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Computer Modeling of a Wireless Wi-Fi Channel Considering Packet Lost in Dams for the Telemetry Control of Bridge Structures and Construction Buildings

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Abstract. *This article is devoted to computer modeling of a wireless Wi-Fi channel, taking into account packet loss in a distributed autonomous wireless monitoring system for the technical condition of bridges and buildings. The rationale for the choice of software for computer simulation of a wireless Wi-Fi channel in a distributed system is given. The results of our experiments demonstrate a significant improvement in the accuracy of the study using new methods. The discovered patterns can become key when creating a computer model of a wireless system that provides high data transfer rates with minimal packet loss. The obtained results emphasize the importance of using modern methods in the field of wireless technologies to improve the efficiency of monitoring systems. Based on experiments, it can be concluded that new methods significantly increase the accuracy of the collected data in wireless monitoring systems. Thus, this work will contribute to the development of wireless monitoring methods and the creation of more accurate computer models capable of providing stable data transmission under real network loads.*

Keywords: *wireless Wi-Fi system, computer model, wireless devices, network mode, channel settings, authentication, information encryption, identification of optimal parameters, computer networks.*

Introduction

With advancements in communication systems and intelligent technologies, alongside improvements in analog and digital electronics and measurement devices, new opportunities arise for creating continuous remote monitoring systems for infrastructure, such as bridges and buildings. A key factor for societal progress today is the widespread availability, security, quality, and accessibility of high-speed networks, with the development of information and communication infrastructure being crucial to economic progress in the Republic of Kazakhstan. This work will cover:

- Key parameters of a wireless Wi-Fi system for selecting optimal computer model data;
- Selection of software for simulating wireless channels in distributed systems;
- Development and testing of a Wi-Fi channel model in MATLAB/Simulink, addressing packet loss.

Research has addressed various aspects, such as system security and functionality [1-3], improvements in communication infrastructure for monitoring and data management [4-7], and advanced simulation tools for optimizing wireless networks [8-10]. Ongoing studies contribute to furthering distributed monitoring systems, ensuring reliability and precision in critical infrastructure management [11-13].

Methods of the research

In the process of conducting dissertation research, proven methods for processing and

analyzing measurement information, methods for remote identification of measurements, methods for creating software and hardware systems based on microcontrollers and computer modeling methods were used. In addition, laboratory tests were conducted to monitor the technical condition of building structures during their operation.

Purpose

The purpose of this work is to develop a distributed autonomous wireless Wi-Fi system for remote monitoring of technical condition with high data transfer rates, long range and support for multiple access with carrier listening and collision avoidance. Various programs were considered during the research, but the main focus was on MATLAB and Simulink. The choice of these programs is due to their high level of functionality and the ability to effectively solve the problems that our experiments face. Thus, the purpose of the work is to identify and select the optimal software tools that ensure the successful implementation of tasks in the field of programming and modeling.

General characteristics of the key parameters of a wireless Wi-Fi system for selecting optimal computer model data

In order for wireless devices to exchange information over a wireless network, they first need to connect (associate) with the nearest available access point or directly with a wireless router. The most important step in the wireless connection process is to discover the Wireless Local Area Network (WLAN) and then connect to it. Wireless access point detection. User authentication at the connected access point. Association (connection) with a connected access point.

The original 802.11 standard introduces two types of authentication: Open System authentication – any wireless client should be easily connected and used only in situations where security does not matter, for example, in cases where free Internet access is provided, for example in cafes, hotels and remote areas. Public Key Authentication – provides authentication and encryption mechanisms for information that is transmitted between wireless clients and an access point or wireless router. However, for a successful and final connection, the password must be agreed upon between the parties beforehand [1]. There are four methods of authentication with a shared key, as described in Table. Until the availability of WPA3 devices becomes widespread, 802.11 wireless networks use the WPA2 standard.

Direct Sequence Spectrum (DSSS) is a modulation technique designed to propagate a signal over a wider frequency band. Spectrum expansion techniques were developed during the war to make it more difficult for enemies to intercept or jam a communication signal. This is achieved by spreading the signal over a wider frequency, which effectively hides the noticeable peak of the signal, as shown in the figure. DSSS is used by 802.11b devices to avoid interference from other devices using the same 2.4GHz frequency [3].

The Frequency Hopping Propagation Spectrum (FHSS) is based on extended spectrum communication techniques. This process of simultaneous signal transfer between different channels ensures their more efficient use, which reduces the overload of the entire wireless network. FHSS was used in the original 802.11 standard, as well as in walkie-talkies and radiotelephones, for which the operating frequency is 900 MHz, while Bluetooth uses only one of the variations of this technology [4].

The orthogonal frequency division multi-

Four authentication methods with a shared key [2]

Authentication method	Description
A security protocol similar to the protection of a wired network (Wired Equivalent Privacy, WEP)	The original 802.11 specification is for data protection, which uses an encryption method called Rivest Cipher 4 (RC4) with a static key. However, the key never changes during the packet exchange process, which makes it easy to crack it.
Secure access to a wireless Wi-Fi network using the WPA method	It is a Wi-Fi Alliance standard that uses WEP, but protects data using a much more reliable encryption algorithm, the Temporary Key Integrity Protocol (TKIP).
WPA2	WPA2 is the current industry standard for protecting wireless networks. It uses the Advanced Encryption Standard (AES) for encryption.
WPA3	The next generation of Wi-Fi security. All WPA 3-enabled devices use the latest security techniques, prohibit outdated protocols, and require the use of secure Management Frames (PMF).

plexing method, called OFDM, is a subset of frequency division multiplexing in which a particular channel uses several of its subchannels at adjacent frequencies. The new 802.11ac standard uses a variation of OFDM called orthogonal frequency division Multiple Access (OFDMA) [5].

Justification of the choice of the software environment necessary for computer simulation of the wireless Wi-Fi channel of a distributed system

In the first chapter, a theoretical analysis of wireless technologies was carried out and, based on the results of the review, the validity of the choice of Wi-Fi technology was indicated [6]. The review of the parameters, security modes and frame structure of the wireless Wi-Fi system conducted in Chapter 1 revealed the main characteristics of this technology and the parameters that depend on quality, speed and security [7]. The following modeling programs are reviewed and their main characteristics and disadvantages are identified, which do not allow them to be used in the framework of a research:

1. The Enterprise Network Modeling Platform (eNSP) is a free extensible graphical network modeling platform developed by Huawei [8]. eNSP can simulate the functions supported on various device models, achieving a high degree of simulation [9].

2. Packet Tracer is a medium-precision simulation-based learning environment with the ability to work in a network, designed for beginners in the field of network technology, allowing you to design, configure and troubleshoot computer networks at the CCNA complexity level [10]. The simulation can be carried out using the following protocols: LAN: Ethernet (including CSMA/CD), wireless 802.11a/b/g/n, PPPOE. Switching: Vlan, 802.1q, Trunk, VTP, DTP, STP, RSTP, IP CEF. TCP/IP: HTTP, HTTPS, DHCP, DHCPv6, Telnet, SSH, FTP, DNS, TCP, UDP, IPv4, IPv6, ICMP, ICMPv6, ARP, IPv6 ND, FTP, SMTP, POP3, VOIP(H323). WAN: HDLC, SLIP, PPP and Frame Relay [11]. Security: IPsec, GRE, ISAKMP, NTP, AAA, RADIUS, TACACS, SNMP, SSH, SYSLOG, CBAC, Zonal Firewall Policy, IPS. QoS: Level 2 QoS, FIFO hardware queues, priority queue, user queue, weighted fair queue, MQC, NBAR [12].

3. VisSim (since 2014 Altair Embed) is a program with a visual flowchart for modeling dynamic systems and modeling embedded systems with its own visual language. The program automatically converts the control circuits into C-code, ready to be uploaded to the target equipment.

4. MATLAB is a special language that has an interactive environment for calculating numbers, visualizing created mathematical models and building their functional dependence and programming at a high level [13].

5. Simulink is an environment that allows you to work with flowcharts designed for multi-domain modeling and model-oriented design or programming. The application is integrated into MATLAB, which allows you to include algorithms created in MATLAB in Simulink models and export the simulation results of the MATLAB software environment for further analysis.

Development and debugging of a computer model of a wireless Wi-Fi channel taking into account packet loss in the MATLAB/Simulink program

The signal generated at the output of the sensor block according to the functional scheme is subjected to various attenuations described in the second chapter, but the attenuation depends on the parameters of the transmitter and receiver, which can be selected and changed depending on the characteristics of the wireless communication channel. To perform computer modeling in the MATLAB/Simulink program, the following equation is used, described in the second chapter:

$$y_{\text{пд}}'(t) + ap(t)y^2(t) = \beta R^{-1}(1 - p(t)). \quad (1)$$

In the formula $y_{\text{пд}}'(t)$ – information transfer rate [packets/s];

a – the set parameter for multiplicative reduction of the size of the data transmission window (in case of packet loss);

$p(t)$ – wireless Wi-Fi network packet loss probability function;

β – the set parameter for additive window size increase in the absence of packet loss;

R – delay [s].

For the convenience of working with the equation, we convert some values into coefficients:

$$y_{\text{пд}}'(t) + Ay^2(t) = B. \quad (2)$$

Then the data transfer rate will be equal to:

$$y_{\text{пд}}'(t) = B - Ay^2(t). \quad (3)$$

Figure 1 shows the general scheme of the model based on the above equations. For a correct and visual demonstration, the corresponding elements of the equation are combined into blocks of coefficients B and A, shown in Figures 2 and 3, respectively.

Block A, B – blocks A and B, the detailed description of which will be given below;

Integrator 1 – integrator;

The Sum adder;

Product is an element that performs multiplication;

Scope is an oscilloscope that displays the output signal.

Constant "1/R" – constant value of the re-

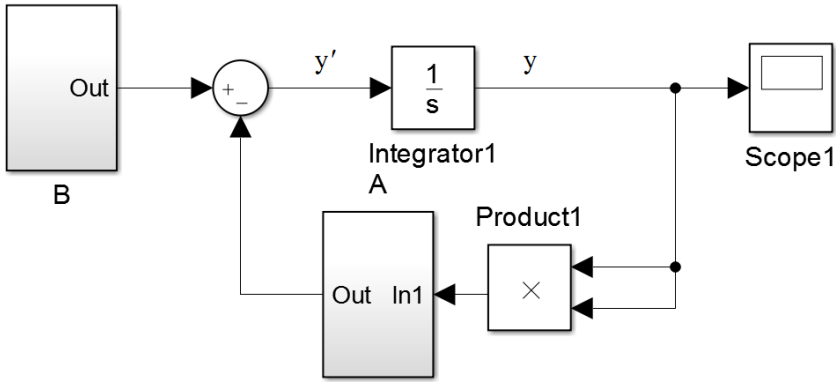

Figure 1 – General diagram of the model in the MATLAB/Simulink program

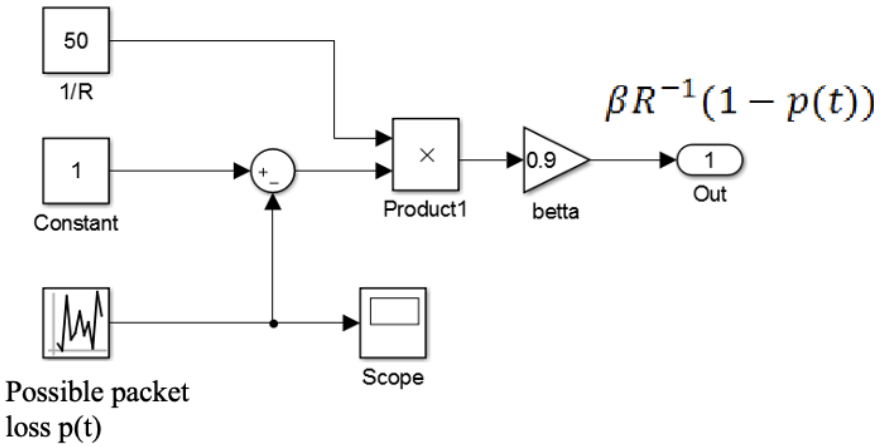

Figure 2 – Block B

verse signal delay reading;

Constant is the value of 1, according to the equation;

The Sum adder;

Product is an element that performs multiplication;

"Possible packet loss" – generator;

"Scope" is an oscilloscope. The coefficient B described in the block fulfills the equation βR^(-1) (1-p(t)), the parameters of which are as follows: the delay of the signal R is equal to an average time of 20 ms, therefore, when specified in the computer model block, the probability of packet loss is in the range from 0 to 0.1, due to the fact that the Wi-Fi technology used provides for minimal loss of transmitted packets; the value of β is 0.9. Figure 3 shows the structure of block A, which performs the mathematical operation of multiplying the parameters α and p(t). The probability of packet loss is in the range from 0 to 0.1, as mentioned in the previous block, and the value of α is assumed to be 0.1.

All mathematical operations are based on equations describing the data transfer rate over a wireless communication channel and, accordingly, all elements of the computer model comply with the requirements specified when forming the final signal. Figures 4 and 5 show possible packet losses during data transmission over a wireless communication channel and the final output signal on a computer model, respectively.

Problem statement

The use of a distributed wireless system allows you to reduce the financial costs of carrying out measures to eliminate defects by accurately determining the location, angle of inclination, vibrations, temperature influences and the need for repair work. In most cases, in these distributed systems, various sensors act as measuring devices that measure parameters according to data identification and tracking technologies.

Research methods

During the research, proven methods of processing and analyzing measurement data, techniques for remote identification of mea-

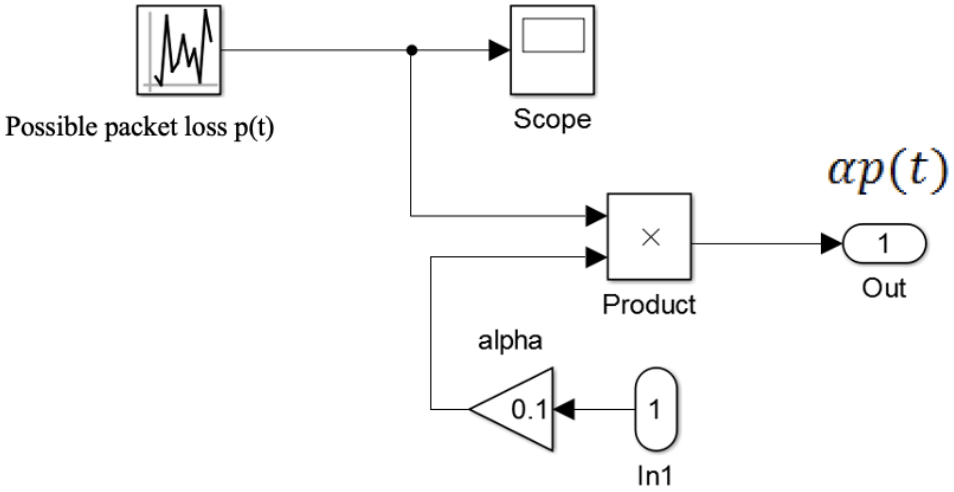

Figure 3 – Block A

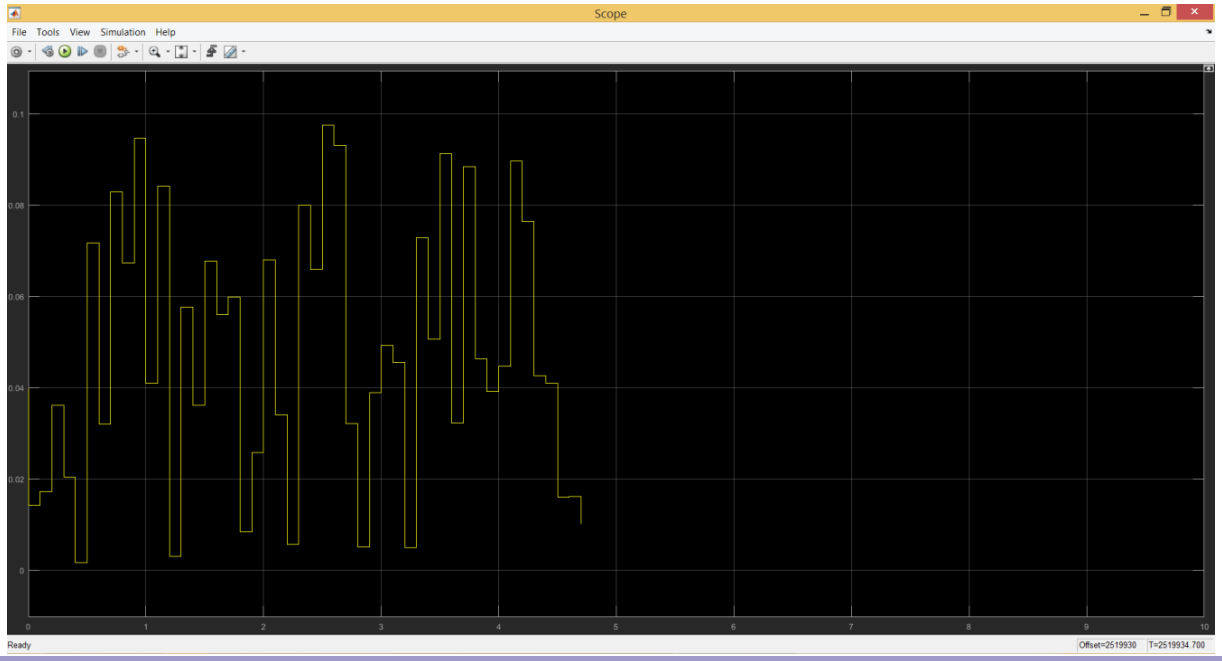

Figure 4 – Possible packet loss during data transmission over a wireless communication channel

surements, creation of software and hardware systems using microcontrollers, as well as computer modeling methods were applied:

1. The Enterprise Network Modeling Platform (eNSP) is a free extensible graphical network modeling platform developed by Huawei.

2. Packet Tracer is a medium-precision simulation-based learning environment with the ability to work in a network, designed for beginners in the field of network technology, allowing you to design, configure and troubleshoot computer networks at the CCNA complexity level.

3. VisSim (since 2014 Altair Embed) is a program with a visual flowchart for modeling dynamic systems and modeling embedded systems with its own visual language [14].

4. MATLAB is a special language that has an interactive environment for calculating numbers, visualizing created mathematical models and building their functional dependence and programming at a high level.

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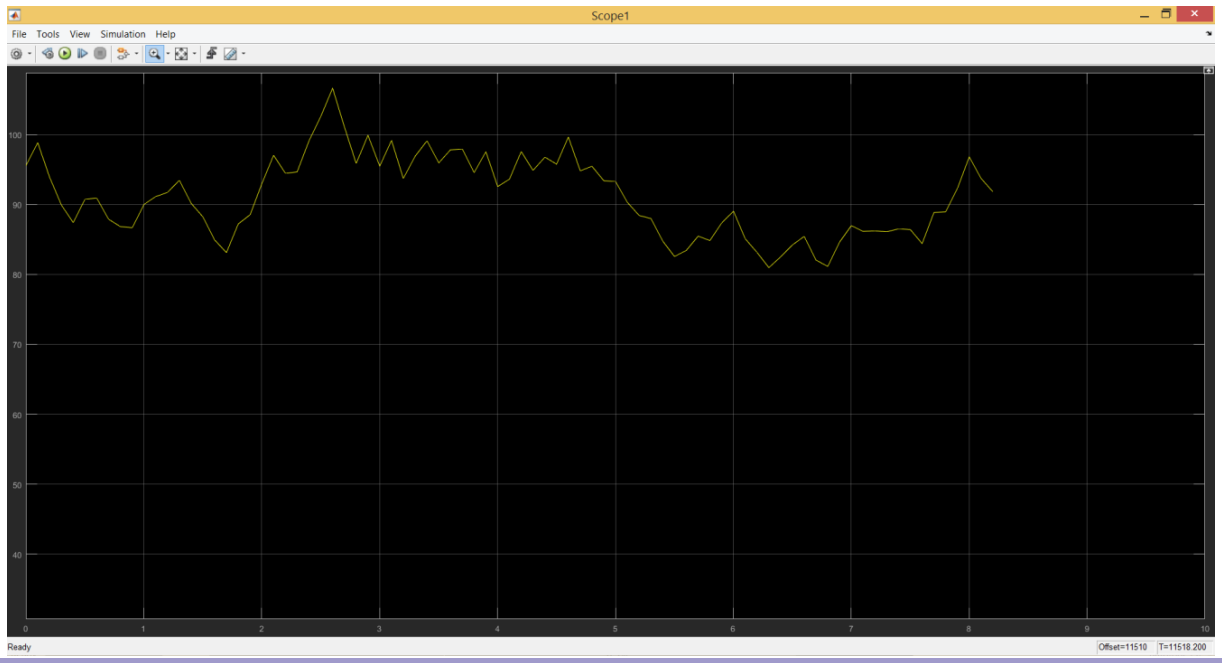

Figure 5 – Final output signal on a computer model

Conclusion

In conclusion, it can be summarized that the research conducted in the field of distributed wireless systems and their computer modeling has acquired significant importance in modern science and technology. The development and analysis of mathematical models has become a key element in determining the optimal parameters of a wireless channel, taking into account high data transfer rates and minimal packet loss. The choice of a software environment for computer modeling is an important stage of the research process. As part of this work, MATLAB and Simulink were selected as key tools for the development and testing of created mathematical models. Their use provided convenience in creating graphical models, flexibility in developing algorithms, as well as the ability to conduct effective experiments and analyze the results. Thus, the research results have made a significant contribution to the field of distributed wireless systems and their modeling, emphasizing the importance of choosing the right software tools for the successful implementation of tasks related to the optimization of wireless channels. These findings contribute not only to academic research, but can also be in demand in industrial and engineering applications, where high-precision modeling and analysis of wireless systems play a critical role in ensuring the efficiency and reliability of technological solutions.

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Көпір құрылыстары мен құрылыс ғимараттарын телеметриялық басқаруға арналған бөгеттердегі пакеттердің жоғалуын ескере отырып, Wi-Fi сымсыз арнасын компьютерлік модельдеу

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Аңдатпа. *Көпірлер мен ғимараттардың техникалық жағдайын бақылаудың таратылған автономды сымсыз жүйесінде пакеттің жоғалуын ескере отырып, сымсыз Wi-Fi арнасын компьютерлік модельдеуге арналған. Таратылған жүйеде сымсыз Wi-Fi арнасын компьютерлік модельдеуге арналған бағдарламалық жасақтаманы таңдаудың негіздемесі келтірілген. Біздің эксперименттеріміздің нәтижелері жаңа әдістерді қолдана отырып, зерттеу дәлдігінің айтарлықтай жақсарғанын көрсетеді. Табылған үлгілер пакеттің минималды жоғалуымен деректерді берудің жоғары жылдамдығын қамтамасыз ететін сымсыз жүйенің компьютерлік моделін құру кезінде маңызды бола алады. Алынған нәтижелер бақылау жүйелерінің тиімділігін арттыру үшін сымсыз технологиялар саласындағы заманауи әдістерді қолданудың маңыздылығын көрсетеді. Тәжірибелерге сүйене отырып, жаңа әдістер сымсыз бақылау жүйелерінде жиналған деректердің дәлдігін айтарлықтай арттырады деген қорытынды жасауға болады. Осылайша, бұл жұмыс сымсыз бақылау әдістерін дамытуға және нақты желілік жүктемелер кезінде деректердің тұрақты берілуін қамтамасыз етуге қабілетті дәлірек компьютерлік үлгілерді жасауға ықпал етеді.*

Кілт сөздер: *сымсыз Wi-Fi жүйесі, компьютер моделі, сымсыз құрылғылар, желі режимі, арна параметрлері, аутентификация, ақпаратты шифрлау, оңтайлы параметрлерді анықтау, компьютерлік желілер.*

Компьютерное моделирование беспроводного канала Wi-Fi с учетом потерь пакетов в плотинах для телеметрического управления мостовыми сооружениями и строительными зданиями

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**автор-корреспондент.*

***Аннотация.** Данная статья посвящена компьютерному моделированию беспроводного канала Wi-Fi с учетом потери пакетов в распределенной автономной беспроводной системе мониторинга технического состояния мостов и зданий. Приведено обоснование выбора программного обеспечения для компьютерного моделирования беспроводного канала Wi-Fi в распределенной системе. Результаты наших экспериментов демонстрируют значительное повышение точности исследования с использованием новых методов. Обнаруженные закономерности могут стать ключевыми при создании компьютерной модели беспроводной системы, обеспечивающей высокие скорости передачи данных с минимальной потерей пакетов. Полученные результаты подчеркивают важность использования современных методов в области беспроводных технологий для повышения эффективности систем мониторинга. Основываясь на экспериментах, можно сделать вывод, что новые методы значительно повышают точность собираемых данных в беспроводных системах мониторинга. Таким образом, данная работа будет способствовать развитию методов беспроводного мониторинга и созданию более точных компьютерных моделей, способных обеспечить стабильную передачу данных при реальных сетевых нагрузках.*

***Ключевые слова:** беспроводная система Wi-Fi, модель компьютера, беспроводные устройства, режим сети, настройки канала, аутентификация, шифрование информации, определение оптимальных параметров, компьютерные сети.*

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