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MODELING OF A DIGITAL COMMUNICATION SYSTEM WITH INTERFERENCE-RESISTANT CODING OVER DELAYED MULTIPATH CHANNELS FOR A FIXED WIRELESS ACCESS SYSTEM

Abstract: In this study, an analysis of the performance of a digital communication system was conducted to improve the efficiency of the communication channel. The system was designed and evaluated in the MatLab/Simulink environment, specifically for the transmission of binary data in a multipath channel with static fading. One of the main advantages of this system is its ability to provide high noise immunity, even in the presence of noise, interference, and signal delays. The performance of the system was investigated in terms of bit error rate (BER) over both an additive white Gaussian noise (AWGN) channel and a multipath Rayleigh fading channel. The study also considered the impact of inter-symbol interference (ISI) and explored different parameters for a static channel, resembling a wireless LAN system based on IEEE 802.11 (as defined by Rec ITU-R M.1225). This study uses a solution to suppress inter-symbol interference using cascading coding (convolutional turbo codes with Reed Solomon code), Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT), amplifiers at the transmitter side and normalizer at the receiver side, by regulating the amplification ratios of transmitter and receiver sides. Modeling of a digital communication system for a wide-band fixed wireless LAN system (for Indoor office and Outdoor to indoor systems) has been performed. The modeling outcomes show that the applied method provides a good performance improvement in channels with ISI with static fading.

The application of cascading coding (turbo code together with RS code), amplifiers, and FFT on the transmitter side, and IFFT on the receiver side will eliminate the effects of inter-symbol interference on digital signals in a multipath channel with static fading (as defined by Rec. ITU-R M.1225 for internal and external transmission systems) for wireless fixed systems.

Keywords: Rayleigh, Fast Fourier Transform, Inverse Fast Fourier Transform, Turbo Convolutional Codes, Reed-Solomon code, intersymbol interference

Introduction

During the transmission of radio signals in open space, a negative phenomenon such as multipath interference is inevitable, which leads to distortion of the received signal. The effect of multipath interference is that, as a result of multiple reflections, the same signal can reach the receiver by different paths. But different paths of propagation have different lengths, and therefore the attenuation of the signal for them will not be the same. Consequently, at the receiving point, the resulting signal is a superposition of many signals with different amplitudes and initial phases, which is equivalent to summing signals with different phases. In [1] examines the characteristics of signal propagation and the key challenges faced by signals when transmitted from outdoor to indoor antennas for college buildings. Multipath interference is inherent in any type of signal, but it is particularly detrimental to wideband signals. Using a wideband signal, interference causes some frequencies to fold in-phase, increasing the signal, while others, on the contrary, fold out-of-phase, causing signal attenuation at a given frequency. Speaking of multipath interference, which occurs during the transmitting of signals, there are two extreme cases. In the first case, the maximum delay between different signals does not exceed the duration of one symbol and the interference occurs within a single transmitted symbol. In the second case, the maximum delay between different signals is longer than the duration of a single symbol, and as a result of interference added signals representing different symbols, thus there is an inter-symbol interference (ISI). Inter-symbol interference has a significant impact at high data rates, because the distance between bits (or symbols) is small. Using the mechanism of multiplexing by means of Orthogonal Frequency Division Multiplexing (OFDM) will allow to suppress inter-symbol interference and carry out protected data transmission at high speeds. About ISI and the use of the Fast Fourier Transform (FFT) method to ISI suppression of communication channel and improve the throughput and spread spectrum capacity of communication channel is described in [2]. The use of FFT can implement OFDM technology well. References [3] and [4] cover the principles of noise-coding in the multipath channel with inter-symbol interference and provide information on OFDM technologies.

To avoid, or rather partially offset the multipath effect, the frequency equalizers are used, however, as the data rate increases, either by increasing the symbol rate or by complicating the coding scheme, the effectiveness of their use decreases. At transmission speeds of 11 (standard 802.11b) or 22 Mbit/s in the case of using CCK (Complementary Code Keying) or packet convolutional coding schemes are quite successful in their task, but at higher speeds this approach becomes unacceptable. Therefore, to realize higher data rates it is possible to apply a fundamentally different method of coding data - cascading, which includes Turbo coding and Reed Solomon code and the application of FFT.

According to [5], increasing the power of the emitted signal directly can offset the decrease in signal level caused by the attenuation of electromagnetic waves in line-of-sight conditions. Amplifiers are one of the methods that can be utilized to compensate for energy loss due to fading and distortion resulting from multipath propagation effects.

Signal boosters play a crucial role in enhancing weak signals by amplifying and retransmitting them to reach areas with poor coverage. These boosters come in various types, with differences in their construction, range, operation method, deployment, and cost. The types of boosters are detailed in [6]. In this study, the units used to measure the amplification capabilities of these boosters are in dB Gain.

Channel coding

To prevent loss of information due to inter-symbol interference when single symbols or their fragments are lost, many standards (e.g., IEEE 802.16) provide effective channel coding facilities. In the work channel coding and FFT is used to improve noise immunity and suppression of ISI. Data coding on physical level includes three stages: randomization, protective coding and interleaving. Data coding implies cascading code with two stages: convolutional turbo codes and Reed-Solomon coder.

Turbo code is a parallel cascade block systematic code capable of correcting errors arising during transmission of digital information over a communication channel with noise. A synonym of turbo code is a term known in coding theory - concatenated code. The cascade method of constructing codes was first proposed in 1966 by the American mathematician D. Forney.

Turbo code consists of a cascade of systematic codes connected in parallel. These components are called component codes. Component codes can be convolutional codes, Hamming code, Reed-Solomon codes, Bose–Chaudhuri–Hocquenghem codes and others. Depending on component code selection, turbo codes are divided into Turbo Convolutional Codes (TCC) and Turbo Product Codes (TPC) [7].

The study considers convolutional turbo codes. A feature of turbo codes is a parallel structure consisting of Recursive Systematic Convolutional (RSC) codes that operate in parallel and use creating a random version of the message. Parallel structure uses two or more RSC codes, each with a different interleaver. The purpose of the interleaver is to offer each encoder an uncorrelated or random version of the information, making the parity bits of each RSC independent. The encoders' algorithm can be seen in formulas (1)-(3). Figure 1 shows a schematic diagram of a turbo encoder [8].

The first sequence transmitted by the first encoder is the following expression (1):

$$y(1) = \left(y_1^{(1)}, y_2^{(1)}, \dots\dots y_{k-1}^{(1)}\right) \tag{1}$$

The second encoder generates a parity sequence as (2) expression.

$$y(2) = \left(y_1^{(2)}, y_2^{(2)}, \dots\dots y_{k-1}^{(2)}\right) \tag{2}$$

The final transmitted codeword is given as (3) expression.

$$y = \left(y_1^{(1)}, y_1^{(2)}, y_2^{(1)}, y_2^{(2)}, \dots\dots y_{k-1}^{(1)},\ y_{k-1}^{(2)}\right) \tag{3}$$

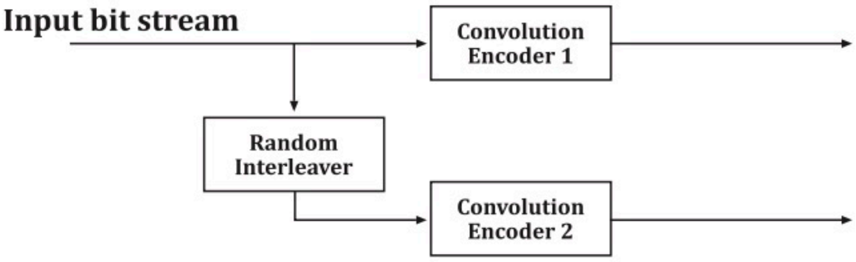


Figure 1. Structure of Turbo Encoder

The structure of the turbo decoder is depicted in Figure 2. The decoders 1 and 2 are interconnected through interleavers and deinterleavers, allowing for an iterative process. This arrangement exploits the likelihood that bits received by the second decoder will also be received by the first decoder. The iteration continues until the bit error rate (BER) reaches its minimum. Finally, a hard decision is made based on the output of decoder 2 at the conclusion of the decoding process.

The systematic flow of bits from the channel, fed as input data to decoder 1, is given by formula (4).

$$y^{(s)} = \left\{y_1^{(1)}, y_2^{(1)}, \ldots\ldots y_{k-1}^{(1)}\right\} \tag{4}$$

Decoder 1 also accepts parity bits given by the following formula (5).

$$y^{(p)} = \left\{y_1^{(2)}, y_2^{(2)}, \ldots\ldots y_{k-1}^{(2)}\right\} \tag{5}$$

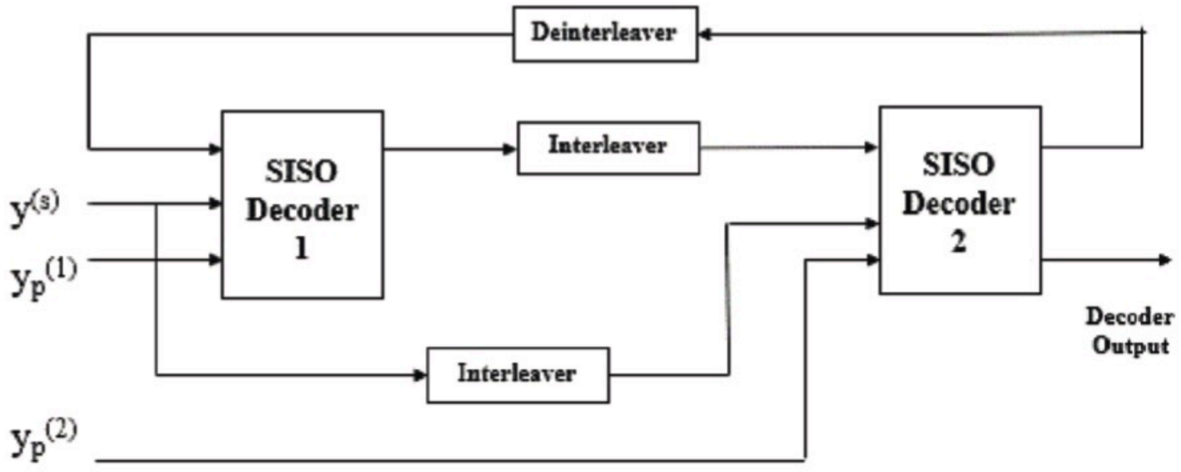


Figure 2. Turbo decoder

Reed-Solomon (RS) codes, which operate on the principle of block error correction, are extensively utilized in various digital telecommunications and memory applications. These codes play a crucial role in error correction in numerous systems, including:

- Memory devices such as magnetic tapes, CDs, DVDs, and barcodes.
- Wireless or mobile communication systems, including cell phones and microwave links.
- Satellite communications.
- Digital television (DVB - digital video broadcasting).
- High-speed modems like ADSL, xDSL, and others.

The Reed-Solomon encoder takes a block of digital data and adds extra "redundant" bits. Errors occur during transmission over the communication channels or for various reasons during memorization (e.g., due to noise or interference, scratches on the CD, etc.). The Reed-Solomon decoder processes each block, tries to correct errors, and recovers the original data. The number and types of errors that can be corrected depend on the characteristics of the Reed-Solomon code [9].

In the Simulink environment the RS coding block with binary input creates a Reed-Solomon code. The symbols for the code are binary sequences of length M corresponding to elements of the Galois field GF(2 M). The first bit in each symbol is the most significant bit [4].

Let's assume that $M = 3$, $N = 2^{3-1} = 7$ and $K = 2$ (Fig.3). Then the message is a vector of length 2, whose entries are integers from 0 to 7. The corresponding codeword is a vector of length

7, the elements of which are integers from 0 to 7. The following figure shows the possible input and output signals for this block when the codeword length $N = 7$ and the message word length $K = 2$. Since $N = 2^{M}-1$, when $N = 7$ the symbol length $M = 3$.

Each input message word is a binary vector of length 6 representing 2 three-digit integers. Each corresponding output codeword is a binary vector of length 21 representing 7 three-digit integers.

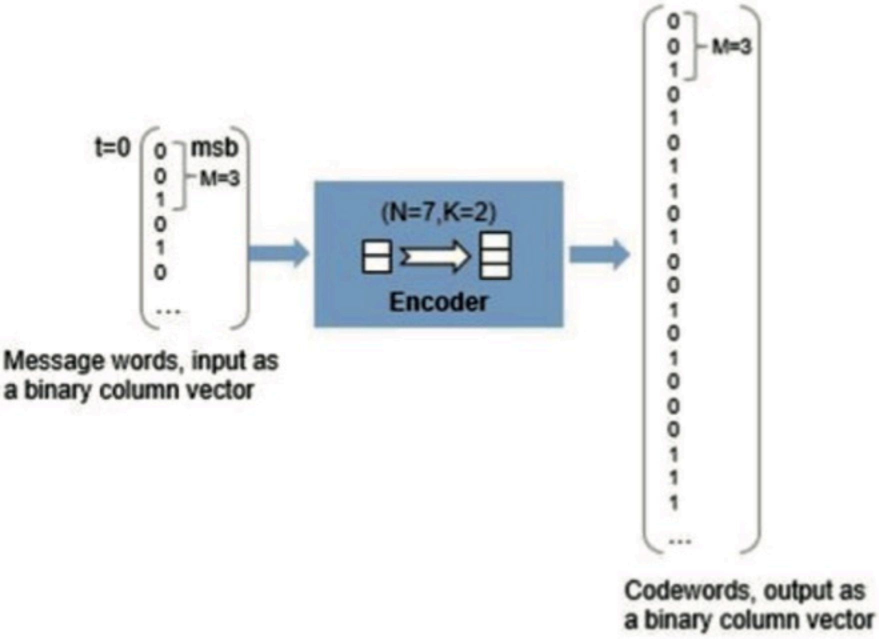


Figure 3. RS encoder

Creating a channel simulation model to experimentally assess the efficiency of the channel's performance

This study involved the construction of a channel model specifically designed for wireless LAN systems, including both indoor office and outdoor to indoor systems. The purpose of this model was to implement techniques that address the various challenges that arise when signals traverse the communication channel (Fig. 4). For modeling, the Simulink environment was used. A study was conducted, the effect of signal delays on the behavior of the multipath channel was analyzed. The result of the task was to estimate the error probability and compare the sent and received signal. To facilitate the design process in the Matlab environment, the following sources were consulted and studied: references [10], [11], and [12]. In [10] presented several examples are to give some idea of the MIMO system design. [11] is on the analysis of Reed-Solomon (RS) Codes as an efficient code for error detection and correction. The source [12] was used as a guide to understand the main aspects of the implementation of a wireless system, as examples of building simulation models for wireless systems in Matlab are given here.

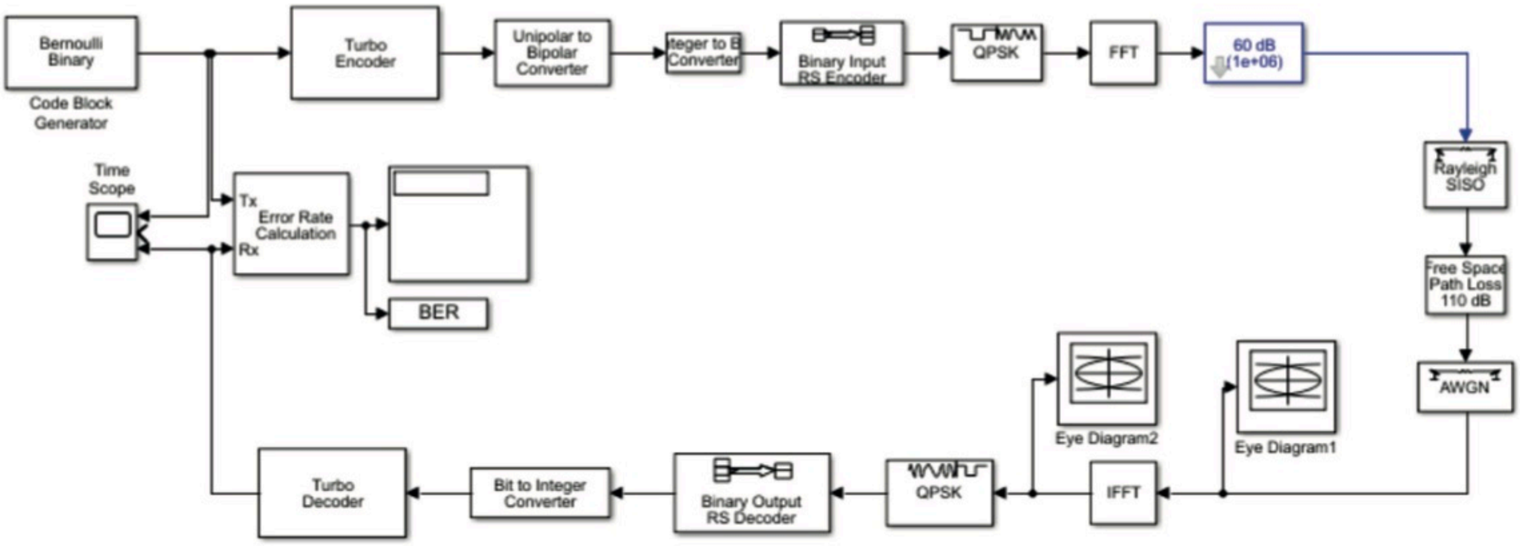


Figure 4. Transmitter-receiver of fixed system for data based on IEEE 802.11

In the Matlab/Simulink environment, the channel models were constructed using the following functions: AWGN, which represents the additive Gaussian channel, and Rayleigh channel, which simulates the Rayleigh fading channel. To conduct a comprehensive analysis of the noise immunity of the model, the channel parameters were modified (Table 1, 2, 3). The channel parameters chosen were the Indoor office system, corresponding to the model for the local network inside the office and the Outdoor to indoor systems, corresponding to the model for the local network from the street to the office. The considered models can be applied to fixed systems. As a parameter for Bernulli Binay, Turbo encoder/decoder blocks were taken from the example in Matlab/Simulink environment: openExample('comm/TurboCodingSimulinkExample')

Table 1. The characteristics of the Rayleigh multipath channel parameters

Characters	Indoor system	Outdoor system
Max Doppler shift (f)	1/1000	1/1000
Doppler spectrum type	doppler('Flat')	doppler('Jakes')
Path delay vector (s)	[0, 50, 110, 170, 290, 310]*10^(-9)	[0, 110, 190, 410]*10^(-9)
Average Path gain vector (dB)	[0,-3,-10,-18,-26,-32]	[0,-9.7,-19.2,-22.8]
Fading distribution:	Rayleigh	Rayleigh
Initial seed	73	80

Table 2. Noise characteristics of the AWGN channel

Parameter	Value
Initial Read	67
Mode	Signal to Noise rate (Eb/No)
Eb/No(dB)	[0 16]
No. of bits/symbol	1
Input signal power	1
Symbol Period	1

Table 3. Bit To Integer Converter unit on the receiving side

Block parameter	Indoor-system	Outdoor-system
After bit packing, treat resulting integer values as:	Signed	Unsigned

Also, to account for additional energy losses during signal transmission, the Free space path loss block is used, where the Loss (dB) parameter: 110 (for Outdoor system). When taking this parameter into account, you must use a decibel amplifier - dB Gain Power (hereinafter K value), with a value of 60 dB, where the value must be 0.55*Loss (dB).

The dB Gain block multiplies the input data by the decibel values specified in the amplifier parameter [9]. For an input matrix u of size M by N with elements u_{ij} the amplification parameter can be a valid matrix of size M by N with elements g_{ij} to be multiplied by the input data element by element, or a valid scalar (6):

$$y_{ij} = u_{ij} * 10^{(g_{ij}/k)} \tag{6}$$

The value of k is equal to 10 for Power signals (if Power is the input signal parameter) and 20 for Voltage signals (if Amplitude is the input signal parameter). In the work, Power is selected as the amplification parameter.

The equivalent linear amplification value is shown in the block icon under the amplification value in dB. The output data has the same size as the input data (7):

$$g_{ij}^{lin} = 10^{(g_{ij}/k)} \tag{7}$$

Fixed data transmission with fading with different amplifier values of 0 dB, 4 dB for Indoor system and 60 dB for Outdoor system are shown in Table 4 and Figures 5, 6.

Table 4. Probability of an erroneous bit at small SNRs

SNR (дБ)	BER	SNR (дБ)	BER	SNR (дБ)	BER
Indoor system				Outdoor system	
K=0		K=4		K=60	
16	0	8	0	7	0
15	8.237e-4	7	8.237e-4	6	0.006894
14	2.876e-3	6	2.876e-3	5	0.02024
13	5.896e-3	5	5.896e-3	4	0.06535
12	0.01119	4	0.01119	3	0.1173
11	0.01803	3	0.01803	2	0.1854
10	0.02851	2	0.02851	1	0.3343
8	0.05987	1	0.04213	0	0.4836
6	0.1142	0	0.05987		
4	0.1993				
2	0.2747				
0	0.3454				

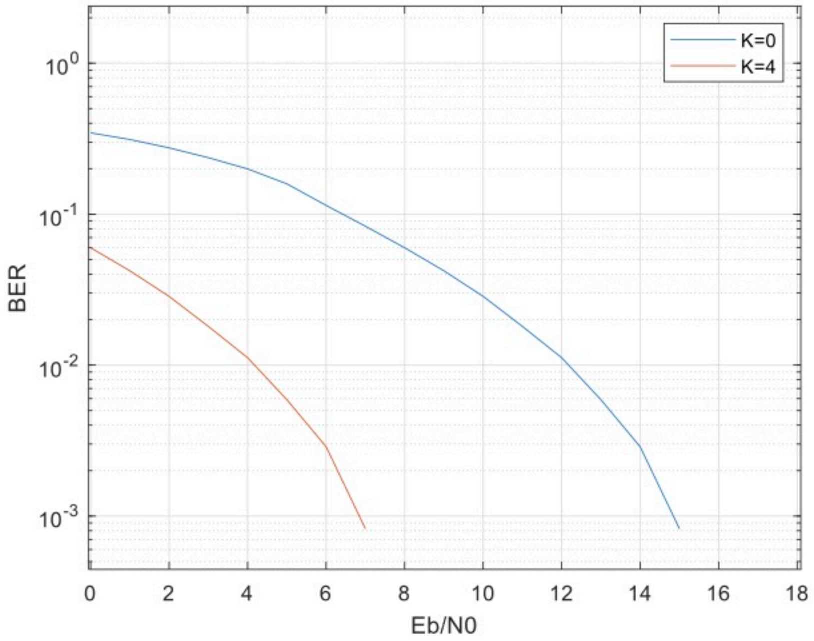


Figure 5. Rayleigh and Gaussian channel error probabilities at different values of amplifier coefficient K for Indoor system

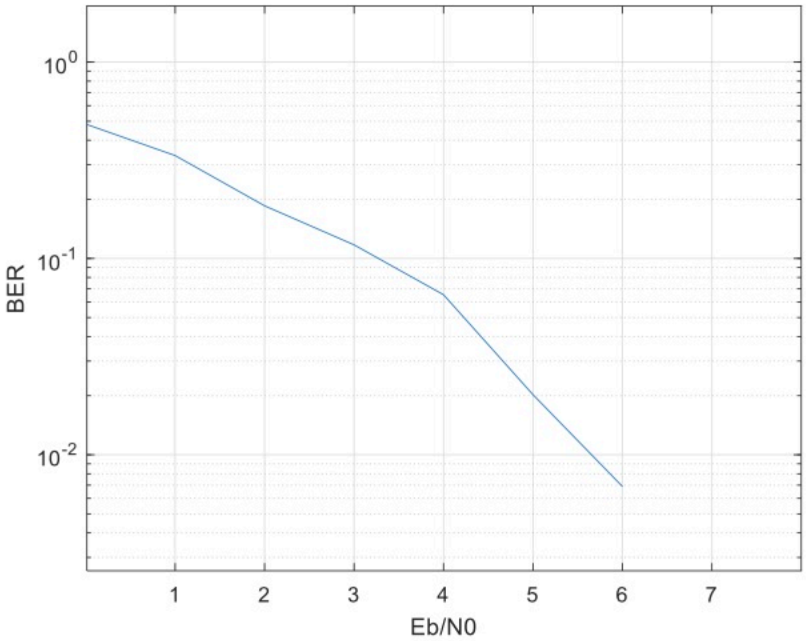
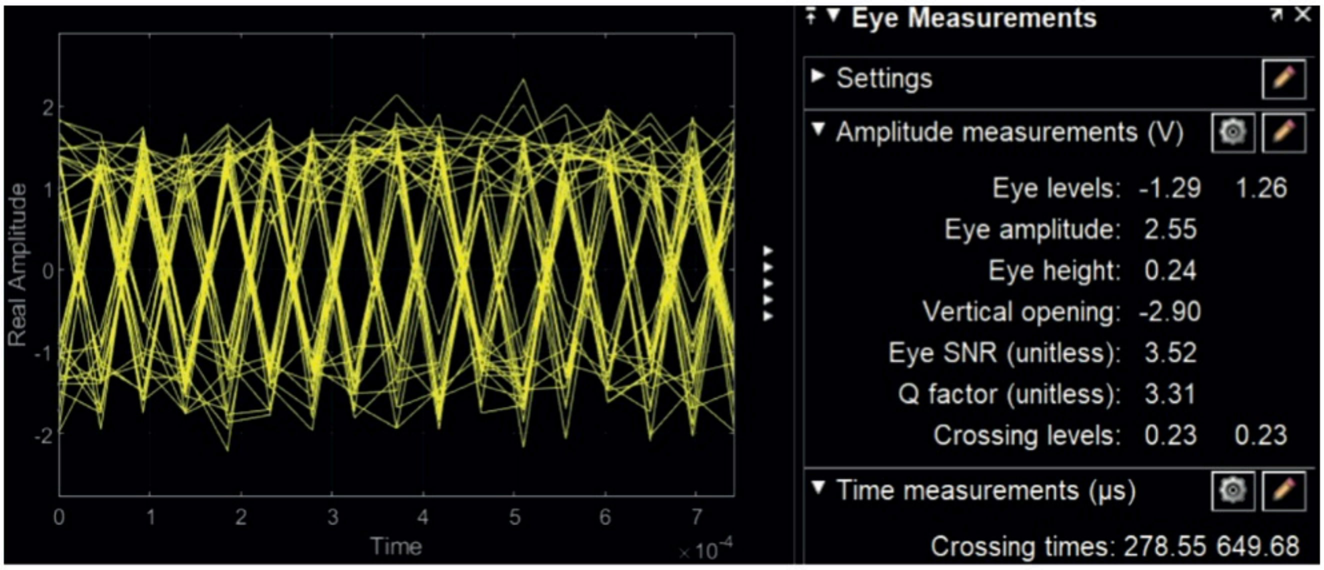


Figure 6. Rayleigh and Gaussian channel error probabilities for Outdoor – system

The occurrence of inter-symbol interference (ISI) within the system results in errors at the output of the receiver's decision-making device. To assess the extent of ISI in the system, the Eye Diagram Scope block was employed. This block provides a visual representation of the eye diagram, enabling the analysis of ISI effects.

Ideally the eye diagram, based on the name, is an "open eye", in Figure 7 with amplifier K = 60 dB at SNR= 7dB it is possible to see "open eyes". The signal to noise ratio of the eye (SNR of the eye) is defined as the ratio of the amplitude of the eye to the sum of the standard deviations of the two eye levels, which is 3.52. In Figure 8, without an amplifier, we see the obvious superposition of waves on each other – the phenomenon of interference. Also Fig. 9 shows a comparative analysis of the transmitted, distorted and received signal using Time Scope block at SNR= 7dB (Outdoor system with K=60dB).



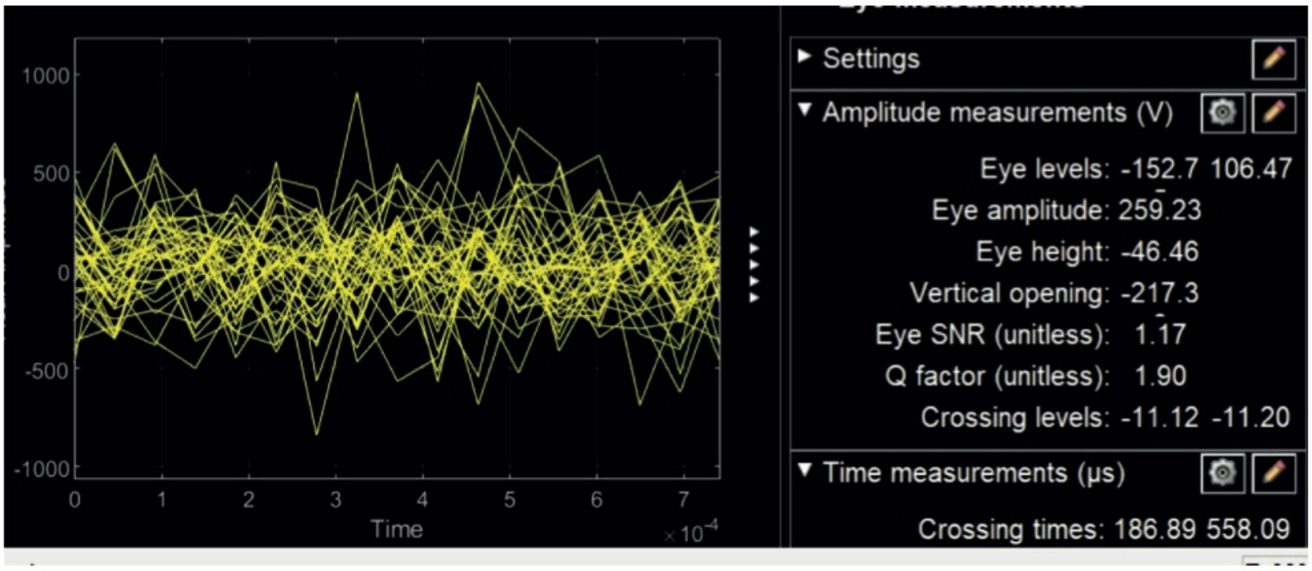
Amplitude measurements (V)

Eye levels: -1.29 1.26
Eye amplitude: 2.55
Eye height: 0.24
Vertical opening: -2.90
Eye SNR (unitless): 3.52
Q factor (unitless): 3.31
Crossing levels: 0.23 0.23

Time measurements (μs)

Crossing times: 278.55 649.68

Figure 7. Eye diagram at SNR = 7 for Outdoor system scheme at K=60dB



Amplitude measurements (V)

Eye levels: -152.7 106.47
Eye amplitude: 259.23
Eye height: -46.46
Vertical opening: -217.3
Eye SNR (unitless): 1.17
Q factor (unitless): 1.90
Crossing levels: -11.12 -11.20

Time measurements (μs)

Crossing times: 186.89 558.09

Figure 8. Eye diagram at SNR = 7 for Outdoor scheme without amplifier

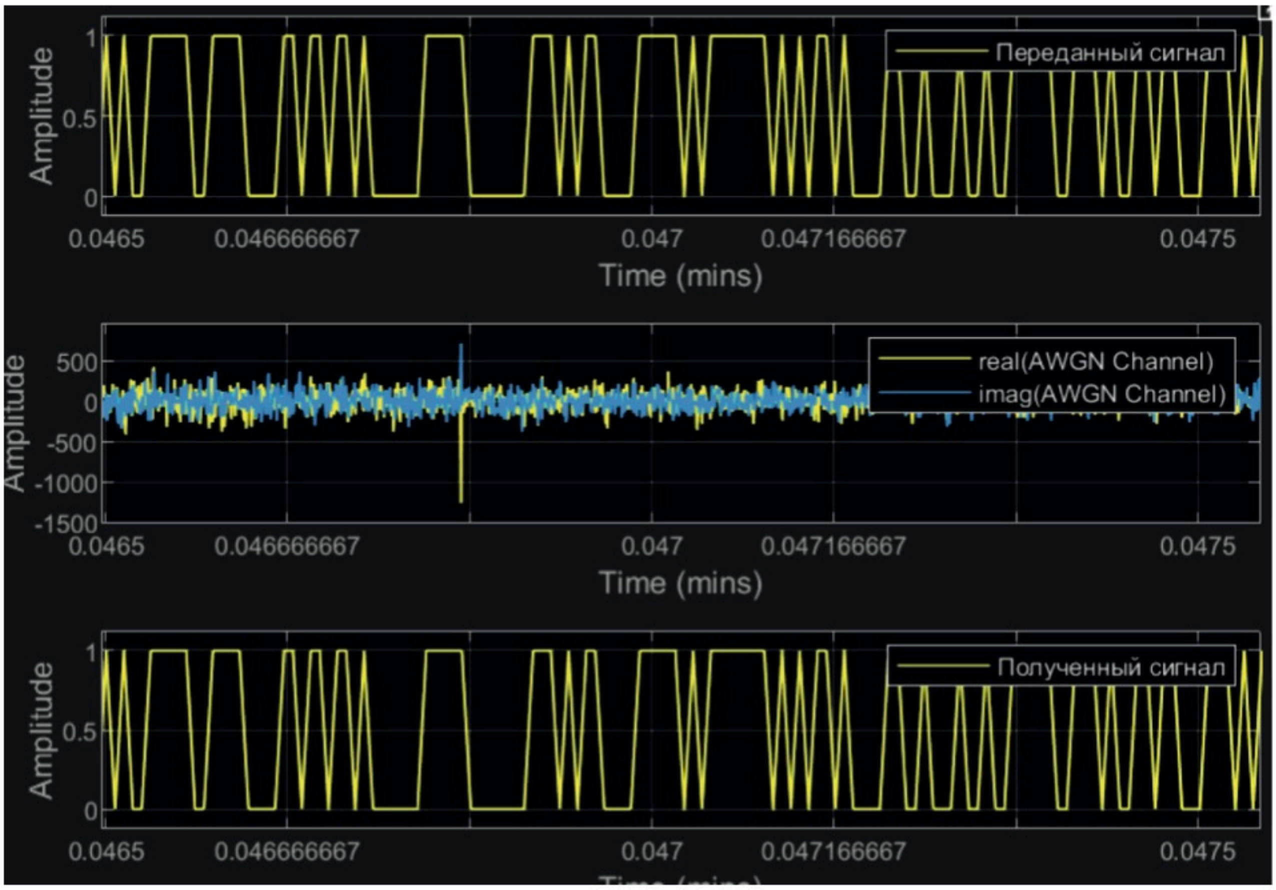


Figure 9. Analysis of the transmitted and received signal with Time Scope block at SNR = 7 (Outdoor system with K = 60dB)

Conclusion

In this study, a performance evaluation of a wireless system for fixed systems with SISO technology is presented. To improve the performance of the multipath channel with fading, cascading coding (convolutional turbo code together with RS code), fast Fourier transform, and amplifiers were used. An evaluation of the proposed system for transmitting binary data in wireless network for Indoor system and Outdoor system has been performed. The proposed model is simulated using MATLAB-based Simulink. A graph of transmission performance with different dB Gain values is obtained (Gain values change for transmitter and receiver respectively) in a multipath channel with fading with respect to BER and SNR. BER value reaches 0 when SNR is 16 dB and 8 dB for Indoor system, when dB Gain values are 1 dB and 4 dB respectively and when SNR is equal to 7 dB for Outdoor system with dB Gain values of 60 dB.

The data from the study can be used in the design of the local wireless system (Indoor and Outdoor systems), for example for data transmission from indoor and outdoor data centers. In addition, the developed model can be used as a teaching aid to study the various features of wireless local systems.

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