Optical CDMA Networks Using Different Detection Techniques and Coding Schemes

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Abstract

This paper presents the comparative performance of different detection and coding schemes for spectral-amplitude-coded optical code division multiple access (SAC-OCDMA) system. SAC-OCDMA systems are receiving more attention because of their ability to completely eliminate multiple access interference (MAI). Fiber Bragg grating (FBGs) are used as encoder/decoder. Experimental simulation was carried out using OptiSystem version 5.0 and performance of OCDMA network is characterized through bit error rate (BER) received power and no of filters required for a particular code.

Keywords: FBG (Fiber brag rating), OCDMA (optical CDMA), BER (bit error rate), MAI (multiple access interference), DW (double weight code), and MDW (modified DW)

1. Introduction

There has been a tremendous interest in applying Code Division Multiple Access (OCDMA) techniques to fiber optic communication systems. This technique is one of the multiple access schemes that are becoming popular because their advantages such as the flexibility in the allocation of channels, ability to operate asynchronously, enhanced privacy and increased capacity in bursty networks, specially, direct detection OCDMA systems have been investigated widely to apply for high speed LAN, because they allow multiple users to access network simultaneously [1-2]. In the case of data transfer where traffic tends to be bursty rather than continuous, CDMA can be used for contention-free, zero delay access. Several code families have been developed for SAC-OCDMA such as modified quadratic congruence codes M-sequence codes [3], double weight codes, etc. Therefore it is desirable to develop a detection technique that provides the multiple access interference (MAI) elimination capability. This paper is based on the design of encoder and decoder modules for SAC-OCDMA system based on Fiber Bragg Gratings (FBGs). The codes used in this research are DW and MDW codes.

2. Theory

2.1. Spectral Direct detection technique-

This is the simplest technique for DW code implementation. The implementation of spectral direct detection technique is completely different from AND subtraction detection technique. For this detection scheme, only desired spectral chip in the optical domain is

filtered. This detection scheme doesn't need subtraction detection technique. Therefore, MAI and Phase Induced Intensity Noise (PIIN) will not exist in this detection scheme. Nevertheless, this technique is only applicable to codes, which the spectral chips are not overlapped with other spectral chips of the other channel, i.e. a minimum of one clean chip in every code sequence. MDW and DW are the examples of codes having this property.

2.2 Complementary Subtraction Technique-

Transmitter model of Complementary model is similar to that of direct detection. In the receiver, the received signal is divided into two complementary branches of spectral chips as shown in figure-1. In receiver, the received signal is divided into two complementary branches of spectral chips as shown in figure-1. These two branches of spectral signals are sent to a balanced detector that computes the correlation difference.
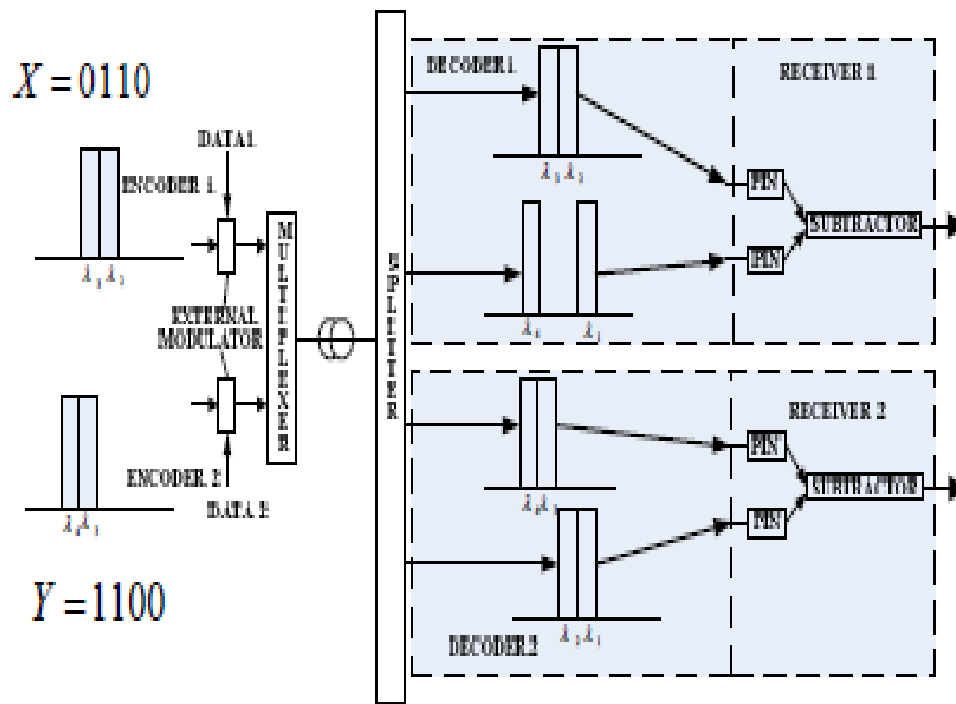

Figure 1. Implementation of the Complementary Subtraction Technique

In complementary subtraction technique, the cross-correlation is defined as:-

$$\theta_{XY}(k) = \sum_{i=0}^{N-1} x_i \, y_{i+k} \qquad (1)$$

where X and Y are two OCDMA code sequences. The complement of sequence (X) is given by $(\overline{X})$ whose Elements are obtained from (X) by $\overline{X} = 1-x_i$. Let X = 0011 and Y = 0110 and therefore $\overline{X}$ = 1100. The periodic cross correlation sequence between $(\overline{X})$ and(Y) is similar to Equation (1) and is expressed as:

$$\theta_{\overline{X}Y}(k) = \sum_{i=0}^{N-1} \overline{x}_i \, y_{i+k} \qquad (2)$$

We look for sequences for which

$$\theta_{XY}(k) = \theta_{\overline{X}Y}(k) \tag{3}$$

At the receiver, the photo detectors will detect the two complementary inputs which will be fed to the subtractor whose cross-correlation output, Z can be expressed as:

$$Z_{Complementary} = \theta_{XY}(k) - \theta_{\overline{X}Y}(k) \tag{4}$$

By the end the answer is 0, which means that, at the output of the subtractor, there will be no more cross-correlation terms indicating that there is no more signal from other users in the intended channel.

2.3 AND Subtraction Technique

In this technique, the received signal is divided into two AND branches of spectral chips as shown in figure-2. In AND subtraction technique, the cross-correlation $\theta_{\overline{X}Y}(k)$ is substituted by $\theta_{(x\&y)y}$ where $\theta_{(x\&y)}$ represents the AND operation between sequences X and Y. For example, let X = 0011 and Y = 0110 and therefore (X AND Y) = 0010. Example of an AND receiver is shown in figure-2.
At the receiver,

$$Z_{AND} = \theta_{XY}(k) - \theta_{(X\&Y)Y}(k) \tag{5}$$

Equation (5) shows that, with AND subtraction technique, the multiple access interference or the interference from other channels can also be cancelled out. This subtraction technique can be implemented with any OCDMA codes, but for comparison purposes, the Double Weight (DW) code is used as an example.
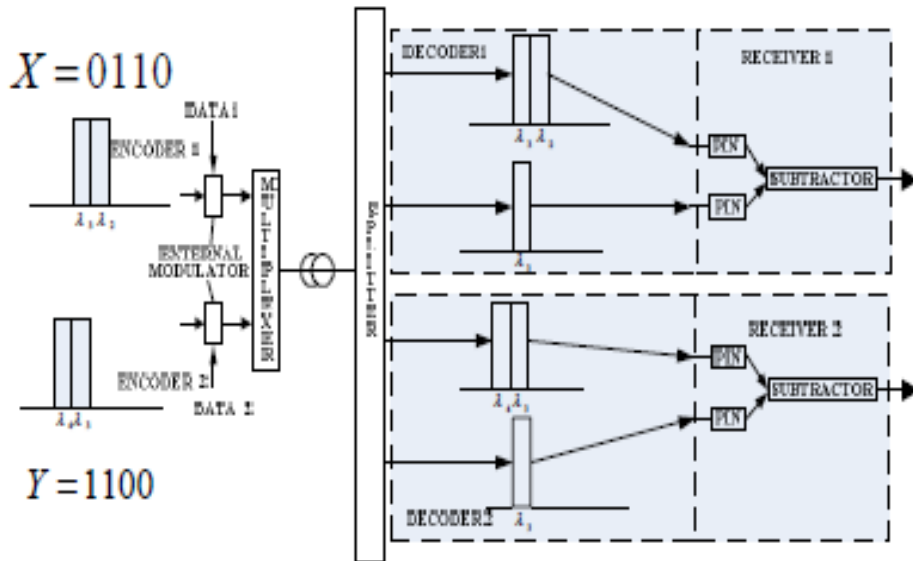

Figure 2. Implementation of the AND Subtraction Technique

Comparison between AND and Complementary subtraction technique using DW code is shown in Table-1

Table 1. Comparison between AND & Complementary Subtraction Technique

	AND Technique				Complementary Technique			
	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4
User 1 (X)	0	0	1	1	0	0	1	1
User 2 (Y)	0	1	1	0	0	1	1	0
	$\theta_{XY}=1$				$\theta_{XY}=1$			
	X&Y=0010				$\overline{X}$=1100			
	$\theta_{(X\&Y)Y}=1$				$\theta_{\overline{X}Y}=1$			
	$Z_{AND}= \theta_{XY}(k) - \theta_{(X\&Y)Y}(k) =0$				$Z_{Complementary} = \theta_{XY}(k) - \theta_{\overline{X}Y}(k)=0$			

The complete subtraction (result is zero) shows that the multiple access interference (MAI) can be cancelled out by using both techniques. In term of architecture, AND subtraction needs less number of filters in the decoder. The filter is only needed at the position of overlapping spectra occurring in the code sequences (refer to the above example of AND operation, (X AND Y) = 0010). In complementary technique the number of filter needed depends on the value of weight in the code sequence. The overall system cost and complexity can be reduced by using fewer number of filters in AND subtraction. At the same time, the performance of the OCDMA system is improved significantly because with less number of filters in the decoder, the total power loss can be reduced and this will be clearly seen in the simulation result.

3. Experimental Simulation Setup

This system is designed and simulated, using OptiSystem Version 5.0 which is widely used for optical communication system simulations .One of the simulation setup is shown in figure-3 and simulation was carried out for MDW and DW code family. ITU-T G.652 standard single-mode optical fiber without any amplifier is employed for a point to point optical transmission link. Each chip has a spectral width of 0.4nm. PIN photodiodes are used to convert the optical signals into electrical signals. The nonlinear effects were activated according to the typical industry values to simulate the real environment as close as possible. Table -2 shows the parameter values used for the simulation of the OCDMA system.
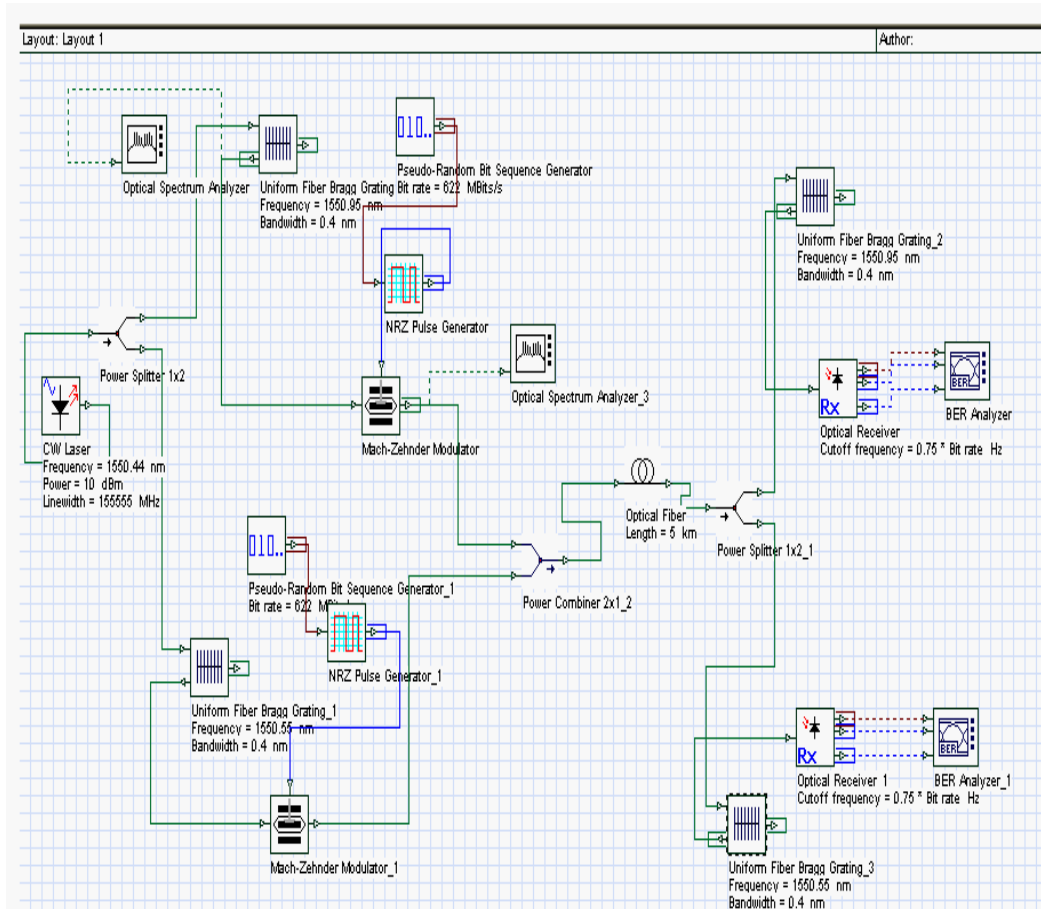
Figure 3.Layout design of OCDMA system using DW direct detection technique

Table 2. Simulation Parameters

Parameter	Value (Transmitter)	Value (Receiver)
Length of fiber	0 to 100 Km	
Broad Band source power	10dbm	
Bit rate	155 to 25000 Mbps	
Wavelength	1550nm	
Chromatic Dispersion coefficient	18ps/nm-km	3.5ps/nm-km
Dark current	5 nA	
Polarization Mode dispersion coefficient	0.07ps/km	

4. Results and Discussions

Performance of the system is checked on the basis of BER, fiber length, received power and the cost of system. Figure-4 shows, the effect of transmission length on BER for different codes and detection schemes. For this purpose fiber length is varied from 5 to 100 Km, other parameters like source power (10dbm) and bitrate (622 Mbps) are kept constant.
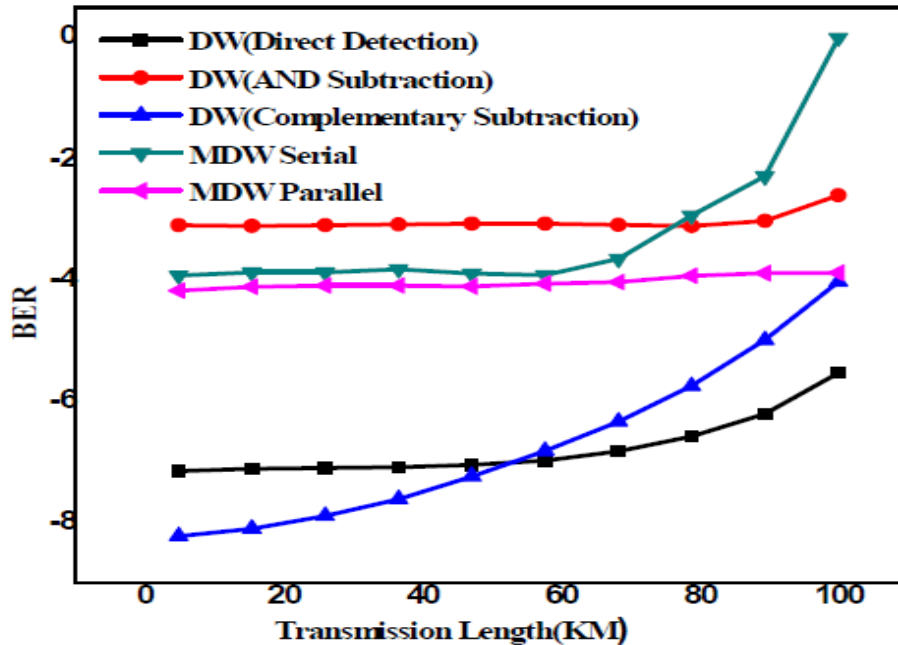

Figure 4. BER versus Transmission Length

This graph shows that an increase in fiber length causes increment in dispersion of the input signal, so BER also increases with distance. Graph shows that DW Direct detection scheme shows best performance and DW AND subtraction shows the worst. On performance basis we can arrange these configurations in the following order:

DW Direct > DW Complementary > MDW parallel> MDW serial> DW AND subtraction.

Figure-5 shows effect of Bit rate on Received power, for this purpose bit rate is varied from 100 to 2500 Mb/s and other parameter like source power (10dbm) and Fiber length (10km) are kept constant. This graph shows that when bit rate increases pulse width decreases, pulse become more sensitive to the dispersion, dispersion losses increases results in the loss of power so received power decreases. Graph shows that DW Direct shows best performance and MDW parallel shows worst performance. Again on performance basis we can arrange these configurations in the following order:

DW Direct > DW Complementary> DW AND subtraction> MDW serial> MDW parallel

Figure 6 shows the effect of bit rate on BER, for this purpose bit rate varied from 100 to 1000 Mb/s and other parameter like source power (10dbm) and Fiber length (10km) kept constant. This graph shows that when bit rate increases then BER of the system increase.

Graph shows that DW AND subtraction shows best performance and DW direct shows worst performance.

Performance wise arrangement can be done in the following order:

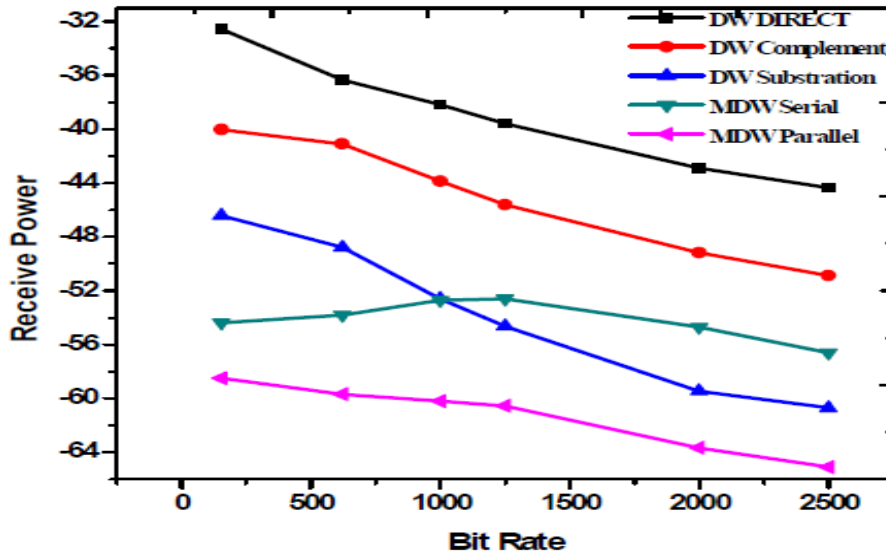*DW AND subtraction> DW Complementary >MDW parallel> MDW serial> DW Direct*
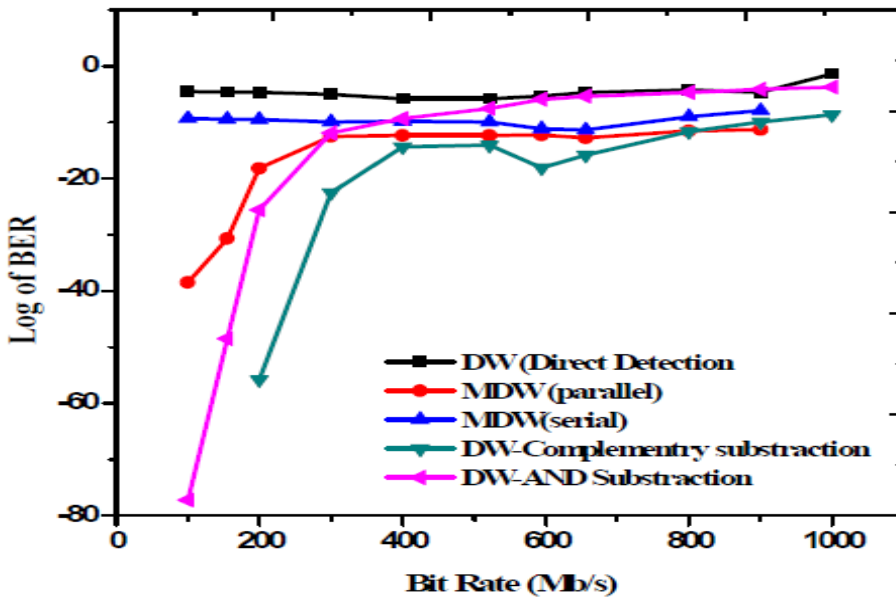

Figure 5. Received power versus Bit rate

Figure 6. Bit rate versus BER

4.1 Cost Performance

Implementation of Direct Detection, AND Subtraction and complementary Subtraction techniques have been described in the previous section. It is obvious that the advantage of Direct Detection is in terms of number of filters required for the decoders. The number of

filters that is needed in the decoders depends on the code weight, W and the basic code's row size or the basic number of users, KB. Therefore, the need of fewer components to implement the Direct Detection technique leads to a substantial cost reduction of the overall system.
On cost basis we can arrange them in the following order:

AND Complementary > AND Subtraction > Direct Detection
For Direct Detection, the filters that are needed
$\quad$ $F_{direct\ Detection}$ = W
For complementary subtraction, the filters that are needed
$\quad$ $F_{Comp.} = (W \times KB) + N$
For AND subtraction, the filters that are needed:
$\quad$ $F_{AND} = W \times KB$
$\quad$ *W=2, 4, 8, 16, 32*
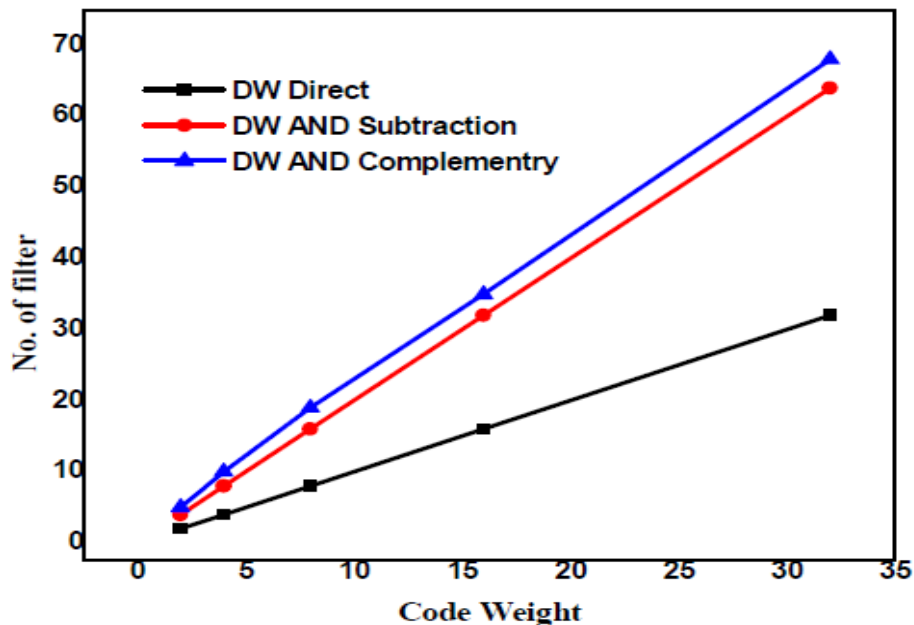$\quad$ *N=1, 2,3,4,5*
$\quad$ KB=2

Figure 7. No. of Filter versus Weight

5. Conclusion

Performance of the OCDMA system decreases as the bit rate increases. This is due to effect of attenuation and dispersion in the fiber. In this paper, we have used amplitude spectrum detection Technique and implemented with MDW and DW codes. On the basis of these results, we made some conclusion, if the designer is looking for economical point of view then DW Direct detection is the best technique, if the designer is looking for accuracy and higher performance, then DW Complementary is the best Technique. If designer is considering economical and higher performance, AND subtraction detection technique is most suitable. If we compare performance of both coding scheme and three detection techniques, then MDW coding and complementary subtraction shows best results.

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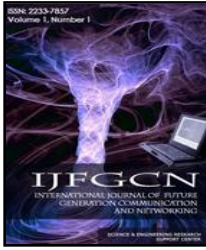
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