УПРАВЛІННЯ У ТЕХНІЧНИХ СИСТЕМАХ

CONTROL IN TECHNICAL SYSTEMS

УПРАВЛЕНИЕ В ТЕХНИЧЕСКИХ СИСТЕМАХ

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DEVELOPMENT AND RESEARCH OF A WIRELESS CONTROL SYSTEM FOR DEVICE "BIONIC EAR"

Arutyunov S. D. – Dr. Sc., Head of Department "Propaedeutics of dental diseases", A. I. Yevdokimov Moscow State University of Medicine and Dentistry, Moscow, Russia.

Astashina N. B. – Dr. Sc., Head of Department "Orthopedic Dentistry", E. A. Vagner Perm State Medical University, Perm, Russia.

Bajdarov A. A. – PhD, Vice Rector for Information Technology and Innovation Development, E. A. Vagner Perm State Medical University, Perm, Russia.

Gurko V. A. – Senior Lecturer of Department "Automatics and telemechanics", Perm National Research Polytechnic University, Perm, Russia.

Mayorov P. V. – Student of Department "Automatics and telemechanics", Perm National Research Polytechnic University, Perm, Russia.

Freyman V. I. – Dr. Sc., Professor of Department "Automatics and telemechanics", Perm National Research Polytechnic University, Perm, Russia.

Yuzhakov A. A. – Dr. Sc., Head of Department "Automatics and telemechanics", Perm National Research Polytechnic University, Perm, Russia.

ABSTRACT

Context. The analysis of reliability indicators of information transfer between elements of wireless control systems – a control device implemented on a smartphone and a communication processor of the developed hearing aid is carried out. The object of research is the reliability indicators of the wireless control channel. The subject of the study is a theoretical and experimental analysis of the dependencies of reliability indicators of the designed wireless control system.

Objective. The purpose of the work is to determine and study the analytical and experimental dependences of the reliability of transmission over the wireless control channel on the properties of the communication channel and settings of the system elements, forming recommendations for setting the parameters of the elements of the control system.

Methods. The elements of the reliability theory are used to determine the dependences of the bit and block error coefficients on the properties of the communication channel of the configuration of the elements of the control system. Analytical relationships are obtained to determine the reliability of transmission taking into account possible signal distortions. The dependences of reliability indicators on the parameters of the elements of the control system are investigated, illustrative examples are given. Simulated circuit models of a control system with selected Bluetooth wireless technology have been developed. Experimental studies have been carried out, on the basis of the data obtained, conclusions have been drawn and recommendations have been made on the choice of control system configurations in order to ensure specified reliability indicators at maximum efficiency (information transfer rate).

Results. The dependences of reliability indicators (bit and block error coefficients) on the properties of the wireless information transmission channel and the parameters of the control system elements are obtained. Recommendations are given on the use of the results obtained when choosing the settings for the control element (smartphone) and the controlled element (communication processor of the hearing aid). To conduct experimental research, control system models in the MathWorks MatLab Simulink environment were created and tuned.

Conclusions. The studies carried out in the work allow us to calculate and reasonably choose the parameters of the devices of the wireless control system for the given reliability indicators taking into account the error behavior model in the transmission channel and the settings of the associated equipment. This makes it possible to design and implement reliable control systems with specified reliability indicators and maximum information transfer rate.

KEYWORDS: information management systems, reliability, error rate, simulation, Bluetooth.

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ABBREVIATIONS

ARQ – Automatic Repeat Request;
AWGN – Additive White Gaussian Noise;
BER – Bit Error Rate;
BLE – Bluetooth Low Energy;
CRC – Cyclic Redundancy Check;
DSP – Digital Signal Processing;
FEC – Forward Error Correction;
FER – Frame Error Rate;
HEC – Hybrid Error Correction;
HV – High quality Voice;
IEEE – Institute of Electrical and Electronics Engineers;
SEQN – Sequence Numbering;
VoIP – Voice over Internet:
Wi-Fi – Wireless Fidelity;
3-D – 3-Dimensional;
av – average value.

NOMENCLATURE

B – number of error bits;
B_0 – total number of transmitted bits;
C – speed of light;
Ch – Wi-Fi channel number;
d – distance between devices;
Es/No – signal to noise ratio;
f – functional;
F – frequency;
F – number of error frames;
F_0 – total number of transmitted frames;
k – signal transmission channel number;
L_0 – attenuation in free space;
N – availability and settings of other devices operating in the same frequency range;
P – transmitter power;
t – simulation time;
T – type of technology;
V_p – phase speed;
α – the actual part of the distribution coefficient;
β – the imaginary part of the propagation coefficient (phase coefficient);
γ – distribution coefficient;
λ – wavelength;
ρ – interference characteristics;
ω – angular velocity.

INTRODUCTION

Over the past seventy years, active aging of the society of all developed countries has been observed throughout the world. According to the United Nations, in 1950 the number of people over 60 years old was approximately 202 million. To date, the number of older people is close to one billion people. There is also information about the continuation of the aging trend of society. An increase in the number of elderly people entails an increase in age-related diseases [1]. Also, with the increase in the number of vehicles, with the development of industry, the number of emergencies and, as a result, the number of injuries sustained by a person are growing [2].

From the above facts, it can be concluded that the replenishment of the functional capabilities and aesthetic appearance of a person is an urgent problem and requires special attention, both from doctors and engineers.

So, for example, with complete or partial lack of hearing, we suggest using an ear implant, which will be an apparatus to restore the ability to perceive sound information [3]. An important role for ensuring the quality functioning of the hearing aid is played by the organization of a high-speed and reliable control channel using specialized software running on a modern smartphone [4, 5]. One of the most significant parameters is the reliability of communication, which is characterized by error rates (bit and block) and depends on the data transfer rate, interference parameters, type of protocol selected, etc. [6].

The object of study was a wireless control channel between a smartphone and a hearing aid, implemented using Bluetooth technology.

The subject of the study is an experimental study of the program model of the wireless control channel in order to determine the characteristics of reliability and quality of information transfer.

The purpose of the work is the formation of practical recommendations on the use of Bluetooth technology in wireless channels for controlling medical devices using an example of a hearing aid.

1 PROBLEM STATEMENT

It was found, that during the operation of the hearing aid, there is a need for its increased functionality [7], such as:

– volume control from a smartphone;
– the ability to answer incoming calls;
– wireless charge;
– several settings modes.

Different settings modes are needed for a more comfortable use of the hearing aid. For example, one of them will be for everyday use, in which the amplifications at different frequency intervals will be individually configured for each patient, based on data obtained from an examination by an audiologist. And the second mode is for use in noisy places. It will be tuned to sufficiently strong noise reduction and speech emphasis. There may also be more modes, depending on the wishes of the patient. Switching between modes, as well as adjusting the volume, will be carried out through a special application in the smartphone.

To solve the problem of choosing wireless technology for the implementation of the control channel with the specified confidence indicators, we perform the mathematical formulation of the problem.

Let there be a combination of communication channel parameters and control system devices: interference characteristics (Es/No), transmitter power (P), distance between devices (d), the presence and settings of other devices operating in the same frequency range (N), type

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of technology (T). An urgent task is to determine and study the functional dependencies of reliability (quality) indicators of communication, which are characterized by error coefficients, from these parameters. Each indicator can be represented by a set of functional dependencies of the following form:

$$\text{BER, FER} = f(\rho); d = \text{const}; P = \text{const}. \quad (1)$$

$$\text{BER, FER} = f(\rho); d = \text{const}; N = \text{const}. \quad (2)$$

$$\text{BER, FER} = f(d); \text{Es/No} = \text{const}; P = \text{const}. \quad (3)$$

$$\text{BER, FER} = f(d); \text{Es/No} = \text{const}; T = \text{const}. \quad (4)$$

...

To solve the problems of synthesis of a control system with predetermined reliability indicators, it is necessary to study the dependences of the entered transmission indicators at various values of the communication channel parameters that may occur during the practical implementation of the control system.

Reliability is characterized by the coefficients of bit and block errors. Efficiency is specified by the channel bandwidth efficiency, while the actual task is to maximize it (minimize symbolic redundancy) while observing a given reliability. Therefore, questions are further resolved to determine and study the dependences of reliability and efficiency indicators on the parameters of the transmission medium and control system devices. This makes it possible to select and implement in the elements of control systems ways to ensure a given reliability at the maximum information transfer rate.

Based on the foregoing, an urgent task is to choose the technology for communication between a smartphone and a hearing aid. This article will consider the possibility of using modern wireless technologies. In addition, control system models will be built and analyzed, as well as recommendations for the practical implementation of the control channel and the settings of the control system devices will be given.

2 REVIEW OF THE LITERATURE

In recent years, rehabilitation medicine has made great strides, which mainly occur due to the appearance of bionic prostheses. Bionic prosthetics is the replacement of lost body parts with electronic implants. The creation of such implants allowed the study of biocurrents generated by the human brain [8].

The era of bionics began not so long ago, but it is already difficult to surprise people with an artificial organ or limb, which perform all the necessary functions and almost do not differ in appearance from biological ones. Patients, whose situation was not so long ago regarded as almost hopeless, with the use of bionic devices, it became possible to return to full value and improve the quality of their life.

Bionic prosthetics is an innovative, rapidly developing field of science. Many world scientific studies are aimed at further development of various types of bionic implants, aimed both at patients with various acquired diseases or injuries, and for patients with defects from birth. Certain successes in this area have been achieved in the development of bionic arms and legs, artificial heart and retina [9].

To restore hearing, there are many different solutions: hearing aids of air or bone conduction, cochlear implants, but they all have their drawbacks, the main of which is a violation of the aesthetic appearance of a person [10].

The solution offered by our regional research group is unique and consists in creating a bionic ear. The main idea is to create a hearing aid using modern components and place it in the auricle implant printed using 3-D technologies from materials that are most similar in appearance and tactile feel to the biological ear.

To implement the settings and use of the hearing aid, it is necessary to calculate the parameters that critically affect the wireless data transfer [11]. Moreover, it is effective to use modern approaches to ensure the reliability of information transmission [12, 13] against the background of the effects of interference of various nature and properties [14, 15].

For the study, a number of modern wireless communication technologies were analyzed, and Bluetooth-LE was selected based on a comparative analysis [16]. Unlike classic Bluetooth, BLE is designed to provide significantly lower power consumption. This allows smartphone applications to interact with BLE devices with more stringent power requirements, such as proximity sensors, heart rate monitors, fitness devices, in our case, a hearing aid. The basis of interaction between devices operating on the basis of the BLE protocol is the client-server architecture. The phone supports a central role, the hearing aid supports the role of a peripheral device, one of two is required to establish a BLE connection [17]. Devices that support only the role of peripheral devices cannot communicate with each other, and two devices cannot communicate with only a central connection. As soon as the telephone and the hearing aid have established a connection, they begin to transmit metadata to each other [18]. Depending on the type of data they transmit, one or the other may act as a server. For example, if the hearing aid wants to transfer data to the telephone, it might make sense for the hearing aid to act as a server. If the hearing aid wants to receive updates from the phone, then it may make sense for the phone to act as a server, which is important in our project, the point-to-point connection type. In this regard, the urgent task is to develop and study a data transfer model between a smartphone and hearing aids via the Bluetooth LE protocol.

3 MATERIALS AND METHODS

As part of the project, it is necessary to study the physical parameters of the signal during transmission from the source to the recipient. Both the processor of the hearing aid and the smartphone can be a source and recipient, since data transmission must be carried out in both directions. The task was to determine the optimal number of frequency channels, the number of which will achieve the target value – the distance, in the presence of

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interference. Also, determine the noise immunity of data transmission. The result of the analysis was obtained on the basis of modeling.

The designed communication system was modeled on standard blocks Matlab Simulink, DSP Blockset and the Communications Blockset library [19]. One way to build such a system in Simulink is to start by designing the communication channel and developing it by adding modulations, FEC, etc. testing at every stage. You can develop pairs of components separately, for example, a speech encoder and decoder that can be created and tested in their own model, and then built into the system. The generalized structural diagram of the model is shown in Fig. 1.

When creating the network model, the Bluetooth Voice Transmitter model was taken as the basis (Fig. 2), and its structure was adapted to bring the model closer to the research tasks.

Fig. 2 shows the top level of the complete Bluetooth Voice Simulink model. It includes:

1. Master Transmitter – model of the signal transmitter, i.e. a transmitting device, for example, a smartphone;

2. AWGN – model of a radio channel in which «white noise» operates;

3. Free Space Path Loss – a simulator of a long wireless line, which determines the loss in free space;

4. 802.11b Interferer – model of the interference source in the form of a transmitter operating over the IEEE 802.11b Wi-Fi protocol,

5. Slave Receiver – the receiver of the slave node, ie, the receiving device, for example, another smartphone or Hands-Free unit in the car.

The hierarchical features of Simulink modeling allow you to create large, complex structures that are controlled from subsystems. The discovery of these subsystems shows further levels of detail [19].

Consider the principle of building the main blocks of the model.

The transmitter whose internal circuit is shown in Fig. 3, contains: input of random binary values, coding, buffering, framing, HEC/FEC modulations and frequency hopping.

All real-life continuous communications transmitted in communication systems reflect processes whose main part of the spectrum is concentrated in a finite frequency range. This is explained by the frequency properties of message sources and subscribers (message recipients), which are real physical systems [20].

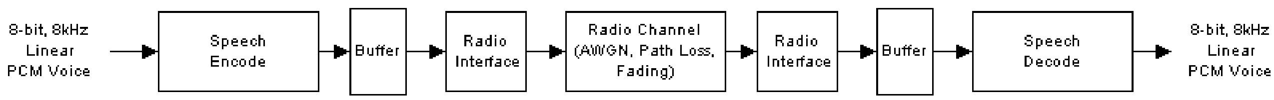

Figure 1 – Generalized block diagram of a Bluetooth control channel model

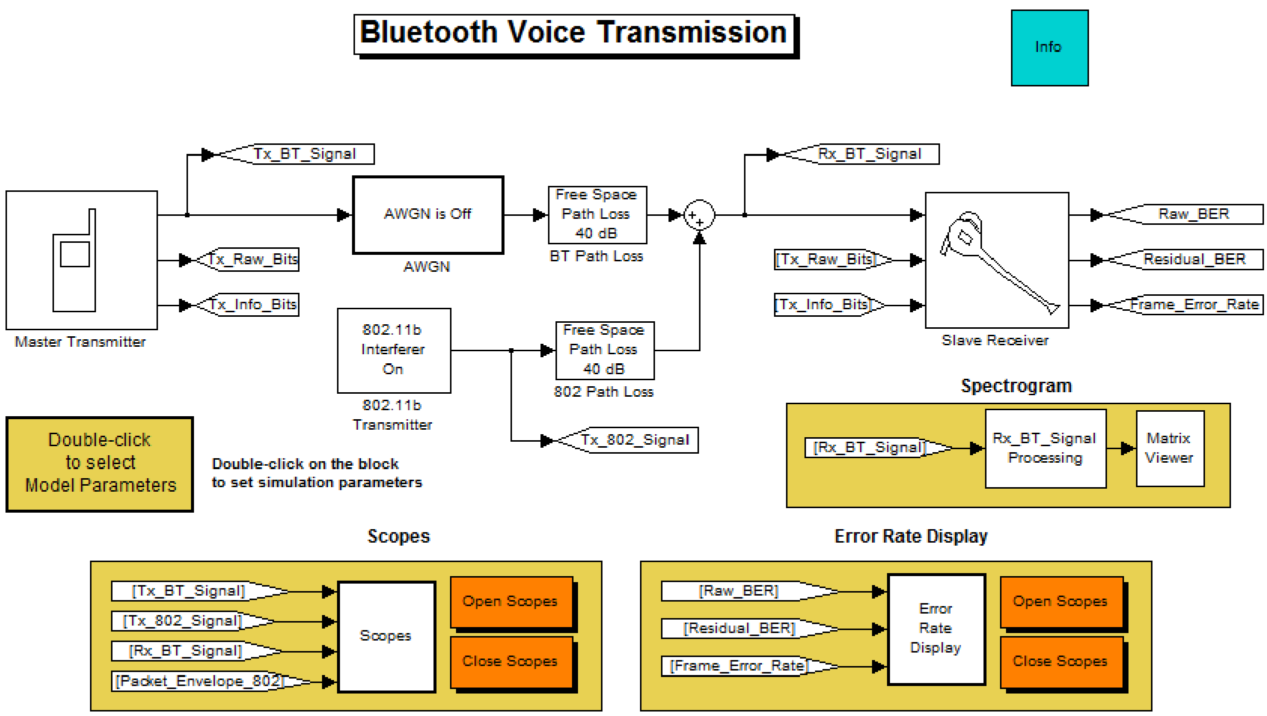

Figure 2 – Bluetooth Voice Transmitter in Simulink

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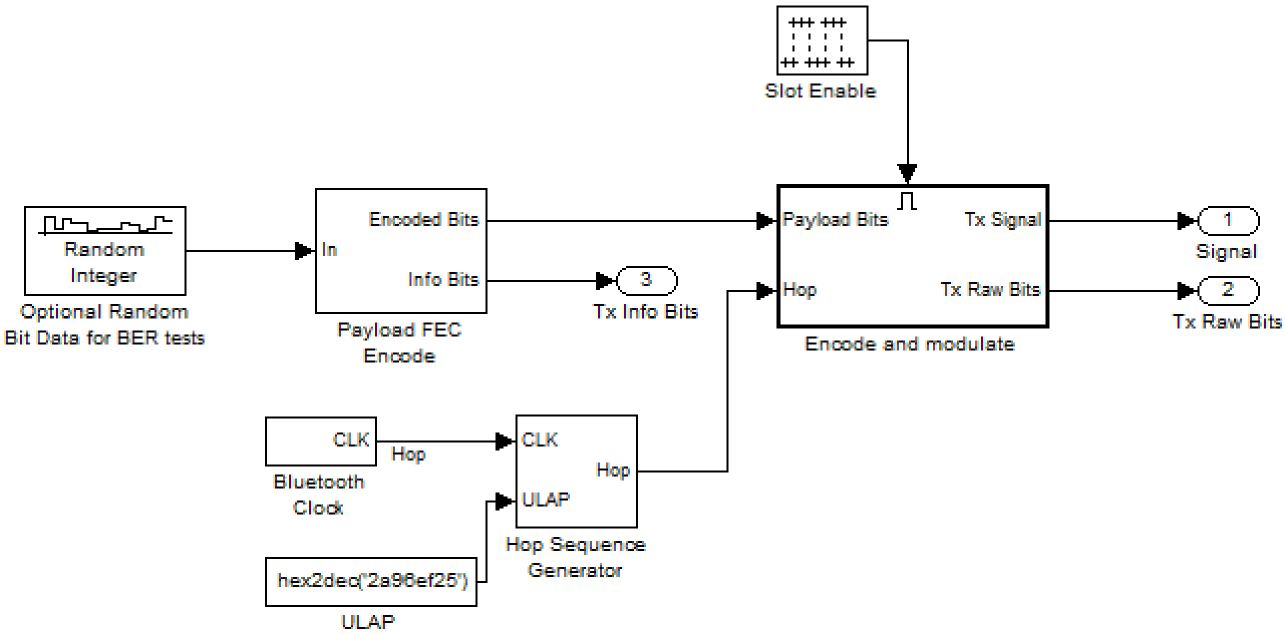

Figure 3 – Internal structure of the signal transmitter unit

Bluetooth technology uses time division duplex (multiplexing). The master device transmits packets at odd time intervals (slots), and the slave device transmits packets at even times. Packages depending on the length can take up to five intervals. Moreover, the channel frequency does not change until the end of the packet transmission [20].

A packet is a format of bits organized into an array that are transmitted over a physical channel. A package consists of an access code, a package header, and user information. The structure of the message packet is shown in Fig. 4.

The access code identifies packets belonging to the same piconet, and is also used for synchronization and request procedures. It includes a preamble (4 bits), a sync word (64 bits), and a frame checksum – 4 bits of a checksum. The header contains information for managing communications and consists of six fields:

1. Address (3 bits) – address of the active element;
2. Type (4 bits) – data type code;
3. FLOW-F (1 bit) – data flow control, shows the readiness of the device to receive;
4. ARQ-A (1 bit) – confirmation of the correct reception;
5. SEQN-S (1 bit) – serves to determine the sequence of packets;
6. Checksum (8 bits) – control checksum.

The final part of the overall package format is user information. It consists of three segments: the header of the user information, the user information itself and the CRC.

The header (8 bits) defines a logical channel, flow control in logical channels, and also has a pointer to the length of user information. User Information CRC (16 bits) – 16 bits of cyclic redundancy code is calculated from the transmitted information, after which it is attached to the information [21].

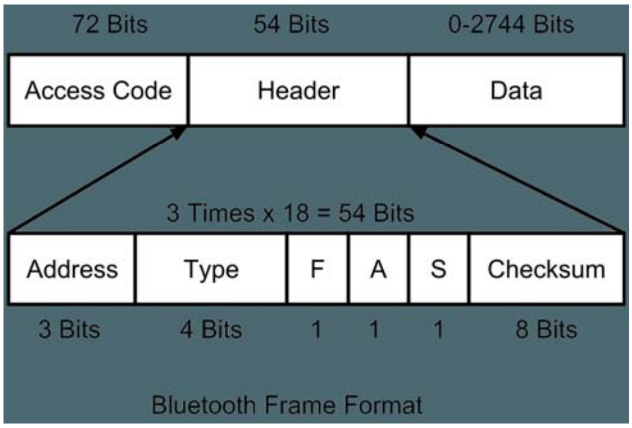

Figure 4 – Bluetooth message packet structure

The AWGN is a simulator of white noise. The Bluetooth Voice Transmitter model allows you to set the signal to noise ratio in the AWGN unit. This ratio is an argument to the function resulting from the study. The menu for setting the parameters of the AWGN block is shown in Fig. 5.

Attenuation in free space is calculated by the formula (5):

$$L_0 = 20\lg\frac{4\pi d}{\lambda}\ \text{[dB]}, \qquad (5)$$

L_0 – attenuation; d – attenuation distance; λ – wavelength [19].

The wavelength, as is known, depends on the phase coefficient β (6) (this is the imaginary part of the propagation coefficient $\gamma = \alpha + j\beta$) [21]:

$$\lambda = \frac{2\pi}{\beta}. \qquad (6)$$

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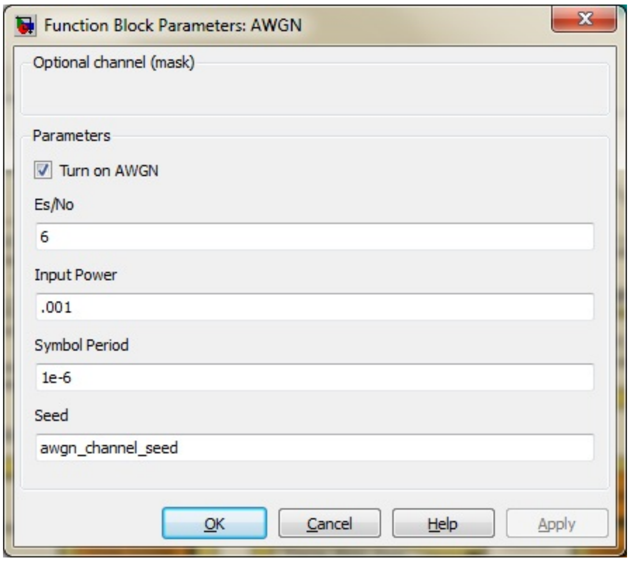

Figure 5 – The menu for setting the parameters of the AWGN block

And the phase velocity also depends on β (7) [21]:

$$V_p = \frac{\omega}{\beta}. \quad (7)$$

In air $V_p = C$ (speed of light ≈ $3 \cdot 10^8$ m/s). So, from (6) and (7) get (8):

$$\beta = \frac{\omega}{V_p} = \frac{\omega}{C} = \frac{2\pi f}{C} \Rightarrow \lambda = \frac{2\pi C}{2\pi f} = \frac{C}{f}. \quad (8)$$

Therefore, the formula for calculating the loss in free space will take the form (9):

$$L_0 = 20 \lg \frac{4\pi d f}{C}. \quad (9)$$

In the considered Bluetooth model, there are two options for setting free space loss during wave propagation:

1. The reference attenuation from 10 to 40 dB, shown in Fig. 6;

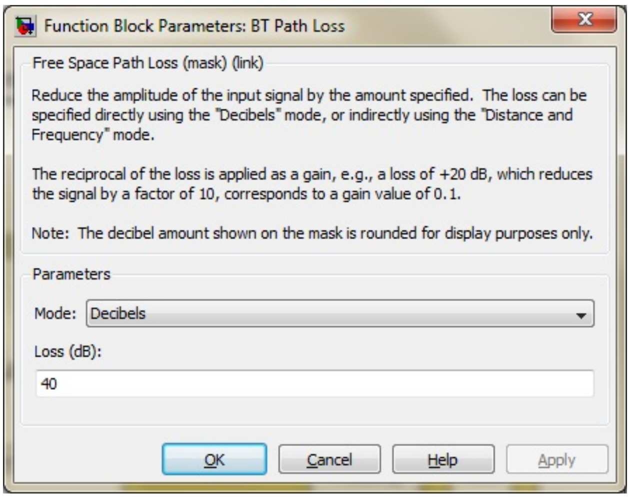

Figure 6 – Window for selecting parameters for setting free space loss in decibels

2. Setting the frequency and transmission distance (with these parameters, the model itself calculates the free space loss in dB) shown in Fig. 7 [21].

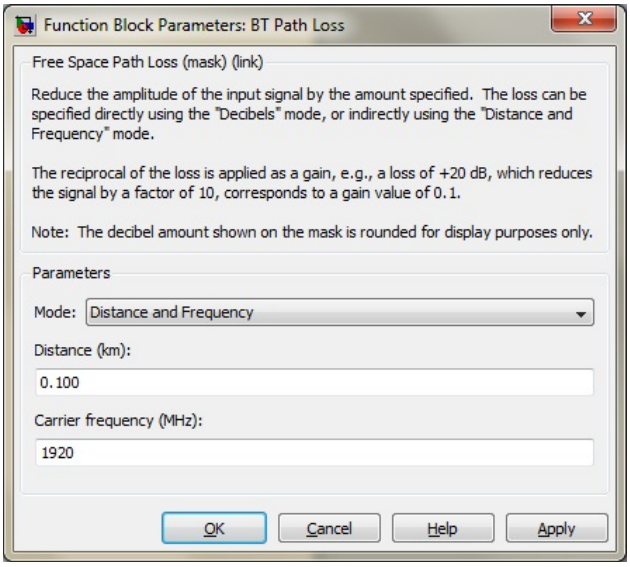

Figure 7 – Parameters selection window for setting the operating frequency and distance

To study the dependence of the error coefficient on the attenuation in the communication line, various parameters were set to set the loss in free space.

To calculate the transmission distance for a given attenuation we solve the logarithmic equation:

$$40 = 20 \lg \frac{4\pi d f}{C}. \quad (10)$$

The calculation formula for determining the transmission range in general is:

$$d = \frac{C \cdot 10^{\frac{L_0}{20}}}{4\pi f}. \quad (11)$$

To calculate the distance d (transmission distance for a given attenuation), we solve the logarithmic equation (11).

For the radio exchange of a Bluetooth device, the frequency range 2400–2483.5 MHz is used. The capacity of this frequency band is 79 subchannels with a bandwidth of 1 MHz. The carrier frequency of the subchannels $f_k = 2402 + k$ (MHz), where $k = 0,...,78$. To reduce the complexity of transceivers, radio channels with binary frequency modulation are used. The coding is simple – the logical unit corresponds to a positive frequency deviation, to zero – negative [22].

On 39th channel, carrier frequency will be equal:

$$f_k = 2402 + 39 = 2441 \text{ MHz}, \quad (12)$$

on 79th channel

$$f_k = 2402 + 78 = 2480 \text{ MHz}. \quad (13)$$

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So for channel 39:

1. Attenuation in free space from formula (7) at d = 2 m (the maximum distance at which Bluetooth is planned to be used when both network nodes are located by one user), f_k = 2.441 GHz, is equal to:

$$L_0 = 20\lg\frac{4\cdot\pi\cdot 2.441\cdot 10^9}{3\cdot 10^8} = 40.19312 \text{ dB}. \qquad (14)$$

2. Transmission distances determined by the formula (11) when L_0 = 40 dB, f_k = 2.441 GHz:

$$d = \frac{3\cdot 10^8\cdot 10^{\frac{40}{20}}}{4\cdot\pi\cdot 2.441\cdot 10^9} = 0.978011\, m. \qquad (15)$$

For channel 79:

1. Attenuation in free space from formula (5) at d = 2 m (the traditional distance at which Bluetooth works stably in practice) and f_k = 2.441 GHz is equal to:

$$L_0 = 20\lg\frac{4\cdot\pi\cdot 2.480\cdot 10^9}{3\cdot 10^8} = 40.3264 \text{ dB}. \qquad (16)$$

2. Transmission distance from formula (11) when L_0 = 40 dB и f_k = 2.441 GHz:

$$d = \frac{3\cdot 10^8\cdot 10^{\frac{40}{20}}}{4\cdot\pi\cdot 2.480\cdot 10^9} = 0.963119\, m. \qquad (17)$$

Thus, for 39 and 79 channels, a difference in attenuation of 0.133 dB was obtained, and a transmission distance of 0.015 m.

The simulation result will be the values of the error rate: bit error rate and frame error rate, which are calculated by formulas (18) and (19), respectively [23]:

$$BER = \frac{B}{B_0}, \qquad (18)$$

$$FER = \frac{F}{F_0}. \qquad (19)$$

4 EXPERIMENTS

Next, the conducted experiments will be described and conclusions made on them.

Parameters of the first experiment: the Wi-Fi unit is turned off, the simulation time t = 0.5 (simulated simulation clocks), the interference power is «white noise» Input Power = 0.001 W.

The dependence of the following form is investigated:

$$\text{BER} = f\,(\text{Es/No}) \mid d = \text{const}.$$

Table 1 – BER, FER versus Es/No dependency, for Input Power = 0.001 W

Es/No	d = 1 m		d = 5 m		d = 10 m	
	BER	FER	BER	FER	BER	FER
2	0.2390	1	0.2416	1	0.2438	1
5	0.1345	0.9174	0.1382	0.9009	0.1366	0.8960
8	0.0554	0.0218	0.0529	0.2030	0.0534	0.2256
11	0.0115	0.0075	0.0118	0	0.0121	0
14	0.0006	0	0.0009	0	0.0008	0
17	0	0	0	0	0	0
20	0	0	0	0	0	0

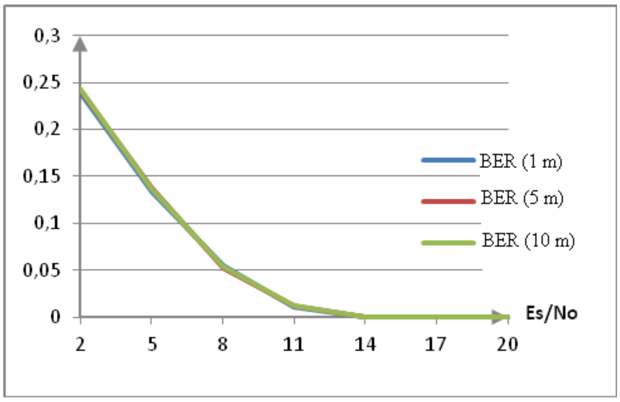
Let's plot the studied dependences (Fig. 8).

The conclusion of Fig. 8: the error rates decrease with increasing signal-to-noise ratio and are not significantly dependent on the distance between the devices. This allows you to provide high-quality communication at the most frequently used in practice, the removal of devices from each other.

Increase the input noise white power to 0.01 watts and run the simulation again.

Let's plot the studied dependences (Fig. 9).

The conclusion of Fig. 9: the error coefficients, as in the previous simulation, decrease with increasing signal-to-noise ratio and depend insignificantly on the distance between the devices. An increase in the power of the white noise signal entailed an increase in the number of bit and frame errors compared to the previous simulation.



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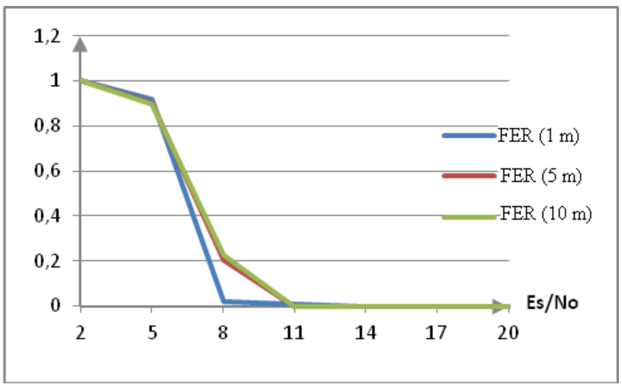

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Figure 8 – Graph of BER and FER versus Es/No for d = const and Input Power = 0.001 W

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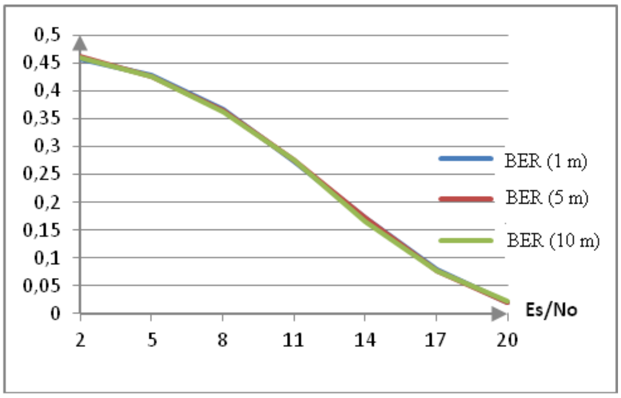
Table 2 – BER and FER versus Es/No dependency for Input Power = 0.01 W

Es/ No	*d* = 1 m		*d* = 5 m		*d* = 10 m	
	BER	FER	BER	FER	BER	FER
2	0.4575	1	0.4610	1	0.4609	1
5	0.4276	1	0.4252	1	0.4261	1
8	0.3668	1	0.3643	1	0.3615	1
11	0.2747	1	0.2763	1	0.2761	1
14	0.1714	1	0.1717	0.9804	0.1658	0.9901
17	0.0797	0.4812	0.0771	0.4586	0.0777	0.4737
20	0.0212	0.0075	0.0206	0.0075	0.0216	0.0150

Once again, increase the white noise power Input Power by 10 times to 0.01 W and perform the simulation again.



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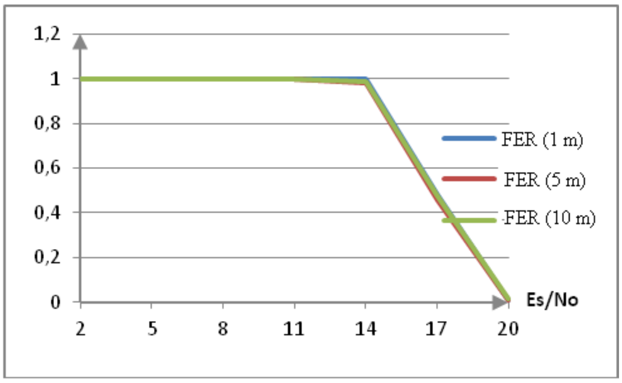

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Figure 9 – Graph of BER and FER versus Es/No at *d* = const and Input Power = 0.01 W

Table 3 – BER и FER versus Es/No dependency for Input Power = 0.1 W

Es/ No	*d* = 1 *m*		*d* = 5 *m*		*d* = 10 *m*	
	BER	FER	BER	FER	BER	FER
2	0.4942	1	0.4937	1	0.4931	1
5	0.4918	1	0.4870	1	0.4887	1
8	0.4875	1	0.4805	1	0.4865	1
11	0.4682	1	0.4662	1	0.4687	1
14	0.4382	1	0.4452	1	0.4342	1
17	0.3911	1	0.3891	1	0.3868	1
20	0.3113	1	0.3084	1	0.3079	1

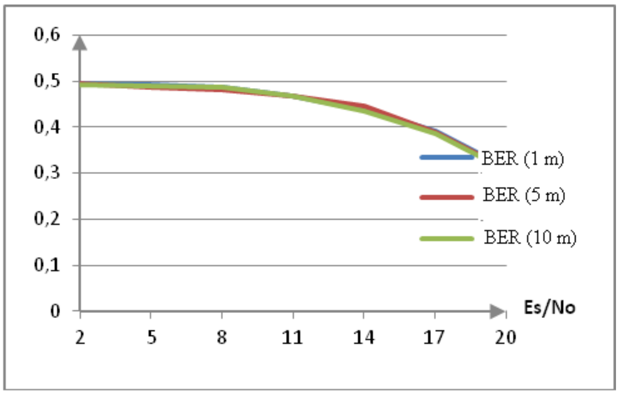
Let's plot the studied dependences (Fig. 10).

The conclusion of fig. 10: as in the previous two cases, the error coefficients decrease with increasing signal-to-noise ratio and depend insignificantly on the distance between the devices. An increase in the power of the white noise signal by another 10 times again entailed an increase in the number of bit and frame errors, and led to the fact that all the received frames at all the studied distances turned out to be erroneous.

Parameters of the second experiment: signal-to-noise ratio = 10, white noise signal power = 0.001, simulation time *t* = 0.5 (simulated simulation clocks), Wi-Fi signal power = 0.1 W.

The dependence of the following form is investigated:

$$\text{BER} = f\,(\text{Wi-Fi } Ch) \mid d = \text{const}.$$



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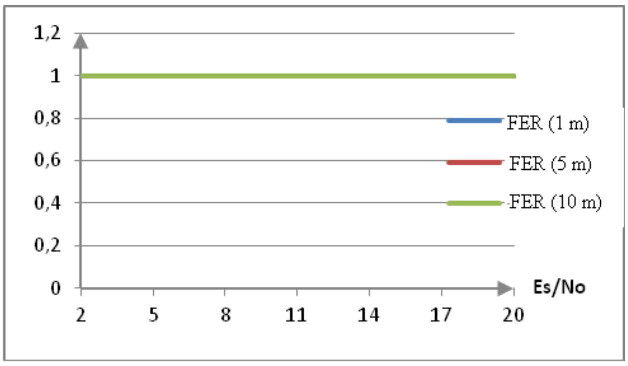

b

Figure 10 – Graph of BER and FER versus Es/No at *d* = const and Input Power = 0.1 W

Table 4 – BER и FER versus Wi-Fi *Ch* dependency for Wi-Fi Power = 0.1 W

Es/ No	*d* = 1 *m*		*d* = 5 *m*		*d* = 10 *m*	
	BER	FER	BER	FER	BER	FER
No Wi-Fi	0.0206	0.0226	0.0196	0.0075	0.0215	0.0075
0	0.0207	0.0225	0.0402	0.0677	0.0335	0.0226
39	0.0330	0.0301	0.0374	0.0602	0.0362	0.0602
78	0.0277	0.0301	0.0344	0.0376	0.0408	0.0827

Let's plot the studied dependences (Fig. 11).

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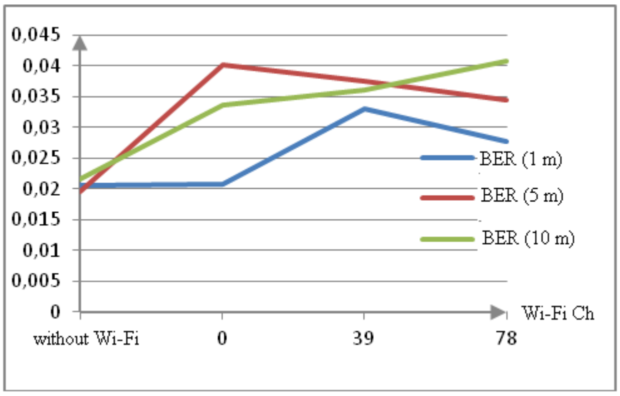
The conclusion of Fig. 11: When interference with a Wi-Fi signal of a relatively high power, the error coefficients have a random distribution pattern, which can be explained by the different influence of the signal in the working frequency range of Bluetooth.

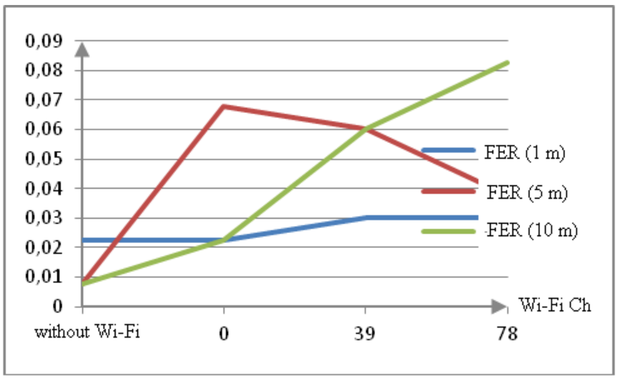
Reduce the power of the Wi-Fi signal to 0.01 and explore.

Table 5 – BER, FER versus Wi-Fi *Ch* dependency for Wi-Fi Power = 0.01 W

Es/No	*d* = 1 m		*d* = 5 m		*d* = 10 m	
	BER	FER	BER	FER	BER	FER
No Wi-Fi	0.0206	0.0226	0.0196	0.0075	0.0215	0.0075
0	0.0242	0.0075	0.0366	0.0376	0.0278	0.0451
39	0.0270	0.0451	0.0302	0.0451	0.0429	0.0677
78	0.0248	0.0150	0.0293	0.0526	0.0222	0.0150



a



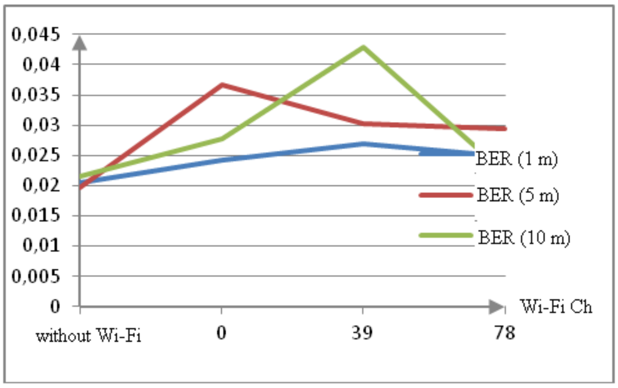
b

Figure 11 – Graph of BER and FER versus Wi-Fi channel for *d* = const and Wi-Fi Power = 0.1 W

Let's plot the studied dependences (Fig. 12).

The conclusion of Fig. 12: The error rates are mostly extreme when connecting a signal source on a Wi-Fi channel, the closest frequency range to the working range of Bluetooth frequencies.

Once again, we reduce the Wi-Fi signal strength so that it is equal to 0.001, and investigate.



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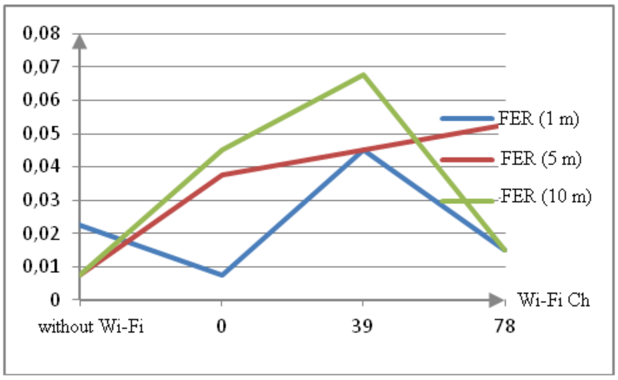

b

Figure 12 – Graph of BER and FER versus Wi-Fi channel for *d* = const and Wi-Fi Power = 0.01 W

Table 6 – BER, FER versus Wi-Fi *Ch* dependency for Wi-Fi Power = 0.001 W

Es/No	*d* = 1 *m*		*d* = 5 *m*		*d* = 10 *m*	
	BER	FER	BER	FER	BER	FER
No Wi-Fi	0.0206	0.0226	0.0196	0.0075	0.0215	0.0075
0	0.0210	0.0226	0.0278	0.0376	0.0262	0.0226
39	0.0230	0.0376	0.0302	0.0451	0.0330	0.0301
78	0.0211	0.0226	0.0244	0.0376	0.0228	0.0075

Let's plot the studied dependences (Fig. 13).

The conclusion of Fig. 13: The error rates are maximum when connecting the signal source on the Wi-Fi channel, the closest frequency range to the working frequency range of Bluetooth.

Third experiment parameters: signal-to-noise ratio = 10, white noise signal power = 0.001, Wi-Fi signal power = 0.01 W, Wi-Fi channel of the Wi-Fi transmitter *Ch* = 39, distance *d* = 5 *m*. The dependence of the following form is investigated:

$$\text{BER} = f(t) \mid d = \text{const}.$$

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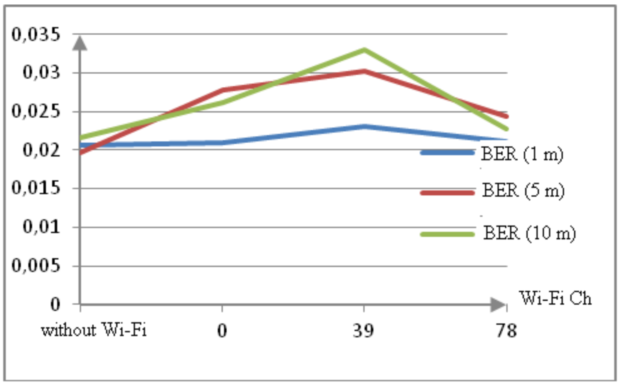

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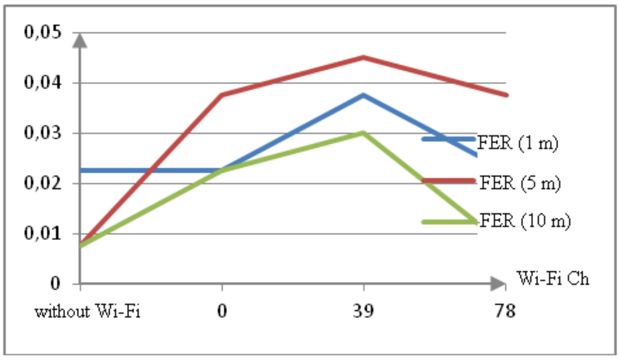

b

Figure 13 – Graph of BER and FER versus Wi-Fi channel for d = const and Wi-Fi Power = 0.001 W

Table 7 – BER versus simulation time t

Simulation time	BER 1	BER 2	BER 3	BER 4	BER_{av}
0.01	0.0191	0.0246	0.0155	0.0228	0.0205
0.05	0.0240	0.0151	0.0246	0.0240	0.02191
0.1	0.0574	0.0447	0.0406	0.0247	0.04185
0.5	0.0356	0.0397	0.0335	0.0315	0.0351
1	0.0309	0.0400	0.0407	0.0273	0.0347
5	0.0358	0.0351	0.0374	0.0366	0.0362
10	0.0387	0.0383	0.0339	0.0374	0.0371

Table 8 – FER versus simulation time t

Simulation time	FER 1	FER 2	FER 3	FER 4	FER_{av}
0.01	0	0	0	0	0
0.05	0	0	0.0769	0	0.0192
0.1	0.1111	0.0741	0.0370	0.0370	0.0648
0.5	0.0677	0.0451	0.0301	0.0451	0.0470
1	0.0375	0.0599	0.0674	0.0300	0.0487
5	0.0533	0.0443	0.0488	0.0503	0.0491
10	0.0516	0.0642	0.0465	0.0533	0.0539

Let's plot the studied dependences (Fig. 14).

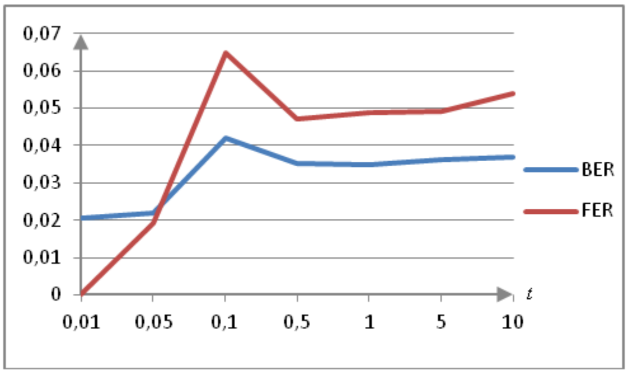

Figure 14 – BER and FER versus simulation time t dependency for d = const

The conclusion of Fig. 14: the graphs show an extremum at 0.1 conditional clock cycles of modeling, but this is a consequence of a random set of transmitted data and the random nature of the interference. When conducting repeated simulations, the extremum may correspond to a different value of the simulation time, or it may be absent altogether (modeling was carried out, but the graphs are not given). There is also averaging and stabilization of the values of bit and block errors with increasing simulation time.

Parameters of the fourth experiment: signal-to-noise ratio = 10, white noise signal power = 0.001, Wi-Fi signal power = 0.01 W, Wi-Fi channel of the Wi-Fi transmitter Ch = 39, distance d = 5 m, simulation time t = 0.5 (conditional cycles of modeling). The dependence of the following form is investigated:

$$\text{BER} = f(\text{HV}) \mid d = \text{const}.$$

Table 9 – BER and FER versus Bluetooth transmission packet type

Packet type	BER	FER
HV1	0.0296	0.0324
HV2	0.0395	0.0498
HV3	0.0368	0.0602

Let's plot the studied dependences (Fig. 15).

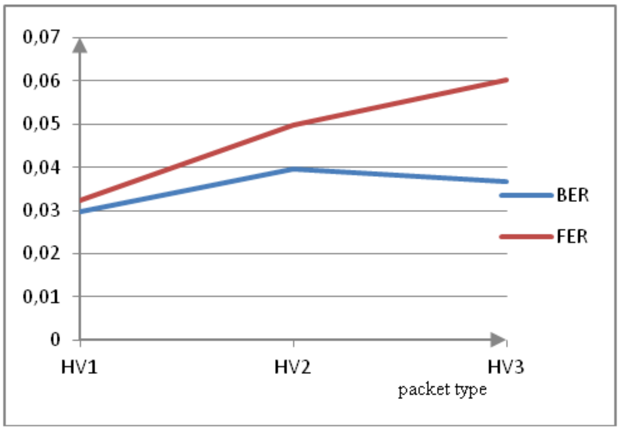

Figure 15 – BER and FER versus packet type dependency for d = const

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The conclusion of Fig. 15: the smallest value of bit and frame errors is observed when using a packet of type HV1. Also noticeable is the change in the difference between the values of bit and block errors when transmitting different packets. This is due to the peculiarities of data structures in packets of different types.

5 RESULTS

As a result of the theoretical studies, dependencies are obtained that are essential for the design of wireless control channels, reliability indicators for interference characteristics, signal power, distance, the presence of sources of interfering signals of other technologies, etc. Analytical dependencies were determined, the influence of parameters on the integral indicators of reliability was investigated, their graphic illustrations were obtained, and an analysis of their nature was made.

The simulation circuit model of a wireless control system that implements the communication technology under study in the modeling package MatLab Simulink is investigated. With its help, experimental studies were carried out. They confirmed the introduced mathematical position. Another purpose of the studied models is the tasks of analysis and synthesis of control systems with given indicators of reliability and efficiency.

6 DISCUSSION

The several wireless technologies are selected for comparison: Bluetooth, Wi-Fi, ZigBee [7]. The protocol specifications similar in technical characteristics (IEEE 802.11b and IEEE 802.15.4) are chosen. A comparison is based on the results of data presented in scientific publications and open information sources [14, 16, 17, 20]. The comparison was carried out according to several basic characteristics: the signal-to-noise ratio, power consumption, transmission speed, noise immunity. The conclusion of comparison is Bluetooth technology has large advantages. Therefore, it was chosen for modeling and research in order to obtain effective characteristics for configuration in the developed device.

The studies of reliability indicators of the wireless control channel between the smartphone and the hearing aid and the resulting dependencies were used for choosing the configurations and settings of the control system elements. For given technical conditions – the signal-to-noise ratio, protocol type, packet size, distance between devices, the presence or absence of other signal sources, one can select such settings to ensure maximum reliability of information speed for high efficiency of using the resources of the developed control system.

CONCLUSIONS

The results of the study confirmed that to solve the problem – “Wireless interaction between the smartphone and hearing system”, Bluetooth LE technology meets all the requirements for frequency and energy characteristics.

The scientific novelty of the presented results lies in the fact that, as a result of analytical and experimental research, the nature of the influence of interference parameters, transmission channel characteristics and network configuration on the appearance, structure and level of errors in the operation of the wireless control system was revealed.

The practical significance of the results of the work lies in the implementation of simulation circuit models of a wireless control system using the selected wireless transmission technology. They allow you to perform studies of reliability indicators and evaluate the effectiveness of using reliability indicators for various interference characteristics, device parameters and system configurations. Models are an effective toolkit for the analysis and synthesis of control systems with predetermined indicators of reliability and energy efficiency.

Prospects for further research are expected in the development of algorithmic and software tools for calculating and comparative analysis of the characteristics of wireless communication technologies to select an effective data transfer platform for control systems.

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РОЗРОБКА І ДОСЛІДЖЕННЯ БЕЗДРОТОВИХ СИСТЕМ УПРАВЛІННЯ ПРИЛАДОМ «БІОНІЧНЕ ВУХО»

Арутюнов С. Д. – доктор наук, завідувач кафедрою «Пропедевтика стоматологічних захворювань», Московський державний медико-стоматологічний університет імені А. І. Євдокимова, м. Москва, Росія.

Асташина Н. Б. – доктор наук, завідувач кафедри «Ортопедична стоматологія», Пермський державний медичний університет ім. академіка О. О. Вагнера, м. Перм, Росія.

Байдаров А. А. – кандидат технічних наук, проректор з інформаційних технологій та інноваційного розвитку, Пермський державний медичний університет ім. академіка О. О. Вагнера, м. Перм, Росія.

Гурко В. А. – старший викладач кафедри «Автоматика і телемеханіка», Пермський державний технічний університет, м. Перм, Росія.

Майоров П. В. – студент кафедри «Автоматика і телемеханіка», Пермський державний технічний університет, м. Перм, Росія.

Фрейман В. І. – доктор технічних наук, професор кафедри «Автоматика і телемеханіка», Пермський державний технічний університет, м. Перм, Росія.

Южаков А. А. – доктор технічних наук, завідувач кафедри «Автоматика і телемеханіка», Пермський державний технічний університет, м. Перм, Росія.

АНОТАЦІЯ

Актуальність. Проведено аналіз показників достовірності передачі інформації між елементами бездротової системи управління – керуючим пристроєм, реалізованим на смартфоні, і комунікаційним процесором створюваного слухового апарату. Об’єктом дослідження є показники достовірності бездротового каналу управління. Предмет дослідження – теоретичний і експериментальний аналіз залежностей показників достовірності проектованої бездротової системи управління.

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Мета роботи. Визначення і дослідження аналітичних і експериментальних залежностей показників достовірності передачі по бездротовому каналу управління від властивостей каналу зв'язку і налаштувань елементів системи, формування рекомендацій налаштування параметрів елементів системи управління.

Методи. Використано елементи теорії надійності для визначення залежностей коефіцієнтів бітових і блокових помилок від властивостей каналу зв'язку конфігурації елементів системи управління. Отримано аналітичні співвідношення для визначення показників достовірності передачі з урахуванням можливих спотворень сигналів. Досліджено залежності показників достовірності від параметрів елементів системи управління, наведені ілюструють приклади. Розроблено імітаційні схемотехнічні моделі системи управління з обраної бездротової технологієї Bluetooth. Проведено експериментальні дослідження, на підставі отриманих даних зроблено висновки і запропоновані рекомендації щодо вибору конфігурацій системи управління з метою забезпечення заданих показників достовірності при максимальній ефективності (інформаційної швидкості передачі).

Результати. Отримані залежності показників достовірності (коефіцієнти бітових і блокових помилок) від властивостей бездротового каналу передачі інформації і параметрів елементів системи управління. Надано рекомендації щодо використання отриманих результатів при виборі налаштувань керуючого елемента (смартфона) і керованого елемента (комунікаційного процесора слухового апарату). Для проведення експериментальних досліджень створено і налаштовано моделі системи управління в середовищі MathWorks MatLab Simulink.

Висновки. Проведені в роботі дослідження дозволяють розрахувати і обґрунтовано вибрати параметри пристроїв бездротової системи управління для заданих показників достовірності з урахуванням моделі поведінки помилок в каналі передачі і налаштувань супутнього обладнання. Це дає можливість проектувати і реалізувати надійні системи управління із заданими показниками достовірності та максимальної інформаційної швидкістю передачі.

КЛЮЧОВІ СЛОВА: інформаційно-керуючі системи, достовірність, коефіцієнт помилок, модель, Bluetooth.

УДК 621.391:004.052

РАЗРАБОТКА И ИССЛЕДОВАНИЕ БЕСПРОВОДНОЙ СИСТЕМЫ УПРАВЛЕНИЯ УСТРОЙСТВОМ «БИОНИЧЕСКОЕ УХО»

Арутюнов С. Д. – доктор наук, заведующий кафедрой «Пропедевтика стоматологических заболеваний», Московский государственный медико-стоматологический университет имени А. И. Евдокимова, г. Москва, Россия.

Асташина Н. Б. – доктор наук, заведующая кафедрой «Ортопедическая стоматология», Пермский государственный медицинский университет им. академика Е. А. Вагнера, г. Пермь, Россия.

Байдаров А. А. – кандидат технических наук, проректор по информационным технологиям и инновационному развитию, Пермский государственный медицинский университет им. академика Е. А. Вагнера, г. Пермь, Россия.

Гурко В. А. – старший преподаватель кафедры «Автоматика и телемеханика», Пермский национальный исследовательский политехнический университет, г. Пермь, Россия.

Майоров П. В. – студент кафедры «Автоматика и телемеханика», Пермский национальный исследовательский политехнический университет, г. Пермь, Россия.

Фрейман В. И. – доктор технических наук, профессор кафедры «Автоматика и телемеханика», Пермский национальный исследовательский политехнический университет, г. Пермь, Россия.

Южаков А. А. – доктор технических наук, заведующий кафедрой «Автоматика и телемеханика», Пермский национальный исследовательский политехнический университет, г. Пермь, Россия.

АННОТАЦИЯ

Актуальность. Проведен анализ показателей достоверности передачи информации между элементами беспроводной систем управления – управляющим устройством, реализованным на смартфоне, и коммуникационным процессором разрабатываемого слухового аппарата. Объектом исследования являются показатели достоверности беспроводного канала управления. Предмет исследования – теоретический и экспериментальный анализ зависимостей показателей достоверности проектируемой беспроводной системы управления.

Цель работы. Определение и исследование аналитических и экспериментальных зависимостей показателей достоверности передачи по беспроводному каналу управления от свойств канала связи и настроек элементов системы, формирование рекомендаций настройке параметров элементов системы управления.

Методы. Использованы элементы теории надежности для определения зависимостей коэффициентов битовых и блоковых ошибок от свойств канала связи конфигурации элементов системы управления. Получены аналитические соотношения для определения показателей достоверности передачи с учетом возможных искажений сигналов. Исследованы зависимости показателей достоверности от параметров элементов системы управления, приведены иллюстрирующие примеры. Разработаны имитационные схемотехнические модели системы управления с выбранной беспроводной технологией Bluetooth. Проведены экспериментальные исследования, на основании полученных данных сделаны выводы и предложены рекомендации по выбору конфигураций системы управления с целью обеспечения заданных показателей достоверности при максимальной эффективности (информационной скорости передачи).

Результаты. Получены зависимости показателей достоверности (коэффициенты битовых и блоковых ошибок) от свойств беспроводного канала передачи информации и параметров элементов системы управления. Даны рекомендации по использованию полученных результатов при выборе настроек управляющего элемента (смартфона) и управляемого элемента (коммуникационного процессора слухового аппарата). Для проведения экспериментальных исследований созданы и настроены модели системы управления в среде MathWorks MatLab Simulink.

Выводы. Проведенные в работе исследования позволяют рассчитать и обоснованно выбрать параметры устройств беспроводной системы управления для заданных показателей достоверности с учетом модели поведения ошибок в канале

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передачи и настроек сопутствующего оборудования. Это дает возможность проектировать и реализовать надежные системы управления с заданными показателями достоверности и максимальной информационной скоростью передачи.

КЛЮЧЕВЫЕ СЛОВА: информационно-управляющие системы, достоверность, коэффициент ошибок, модель, Bluetooth.

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