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Interference immunity and energy efficiency of digital communications systems in multipath channel with fading

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ABSTRACT

In the study of measures to improve channel efficiency, we developed and presented a performance analysis of a digital communication system for image transmission in a multipath channel with fading, in the MATLAB/Simulink environment, one of the main advantages being that it provides high interference immunity in the presence of noise and interference and signal delays. The scheme has been investigated for bit error rate (BER) on additive white Gaussian noise (AWGN) channel and multipath Rice and Rayleigh fading channel operating under the influence of inter-symbol interference (hereinafter ISI) and different parameters for the channel, where we considered cases of signal delay similar for EPA (extended pedestrian a model (EPA) standards). In this paper, we estimate the effectiveness of compensation for signal distortion in radio channels with fading on the basis coded orthogonal frequency-division multiplexing (COFDM) technology, an adaptive equalizer, amplifiers on the transmitter side and a normalizer on the receiver side, which is an acute problem in the field of wireless communication. This system can be applied to transmit better quality high-resolution radiological images over a wireless network inside a building and for a model analogous of pedestrian traffic.

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1. INTRODUCTION

Wireless communication has evolved considerably over the past few decades, primarily due to the need to meet the ever-increasing demands for high data throughput rates over the wireless medium. A variety of equipment has been developed for both indoor and outdoor networks. Mobility is a very important aspect of system specification. One of the key elements in designing wireless communication systems is understanding the characteristics of the wireless channel.

A type of wireless communication that uses radio waves that propagate freely in space as a signal carrier is called radio, translated from the Latin radio-I radiate. Radio waves propagate in space in all directions. Radio waves are used to transmit signals wirelessly, radio waves are radiated into space by

antennas. Such antennas are called transmitting antennas. Transmission scheme: a signal with the required characteristics (frequency and amplitude of the signal) is formed on the transmitting side. Then the signal modulates a higher frequency oscillation (carrier) and is radiated into space by the antenna. Meeting on its way the receiving antenna, the wave excites a high frequency current in it, which is registered by the receiving device. To extract a useful signal on the receiving side of the radio wave induces a modulated signal in the antenna, it is demodulated and filtered. The received signal can be distorted by noise and interference and thus be different from that transmitted by the transmitter. Signals are always distorted when transmitted through a channel: multiple symbols can arrive at the receiving antenna instead of a single radiated symbol and they can differ in form from each other and from the original pulse. The channel can also add interference, so the characteristics of the channel have a great impact on the quality of information transmission and knowing them is of great importance for the construction of communication systems. In urban environments the phenomenon of multipath (or multipath) signal propagation is encountered [1].

The purpose of this study is to develop of measures to improve the efficiency of the communication channel based on the extended pedestrian a model (EPA) standard. We shall con also we shall plot the dependence of the error probability on the signal-to-noise ratiosider the criterion of efficiency in this work to be the error-free transmission of the image. Also we shall plot the dependence of the error probability on the signal-to-noise ratiosider the criterion of efficiency in this work to be the error-free transmission of the image.

Signal-to-noise ratio E_b/N_0 (hereinafter referred to as SNR), signal distortion by inter-symbol interference-with the help of these factors we can determine the authenticity of the transmitted information. The error probability in digital communication depends on the normalized E_b/N_0 ratio, where E_b is the bit energy, N_0 is the spectral noise power density. By decreasing the signal power, increasing the noise power, or increasing the power of signals that interfere with the useful signal, it is possible to cause a decrease in the signal-to-noise ratio. These mechanisms are called loss (attenuation) and noise (interference), respectively. As a result of absorption of signal energy, reflection of part of the signal energy, or scattering, relaxation can occur. There are several sources of noise and interference: galactic noise, thermal noise, atmospheric and industrial interference, crossing and interfering signals from other sources. Inter-symbol interference is one of the causes of energy loss [2].

Intersymbol interference (ISI) can occur during the operation of the communication system, which affects the quality of communication. Therefore, in order to optimize the quality of communication transmission, the method of ISI suppression in the communication system is being studied. Based on the analysis of the ISI principle in the communication system, it is known that a delay in several channels can lead to ISI [3]. Guo *et al*. [4], the mechanism of channel wave multipath propagation to determine features of a channel wave in a coal seam. MATLAB software was used to simulate the model.

2. METHODS TO COUNTER INTERFERENCE IN THE RADIO CHANNEL

This section discusses methods of dealing with interference, such as attenuation, fading, and intersymbol interference in the communication channel. A typical scenario of multipath propagation of radio waves in the city and the radio channel of mobile communication systems is considered. The features of the signal distribution over the Rayleigh channel are also considered.

2.1. Effects of multipath on digital transmission

In the radio channel there is a range of interference and distortion. In the radio wave propagation there is a multipath effect, because in the presence of obstacles, reflections on the trace the signal may be transformed with different delays and attenuation coefficients, because of the obstacles it is re-reflected and there are many copies of the same signal because of this effect on the signal, to the receiving antenna comes many electromagnetic waves with different delays, attenuation and phase, consequently, their superposition causes the amplitude and phase distortion of the received signal. If it turns out that these signals in the sum carry a considerable amount of signal energy, it can lead to an increase in the number of errors and reduce the quality of the communication channel. This phenomenon is called signal fading [5]. The role of fading signals in the overall set of problems of noise immunity of modern telecommunications systems can be seen from the share of attention to channels with fading in a popular monograph by Sklyar [6].

Cheng [7], you can see that multiple in, multiple out-orthogonal frequency division multiplex (MIMO-OFDM) is a particularly powerful combination because multiple-input multiple-output (MIMO) does not attempt to mitigate multipath propagation and orthogonal frequency division multiplex (OFDM) avoids the need for signal equalization. In order to counter the interference, we use coded orthogonal frequency-division multiplexing (COFDM) technology with cascade coding (low-density parity-check code together with Bose–Chaudhuri–Hocquenghem code), adaptive equalizer based on the least mean squares (LMS) algorithm, amplifiers on the transmitter side and normalizer on the receiver side.

The purpose of using a COFDM system is to eliminate signal quality degradation during ground propagation of radio waves. Noiseproof coding is an obligatory transformation of information data in modern

digital communication channels. Coding methods are constantly improving. A study of the principles of noise-coding in the multipath channel with inter-symbol interference and about OFDM technologies can be found in [8], [9]. Direct increase in the power of the emitted signal can compensate for the decline in signal level, which is associated with the attenuation of electromagnetic waves during propagation in line-of-sight conditions. Amplifiers are one of the ways that can be applied to compensate the energy loss due to fading and distortion, which is caused by the effects of multipath propagation [10]. Signal boosters help in receiving the weak signal, amplifying and then re-transmitting it to reach the uncovered areas. These boosters are diverse in make, range, method of operation, deployment and cost [11]. In this study these units are dB Gain, Gain.

In order to extract the desired information, such as signals that have certain characteristics, filtering is used [12]. Filters based on the LMS algorithm are used in the work. The LMS algorithm is most widely used in wireless communication, as alignment and adaptive filtering in image processing, communications, etc. Initialization of the LMS equalizer is the result of channel evaluation based on the pilot signal. This method is achieved by using algorithms that adapt the parameters of the finite impulse response equalizer (FIR) to reduce interference and ISI to obtain an accurate received signal [13]. In this study we use adaptive equalizer with feedback based on the LMS algorithm, with a step of 10^{-9}. Pilot signals are used for feedback.

2.2. Implementation of methods to combat fading and freezing in the communication channel.

Depending on the nature of the radio propagation environment, there are different models that describe the statistical behavior of the multipath channel. See Rhattoy [14] and Stefanovic *et al.* [15] for the mechanisms of formation of small-scale fading and their description using the Nakagami, Rice, and Rayleigh distributions, and for the average duration of fading. The Rayleigh distribution can be described as shown in: i) no line-of-sight between antennas, only reflected signals are received; ii) is caused by Gaussian noise with Doppler shift; and iii) signal power is distributed exponentially.

This channel is considered the main channel in urban conditions and is inherent in cities with medium and high buildings. Radio channel of mobile communication systems is characterized by multipath due to various obstacles in the path of radio waves, which in the city can be a variety of buildings and structures [16]. Figure 1 illustrates a typical scenario of multipath radio wave propagation (MRWP) in the city. Figure 2 illustrates a model of delays and attenuations of received signal copies in Rice multipath radio channel including one line-of-sight (LOS) beam and three non line of sight (NLOS) beams which arrived at the receiver input with delays and attenuations due to reflections [17].

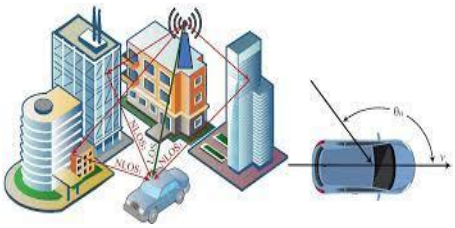

Figure 1. Multipath radio channel scenario

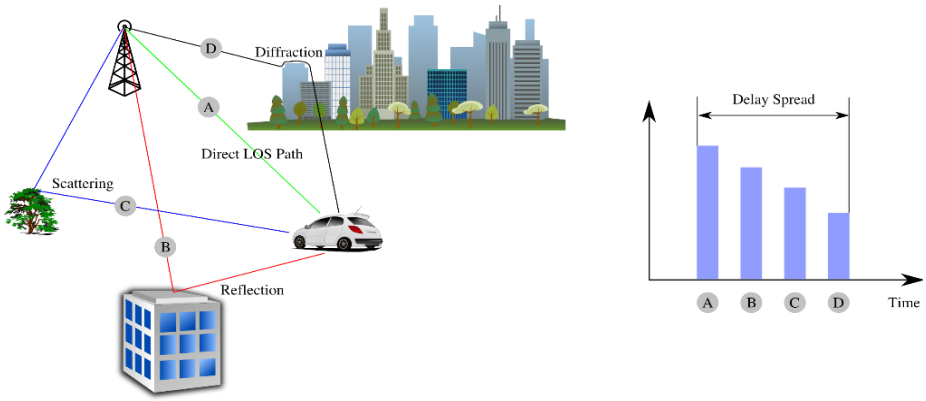

Figure 2. Delay and attenuation models of reflected signals

The direct path 1 between the antennas greatly increases the field strength at the receiving end. Only doppler effect can influence this path. Reflected signals also arrive at the receiving point, except for the signal that passes through the direct line of sight. The multipath propagation of radio waves is also found when using satellite systems. As of 2020, various countries have launched and are operating their own location satellites, and there are approximate 30 satellites available for positioning on average [18].

3. DEVELOPMENT OF A CHANNEL SIMULATION MODEL FOR EXPERIMENTAL EVALUATION OF CHANNEL EFFICIENCY

In this study, a channel model was built to implement methods for dealing with problems of various kinds that arise when a signal passes through a communication channel (Figure 3). The Simulink environment was used for modeling. We performed a study and analyzed the influence of the following characteristics on the behavior of the multipath channel: doppler shift, over-reflection, signal attenuation, and delays. The outcome of the task was the assessment of the error probability and the quality of the received image. For the design in the MATLAB environment, the following sources were studied [19]–[21].

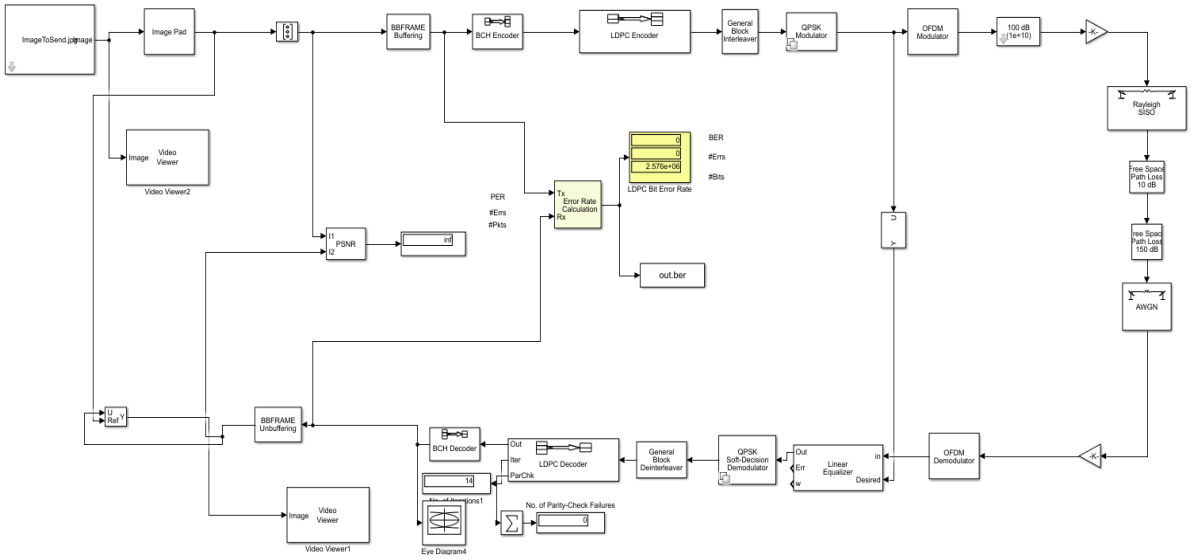

Figure 3. Rayleigh multipath channel model

The following functions were used to form channel models in MATLAB/Simulink environment: AWGN-for additive Gaussian channel, Rayleigh channel–for Rayleigh channel. For deeper investigation of interference immunity of the considered model, the channel parameters were changed (Tables 1 and 2). The standard EPA (extended pedestrian a model (EPA)) was chosen as the channel parameters, corresponding to the case of pedestrian movement. EPA is an extended pedestrian model, which is used to form a multipath channel in wireless communication systems and is based on the International Telecommunication Union (ITU) pedestrian a model. The object speed is 3 km/hour. The analysis of the communication channel includes the channel budget–the calculation of signal energy losses associated with physical processes occurring in devices and the propagation medium. The budget is an evaluation method that allows you to determine the reliability of the transmission of a communication system. In the free space path loss block we specify distance and carrier frequency value: distance (km): 20; carrier frequency (MHz): $3.7*10^{-3}$. Also to take into account additional losses of energy during the signal transfer we use the second *free space path loss* block, where loss (dB): 150.

Table 1. Parameters of the Rayleigh multipath channel

Parameter	Value
Max Doppler shift (f)	5 and 70
Doppler spectrum type	Jakes
Path delay vector (s)	[0 30 70 90 110 190 410] *10^ (-9)
Average Path gain vector (dB)	[0 -1 -2 -3 -8 -17 -20.8]
Fading distribution:	Rayleigh
Initial seed	50

Table 2. Noise characteristics of the AWGN channel

Parameter	Value
Initial Read	67
Mode	Signal to Noise rate (Eb/No)
Eb/No(dB)	[-5 7]
No. of bits/symbol	1
Input signal power	5
Symbol Period	1

4. RESULTS AND DISCUSSION

This part presents the numerical results obtained via the Simulink simulation to validate the derived results. It can be seen (see Figure 4), that the sharpness of the obtained image improves by increasing the signal-to-noise-ratio (SNR) value and the identity of the received and transmitted image is reached when the SNR=7dB. Error probabilities in Rayleigh channel (with delays typical for EPA standard) and Gauss channel at amplifier ratio $K=10^6$ values can be seen on Figure 5.

Figure 4. Image transmission at different values of the error amplitude range

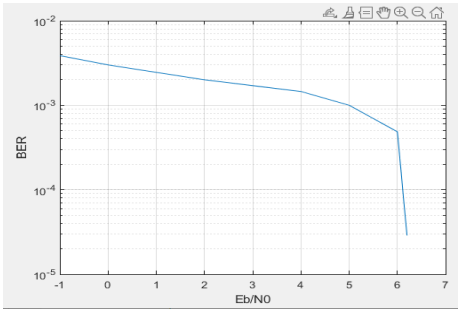

Figure 5. Probabilities of errors in the Rayleigh channel (with delays typical for the EPA standard) and Gauss channel at $K=10^6$

The long-term evolution (LTE) system was considered over the Rayleigh and the Rician channel with fading [22]-[24]. The channel with such characteristics has been studied in [25], which presents a study of multi-frequency spectrally efficient frequency division multiplexed signals (SEFDM) in a multipath channel. In that paper they investigate the efficiency of using SEFDM signals in multipath propagation compared to OFDM signals. Two multipath channels, Rayleigh and Rice, are used to simulate the multipath channel. As a result of the simulation, interference immunity curves were derived for the reception of OFDM and SEFDM signals under multipath propagation channel conditions. In the paper, the value of BER≈0 at SNR=12 dB was obtained. In our system by improving the system (we used converters of size and type of transmitted and received data, amplifier, and Gain normalizer) we obtained the value of BER≈0 at SN =7 dB for Rayleigh channel.

One of the promising areas of research is the application of similar approaches for data transmission via underwater acoustic channels and the use of machine learning methods, also for the transmission of a

protected speech signal. The ways of determining speech intelligibility, assessing the level of protection of speech information and the algorithm of autonomous speech segmentation can be found in [26], [27].

5. CONCLUSION

This study presents a performance evaluation of an EPA-based wireless system with SISO technology using amplifiers and converters. An evaluation of the proposed system for transmitting images in a wireless network is performed. The proposed model is simulated using MATLAB based Simulink. The data from this study is usable in the design of radiotechnical devices for transmitting better quality high-resolution radiological images over a wireless network to remote workers. In this study, using COFDM technology with cascade error correction codes and additional enhancers, such as size and type converters, amplifiers and gain normalization, to reduce the ISI even further, we obtained a high-quality image at quite low SNR values. The results obtained met expectations and were better than those of similar studies. Thus, the hypothesis of the work has been proven true. In addition, the advanced model can be applied as a teaching aid to study various features of digital broadcasting systems.

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