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TCM-coded OFDM assisted by ANN in Wireless Channels

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Abstract—*The objective of this paper is to use Artificial Neural Network (ANN) in conjunction with M-ary PSK Trellis Coded Modulation (TCM) based Orthogonal Frequency Division Multiplexing (OFDM) as a means of achieving higher throughput and performance improvement in multipath fading channel. Simulation results are presented, that shows the superiority of the ANN-based approach, as a means to decode the signal at the receiver side, over conventional TCM decoding schemes. The performance gain is due to the adaptive learning capability of the ANN that can use the Transmitter Side Information (TSI), Receiver Side Information (RSI) and Channel Side Information (CSI) to perform decoding and symbol recovery simultaneously. 4-PSK and 8-PSK TCM-codes have been considered in this work along with OFDM transmission technique.*

Keywords-OFDM; ANN; Trellis Coded Modulation; Euclidean Distance; Coding Gain

I. INTRODUCTION

With advances in wireless networking and growing demand for high data rates and throughput, OFDM is an option with wideband transmission characteristics to transmit modulated data over parallel frequency channels. OFDM allows multiple users to transmit in an allocated band by sub-dividing the entire bandwidth into several narrowband channels. These sub-channels are generated such that they are orthogonal to each other, thus allowing them to be closely spaced in the spectrum. The overlapping sub-channels make the OFDM system more spectrum efficient than the standard Frequency Division Multiplexing (FDM) system. The use of Guard Interval (GI) before each transmitted block helps to reduce the effect of Inter Symbol Interference (ISI) on OFDM signal. OFDM, therefore, yields parallel subcarriers that operate at lower data rates and are relatively insensitive to frequency selective fading in multipath environment [1].

The scope and application of OFDM can be expanded by combining it with Trellis Code Modulation (TCM). TCM combines both modulation and coding such that the data rate is increased without increasing the bandwidth requirement. Therefore, TCM-coded OFDM can transmit more number of bits then the conventional OFDM signal within the same bandwidth. This is achieved by doubling the number of constellation points in the mapping process [2]. The concept of TCM was first introduced by Ungerboeck [3] for band-limited Additive White Gaussian Noise (AWGN) channels. He used the rule of set partitioning based on the concept of maximizing the minimum Euclidean distance between any two distinct code sequences. Code design and performance of 4-state and 8-state TCM schemes for asymmetric 8-PSK signals have been described in [4]. A neural network TCM decoder constructed using specific neuron types, is shown to be equivalent to a standard decoder in performance measures in [5].

The rest of the paper is organized as follows: Section II gives an overview of the TCM coded OFDM system and the constituents of the system model. In section III, TCM scheme implementation with ANN has been explained. The parameters used for the simulation have been specified in Section IV. Section V presents the results of the simulation and conclusion is provided in section VI.

II. SYSTEM MODEL

The ANN assisted TCM-coded OFDM system is modeled as shown in Fig 1. The system consists of a simple transmitter-receiver pair and the propagation channel. The block diagram clearly shows how the ANN has been fitted into the system model. The steps of the algorithm for simulation of the system are given below:

- Generate ANN training data
- Perform ANN training till goal is met
- Generate the input data
- For each input block
    - Do TCM Encoding
    - Do OFDM Modulation
    - Transmit through Rayleigh faded channel
- For each received block
    - Do OFDM Demodulation
    - Do de-mapping by finding minimum Euclidean distance
    - Do decoding using ANN decoder
- Calculate Bit Error Rate

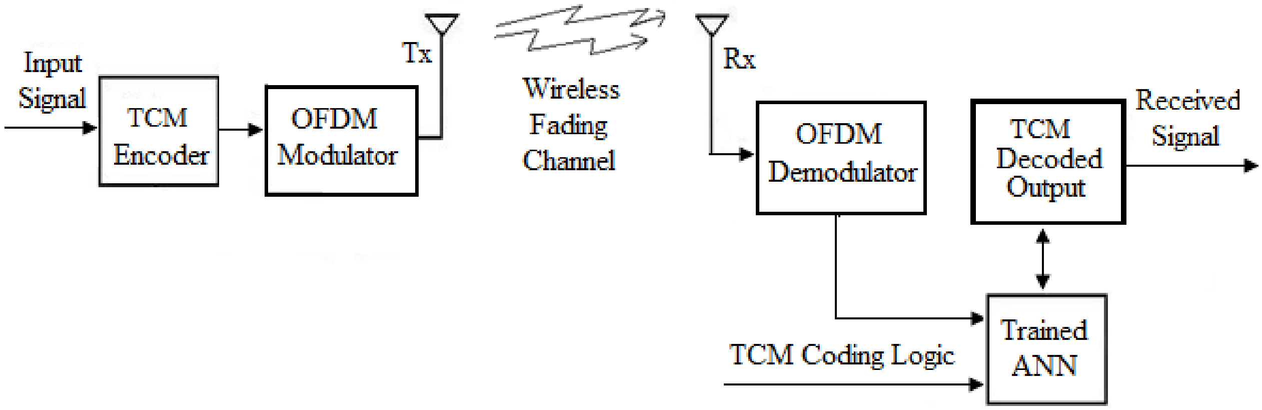


Figure 1. TCM-coded OFDM System

A. Trellis Code Modualtion (TCM)

TCM is a bandwidth and power efficient scheme that combines error correction coding and modulation [2]. The error correcting code mainly used is the (m/m+1) rate Trellis code or convolutional code.

The input to the encoder is a sequence of binary digits denoted as,

$$U = [\ u_1\ u_2\ u_3....u_k...]$$

and the output is a sequence of coded PSK symbol, denoted by,

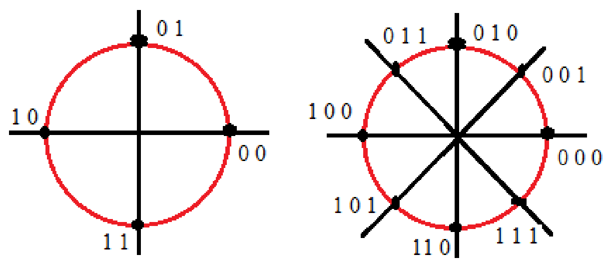
$$C_i = [c_{i1}\ c_{i2}\ ....c_{ik}....]$$

where C_i is the i^{th} codeword of the TCM scheme. c_{ik} is a point in the complex plane and the set of all c_{ik}s form the constellation of the TCM scheme. For 4-PSK TCM, 1/2 rate convolutional code is combined with PSK modulation having 4 constellation points as shown in Fig 2(a). In case of 8-PSK TCM scheme, since a rate 2/3 code is used, the constellation set should have 8 points as shown in Fig 2(b). A 4-state 8-PSK TCM encoder is shown in Fig. 3.

The TCM code can be successfully decoded using the standard Viterbi decoder. However, in this paper a different approach to decode the TCM code using soft computational tools has been discussed. This approach first de-maps the received symbols to bit sequences and then removes the redundant bits using ANN. For this, the network has to be first trained properly so that it can configure itself to perform the decoding process. This aspect of the decoder has been discussed in section III.

B. OFDM System

The OFDM system used in the work has been modeled as shown in Fig 4. The input to the OFDM system is the PSK modulated output symbols from the TCM encoder. The input symbols are assigned to orthogonal sub-carriers through the Inverse Fast Fourier Transform (IFFT) technique. Cyclic prefix is added so as to deal with the effect of delay spread in



a) 4-PSK Constellation b) 8-PSK Constellation

Figure 2. Constellation diagram for 4-PSK and 8-PSK Mapping

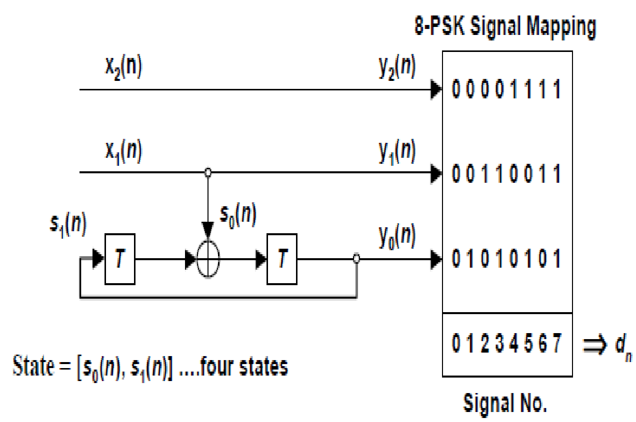


Figure 3. 4 state TCM with rate 2/3 Trellis Encoder and 8-PSK Signal Mapping

multipath channel, which causes ISI to occur. This is done by cyclic extension of the OFDM symbol during the guard interval. At the receiver, the cyclic prefix is removed and the signal is converted from time to frequency domain by using Fast Fourier Transform (FFT).

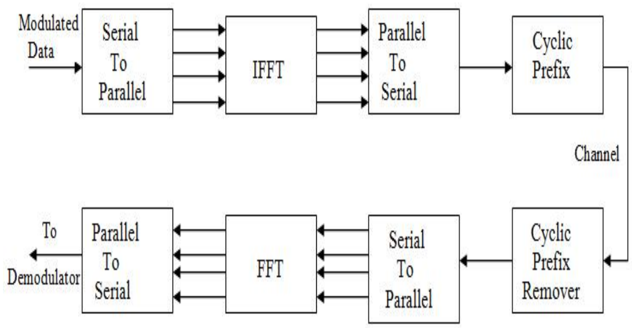


Figure 4. OFDM Block Diagram

C. Wireless Channel

Fading effects of the channel cause the transmitted signal to distort considerably and the information content of the signal may be changed under severe channel conditions. The multipath channel is modelled as being Rayleigh faded with AWGN. The Rayleigh faded channel can be generated as the sum of complex Gaussian random variables given by,

$$h(t) = x(t) + j^* y(t) \tag{1}$$

where h is the impulse response of the channel, x and y are Gaussian random variables. The channel output can be expressed as,

$$y= s(t)^*h(t) + n(t) \tag{2}$$

where s is the transmitted signal and n is AWGN. The probability density function (pdf) of a Rayleigh faded channel [7] is given as,

$$p(r) = \begin{cases} \frac{r}{\sigma^2}\exp(-\frac{A^2}{2\sigma^2}) & for (0 \le r \le \infty) \\ 0 & for (r < 0) \end{cases} \tag{3}$$

where σ^2 is the time average power of the received signal. A distribution that can be used to model a large number of fading environments is the Nakagami-m distribution with pdf given as,

$$p_r(r) = \frac{2m^m r^{2m-1}}{\Gamma(m)\Omega^m}\exp(-\frac{mr^2}{\Omega})\ ; r \ge 0 \tag{4}$$

where, $m > ½$ is the Nakagami parameter, Ω is the average signal power and $\Gamma(\cdot)$ is the gamma function. For m=1, the Nakagami distribution represents Rayleigh faded channel. The Nakagami channel envelope, R_{naka}, is generated using the envelope for Line of Sight (LOS) i.e Rayleigh and Non Line of Sight (NLOS) i.e Rician channel as shown in (5) [1],

$$R_{naka}(t) =|R_{Ray}(t)|\ exp(1-m) + |R_{Rice}(t)|\ (1-exp(1-m)) \tag{5}$$

D. Artificial Neural Network (ANN)

ANN is an excellent mathematical tool, composed of simple elements called neurons that can perform parallel operations [8]. It is a network inspired by biological nervous system and can establish a relationship between the input and output data by adjusting its weights through a learning process. From the structural point of view, an ANN may be single layered or it may be multi-layered. Each neuron of one layer is connected to each and every neuron of the next layer [8]. The knowledge gained during the training phase is stored in the interconnecting neurons. The network type that has been used here is a Multi Layer Perceptron (MLP) which consists of input, output and the hidden layers.

The ANN has gained its popularity in solving different complex problems in communication as it can use information from the transmitter, channel or receiver side to update its learning.

III. ANN AND TCM

The proposed system implements the TCM scheme using an ANN, where the advantages of a neural network have been exploited to perform the decoding process of TCM with OFDM signal.

During the training phase, the ANN is fed with a set of training samples consisting of a number of bit sequences, encoded according to the Trellis encoder used in the transmitter side. The target sample set for the ANN consists of the corresponding decoded bit sequences. Both the training and the target samples are presented in the form of a matrix to the network. The number of neurons in the output and the hidden layer are carefully chosen as to meet the requirements of the complex decoding operation. The training session of the ANN is continued for a number of epochs until the network converges to the required Mean Square Error (MSE).

The TCM decoder designed for the work consists of a constellation de-mapper followed by the ANN decoder as shown in Fig 5. The input to the TCM decoder is a set of complex symbols obtained from the output of the OFDM demodulator. Each received symbol is de-mapped to a sequence of bits by finding the nearest constellation point using the minimum Euclidean distance. The Euclidean distance between two points S_1 (x_1,y_1) and S_2 (x_2,y_2) is defined as,

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{6}$$

The output of the de-mapper is finally decoded by the ANN to get the original bit sequence.

By using a soft computation tool like ANN, a simple decoder design is obtained, that overcomes the hardware constraints of the complex Viterbi decoder and operates at a much faster rate. The specifications of the TCM code used and its performance in a fading environment are discussed in the next two sections.

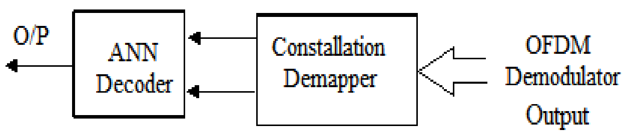


Figure 5. ANN based TCM decoder

IV. SPECIFICATIONS

The performance of the designed system is evaluated considering BER as the performance parameter. The details of the signal and system characteristics have been elaborated in this section.

Rate 1/2 convolutional code is combined with QPSK mapping to generate 4-PSK TCM-coded signal whereas 8-PSK TCM-coded signal is obtained by combining a rate 2/3 trellis code with 8 point constellation mapping. The details of the encoder are specified in Table I.

OFDM signal is generated according to the IEEE802.11a specifications [9]. The parameters used for the OFDM signal are tabulated in Table II.

The ANN used in the work is a MLP [8] which is a feed-forward structure and consists of three layers-input, output and one hidden layer. The learning process is of supervised kind using Back Propagation (BP) Algorithm. The specifications of the ANN used for training have been tabulated in Table III.

TABLE I. SPECIFICATIONS OF TCM ENCODER

Rate	1/2 for 4-PSK, 2/3 for 8-PSK
Generator polynomial	G=[1 0 0 ; 0 2 5]
Decoder type	Viterbi / ANN based

TABLE II. SPECIFICATIONS OF OFDM SIGNAL

No of Subcarriers	52
FFT length	64
Cyclic Prefix length	16
Symbols per carrier	1000
SNR	±10 dB
Modulation Types	BPSK, QPSK,8PSK

TABLE III. ANN PARAMETERS USED FOR TRAINING

ANN type	Feed forward
Number of Layers	One input, one hidden, one output
Hidden layer size	1.5 times of input
Input layer size	Size of the signal sample at the receiver end
Transfer function combination	Logsig -tansig –tansig- logsig
Convergence limit	10^{-2}
Training type	Back propagation with adaptive learning rate

V. SIMULATION RESULTS

The BER performance has been observed for the ODFM signal for M-PSK (M=2, 4, 8, 16) and M-QAM [6] digitally modulated signals in Rayleigh faded channel (Fig. 6). In AWGN as well as faded channel, the BER performance is as follows:

$$BER_{BPSK} < BER_{QPSK} < BER_{8PSK} < BER_{16PSK}$$

The ANN is trained with signal input from the transmitter side. For 8-PSK TCM, the training sample set is a ($2^{10}\times15$) matrix, each row of the matrix being a Trellis encoded bit sequence. The target sample set is formed with the corresponding 10 bit decoded data, also presented to the ANN in the form of a matrix of size ($2^{10}\times10$). The learning of the ANN is done in the training phase during which the ANN adjusts its weights according to the specific coding logic applied at the transmitter end. The ANN is trained for 1500 epochs and it converges to an MSE of 10^{-2} in 42.51 seconds. During this phase, on an average, the ANN reaches this MSE goal in around that 42 second limit with an accuracy of nearly 100%. This is confirmed by over twenty trials.

During simulation, severely faded data, mixed with AWGN is decoded by the trained ANN to test its effectiveness as a decoder and confirm its feasibility in that role. This test also assesses its accuracy of performance. Fig. 7 shows the comparison of TCM coded OFDM using standard and ANN based decoding schemes. It is seen that ANN based decoder exhibits better performance in terms of accuracy of decoding and lower Bit Error Rate (BER). Also the simulation time required for ANN based TCM coded OFDM system is lesser than the standard decoder. This is because of the low computational complexity of the ANN decoder where complex metric calculations are not utilised in the decoding process. Table IV shows a comparison of the simulation time required by the standard and ANN based TCM decoder systems. For bit size varying between 4 to 12, the improvement in simulation time for ANN based TCM-coded OFDM is between 4.42 % to 6.67 % which is significant.

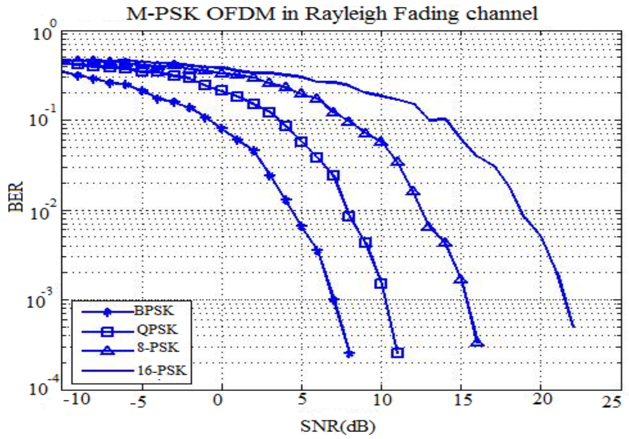


Figure 6. BER plot for M-PSK OFDM signal in Rayleigh channel

Fig. 8 and 9 shows the comparison of BER plots of 4-PSK and 8-PSK TCM, respectively, with the uncoded signals of the same bandwidth. Accordingly, 4-PSK coded OFDM signal is compared with uncoded BPSK signal and a coding gain of 2.5 dB (approx.) is obtained at BER of 10^{-4}. Similar comparison of 8-PSK TCM-coded OFDM with uncoded QPSK modulated OFDM signal shows a coding gain of approximately 6 dB at 10^{-4} BER. Coding gain is defined as the amount of additional Signal Noise Ratio (SNR) that would be required to provide the same BER performance for an uncoded signal. At a particular BER,

$$\text{Coding Gain, } G = SNR_{uncoded} - SNR_{coded}$$

A summary of the various coding gains obtained for the two cases at different BER values is provided in Table V.

The performance of TCM 8-PSK OFDM in Nakagami–*m* channel for different values of *m* has been shown in Fig. 10. The BER performance improves with increase in *m* value.

TABLE IV. PROCESSING TIME TAKEN BY CONVENTIONAL AND ANN BASED TCM DECODER

Bit size	Conventional TCM decoder (in seconds)	ANN based TCM decoder (in seconds)	Percentage Improvement (%)
4	3.02	2.86	5.3
6	3.05	2.92	4.2
8	3.15	2.94	6.67
10	3.18	3.01	5.35
12	3.18	3.03	4.72

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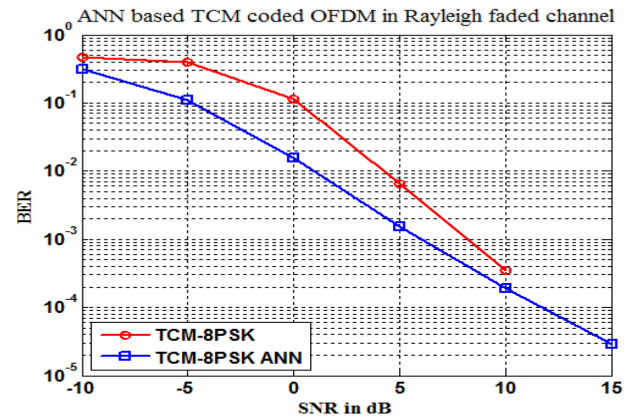

Figure 7. Comparison of the BER plot for standard and ANN decoded 8-PSK TCM-coded OFDM

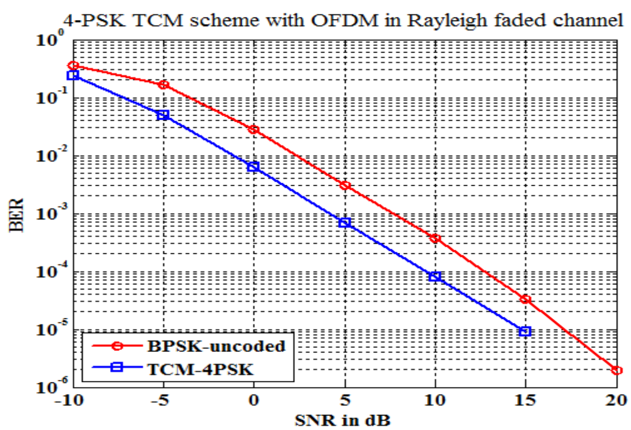

Figure 8. Comparison of the BER plots for ANN decoded 4-PSK TCM-coded OFDM with uncoded BPSK OFDM signal in Rayleigh faded channel

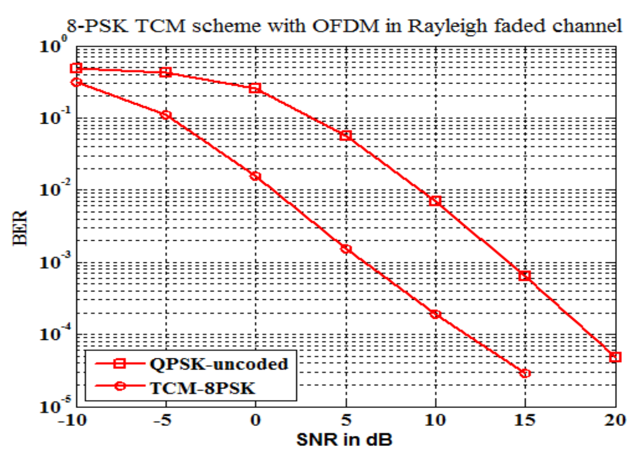

Figure 9. Comparison of the BER plots for ANN decoded TCM-8PSK OFDM with uncoded QPSK OFDM signal in Rayleigh faded channel

TABLE V. CODING GAIN OF TCM OFDM

Signal Type	Standard 8 PSK TCM	ANN-8-PSK TCM	ANN 4-PSK TCM
Coding gain at BER=10^{-1}	5 dB	7.5 dB	3.5 dB
Coding gain at BER=10^{-2}	4.5 dB	8 dB	3.5 dB
Coding gain atBER=10^{-3}	2.9 dB	8 dB	3 dB
Coding gain at BER=10^{-4}	-	6 dB	2.5 dB

VI. CONCLUSION

The hardware implementation of standard TCM decoder requires the use of costly memory. This is again dictated by the number of trellis states and the trellis depth. The use of soft computing tools like ANN overcomes this drawback along with substantial improvement in performance. The significant improvement in BER values at low SNR suggests low power transmission of the signal to obtain reliable signal quality at the receiver. A coding gain of around 6 dB is obtained for 8-PSK TCM coded OFDM over uncoded QPSK signal at higher SNRs. Thus on comparison of the ANN based decoding scheme with the conventional TCM decoder, the ANN yields a superior decoder in terms of BER values as well as design complexity.

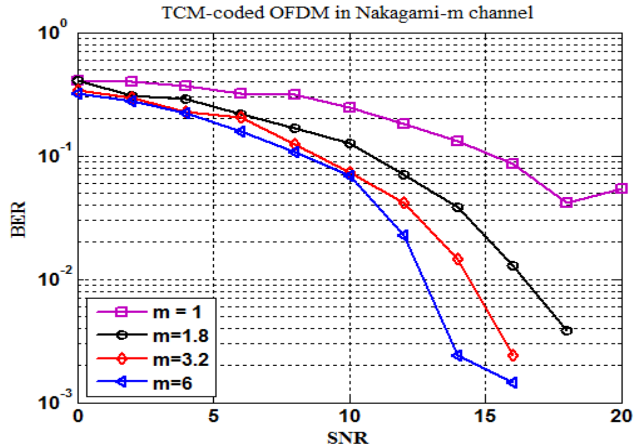

Figure 10. Comparison of the BER plot for ANN decoded TCM-8PSK OFDM for different *m* values in Nakagami-*m* channel.

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