OFDM Blind Parameter Identification in Cognitive Radios

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Abstract— **In this paper we introduce a blind parameter identification algorithm for Orthogonal Frequency Division Multiplexing (OFDM) signals. The algorithm correlation-based processes automatically estimate all parameters of OFDM signals with a blind process that works from a limited amount of data without any prior information. We also derive novel identification performances of algorithms under various conditions, assuming actual conditions in feasible systems: data offset, AWGN, frequency offset, and fading channels. The algorithm is essential for two systems: first, Cognitive Radios, one of the most exciting being radios that change fundamental parameters frequently to provide high throughput and high quality of services; and, second, Radio Monitoring Systems that detect illegal signals transmitted by unlicensed devices.**

Index Terms— **Blind processes, Parameter identifications, OFDM systems, Cognitive Radios, Radio monitoring.**

I. INTRODUCTION

Currently, there is much interest in applying OFDM systems to the wide area of communication systems for the advantages of optimal spectrum efficiency and of transmissions over frequency-selective fading channels. In fact, several types of new communication systems using OFDM technologies are in service, such as satellites, terrestrial Digital Audio Broadcasting (DAB)[1], wireless local area networks, and short range wireless access standards (IEEE 802.11a[2], HiperLAN/2[3]). However, merging of new services through wireless communications requires innovative systems enabling the provision of higher data transmission rate than ever before. For this purpose, the technical concept called Cognitive Radios has gained increased interest in the last few years [4][5]. The radio systems recognize the conditions of radio channels, and they can frequently set appropriate parameters such as constellation patterns and frame structures to maintain high data throughput. Two main strategies have been proposed for the change of parameters [6][7].

1) There is the case in which specific commands will be delivered between a transmitter and a receiver before beginning to change parameters. In this case, it is necessary for the system to allocate data fields for these commands. In addition, the system is delayed to catch up with the variation in radio conditions.

2) There is the case in which a transmitter will individually decide the timing to switch the parameters depending on the conditions. A receiver recognizes these parameters by analyzing received signals. In this case, systems can catch the variation in a short time and then apply another type of structure for data-transmission. Therefore, the system gives a faster data-rate than regular systems. However, specific algorithms to identify OFDM parameters with a blind process are required in the receivers, but to date no such algorithms have been developed.

In this paper we will propose a parameter identification algorithm with blind processes. Without any prior information, this algorithm estimates fundamental parameters necessary for a demodulation process: number of pilot symbols, data symbols, prefix symbols, sub-frames in the fundamental frame, symbols of the fundamental frame, and the fundamental frames in received signals. Additionally, the algorithm has a particular function to detect and adjust offset from the initial point of frames caused by the data acquisition timing. The proposed algorithm has good performances in the channels: frequency offset - one of the leading factors causing system performance deteriorations-, AWGN, and Rayleigh fading.

II. SIGNAL MODELS

We considered a common OFDM data structure used in the actual systems [8], shown in Figure 1, as a basis for developing algorithms. The structure consists of a pilot frame and R sub-frames in a basic frame. Pilot symbols (Np) could roughly trace tuning errors in the time domain. Prefix symbols (Ng) in sub-frames are used to avoid effects of ICI caused by multi-paths and to adjust the frequency offset errors remaining after the synchronization by pilot symbols. User data is modulated on Ns carriers. The period of the basic frame (Nf) is defined as $Np+R(Ns+Ng)$. This system will transmit the data connected with T basic frames. Here R indicates the number of sub-frames in a basic frame, and T means the number of basic frames in transmitted data. Output data (X_n) after IFFT is as follows:

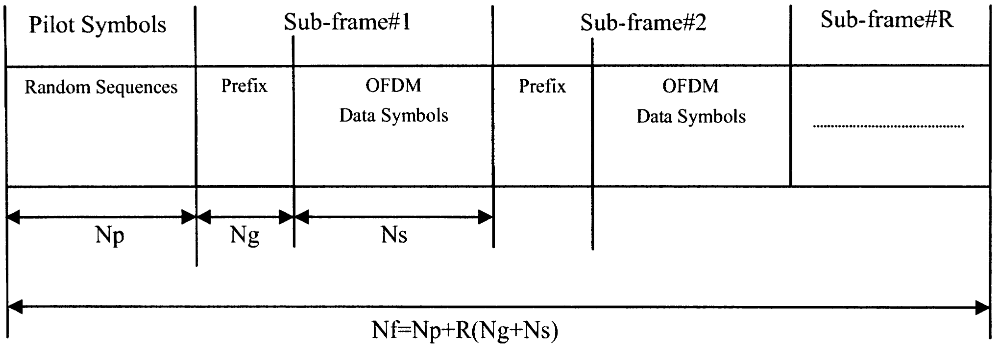

Fig. 1 The frame structure of OFDM

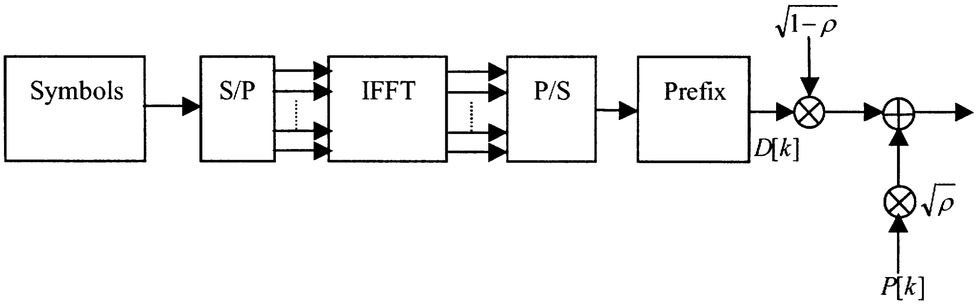

Fig. 2 OFDM signal generation schemes

$$\chi_n = \frac{1}{\sqrt{Ns}} \sum_{k=0}^{Ns-1} X_k e^{\frac{j2\pi kn}{Ns}}, \quad n = 0,1,2,\ldots,Ns-1 \qquad (1)$$

where X_k is the kth symbol data of Ns sub-carriers.

Figure 2 shows the schemes to generate OFDM signals at the transceiver. The modulated source symbols of user's data are paralleled on Ns carriers, and then IFFT transforms them into time domain signals. Prefix symbols, which are the same as the last Ng symbols of Ns, are put at the front of data sequence. The pilot sequences are superimposed at the top of the sub-frame with respective coefficient $\sqrt{\rho}$ and $\sqrt{1-\rho}$. Here, $\sqrt{\rho}$ adjusts the portion of the power between pilot symbols and sub-frames in a fundamental frame. In AWGN channel, received signals $\{f(k)\}$ are shown as follows when the transmitted signal sequences are $S(k)$ and the white Gaussian noise is $N(k)$:

$$\begin{aligned} f(k) &= S(k) + N(k) \\ &= (\sqrt{\rho}\sigma_s^2 P(k) + \sqrt{1-\rho}\sigma_s^2 D(k)) e^{j(\frac{2\pi f_o k}{N_s + N_g} + \vartheta_c)} + N(k) \end{aligned} \qquad (2)$$

Where $P(k)$ is the training sequence for the synchronization, and $D(k)$ is sub-frames of OFDM data sequence with prefix symbols. θ_c is the carrier phase and f_o is the frequency offset normalized by the sub-carrier spacing. The power of received signals and noise is defined as $\sigma_s^2 = E[|S(k)|^2]$ and $\sigma_n^2 = E[|N(k)]|^2]$.

III. ALGORITHMS

The correlation-based algorithm automatically estimates essential parameters for the demodulation under the condition that the receiver only knows approximate center frequency of received signals. To recognize each OFDM parameter requires a process with just four steps.

Step 1: Estimation of Ns and Nf

In this step, auto-correlation extracts the specific sequential components corresponding to Ns and Nf from received signals. Note that OFDM signals in this model involve two types of sequential parts shown in Figure 1: one is the prefix symbols which are copied from the last part of Data Symbols and the extracted peaks with correlations equal to Ns. The other is the pilot symbols that are presented in the front of every fundamental frame and these sequential peaks repeatedly appear every Nf. A simulation result shows several featured peaks in Figure 3.

Here, if received signals are $f(k)$, auto-correlation results $\{\rho_1(\tau)\}$ can be shown in the following form:

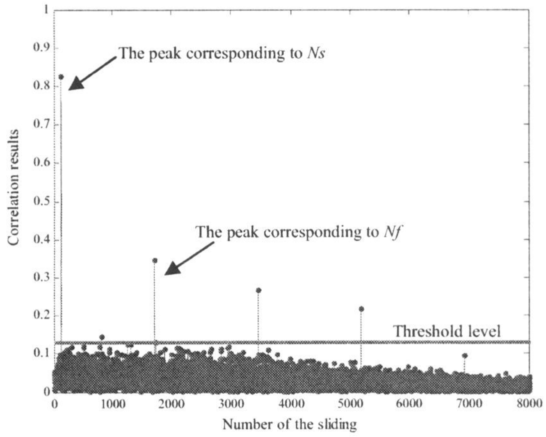

Fig. 3 Correlation results in Step 1

$$\rho_1(\tau)=\frac{2}{M}\sum_{k=0}^{M/2} f(k)\cdot f(k+\tau), \qquad \tau=0,1,2,\cdots,M/2 \tag{3}$$

where M is the total number of received signals in the process and τ is the shift number of correlations. A threshold defined by the peak power determines the desirable peaks.

$$L_1=\{\ \tau\ for\ \rho_1(\tau)\geq C_{TH}\ \} \tag{4}$$

$$C_{TH}=\rho_1(0)\cdot\alpha \tag{5}$$

where L_1 is positions corresponding to the sequential components, C_{TH} is a threshold level, and α is less than 1. Here we can define Ns as the position of the maximum peak because many prefix symbols involved in the frames correlate highly.

$$Ns=\tau\ for\ Max\{L_1\}, \quad \tau\neq 0 \tag{6}$$

Let us define the components $\{L_2\}$ that exceed the threshold level as shown below:

$$L_2=\{\tau\ for\ \rho_1(\tau)\geq C_{TH}\}, \qquad \tau\neq Ns, \tau\neq 0 \tag{7}$$

Here we can assume that the peaks corresponding to Nf repeatedly appear. Thus, the most frequent value in the histogram showing distances between neighboring peaks can define Nf.

$$L_{21}<L_{22}<L_{23}<\ldots \tag{8}$$

$$H(k)=Hist\lfloor L_{2(j+1)}-L_{2j}\rfloor, \qquad j=1,2,3,\ldots \tag{9}$$

$$Nf=Max\ H(k) \tag{10}$$

where $H(k)$ is a histogram of the distances and k is an index corresponding to each distance.

Step 2: Estimation of approximate Np and Noft

In this step, we will estimate approximate *Np* and *Noft*, that is offsets from the edge of the frames. The receiver can start the processes from a point of the frame corresponding to some point in time. Pilot symbols are regularly used to synthesize the frame in communication systems. However, Cognitive Radios are required to work under the condition that the pilot sequences are unknown. This algorithm can estimate the offset errors using correlations and pattern matching.

The correlation results $\{\rho_2(m)\}$ with the two windows set apart at length Nf are defined as follows:

$$\rho_2(m)=\sum_{k=0}^{m} f(k)\cdot f(k+Nf), \qquad m=0,1,2,\ldots,N_f-1 \tag{11}$$

Correlations can extract the specific character of a pilot symbol part shown in Figure 4, but in the case that data offset from the initial point of frames exists, the aspects are significantly influenced. To adjust the offsets and shift the data to the appropriate position, we first estimate the center position of pilot symbols by the peak of differential values. The differential values $\{\rho_2'(m)\}$ and signals $\{\rho_3(m)\}$ after centering have the following form:

$$\rho_2'(m)=\rho_2(m+1)-\rho_2(m), \qquad m=0,1,2,\cdots,N_f-2 \tag{12}$$

$$L_3=m\ for\ Max\ \{\rho_2'(m)\} \tag{13}$$

$$\rho_3(m)=\sum_{k=0}^{m} f(k+L_3)\cdot f(k+L_3+Nf), \quad m=1,2,3,\ldots,N_f-1 \tag{14}$$

Here, L_3 corresponds to the center of the pilot symbol because the values of correlations are growing doubly. And $\rho_3(m)$ is the correlation result for the centered data.

A pattern matching for the two types of correlation results detects the number of data offsets and pilot symbols.

$$\rho_4(m)=-\rho_3(Nf-m) \tag{15}$$

$$d_1(n)=\left[\sum_{j=0}^{Nf-1}\rho_3(m+j)-R(n+j)\right]^2, \qquad n=0,1,2,\ldots,N_f-1 \tag{16}$$

$$d_2(n)=\left[\sum_{j=0}^{Nf-1}\rho_4(m+j)-R(n+j)\right]^2, \tag{17}$$

$$L_4=n\ for\ Min\ \{d_1(n)\} \tag{18}$$

$$L_5=n\ for\ Min\ \{d_2(n)\} \tag{19}$$

where $\rho_4(m)$ is the reversed data of $\rho_3(m)$. $R(n)$ is a reference line corresponding to the aspects of pilot symbols. $d_1(n)$ and $d_2(n)$ are the values of pattern matching, while L_4 and L_5 are the positions best matched with a pilot symbol part.

Here L_4 matches the number of data offsets as well as the beginning point of pilot symbols, while L_5 indicates the end

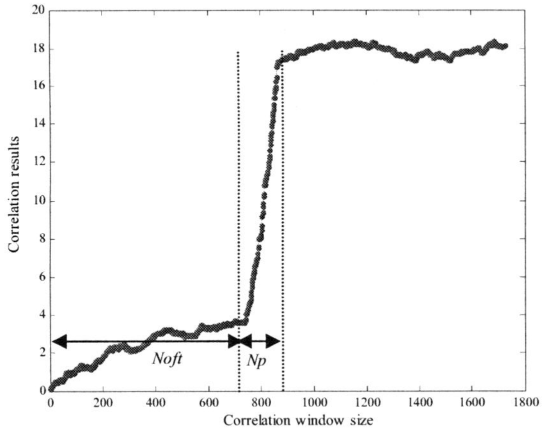

Fig. 4 Characteristics of extracted pilot symbol part in Step 2

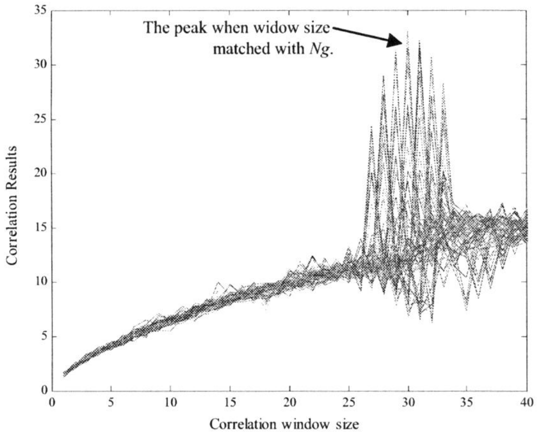

Fig. 5 Estimation of prefix symbols in Step 3

point of the pilot symbol. Therefore, *Np* and *Noft* are estimated below:

$$Noft = L_4 \tag{20}$$

$$Np = L_5 - L_4 \tag{21}$$

The estimated values, *Np* and *Noft*, still have some errors remaining. To improve estimation performance of *Noft*, another correlation with the window shifting is applied. Here the correlation value reaches a peak in the case that the number of shifts on the correlations is exactly *Noft*. Otherwise, the peak will not appear. Signals after data shifting with L_4 and the data offset estimation errors can be written as:

$$\rho_5(m) = \sum_{k=0}^{Nf-1} f(k + L_3 + L_4 + m) \cdot f(k + L_3 + L_4 + Nf + m), \quad m = 0,1,2,\ldots,\frac{1}{4}N_p \tag{22}$$

$$L_6 = m \ for \ Max\{\rho_5(m)\} \tag{23}$$

where L_6 is the estimated error of data offsets. Therefore, the final estimation value of *Noft* in this step can be defined as follows:

$$Noft = L_4 - L_6 \tag{24}$$

We have confirmed that this idea improved the estimation performance by over 20% in the AWGN channels.

Step 3: Estimation of Ng and error adjustment of Noft and Np

In estimated values in the previous step, some errors still exist that affect overall estimation performances. Step 3 adjusts the remaining estimation error of *Noft* and *Np* in Step 2, and also identifies *Ng*. The received data is divided into each frame without pilot symbols based on the estimated parameters above. The divided frames include several prefix symbols. Here we can assume that the value of a correlation with three parameters (correlation window size, and the number of data shifts and pilot symbols) will come at the peak, shown in Figure 5, when the window size coincides with *Ng* and the number of data shifts and pilot symbols match the estimation error of *Noft* and *Np*. The reason is that prefix symbols highly correlate with each other under this limited condition. The frame data without pilot symbols $\{ f_1(k) \}$ and the correlation result $\{ \rho_6(k) \}$ can be written as:

$$\begin{aligned} f_1(k) &= f(k + Np + Noft) \\ &= f(k + L_5 - L_6) \end{aligned} \tag{25}$$

$$\rho_6(L,M,N) = \sum_{k=0}^{L} f_1(k+M+N) \cdot f_1(k+Ns+M+N), \quad L = 0,1,2,\ldots Ns-1 \tag{26}$$

Here, *M* and *N* are an integer number and the ranges are defined by the estimation performances in Step 2. The algorithm in Step 2 realizes the reduction of calculation time in Step 3. The values corresponding to *Ng* and estimation errors of data offsets are defined as follows:

$$(L_7, L_8, L_9) = L, M, N \ for \ Max\{\rho_6(L,M,N)\} \tag{27}$$

Therefore, we can define *Ng, Noft* and *Np* below:

$$Ng = L_7 \tag{28}$$

$$Noft = L_4 - L_6 - L_8 \tag{29}$$

$$Np = L_5 - L_4 - L_9 \tag{30}$$

Step 4. Estimation of R and T

R and *T* are calculated below:

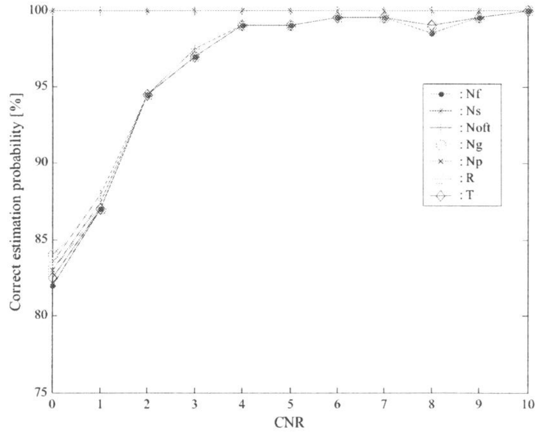

Fig. 6 Estimation results in AWGN channels

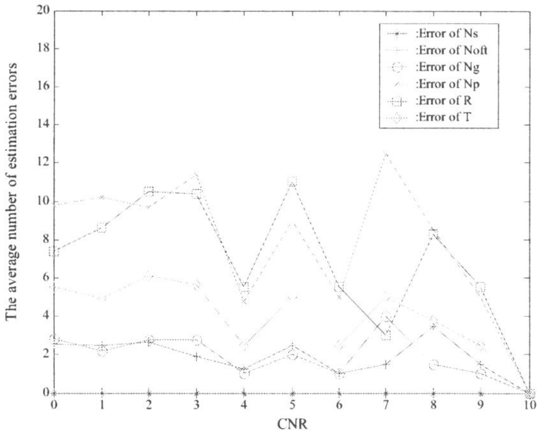

Fig. 7 The number of estimation errors in AWGN channel

$$R = (Nf - Np)/(Ns + Ng) \tag{31}$$

$$T = M / Nf \tag{32}$$

where M is the total number of received signals.

IV. SIMULATION RESULTS

In this section, the proposed algorithm shows the estimation performances for OFDM signals in AWGN, frequency offset, and Rayleigh-fading channels. The simulations were performed for the base-band model of signals. Data symbols are modulated with each carrier by the DQPSK modulation scheme. Frequency offsets are defined as the amount of offsets of the sub-carrier spacing, while fading pitches are normalized by the total number of data sub-carriers. We concentrate on the experimental conditions as strictly as possible to apply the algorithm for the various types of system. The OFDM signal models in the simulations are as follows:

Nf=1728, Np=128, Ng=32, Ns=128, R=10, $Noft$=64

Simulations were performed under 1% frequency offset error, 1% Rayleigh fading pitch for signals given data-offset of 64 symbols from the original frame. Each simulation is repeated 1000 times to make one point of data in the graphs. In this blind estimation process, only 10 frames of data, i.e., 17,280 symbols, were employed.

The estimation performances with varying parameters of AWGN channels in shifted data are shown in Figure 6. Here the correct estimation probability in the graph indicates the likelihood of the proposed algorithm exactly estimating each parameter. From the result, *Ns* is recognized with 100% probability. The reason is that many prefix symbols implemented in the frame featured a comparatively tough peak for the estimation, as shown in Figure 3. Estimation performances for the other parameters are affected by the value of CNR. The performances begin to degrade from approximately 4dB and dropped down to 80% at 0dB. Here the proposed algorithm seeks for the other parameters by using the results identified in previous steps. Therefore, the estimation errors in the previous steps have an effect on the performances later. The estimation probabilities of the other parameters were

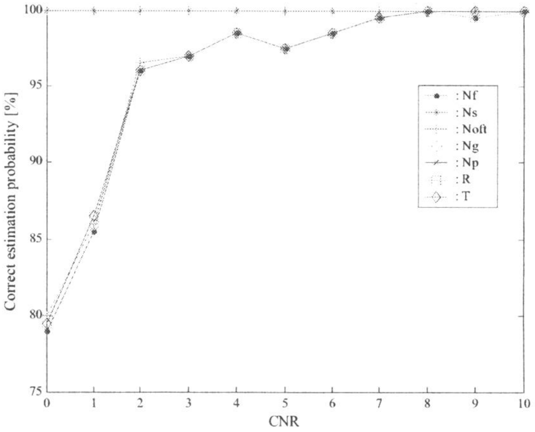

Fig. 8 Estimation results in frequency offset channels with AWGN

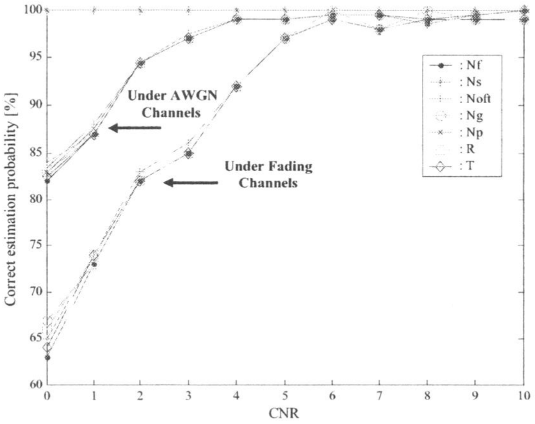

Fig. 9 Estimation results in fading channels with AWGN

almost equal to those of *Nf*. Thus the result concludes that the algorithm Step 1 suffices to establish the total estimation performances because the other parameters demonstrated perfect estimation performances in the event that *Nf* was identified correctly. The average number of estimation errors when errors occurred, shown in Figure 7, indicates that the number of estimation errors does not depend on CNR strongly, but the error is determined by the *Nf* estimation performance. In fact, the performance is error-free when *Nf* is estimated correctly at 10dB. Therefore, we can assume that the estimation error of *Nf* loses sequential characteristics used in the estimation processes and leads to the estimation error of the other parameters.

The performances added to both AWGN and frequency offset, shown in Figure 8, are close to the results under AWGN channels. The correlation-base algorithm making use of detected power-valued peaks reduced the effect of frequency offset in the estimation.

The estimation performances in Rayleigh fading channels as shown in Figure 9 indicate that fading with AWGN under CNR 5dB causes approximately two times less deterioration than the results of AWGN channels, except *Ns*. However, the performance comes to almost 100% probability at 5dB or more despite 1% fading pitch which is considered to be difficult operating conditions for a communication system.

V. CONCLUSIONS

Blind parameter identification algorithms for OFDM signals have been proposed. Without any prior information, the algorithms are able to synchronize the frame automatically and to estimate OFDM parameters using only ten fundamental frames of data. In their realization, the algorithms are evaluated by simulations for the signals given data offsets in AWGN, data offset, frequency offset and Rayleigh-fading channels. The algorithm achieves almost 100% probability at CNR 4dB or more in AWGN channels. In addition, we confirmed that it is robust for data offsets caused by data acquisition timing and frequency offsets of tuning errors. Furthermore, despite the Rayleigh fading channel, the algorithm realizes better estimation performances. These advantages conclude that the proposed algorithm could have acceptable performances for both Cognitive Radios and Radio Monitoring Systems.

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