UDC 004.9 **doi:** https://doi.org/10.20998/2522-9052.2026.1.08

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RESEARCH OF THE EFFICIENCY MULTISERVICE NETWORKS USING MIMO TECHNOLOGY

Abstract. The presented research relates to the field solving the problem of increasing the efficiency transmission and noise immunity reception discrete messages used for the exchange traffic flows between communication systems and radio engineering complexes of entities. The **object of the study** is hardware and software systems and radio channels multiservice communication networks using multi-antenna technologies. Multi-antenna systems in multiservice communication networks allow increasing the capacity radio channels by transmitting a signal using several antennas on the transmitter side and several antennas on the receiver side. It is worth noting that the capacity of the radio channel is still limited due to the use of a power distribution algorithm. The efficiency and noise immunity indicators of the functioning of communication systems in the presence of interference sources are analyzed based on the architectural concept of the following and future public communication networks. The **subject area is the problems** applying a new approach to multiservice communication networks for optimal use resources end-to-end digital technology and modern wireless cellular communication technologies. The **purpose of the study** is to develop a new approach to constructing a method for calculating the evaluation of the characteristics of transmission efficiency and noise immunity when receiving traffic flow messages in a complex signal-noise environment. Based on the methods for calculating the evaluation of the performance indicators of multiservice communication networks, important analytical expressions for further research were obtained. As a result of the study, **the main conclusions of the study** were obtained, which can be implemented and used in multiservice stationary and wireless cellular networks to calculate the transmission efficiency and reception noise immunity indicators. The technical and economic effect for multiservice networks and radio engineering complexes consists in increasing their throughput by attracting funds and resources of modern cellular mobile network technologies. The substantiation proposed main stages of the study is provided, the results of the analytical study and simulation modeling are presented, confirming the validity of the theoretical conclusions made.

Keywords: multiservice networks; efficiency; fixed communication networks; throughput; MIMO; power distribution; cellular mobile communication; networks.

Introduction

Construction and development of multiservice public communication networks based on the architectural concept of the following NGN (Next Generation Network) [1] and future FN (Future Network) networks [2], given the intensive growth of the volume transmitted heterogeneous traffic, requires the creation of a new approach to the construction highly efficient communication systems using modern multi-antenna technologies, ensuring high transmission efficiency and noise immunity discrete signal reception [3].

The studied characteristics efficiency and noise immunity multiservice public communication networks under the influence of various interferences, including general fading, are complex characteristics of the quality of functioning communication systems when using end-to-end digital technologies and modern wireless cellular communication technologies [4. 5].

Modern technologies for future generation networks (ITU-T, Y.3000) include MIMO (Multiple Input Multiple Output) [6], SDN (Software Defined Networking) [7], NFV (Network Functions Virtualization) [8], IMS (Internet Protocol Multimedia Subsystem) [9], WDM&DWDM (Wavelength Division Multiplexing & Dense WDM) [10], OFDM (Orthogonal Frequency-Division Multiplexing) [11], 4G-LTE (Long Term Evolution), IoT (Internet of Think) [12], 5G–NR-U (New Radio-Unilence) and AI (Artificial Intelligence) [13].

The analyzed advanced and digital technologies for building communication systems with increased efficiency and noise immunity, a special place is occupied by MIMO technologies, where algorithms are implemented – multiple input and multiple output [14, 15].

It is known that MIMO technologies are a method of organizing data transmission in wireless cellular networks, in which several antennas are used simultaneously on both the transmitting and receiving sides [16, 17]. With the help of MIMO technology, tasks such as increasing the transmission speed mixed-type traffic [18], increasing the reliability communication networks [19] and improving the spectral efficiency communication systems are implemented [20].

Depending on the place of use of MIMO technology, important varieties are widely used: SU-MIMO (Single User MIMO) – MIMO for one device [21], MU-MIMO (Multi User MIMO) – transmission of different streams of traffic packets simultaneously to different devices, where it is actively used in the Wi-Fi 5, Wi-Fi 6 system [22], as well as Massive MIMO - a huge number of antennas at the base station, especially in the 4G-Voice LTE and 5G-New Radio system [23].

In this work [4], algorithms and methods for increasing the efficiency of transmission and noise immunity of reception information traffic flows using MIMO are analyzed and assessments of the indicators information efficiency and throughput of communication systems are carried out. The analysis carried out in this work shows [13] that the problem of studying and evaluating the performance indicators of multiservice telecommunication networks based on MIMO technology with the required parameters has not been solved at a sufficient level.

The solution to the above formulated problem of research and analysis of the characteristics of the efficiency and noise immunity functioning multiservice networks and radio engineering complexes using modern wireless cellular communication technologies MIMO is considered.

General statement of the research problem

The conducted research and analysis have shown that the current state of modern multiservice networks and radio engineering complexes based on modern technologies does not fully satisfy the requirements of the ITU-T and ITU-R recommendations for ensuring the quality of operation digital signal transmission systems in terms of transmission efficiency and noise immunity of discrete signal reception [24–26].

To solve the proposed problem, a comprehensive approach is required in studying the main characteristics of the communication channel capacity, the signal-to-noise ratio (SNR, Signal to-Noise to Rate) and the frequency efficiency communication systems and radio engineering complexes using MIMO technology [27, 28].

At the same time, an important task arises - the development of a new approach to creating methods for calculating the efficiency and noise immunity multiservice public communication networks, which will most accurately reflect telecommunication processes.

To solve the problem under consideration, a calculation method is proposed for assessing the performance of communication systems and was selected as the target function of the constituent technical components of the vector multiservice networks using MIMO technology, which is functionally described by the following relationship:

$$E(\lambda, E_b) = W\left\{ \underset{(\lambda_i, E_b)}{Argmax}\, Q_K\left[H\left(\lambda_i, E_b\right)\right]\right\}, \quad i = \overline{1,k}\,. \quad (1)$$

under the following restrictions

$$\begin{aligned} &\eta_{SE}\left(V_b\right) \ge \eta_{SE.all.}\left(V_b\right);\\ &C_{\max}\left(\lambda_i, V_b\right) \ge C_{\max.all.}\left(\lambda_i, V_b\right);\\ &SNR\left(E_b, N_0\right) \ge SNR_{all.}\left(E_b, N_0\right), \end{aligned} \quad (2)$$

where $C_{\max}(\lambda_i, V_b)$ – the maximum value of the communication channel capacity taking into account the bit rate of signal transmission V_b and the intensity of the incoming traffic λ_i flow using MIMO technology and is equal to:

$$\begin{aligned} &C_{\max}\left(\lambda_i, V_b\right) =\\ &= \Delta F_S \cdot \ell og_2\left[1 + SNR\left(E_b, N_0\right)\right], i = \overline{1,k}; \end{aligned} \quad (3)$$

$\eta_{FE}(\Delta F)$ – frequency efficiency of communication systems and radio engineering complexes using MIMO technology taking into account the frequency band, ΔF;

$Q\left[H\left(\lambda_i, E_b\right)\right]$ – criteria telecommunication processes occurring in multiservice communication networks during transmission and reception of traffic flows, taking into account the indicators λ_i and E_b, which are determined by the functional dependence of both the transmission efficiency function and the noise immunity of reception;

$SNR(E_b, N_0)$ – Signal to Noise to Rate (SNR) at the output of the communication channel, taking into account the energy of the bit signal E_b and the spectral power density of the interference N_0, which characterize the complex indicators of the communication system and radio engineering complexes, and is also a metric of the quality of data transmission in the radio channel is the ratio of the average signal power to the average noise power and can be expressed as [4]:

$$SNR(E_b, N_0) = [P_m / N_0], \text{ dB}. \quad (4)$$

Expressions (4), taking into account the noise covariance matrix and the power of the signal transmitted by the communication system, where it is limited by the value P_m, will take the following form:

$$\begin{aligned} SNR\left(E_b, N_0\right) &= I_{MR}\left[2E_b / N_0\right]_{dBm} =\\ &= E_b[dBm] - N_0[dBm], \end{aligned} \quad (5)$$

where I_{MR} – identity matrix of dimension $M_R x M_R$ [4].

Expressions (1) – (5) define the essence of the proposed new approach, with the help of which the methods for calculating the transmission efficiency and noise immunity signal reception based on MIMO technology are constructed, taking into account the communication quality indicators. In addition, the last formulas characterize the essence of the approach for analyzing the problem of managing telecommunication processes occurring in the communication system under study under the influence many heterogeneous sources interference, including general fading.

Scheme of functioning of the studied systems message transmission using multi-antenna MIMO technologies

For the purpose of system-technical analysis of characteristics transmission efficiency and noise immunity of reception, a structural scheme of functioning of the studied systems of message transmission based on multi-antenna MIMO technologies [26] is proposed, which is shown in Fig. 1.

In the systems of transmission of the message based on MIMO technologies shown in Fig. 1 consists of the following important blocks: the system of transmission and reception of data using MIMO, the MIMO transmitter and the MIMO receiver, and multi-antenna radiotechnical complexes. In addition, the MIMO system, like any data transmission system, is generally divided into three components: the transmitter, the communication channel (channel matrix **H**) and the receiver.

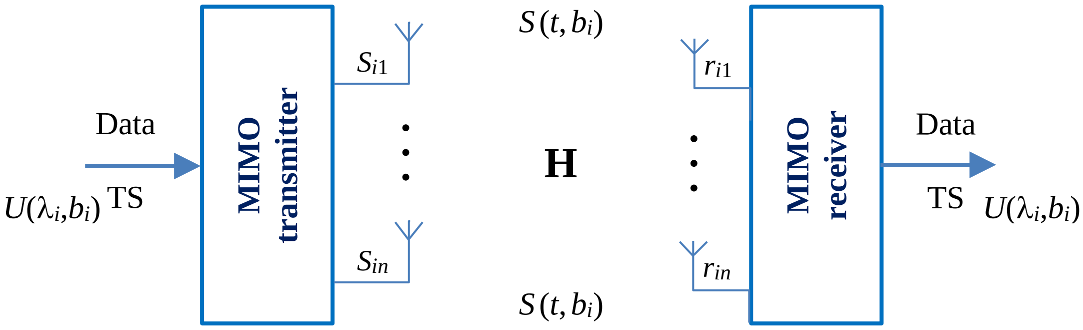

Fig. 1. Structural diagram of message transmission systems based on MIMO technologies

To describe the algorithms of MIMO technology operation, this diagram proposes the principle of operation and functioning of the MIMO configuration in a multiservice network using a MIMO transmitter and receiver - the system.

In these MIMO systems, multiple antennas are used in the transmitter and receiver to create different data transmission paths, the so-called traffic subflows.

The channel capacity in MIMO systems in a single frequency band ΔF without errors is expressed as [2]:

$$G_{Em}\left(P_S,\Delta F\right)=\left(F_2-F_1\right)\cdot \ell og_2\left(1+\left(P_S/N_m\right)\cdot \sigma_0^2\right), \quad (6)$$

where σ_0^2 – noise spectral power; P_S – transmitted signal power; N_m – number of transmitting antennas ($N_m \in M_R \in \mathbf{H}$).

Expressions (6) characterize the capacity of the MIMO system and are limited information and network resources, in these circumstances scientists came up with the idea using multiantenna technologies.

Analysis transmission efficiency and noise immunity indicators for reception discrete signals

Now consider a multi-channel MIMO system, in which several subscriber user stations with M_R receiving antennas each simultaneously operate in a certain frequency band ΔF with one base station with transmitting antennas M_T.

Based on the conducted research, it was established [1] that one of the main and important indicators of the quality of operation of multiservice networks is their transmission efficiency and noise immunity reception of discrete signals in communication systems using MIMO technology. It should be noted that, given the formulation of the problem, the indicators of the quality of operation of multiservice networks as a function of transmission efficiency and noise immunity reception are determined by the following functional dependence:

$$Q_K\left[H\left(\lambda_i,E_b\right)\right]= \\ =F[\left[B_{EF}\left(\lambda_i,V_b\right),D\left(E_b,N_0\right)\right],\ i=\overline{1,k}, \quad (7)$$

where $B_{EF}(\lambda_i,V_b)$ – criteria that take into account the performance indicators of communication systems, taking into account the intensity of incoming traffic λ_i and the bit rate message transmission V_b and are characteristics of network paths and hardware and software complexes and are expressed by the following functional relationship:

$$B_{EF}\left(\lambda_i,V_b\right)= \\ =\left[\eta_{IE}\left(\lambda_i,V_b\right),\eta_{FE}\left(V_b\right),\eta_{EE}\left(P_S\right)\right],\ i=\overline{1,k}, \quad (8)$$

where $\eta_{IE}(\lambda_i,V_b)$, $\eta_{EE}(P_S)$ – information and energy efficiency of communication systems and radio engineering complexes using MIMO technology, taking into account the bit rate V_b of transmission and signal power P_S, respectively; $D(E_b,N_0)$ – criteria that take into account the indicators of noise immunity reception taking into account the energy E_b of the bit signal and the spectral density N_0 of the interference power, which characterize the complex indicators of the quality of communication when using MIMO technology and are multi-channel characteristics of the system receiver.

The quality of communication when using MIMO technology is expressed by the following functional dependencies:

$$D\left(E_b,N_0\right)=F\left[P_{BER},SNR\left(E_b,N_0\right),V_b\right],, \quad (9)$$

where P_{BER} – bit error probabilities of MIMO signal reception.

First, let's consider a model with data transmission via a downlink - from the station to the subscriber. In this case, an important characteristic of the multiservice network and radiotechnical complex is the signal power at the receiving end, which depends on the user's location. In this case, the signal power received by the *i*-th subscriber is determined by the following expression [21]:

$$U(\lambda_i,b_i)=H_i\cdot S(t,b_i)+n_i(t),\quad i=\overline{1,k}, \quad (10)$$

where $n_i(t)$ – complex Gaussian random vector dimension $M_R \times 1$ independent identically distributed noise of equal power N, *dBm*, on each branch of the distribution.

Results of the analysis numerical calculation and experimental study

In the case under study, we assume that the distributed noises are of the same power and are described by the probability density by the normal law as follows [2]:

$$f(x,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} \cdot \exp\left(-\frac{x^2}{2\sigma^2}\right). \quad (11)$$

Based on formula (6), each component of the vector $n_i(t)$ has a complex normal distribution with zero mathematical expectation and variance σ^2 equal to $\sigma^2 = 0.5N_0$. In this case, the noise covariance matrix and variance are equal to:

$$I_{M\,cov.} = (N_0/2) \cdot I_{MR};$$
$$\sigma^2 = 0.5N_0. \quad (12)$$

Before proceeding directly to the analysis of the numerical calculation of the communication system using MIMO technology, we will present some formulas known from information theory, which will be used in further experimental research [18].

Considering the features Fig. 1 and the communication channels - the channel matrix on the receiving side, in the case of a single-user MIMO system, the probability of a bit error per carrier is calculated using formula [16]:

$$P_{BER} = 1-(1-P_{bc})^2,$$
$$P_{bc} = 2\left[1-M_a^{-0.5}\right] \cdot Q\left[\sqrt{\frac{3}{M_a-1} \cdot \frac{E_b}{N_0}}\right], \quad (13)$$

where M_a – modulation scheme alphabet (M-ary Quadrate Amplitude Modulation, M-ary Phase Shift Keying); $Q(*)$ – complementary gaussian error function [20].

Formula (13) is the theoretical value of the bit error probability when using different modulation schemes such as 4-QAM and 4-PSK.

Based on the obtained results, calculations were carried out using modeling in the Matlab environment (R 2019b, 9.7; 64 bit) of the signal receiver indicators in the MIMO message transmission system using the Communications Toolbox extension package, designed for calculating and modeling multiservice communication networks [20].

In Fig. 2, the dependence of the bit error probability on the signal-to-noise ratio was presented based on numerical values, $P_{BER} = W\left[SNR\left(E_b, N_0\right), V_b\right]$.

Analysis of the graphical dependence shows that an increase leads to a decrease in the probability of bit errors that meets the requirements, communication quality and the level of noise immunity of reception. In this case, the noticeable change in the MIMO scheme starts with the values $SNR(E_b, N_0) \geq (7.0,...,9.5)$ dB at a given bit rate $V_b = 70\,M\,bps$ when using $M_R = 4x4$ and $M_R = 8x8$.

Thus, the conducted studies show that one of the main advantages of MIMO technologies, operating in multi-antenna mode in multi-service networks, is the ability to transmit message streams to several users simultaneously due to the formation of several parallel data streams, which allows to significantly increase the transmission efficiency and noise immunity of the reception communication system.

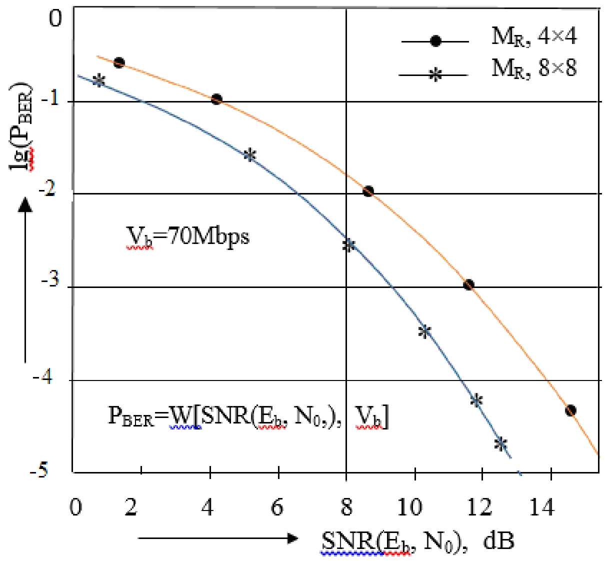

Fig. 2. Graphic dependence of the probability of bit errors on the signal-to-noise ratio at a given transmission rate

Conclusions

As a result of the study, a new approach to the construction of a method for calculating the transmission efficiency and noise immunity of reception indicators is proposed, taking into account the noise covariance matrix and the power of the signal transmitted by the communication system using MIMO technology.

Based on the study of the calculation method, formulas for estimating the minimum required signal-to-noise ratio, the value throughput depending on the signal processing method in the MIMO scheme were obtained. In addition, analytical expressions were obtained for calculating the probability of bit errors in signal reception at a given bit rate of transmission.

A structural diagram of a communication system based on MIMO technologies is proposed and, based on the results obtained, calculations were carried out using modeling in the Matlab environment and a graphical dependence of the probability bit errors on the signal-to-noise ratio at a given transmission rate is given.

The analysis shows that the increase leads to a decrease $SNR(E_b, N_0)$ in the probability of bit errors, meeting the requirements communication quality and the level noise immunity reception in multi-service communication networks and in radio engineering complexes.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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Received (Надійшла) 30.09.2025
Accepted for publication (Прийнята до друку) 21.01.2026

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Дослідження ефективності мультисервісних мереж з використанням технології MIMO

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Анотація. Представлене дослідження відноситься до завдання підвищення ефективності передачі та завадостійкості прийому дискретних повідомлень, що використовуються для обміну потоками трафіку між системами зв'язку та радіотехнічними комплексами. об'єкт дослідження апаратно-програмні системи та радіоканали мультисервісних мереж зв'язку, в яких застосовуються багатоантенні технології. багатоантенні системи в мультисервісних мережах дозволяють збільшувати пропускну спроможність радіоканалів за рахунок передачі сигналу декількома антена на стороні передавача та прийому кількома антена на стороні приймача. Слід зазначити, що пропускна здатність радіоканалу залишається обмеженою через алгоритм розподілу потужності, що використовується. показники ефективності та завадостійкості функціонування систем зв'язку за наявності джерел перешкод аналізуються в рамках архітектурної концепції поточних та перспективних суспільних мереж зв'язку. предметна область включає проблеми застосування нового підходу в мультисервісних мережах для оптимального використання ресурсів наскрізних цифрових технологій та сучасних бездротових стільникових систем. мета дослідження - розробка нового підходу до побудови методу розрахунку та оцінки характеристик ефективності передачі та завадостійкості прийому повідомлень потоків трафіку в складній сигнально-шумової обстановці. на основі розроблених методів розрахунку та оцінки показників функціонування мультисервісних мереж отримано важливі аналітичні висловлювання для подальших досліджень. в результаті роботи сформульовані основні висновки, придатні для практичної реалізації в стаціонарних мультисервісних та бездротових стільникових мережах для розрахунку показників ефективності передачі та завадостійкості прийому. техніко-економічний ефект для мультисервісних мереж та радіотехнічних комплексів полягає у збільшенні їх пропускної спроможності за рахунок залучення коштів та ресурсів технологій сучасних стільникових мобільних мереж. обґрунтовано запропоновані основні етапи дослідження, наведено результати аналітичного аналізу та імітаційного моделювання, що підтверджують справедливість зроблених теоретичних висновків.

Ключові слова: мультисервісні мережі; ефективність; фіксовані мережі зв'язку; пропускна спроможність; MIMO; розподіл потужності; стільниковий мобільний зв'язок; мережі.