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Bayram Ibrahimov[1], Elshan Hashimov[1], Togrul Ismayılov[2]

[1] Azerbaijan Technical University, Baku, Azerbaijan
[2] Azerbaijan Technological University, Baku, Azerbaijan

RESEARCH AND ANALYSIS MATHEMATICAL MODEL OF THE DEMODULATOR FOR ASSESSING THE INDICATORS NOISE IMMUNITY TELECOMMUNICATION SYSTEMS

Abstract. The noise immunity indicators of the functioning telecommunication systems in the presence interference sources are analyzed based on the architectural concept of the next and future networks. **The object study** is the optimal demodulator signal receiver with matched filters. The relevance of this area research is shown. Based on a study algorithms for the operation of a demodulator with matched filters, a new approach to constructing a mathematical model for assessing the noise immunity characteristics receiving traffic messages is proposed. The developed mathematical model takes into account the demodulator synthesis algorithm, effective modulation and coding methods in the detector receiver. **The subject of the research is** a mathematical model for assessing the noise immunity indicators of the functioning multiservice telecommunication networks. Based on a study of the reliability of the transmission traffic messages, a block diagram of an optimal demodulator signal receiver with matched filters is proposed. **The purpose of the research** is to develop a new approach to create a mathematical model for assessing the characteristics communication quality and noise immunity telecommunication systems when receiving message traffic packets in a complex signal-noise environment. Based on a mathematical model for assessing the noise immunity indicators of telecommunication systems, important analytical expressions for further research were obtained. **As a result of the research**, the main conclusions of the study were obtained, which can be implemented and used in multi-service fixed and mobile communication networks to calculate the noise immunity indicators of public telecommunication systems. The rationale for the proposed main stages of the study is given, the results of analytical research and simulation modeling are presented, confirming the validity of the theoretical conclusions made.

Keywords: bit error probability; demodulator; interference immunity; unintentional interference; signal to-noise ratio; modem; bit rate; source of interference.

Introduction

The rapid development of the NGN (Next Generation Network) and FN (Future Network) concepts based on modern end-to-end digital technologies requires a global new approach for building multi-service telecommunication networks with increased noise immunity for transmitting streams of traffic packets [1–4].

Modern digital technologies to ensure the efficiency and noise immunity of future generation networks include ML (Machine Learning), SDN (Software Defined Networking), NFV (Network Functions Virtualization), IMS (Internet Protocol Multimedia Subsystem), artificial intelligence, mobile LTE (Long Term Evolution), IoT (Internet of Think), 5G - NR (New Radio), cloud and edge computing, and quantum technologies [2, 5, 6].

The noise immunity of the functioning of multiservice telecommunication networks based on end-to-end digital technologies under the influence multiple sources interference requires new approaches and mathematical models that make it possible to ensure high reliability systems for transmitting, processing and receiving traffic messages at the physical, channel and network levels [7–9]. To build multi-service type telecommunication systems with high noise immunity when using frequency and energy resources operating under the influence interference sources, the task assessing communication quality parameters is great importance. Taking this into account, the task preliminary assessment of the noise immunity indicators telecommunication communication systems under study is relevant [2, 10–12].

It should be noted that the works [1, 3, 4] analyzed methods for increasing the reliability message transmission and channel resource management. In [5, 6, 7], the optimal reception discrete signals was studied and the probability bit errors was determined. This idea is developed in works [13–16]. However, insufficient attention is paid to methods and algorithms for ensuring communication quality and reliability of message transmission in multiservice telecommunication systems.

This paper examines the solution to the problem formulated above - research and analysis of a mathematical model of a demodulator to assess the noise immunity indicators telecommunication systems when receiving traffic packet messages.

General statement of the research problem

It is worth noting that issues of ensuring noise immunity have always been important for fixed and wireless communication networks when transmitting heterogeneous traffic messages. However, these issues have become especially acute for operators and manufacturers telecommunication systems with the advent of the ability to transmit voice, data and video traffic over high-speed communication channels.

Telecommunication systems use various reception methods, physical transmission media, switching systems, and control systems. Factors and sources interference that affect the quality of data, voice and video transmission are specific to each of the multiservice networks. Therefore, new approaches to constructing a mathematical model of a demodulator are needed to assess the noise immunity indicators of receiving message packets, taking into account the features of the digital method transmitting, processing and receiving discrete signals in telecommunication systems. This means that in telecommunications systems it is necessary to implement a unified mechanism for ensuring noise immunity for the reception of traffic messages, designed for use in different types of demodulators.

One of the main problems for determining optimal algorithms for processing traffic messages in telecommunication systems is that the information required for routing about the quality of transmission of traffic messages in various directions is incomplete or inaccurate. This circumstance significantly complicates the assessment of the noise immunity parameters of transmission systems, and sometimes makes it impossible to use the existing algorithms for meeting the specified QoS (Quality of Service) and QoE (Quality of Experience) requirements in various telecommunication networks. Therefore, it is necessary to study the issues ensuring the quality of transmission and reception digital signals in multiservice telecommunication networks, which are a symbiosis PSTN, NGN and FN networks.

Based on a study of a multiservice telecommunications transmission network, traffic messages are presented in the form of a loaded graph:

$$Q = G(V,\ E)\,,\ (u,v) \in E\,, \tag{1}$$

where V –is the set of graph vertices that correspond to network nodes such as routers, switches, gateways and terminal equipment; E – many loaded edges, telecommunication network links and communication channels.

From (1) it is clear that each edge has a load measured by a certain level of noise immunity and QoS metric:

$$\beta := f(Q,\ z_1, z_2, ..., z_n, C_{an})\,, \tag{2}$$

In expression (2) is a function of the set of network indicators $(z_1, z_2, ..., z_n)$ of the noise immunity of the telecommunications network, the cost of the communication channel C_{an} and the parameter for assessing the quality of transmission and reception of traffic messages Q .

In this case, we assume that each vertex also has a state that can be determined independently or included in the state of incident network edges.

Thus, based on the new approach (1) and (2), the problems of assessing the noise immunity of the system and ensuring the quality of transmission and reception in telecommunication systems have been identified:

- lack of an adequate mathematical model of the demodulator for assessing the quality of transmission and reception of traffic messages;
- lack end-to-end mechanisms to ensure the reliability message transmission in telecommunication systems, as well as inaccuracy information about the network characteristics of demodulators.

Taking into account the above, to synthesize the operation of the demodulator and evaluate the noise immunity indicators of reception in telecommunication systems when transmitting messages, one should take into account the probability of a bit error P_{BER} (BER, Bit error rate), the impact of the interference source $N_n(t)$, the bit rate of the demodulator receiver V_b and the signal-to-noise ratio (Signal-to-Noize Rate) taking into account the energy of the bit signal E_b and the spectral power density of the interference N_0 .

Based on the composite indicators noise immunity receiving traffic messages at time tin the demodulator, the communication quality of the receiver is functionally described by the following relationship [2, 11]:

$$Q(t, k_n) = W\{\min[\,SNR(E_b, N_0), N_n(t), P_{BER}\,]\}\,, \tag{3}$$

where k_n is the transmission coefficient of communication channels. Expressions (3) describe the essence of the new approach under consideration, taking into account complex indicators of communication quality, on the basis of which a mathematical model of a demodulator is proposed for assessing the noise immunity parameters receiving traffic messages.

Taking into account existing problems, the general task of research and development methods for ensuring the quality of communication and the reliability of the transmission of traffic messages in telecommunication networks has been determined with inaccurate information about network characteristics.

Operating diagram of the demodulator under study with a matched filter

Based on the study [6, 7, 17–25], it was established that the demodulator with a matched filter under consideration is a complex communication system, including many different components of the paths of the systems for transmitting, processing and receiving traffic messages.

These compositions provide efficient traffic transmission and noise-resistant reception of digital signals [8, 9] with the required level quality of service QoS and QoE. Based on the study [6, 7], it was established that the demodulator with a matched filter under consideration is a complex communication system, including many different components of the paths of the systems for transmitting, processing and receiving traffic messages. These compositions provide efficient traffic transmission and noise-resistant reception digital signals [8, 9] with the required level of quality of service QoS and QoE.

Taking into account the formulation of the problem, Fig. 1 shows a generalized structural and functional diagram signal receivers with a random initial phase with a matched filter.

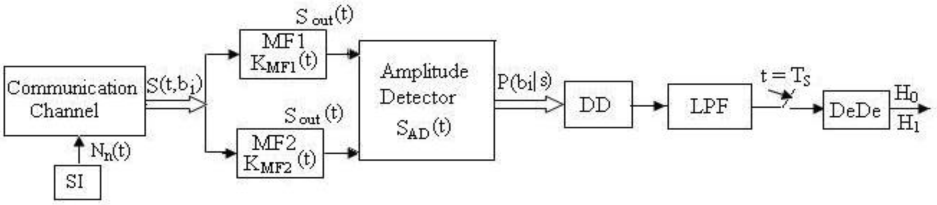

Fig. 1. Block diagram of demodulator signal receivers with a random initial phase: Sources of Interference (SI), Amplitude Detector (AD), Decoding Devices (DD), Low Pass Filter (LPF), Decisive Devices (DeDe), Matched Filters (MF)

The block diagram of the demodulator consists of three important functional blocks that provide the level of noise immunity signal receivers of telecommunication systems [2, 10]: matched filters (MF1 and MF2), $S_{out}(t)$; amplitude detector (Amplitude Detector, AD), $S_{AD}(t)$; decisive devices (Decisive Devices, DeDe), $U(t) \to \{H_0, H_1\}$. Thus, with the help of the above nodes, the problem of incoherent optimal reception of digital signals is solved. In addition, from Fig. 1 it is clear that the proposed demodulator circuit consists of:

- a decoding device (DD) for performing decoding processes using various types of correction code;

- a low-pass filter (LPF) block that cuts off high-frequency components, an electronic switch that closes at time $t = T_S$;

- DeDe solvers, which at the output circuit make a decision in favor of the hypothesis H_0 and H_1.

In this scheme, when receiving a message, we assume that in the useful signal $u(t, b_i)$ some parameter $b_i, 1 \le i \le n$ carries signals.

When digital signals of the binary type are transmitted, the problem is formulated as follows: let's say one of the signals $u_0(t)$ and $u_1(t)$ $u_1(t)$ arrives at the input of the demodulator, so that the input signal has the form [11]:

$$S(t, b_i) = b_i \cdot u_0(t) + (1 - b_i) \cdot u_1(t) + N_n(t)\,,\ 0 \le t \le T_S\,. \quad (4)$$

Expressions (4) allow you to analyze the implementation binary signals in the time interval [0, T_S] in an optimal way [21], in the sense of reliably making decisions in favor of receiving $u_0(t)$ or $u_1(t)$, which distinguishes binary signals and estimates signal parameters (b_i takes the values, $b_0 = 0$ and $b_1 = 1$).

Thus, this scheme is an integral part of the task associated with the quality of reception and processing binary signals in a message transmission system, which helps improve the reliability of the transmission traffic messages.

Demodulator studies using a matched filter

Now let's look at the problems of synthesizing a demodulator using a matched filter. To solve this problem, we choose $u(t, b_i)$ as a useful input signal as a single rectangular pulse with duration T_S and amplitude U_m:

$$u(t, b_i) = \begin{cases} U_m\ , 0 \le t \le T_S \\ 0, \quad t < 0,\ t > T_S \end{cases}. \quad (5)$$

Based on expression (5), we obtain the spectral density of the useful signal, which is expressed as follows [11, 15]:

$$S(j\omega) = U_m \int_0^{T_S} \exp(-j\omega t)\,dt = \frac{U_m}{j\omega}[1 - \exp(-j\omega T_S)]\,. \quad (6)$$

Formulas (5) and (6) determine the required type of complex transmission coefficient of the matched filter, when using the expression:

$$K_{MF}(\omega) = c\,S^*(j\omega) \cdot \exp(-j\omega T_S)\ , \quad (7)$$

where $S^*(j\omega) -$ is the complex conjugate spectrum of the useful signal.

The last expression (6) and (7) is the receiver and detector, helping to ensure optimal signal reception in the demodulator, which allows us to estimate the ratio $SNR(E_b, N_0)$ and is calculated as follows:

$$SNR(E_b, N_0) = S_{out}^2(T_S) \big/ \sigma_{SI}^2 \ge 1\,, \quad (8)$$

where $S_{out}^2(T_S) -$ is the power of the useful signal at the output of the matched filter in the demodulator at time T_S and is expressed as follows:

$$S_{out}^2(T_S) = c \int_{-\infty}^{\infty} S^2(t)\,dt = c\,E_b\,, \quad (9)$$

In formula (8), the parameter σ_{SI}^2 is the interference power and is determined by its dispersion and is equal to:

$$\sigma_{SI}^2 = \frac{1}{2\pi} \cdot c^2 \cdot \frac{N_0}{2} \int_{-\infty}^{\infty} |S(\omega)|^2 d\omega = \frac{N_0}{2} E_b \cdot c^2\,, \quad (10)$$

Thus, the resulting expressions (9) and (10) completely coincide with $SNR(E_b, N_0)$ for optimal reception of the demodulation receiver - detector.

In this case, the filtering processes again do not depend on the shape of the signal under study, which characterizes examples of the synthesis matched filters in the demodulator.

Research and assessment of the probability reception error

Conducted research shows [6, 10] that the quality of convergent networks and the reliability of its operation in telecommunication systems largely depends on the speed transmission traffic messages over communication channels, signal-code design and effective modulation methods.

In the general case, the choice of a signal-code structure for an error-resistant code in convergent communication networks is carried out based on dependencies that connect the probabilistic indicators of the quality of message transmission traffic packets with the parameters of the signal transmission channel and the correcting parameters of the error-resistant code.

This class of noise-resistant codes in a discrete message transmission system includes such block noise-resistant codes as Hamming codes, Reed-Solomon codes, Reed-Miller codes, Bose-Chowdhury-Hocquengham codes [1, 12, 14, 15]. When using block noise-resistant codes for the binomial model of a discrete transmission channel for traffic messages, the probability of erroneous reception of a code word for a group noise-resistant $N = \{n, k, d, r\}$ code with error correction can be limited from above by the inequality:

$$P_{BER} \le \sum_{j=\delta+1}^{n} n_j \cdot P_r(b_j / A_0)\,, \quad j = \overline{1, n}\,, \quad (11)$$

where $n -$ is the bit length of the code word; $\delta -$ the multiplicity of errors in the code word corrected by the noise-resistant (n,k,d,r) code under consideration, d – the minimum code distance, k – information code element, r – the number of check code elements; n_j – number of code words of weight j; PP is the probability that a decision is made in favor of a b_j codeword of weight j when a zero A_0, $j=\overline{1,n}$, was transmitted.

From formula (11) it follows that the probabilities $P_r(b_j/A_0)$ included in inequality (5) are calculated for a given probability of erroneous reception of a codeword symbol in a communication channel p_0, $j=\overline{1,n}$.

It should be noted that the p_0 value in most cases is determined for a model of a traffic message transmission channel with additive white Gaussian noise, which allows the use of analytical expressions relating the p_0 value to the signal-to-noise ratio in the communication channel:

$$p_0=\phi(E_b,n,d,\delta,N_0,k)=\phi\,[SNR(E_b,N_0)]\,, \quad (12)$$

The multiplicity corrected errors δ is related to the total number symbols n and the number information symbols in the codeword, taking into account the well-known Reed-Solomon boundary [9, 15]:

$$\sum_{j=1}^{\delta} C_{k+r}^{k} \le (2^{n-k}-1)\,, \qquad j=\overline{1,n}\,, \quad (13)$$

Based on (13) for a non-redundant code that does not have correction capabilities, $n=k$ and $\delta=0$. In addition, if the noise-resistant (n,k,d,r) – code defined by the Reed-Solomon boundary (6) exists, then it is guaranteed to provide the specified multiplicity of corrected or detected errors.

In order to estimate the probability of a bit error, a modulation scheme such as M-PSK (M-ary Phase Shift Keying) and the Reed–Solomon code were used.

Let us assume that on the transmitting side the signal is generated using an effective modulation method such as M-PSK (M-number modulation levels). In this case, the probability of correctly detecting one subcarrier for M-PSK is expressed as follows:

$$Q(E_b,M)=1-P_{BER}[SNR(E_b,N_0,M)]\,. \quad (14)$$

Using the parameters of the modulation processes, on the basis (14) to move to BER, we transform expression (8) to the following form:

$$SNR(E_b,N_0,M)=(E_b\,/\,N_0)\cdot \ell og_2 M\,, \quad (15)$$

Based on expressions (11), (13), (14) and (15), the formula for the probability bit errors in receiving traffic messages from at least one of the subcarriers will take the following form [1, 9, 10]:

$$P_{BER}=1-2^{-m^2+1}\cdot\left(2\pi\right)^{-m/2}\times$$
$$\times\left(\cdot\int_{-\infty}^{\infty}\left(\begin{matrix}1+erf\left(u/\sqrt{2}\right)^{m-1}\times\\ \times e^{\left(-\left(u-\sqrt{2E_0/N_0}\cdot \ell og_2 M\right)^2/2\right)}\end{matrix}\right)^{m} du\right)^{m}, \quad (16)$$

where $\Phi(u)$ and $erf(u)$ – is the integral of probabilities and is expressed as follows [10, 14]:

$$\Phi(u)=(2/\sqrt{\pi})\cdot\int_{0}^{u/\sqrt{2}}\exp(-y^2)\,dy=erf\,(u/\sqrt{2})\,.$$

Expression (16) is one the important indicators reception noise immunity when using $SNR(E_b,N_0,M)$ and signal-code structures of the signal used, which allow assessing the reliability of the transmission of traffic messages in the telecommunications system.

Results analysis of numerical calculations and experimental research

Based on the results obtained, the performance of a signal receiver in a demodulator in a message transmission system was modeled using the Communications Toolbox extension package - an extension of the standard Matlab environment designed for calculating and modeling multiservice communication networks [4].

Here, one of the important modules of this package is the graphical environment BERTool, which serves to plot the dependence of the BER coefficient on $SNR(E_b,k_n)$. In this case, based on the BERTool environment, the numerical values noise immunity of the demodulator were calculated and a graphical dependence $P_{BER}=F[n,SNR(E_b,k_n),V_b]$ was built using bit rates and parameters of the Reed-Solomon code using the theoretical calculation method. The essence of using this calculation method is that the analyzed graphical dependence is constructed using analytical formulas [4, 10].

As a result, the following numerical values are obtained:

$$SNR(E_b,k_n)=[2,...,24]\,dB\,,\ \ V_b \le (15,...,35)\,Mbps\,,$$

modulation scheme 2-PSK, Reed-Solomon encoding

$$N=32,\ d=4,\ k=1,...,24\,,\ R_k=3/4\,,\ n=4,....,128\,.$$

In Fig. 2 graphs of the error probability per bit are shown, obtained as a result of simulation in the BERTool environment using M-PSK modulation modes and Reed-Solomon $GF(N,k,d)$ coding,

$$P_{BER}=W[V_b,SNR(E_b,k_n),n,R_k]\,.$$

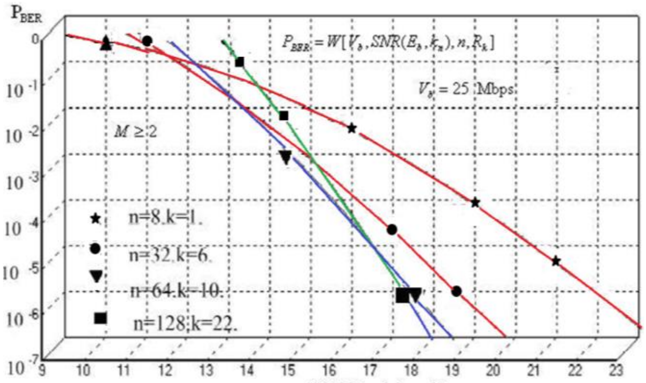

Fig. 2. Graphical dependence of the bit error probability on the signal-to-noise ratio at a given bit rate

Analysis of the graphical dependence (Fig. 2.) shows that an increase in $SNR(E_b, k_n)$ leads to a minimization of the probability P_{BER} that meets the requirements of communication quality and the level of noise immunity of the signal receiver in the demodulator. Its noticeable change begins with the values

$$SNR(E_b, k_n) \geq (14,...,18) \text{ dB}$$

at a given bit rate $V_b = 25$ Mbps.

In addition, the graphical dependencies shown in Fig. 2 clearly demonstrate an improvement in the level of bit error probability with increasing modulation $M > 2$ and coding coefficient $R_k = 3/4$. .

Conclusions

As a result of a study of the noise immunity multiservice telecommunication systems, a new approach to constructing a mathematical model for assessing the reliability of the transmission traffic messages under the influence various sources interference was proposed.

The proposed model takes into account the energy performance of the demodulator signal receiver, the type modulation keying, the coding ratio and bit rates in telecommunication systems.

The analysis allows us to find the required signal-to-noise ratio in communication systems with matched filters depending on the specified bit error probability. In order to analyze the mathematical model, a numerical analysis was carried out, a graphical dependence was constructed $P_{BER} = F[n, SNR(E_b, k_n), V_b]$ and it has been established that due to an increase in the signal-to-noise ratio in telecommunications systems, the probability of bit errors decreases for a given energy efficiency and modulation rate of the system.

Based on a study of the model for receiving traffic messages, the results obtained allow us to estimate the probabilities bit errors taking into account the signal-to-interference ratio, modulation scheme and coding speed multiservice telecommunication systems when providing multimedia services.

References

1. Proakis J.G. (2000), *Digital communications*, Edition 4th, Mc Graw-Hill Book Company, 936 p., available at: https://www.amazon.com/Digital-Communications-John-Proakis/dp/0072321113
2. Ibrahimov, B., Hashimov, E., Talibov, A., and Hasanov, A. (2022), “Research and analysis indicators fiber-optic communication lines using spectral technologies”, *Advanced information systems*, vol. 6, no 1, pp. 61–64, doi: https://doi.org/10.20998/2522-9052.2022.1.10
3. Bianco, B., Fajordo J.O., Cianonoulakis I., Kafetzakis, E., Peng, S., Pérez-Romero, J., Trajkovska, I., Khodashenas, P.S., Goratti, L., Paolino, M., Sfakianakis, E., Liberal, F. and Xilouris, G. (2017), “Technology pillars in the architecture of future 5G mobile networks: NFV, MEC and SDN”, *Computer Standarts & Interfaces*, vol. 54, part 4, pp. 216–228, doi: https://doi.org/10.1016/j.csi.2016.12.007
4. Shelukhin, O.I. (2018), *Modeling of information systems*, Textbook for universities. Hotline - Telecom, 516 p., available at: https://i.twirpx.link/file/754374/
5. Blahut. R.E. (2012), “Algebraic Codes for Data Transmission”, Cambridge University Press, 498 p., available at: https://catdir.loc.gov/catdir/samples/cam033/2001043802.pdf
6. Ibrahimov, B.G., Hasanov, A.H. and Hashimov, E.Q. (2024), “Research and analysis of efficiency indicators of critical infrastructures in the communication system”, *Advanced Information Systems*, vol. 8, no. 2, pp. 58–64, doi: https://doi.org/10.20998/2522-9052.2024.2.07
7. Kuchuk, N., Mozhaiev, O., Semenov, S., Haichenko, A., Kuchuk, H., Tiulieniev, S., Mozhaiev, M., Davydov, V., Brusakova, O. and Gnusov, Y. (2023), “Devising a method for balancing the load on a territorially distributed foggy environment”, *Eastern-European Journal of Enterprise Technologies*, vol. 1(4 (121), pp. 48–55, doi: https://doi.org/10.15587/1729-4061.2023.274177
8. Ismayılov, T. (2024), “Research of Future Generation Multiservice Telecommunication Networks Based on SDN Technology”, *Engineering Headway*, vol. 7, pp. 135–140, doi: https://doi.org/10.4028/p-gvd2zo
9. Gitlin, R.D., Hayes, J.F. and Weinstein, S.B. (1992), “Theoretical Foundations of Digital Communications”, *Data Communications Principles*, Springer, Boston, MA, doi: https://doi.org/10.1007/978-1-4615-3292-7_2
10. Ibrahimov, B. (2023), “Investigation of Noise Immunity telecommunication systems according to the criterion energy efficiency”, *Transport and Telecommunication*, vol. 24, is. 4, 2023. pp. 375–384, doi: https://doi.org/10.2478/TTJ-2023-0029
11. Kovalenko, A. and Kuchuk, H. (2022), “Methods to Manage Data in Self-healing Systems”, *Studies in Systems, Decision and Control*, vol. 425, pp. 113–171, doi: https://doi.org/10.1007/978-3-030-96546-4_3
12. Valiyev, V.M., Ibrahimov, B. G. and Alieva, A. A. (2020), “About one resource control task and optimization throughput in multiservice telecommunication networks”, *T-Comm*, vol. 14, no.6, pp. 48–52, doi: https://doi.org/10.36724/2072-8735-2020-14-6-48-52
13. Stallings, W. (2014), *Data and Computer Communications*, Int. publ. by pearson ed., 10-th Ed., New York, 907 p., available at: https://api.pageplace.de/preview/DT0400.9781292014395_A24576961/preview-9781292014395_A24576961.pdf
14. Pushkina, E.O. (2013), “BER Performance of OFDM-QAM over AWGN channel”, *Infocommunication technologies*, vol. 12, no. 2, pp. 59–62, available at: https://journals.eco-vector.com/2073-3909/article/view/55917
15. İbrahimov, B. and Ismaylov, T. (2023), “Analysis of the model hierarchical state management telecommunications systems using the logistic approach”, *2nd International Conference on Problems of Logistics, Management and Operation in the East-West Transport Corridor* (PLMO 2023), 24-26 May 2023, Baku, pp. 225–229, doi: https://doi.org/10.54381/plmo2023.37
16. Kuchuk, N., Mozhaiev, O., Semenov, S., Haichenko, A., Kuchuk, H., Tiulieniev, S., Mozhaiev, M., Davydov, V., Brusakova, O. and Gnusov, Y. (2023), “Devising a method for balancing the load on a territorially distributed foggy environment”, *Eastern-European Journal of Enterprise Technologies*, vol. 1(4 (121), pp. 48–55, doi: https://doi.org/10.15587/1729-4061.2023.274177
17. Ibrhimov, B. G., Namazov, M., Humbatov R. T., Guliyev, M.N. and Ibrahimov, B. G. (2022), “Investigation and analysis of immunity characteristics receiving discrete messages”, *Proceedings of the 8-th International Conference on Control and Optimization with Industrial Applications*, vol. 2, pp. 237–239, available at: https://www.researchgate.net/publication/366465255_investigation_and_analysis_of_immunity_characteristics_receiving_discrete_messages

18. Petrovska, I., Kuchuk, H. and Mozhaiev, M. (2022), Features of the distribution of computing resources in cloud systems, 2022 IEEE 4th KhPI Week on Advanced Technology, KhPI Week 2022 - Conference Proceedings, 03-07 October 2022, Code 183771, doi: https://doi.org/10.1109/KhPIWeek57572.2022.9916459
19. Hasanov, A. H., Hashimov, E. and Zulfugarov, B. (2023), "Comparative analysis of the efficiency of various energy storages", *Advanced Information Systems*, vol. 7, no. 3, pp. 74–80, doi: https://doi.org/10.20998/2522-9052.2023.3.11
20. Ibrahimov B. G., Hashimov E. G., Talibov A. M. and Hasanov, A. H. (2022), "Research and analysis indicators fiber-optic communication lines using spectral technologies", *Advanced Information Systems*, vol. 6, no. 1, pp. 61–64, doi: https://doi.org/10.20998/2522-9052.2022.1.10.
21. Kovalenko, A., Kuchuk, H., Radchenko, V. and Poroshenko, A. (2020), "Predicting of Data Center Cluster Traffic", *2020 IEEE International Conference on Problems of Infocommunications Science and Technology*, PIC S and T 2020 – Proceedings, pp. 437–441, 9468006, doi: https://doi.org/10.1109/PICST51311.2020.9468006
22. Hasanov, A.H. and Hashimov, E.G. (2022), "Analysis of the effectivness of communication and automated management systems", *Current directions of development of information and communication technologies and control tools*, Proc. of 12-th Int. STC, vol. 1: sect. 1–4, pp. 32–33, available at: https://nure.ua/wp-content/uploads/conf-2022-akov/telecom_2022_volume_1.pdf
23. Attar, H., Khosravi, M.R., Igorovich, S.S., Georgievan, K.N., and Alhihi, M. (2020), "Review and performance evaluation of FIFO, PQ, CQ, FQ, and WFQ algorithms in multimedia wireless sensor networks", *International Journal of Distributed Sensor Networks*, 16(6), June 2020, doi: https://doi.org/10.1177/1550147720913233
24. Ibrahimov, B., Hashimov, E.Q., Hasanov, A.H. and Mammadov, T.H. (2020), "Research throughput multiservice telecommunication networks *Current directions of development of information and communication technologies and control tools*, vol. 1: sect. 1–2, p. 30, available at: https://repository.kpi.kharkov.ua/items/7480fca1-0baf-421c-b4cd-37c932d26a17
25. Ganimat I. B., Qiyas H. E. (2021), "Analysis and Selection Performance Indicators Multiservice Communication Networks Based on the Concept NGN and FN", *Computer and information systems and technologies*, Proc. of 5-th Int. STC, pp. 96–98, doi: https://doi.org/10.30837/csitic52021232904

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ВІДОМОСТІ ПРО АВТОРІВ / ABOUT THE AUTHORS

Ібрагімов Байрам Ганімат – доктор технічних наук, професор, завідувач кафедри радіоелектроніки та аерокосмічних систем, Азербайджанський технічний університет, Баку, Азербайджан;
Bayram Ibrahimov – Doctor of technical sciences, professor, Head of the Department of Radioelectronics and Aerospace Systems, Azerbaijan Technical University, Baku, Azerbaijan;
e-mail: i.bayram@gmail.com; ORCID Author ID: https://orcid.org/0000-0002-5364-1181;
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId=37028384100.

Гашимов Ельшан Гіяс – доктор національної безпеки та військових наук, професор, професор Азербайджанського технічного університету, Баку, Азербайджан;
Elshan Hashimov – Doctor in national security and military sciences, professor, professor of Azerbaijan Technical University, Baku, Azerbaijan;
e-mail: hasimovel@gmail.com; ORCID Author ID: http://orcid.org/0000-0001-8783-1277;
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId=57195631270.

Ісмаїлов Тогрул – старший викладач кафедри «Комп'ютерна інженерія та телекомунікації» Азербайджанського технологічного університету, Баку, Азербайджан;
Togrul Ismayılov – senior lecturer of the department «Computer engineering and telecommunications» Azerbaijan Technological University, Baku, Azerbaijan;
e-mail: ismayilovtogrul26@gmail.com; ORCID Author ID: http://orcid.org/0000-0002-2440-6385;
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId=56175343700&origin=recordpage.

Дослідження та аналіз математичної моделі демодулятора для оцінки показників завадостійкості телекомунікаційних систем

Б. Г. Ібрагімов, Е. Г. Гашимов, Т. Ісмаїлов

Анотація. Проаналізовано показники завадостійкості функціонуючих телекомунікаційних систем за наявності джерел завад на основі архітектурної концепції майбутніх і перспективних мереж. **Об'єктом дослідження** є оптимальний приймач сигналу демодулятора з узгодженими фільтрами. Показано **актуальність дослідження** цього напрямку. На основі дослідження алгоритмів роботи демодулятора з узгодженими фільтрами запропоновано новий підхід до побудови математичної моделі для оцінки характеристик завадостійкості прийому повідомлень трафіку. Розроблена математична модель враховує алгоритм синтезу демодулятора, ефективні методи модуляції та кодування в приймачі детектора. **Предметом дослідження** є математична модель для оцінки показників завадозахищеності функціонуючих мультисервісних телекомунікаційних мереж. На основі дослідження надійності передачі трафіку повідомлень запропоновано структурну схему оптимального приймача сигналу демодулятора з узгодженими фільтрами. **Метою дослідження** є розробка нового підходу до створення математичної моделі для оцінки характеристик якості зв'язку та завадостійкості телекомунікаційних систем при прийомі пакетів трафіку повідомлень у складному сигнально-шумовому середовищі. На основі математичної моделі оцінки показників завадозахищеності телекомунікаційних систем отримано важливі аналітичні вирази для подальших досліджень. **В результаті проведених досліджень** отримано основні висновки дослідження, які можуть бути реалізовані та використані в мультисервісних мережах фіксованого та мобільного зв'язку для розрахунку показників завадостійкості телекомунікаційних систем загального користування. Дано обґрунтування запропонованих основних етапів дослідження, наведено результати аналітичних досліджень та імітаційного моделювання, що підтверджують обґрунтованість зроблених теоретичних висновків.

Ключові слова: ймовірність бітової помилки; демодулятор; перешкодостійкість; ненавмисна перешкода; відношення сигнал/шум; модем; бітова швидкість; джерело перешкод.