUD work properly.

Next, the following parameters have been predetermined to the simulation:

1) There were 10000 information bits in the simulation examined. Generally, higher *simulated sequence length*, the graphs accrete evidence (e.g. low BER value is more authentic). But, it is sufficient for convergence rate observation purposes.

2) Also, the *spreading gain* of 7 is sufficient to examine MAI robustness. PN sequence period is set equal to an information bit duration. Spreading sequences are Gold generated. This implies the maximal number of simulated users to 9.

3) All digital even analog simulated processes are digitally solved in SystemView. Our system frequency (*system timing*) is defined to be $f_s = 2.10^6$ Hz. Theoretically, analog signals with the maximal frequency of 10^6 Hz can be represented. Practically, it is insufficient indeed. So, digital representation of analog signals is computational intensive and prolongs simulation times. Therefore, there is no analog process (e.g. BPSK modulation, filtering) included in a transmission concept. Hence, one PN sequence chip can be represented by one system sample only. Despite this simplification, two system samples represent one chip due to

the Gold sequence generator trigger. It means 14 system samples per information bit.

4) _Background noise_ energy is default set to 0dB compared with users bipolar square signal energy. Noise is given by standard deviation:

$$\sigma = \sqrt{\frac{G \cdot spc}{2} \cdot A_{ef}^2} \tag{12}$$

where, G is a spreading gain, spc is a samples-per-chip number, and A_{ef} is an effective signal amplitude (a desired user received amplitude). In our special case is $\sigma = \sqrt{7}$.

5) It is necessary to select a μ constant fairly. The _iterative constant_ μ can be fixed or time varying. For demonstration fixed constants 0.005 and 0.00088 follow μ-adjusting issues [1, 11]. More about these constants poll is explained below.

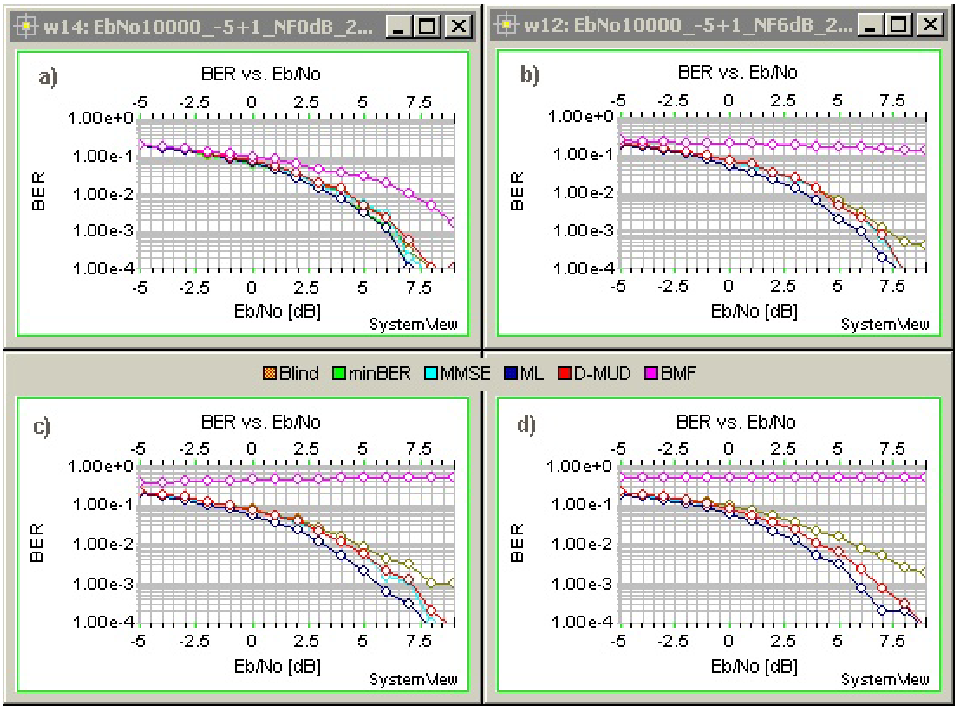

Fig. 6. BER vs. Eb/No; 2 users; G=7; N=10000; μ=0.00088; near-far A_k/A_1 a) 0dB, b) 6dB, c) 12dB, d) 18dB.

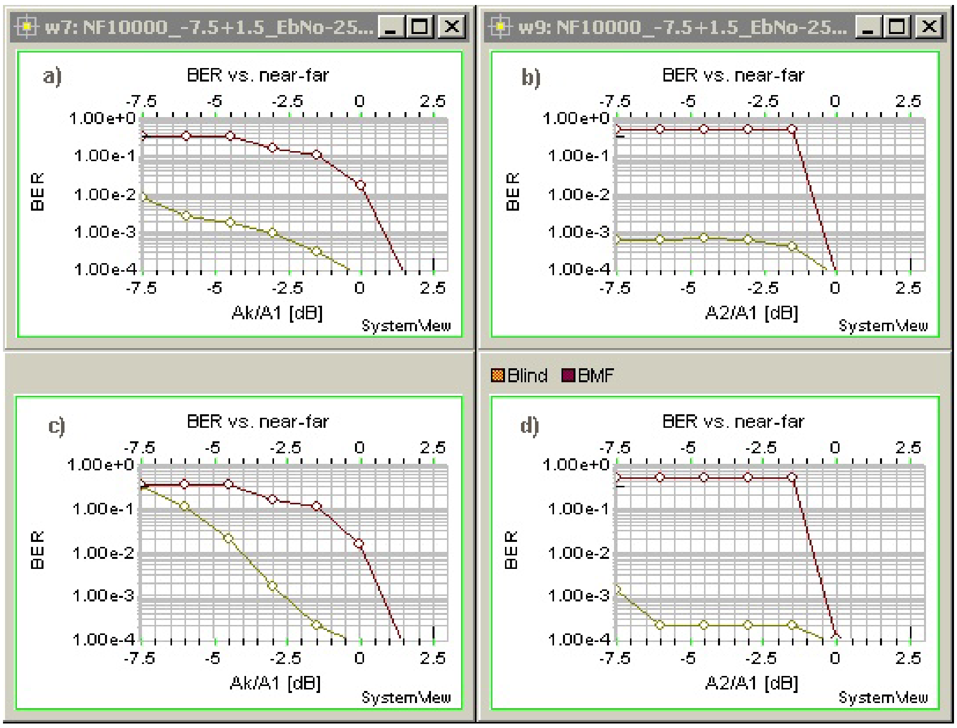

Fig. 7. BER vs. near-far; G=7; N=10000; Eb/No=25dB; a,c) 6 users, b,d) 2 users; a,b) μ=0.00088, c,d) μ=0.005.

Straight simulation follows general fixed global parameters definition. BAMUD is compared with well-known detectors (e.g. decorrelating, MMSE) to imagine characteristics and class the properties (Fig.6). You can see BER deteriorating with near-far growth (A_k is k-th user signal amplitude). BAMUD behavior in the presence of more than two users compared with conventional detector is captured in Fig.7. These graphs are little bit misleading at the first glance but veracious. Simulations are done over all information bits even under adaptive process. Graphs a) and c) are generated under same number of users but different μ with. This μ selection (Fig. 7c.) causes blind detector instability in the presence of strong interfering users and large BER occurs. On the other hand, Fig. 7d (2 users simulation) is not affected by instability and the system can converge faster with lower BER compared with Fig. 7b.

6. Conclusion

BAMUD detector was modeled in the system design tool SystemView. It can handle MAI with a little higher complexity in comparison with a conventional detector. It doesn't need redundant information in order to decode a desired user. It can be seen in Figs. 6, 7, BAMUD has a better performance related to a conventional detector. But it is not near-far resistant. Potential real BAMUD using systems must have the power control. In future, an iterative method could be used to enhance detector properties. For example, with channel coding, an ability to suppress MAI in Fading Channel comes. Iterative Decoding permits to improve an average performance in multi-user case [9].

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