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CONCEPTUAL AND METHODOLOGICAL MODELS FOR DESIGNING WIRELESS NETWORKS

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ABSTRACT

At the stage of working out design solutions, customers first raise questions regarding the possible volume and speed of information transfer. There is no doubt about the high efficiency of mathematical modeling methods in solving such problems. Unfortunately, the existing tools for modeling wireless networks allow taking into account only certain parameters of traffic and are not able to answer the questions related to its effective management and distribution. This leads to the emergence of the need for new models of control and distribution of traffic in wireless networks, which will be able to provide high quality of service, taking into account the various requirements of applications to the network, which determines the relevance and practical significance of this task.

The identified problems and the reasons for their occurrence give reason to consider wireless data transmission as a process where there is a queue and a processing device. Accordingly, to model the control and distribution of traffic in wireless computer networks, the authors propose to use queue management algorithms and cluster reconfiguration methods.

The paper presents the results of modeling the traffic of wireless data transmission in computer networks using the queue control algorithm - parametric identification. This algorithm makes it possible to identify the parameters of the mathematical model of a wireless computer network using only the value of the data transmission window. As a result, there was no overload of network buffers, a decrease in the probability of packet loss, an increase in the efficiency of the distribution of the communication channel, and a guaranteed level of quality of service.

Keywords: *Mathematical Model, Traffic Management, Design, Wireless Networks*

1. INTRODUCTION

Currently, there are a huge number of types of wireless networks that have firmly taken their place in the telecommunications industry. A variety of standards and a wide range of equipment used, a variety of areas and conditions of use, special requirements imposed by a number of customers give grounds to classify the design of wireless networks as a complex multi-criteria task. However, in practice, the calculation of the Fresnel zone is performed, the calculation of the total capacity and the number of access points that provide the required reliability and network performance, and the selection of equipment within the allocated funds. At the same time, such important issues as the placement of access points indoors, the assessment of the influence of building elements on signal propagation, the choice of the topological characteristics of the network and a number of others are solved heuristically, i.e. outside the design schemes.

Kiwiat charts, which are a type of radar charts, have been successfully used to qualitatively compare the technical characteristics and operational capabilities of wireless networks. They allow you to visualize and compare several technical and economic indicators of wireless networks operated in different conditions. The number and composition of the compared indicators can be different, but, as a rule, it varies from 4 to 12.

In figure 1–4 shows Kiwiat diagrams for comparison of six indicators of four types of wireless networks, taken from an Internet source [1].

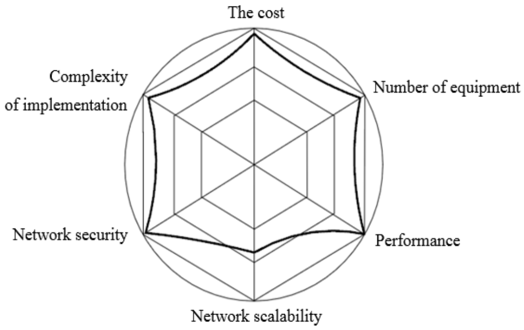

Figure 1: State institution bank

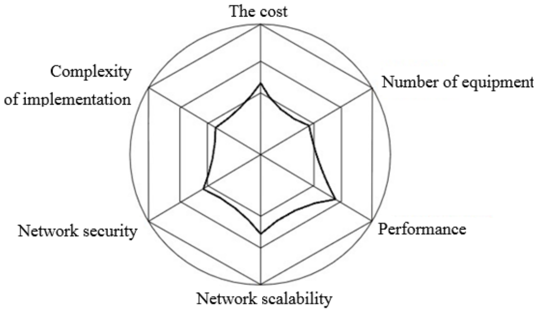

Figure 2: Video surveillance network

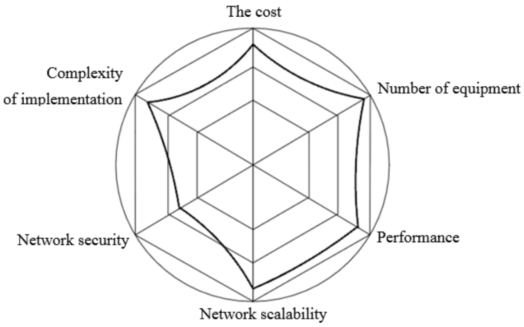

Figure 3: Hospital. Polyclinic

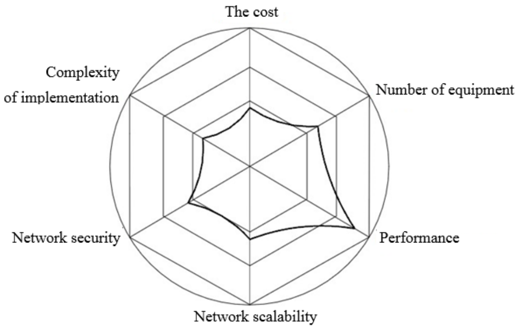

Figure 4: Wireless bridge

From figure 1-4 it can be seen how different technical and economic characteristics of wireless networks can be, depending on the range of tasks to be solved and operating conditions, how significantly different will be the costs of their creation.

The above considerations and the examples considered allow us to state a noticeable lag of the scientifically grounded design methodology from the needs of practice and the need to build mathematical models that could become the basis for computational algorithms for solving problems of optimal design of wireless networks. Certain aspects of this highly topical and science-intensive problem are discussed in this article.

2. WIRELESS TRAFFIC SHAPING MODEL

At the stage of working out design solutions, customers first of all raise questions regarding the possible volume and speed of information transfer. There is no doubt about the high efficiency of mathematical modeling methods in solving such problems. Unfortunately, the existing tools for modeling wireless networks allow to take into account only certain parameters of traffic and are not able to answer the questions related to its effective management and distribution. This leads to the emergence of the need for new models of control and distribution of traffic in wireless networks, which will be able to provide high quality of service, taking into account the various requirements of applications to the network, which determines the relevance and practical significance of this task.

Today, a large number of famous scientists, for example, Kleinrock, S. Blake, D. Grossman, Z. Wang, Steklov V.K., Berkman L.N., as well as research centers such as Mobile Ad-hoc Networks, The Internet Engineering Task Force, Center for Embedded Networked Sensing deals with traffic management and distribution. However, despite the large number of publications and the efforts of manufacturing firms, the task of building traffic models that best reflect its functioning in real conditions has not yet been solved.

The quality of traffic management and distribution in specialized and technical literature is characterized by such a concept as quality of service (QoS), which is the ability of a computer network to provide a sufficient level of service for a given traffic within a certain technological framework [2].

The required service is characterized by many parameters, the main of which are considered to be the following:

- Bandwidth;
- Priority;
- Delay of data transmission;
- Delay variation - jitter;

- Losses of packets during transmission of network data (packet losses).

To determine which particular toolkit is most suitable for modeling the management and distribution of traffic in wireless computer networks, let us consider the typical problems that arise when transferring information during periods of the highest network load.

If the cause of the overload is insufficient performance of the processor unit of the wireless network device, then unprocessed fragments temporarily accumulate in the incoming queue of the corresponding input interface. Note that there can be several queues to the input interface if service requests are differentiated by several classes. In the same case, when the cause of the overload is the limited bandwidth of the output interface, the information is temporarily stored in the outgoing queue (or queues) of that interface.

In addition, depending on the current network topology, the central nodes forming clusters do not always bear the same load (the number of mobile nodes connected to the central node, average distance to cluster nodes, average cluster performance, etc.). This leads to the fact that the gateway nodes, which are the central nodes used for communication between clusters, having the same resources, are loaded unevenly, which entails a delay in the transmission of information. In the same way, if one of the gateway nodes is turned on as a transit one and is overloaded more than the neighboring ones, then with heavy traffic this leads to a decrease in the efficiency of inter-cluster exchange.

These problems and the reasons for their occurrence give reason to consider wireless data transmission as a process where there is a queue and a processing device. Accordingly, to model the control and distribution of traffic in wireless computer networks, it is advisable to use queue management algorithms and cluster reconfiguration methods.

So, let's start modeling the traffic of wireless data transmission in computer networks using the queue control algorithm - parametric identification, which allows identifying the parameters of the mathematical model of a wireless computer network using only the value of the data transmission window. This will help avoid overloading network buffers, reduce the likelihood of packet loss, and increase the efficiency of channel allocation, providing a guaranteed level of quality of service.

1st order nonlinear differential equation describing the data transfer rate in a wireless computer network to control the length of the buffer queue [2-4]:

$$\acute{y}(t) + \alpha\, p(t)y2(t) = \beta\, R - 1(1 - p(t)) \quad (1)$$

where $\acute{y}(t)$ – data transfer rate (packets/c);
$p(t)$ – packet loss probability function;
R – delay (c.);
α – parameter of multiplicative reduction of the size of the data transmission window upon packet loss;
β – the parameter for the additive window size increase without packet loss.

In [4], from where this equation was borrowed, the packet loss function $p(t)$ was proposed to be considered periodic and changing according to a sinusoidal law.

Equation (1) is a typical representative of the family of Riccati equations, for which it is usually impossible to find a solution in quadratures. For this reason, it is of interest to evaluate the type of solution and find out its properties.

It is known [5] that the general Riccati equation is closely related to linear differential equations of the second order. In particular, if the coefficient at the square term is a continuous differentiable function, then each solution y (t) of the Riccati equation is translated by the transformation

$$u = exp(\propto \int p(t)\, y\, dt) \qquad (2)$$

to a nonzero solution to the linear differential equation

$$\infty p(t)u'' + \alpha p'(t)u' + \frac{\infty^2\beta}{R} R^2(t)\big(1 - p(t)\big)u' = 0 \qquad (3)$$

According to the general theory of linear differential equations, the form of a solution to a second-order equation is determined by the type of roots of its characteristic polynomial. If these roots are complex conjugate numbers, then the general solution of the equation is obtained in the form of a family of harmonic functions

$$u = eatc_1 cos\, b\, t + c_1 sin\, b\, t) \qquad (4)$$

a - coefficient at the real part of the roots,
b - modulus of coefficients at the imaginary part.

The condition for the existence of such a solution for equation (3) is the fulfillment of the inequality

$$(p'(t))^2 - \frac{\infty\beta}{R} p^3(t)\big(1 - p(t)\big)^2 < 0 \qquad (5)$$

Since the coefficient of equation (3) are also harmonic functions, real prerequisites are created for the occurrence of parametric resonance, which can cause significant traffic fluctuations. This is fraught with serious disruptions to the normal operation of the wireless network and requires emergency administrator intervention.

The study of the behavior of technical devices that allow the possibility of parametric resonance is very difficult and time-consuming, although it is of undoubted interest, however, it goes far beyond the scope of this article. We only note that the solution to equation (3) is extremely sensitive to changes in the parameters α and β. In other words, even extremely insignificant fluctuations of these parameters can transfer a stably operating system into the parametric resonance mode and completely destabilize her work. Therefore, in order to resolve the issue of successful operation of such systems, it is necessary to accurately establish the boundaries of the regions of resonance modes, which is achieved by constructing the so-called Aynes-Strett diagrams (See, for example, [6]). This is done by processing the results of long-term field experiments, or by means of specially created simulation models.

Equation (1) can hardly be considered a tool suitable for efficient traffic management in wireless networks, but it can well be used to describe the behavior of the network under changing external conditions. Here, this equation is applied to assess the impact of changes in the frequency of the packet loss probability function on the traffic state.

To this end, the Cauchy problem was formulated for equation (1) with natural initial conditions $y(t_0) = 0,\ t_0 = 0$. To determine the values of the parameters α, β, R, materials were used experimental studies published in [7]. The numerical solution of the problem was obtained using a specially written program that implements the Runge-Kutta method. The graphs of the corresponding integral curves are shown in figure 5a, 5b, 5c and 5g.

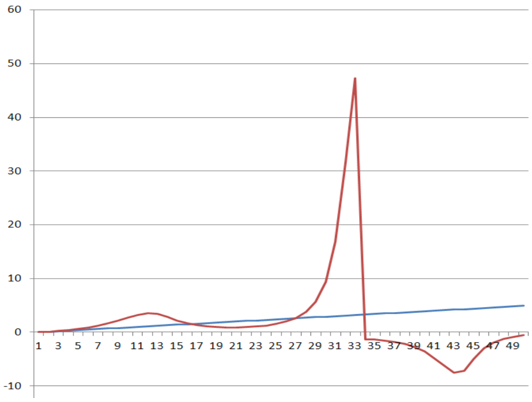

Figure 5a: Graph of the integral curve. Input data: a = 1.2; b = 0.83; r = 0.75; h = 0.1; argument coefficient sin (3t)

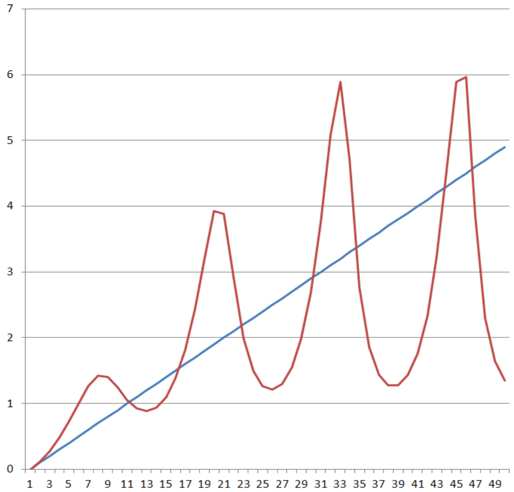

Figure 5в: Graph of the integral curve. Input data: a = 1.2; b = 0.83; r = 0.75; h = 0.1; argument coefficient sin (5t)

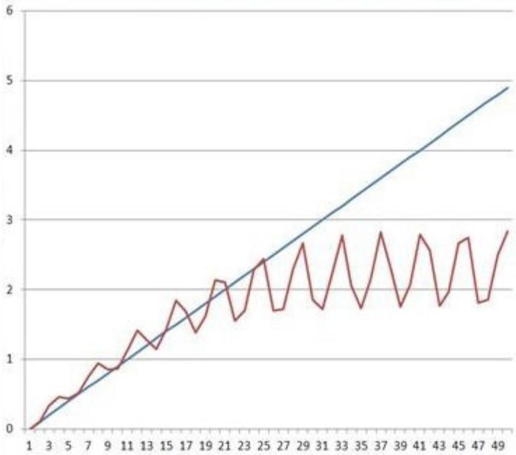

Figure 5c: Graph of the integral curve. Input data: a = 1.2; b = 0.83; r = 0.75; h = 0.1; argument coefficient sin (9t)

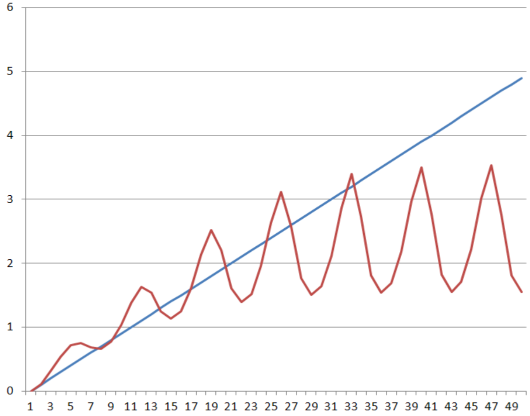

Figure 5g: Graph of the integral curve. Input data: a = 1.2; b = 0.83; r = 0.75; h = 0.1; argument coefficient sin (15t)

Their appearance well illustrates the nature of the changes that occur as the frequency increases. At a frequency of 2 Hz (see figure 5a) there is a high peak, which indicates the immediate proximity of the parametric resonance region. When the frequency increases to 5 Hz (figure 5b), the peak disappears, which can be explained by the distance from the resonance region, although the amplitude of regular oscillations continues to remain rather high. With a further increase in frequency (figure 5c, d), the amplitude of oscillations, without losing regularity, continues to decrease and already at a frequency of 9 Hz reaches values that do not significantly affect the state of traffic.

In case of changes in the parameters of the "window", or the delay time R, the appearance of the integral curves may turn out to be completely different.

When designing a wireless network, several queue management algorithms may be envisaged, for example, FIFO algorithm, priority service algorithms, weighted queuing algorithm. The following sequence of actions is suggested here:

1. Calculation of the generation period

$$\tau = \frac{1}{f} \tag{6}$$

where τ – generation period;
f – the frequency of the network.

2. Determining the speed of the network.

$$b = \frac{1}{m} \tag{7}$$

where b – average service time;
m – data transfer rate.

2. The bandwidth of the channels

$$C = \sum_{k=1}^{k} \frac{1}{t} \tag{8}$$

where C – bandwidth;
t – delay time;
k – number of channels.

Conducting a comparative analysis, in accordance with the proposed algorithm, will make it possible to make a reasonable choice of equipment necessary for building a wireless network, which will minimize the delay in the transmission of information, as well as effectively manage and distribute traffic, as well as assess which of the queue management options is best suited to the emerging situations.

Let's move on to considering the features of traffic modeling using cluster reconfiguration.

In the process of modeling the traffic of a wireless network, in particular a computer network of a state enterprise, educational institution, hospital, etc., it is advisable to provide for the possibility of reconfiguring clusters, which will reduce the time for information transfer and optimize network traffic. Therefore, for the criterion for choosing the structure and size of clusters, an estimate of the efficiency of data transmission should be specified.

$$E = \frac{W_k}{W_k + W_s} \tag{9}$$

where, W_k - the number of transmitted payload data;
Ws - the amount of service information.

Obviously, with a fixed amount of useful information, the efficiency coefficient will monotonically decrease with an increase in service traffic. Thus, the key parameter for improving the efficiency of the network is the amount of service traffic, which should be minimized. Let's define the factors influencing the volume of service traffic in the wireless computer network.

We represent the volume of service traffic as a function of $V_S = f(F_r, V_0)$ on the frequency of network reconfiguration F_r and the number of nodes nV_i in the cluster V_0.

With an increase in the number of configurations in the network, the volume of service traffic increases according to a nonlinear law, which entails a significant decrease in the efficiency of data transmission. Under certain conditions, this can cause unstable network performance.

Therefore, to reduce the overhead traffic in the network, the frequency of reconfigurations at a given time interval ΔT and the number of network clusters should be minimized

$$F_r \to min\ ,V_0 \to min$$

The optimal network size can be characterized by the coefficient k

$$k = \frac{F_r \cdot V_0}{\Delta T} k \ \to \ min$$

At the same time, no matter what kind of mathematical tools will be chosen for traffic control and distribution in wireless computer networks, it is necessary to verify the obtained model. To do this, it is enough to compare the value of the model traffic with the values selected as a reference. A suitable tool for solving such problems is the concordance index $p(t_k)$ of model and reference traffic values at a given time interval

$$p(t_k) = \frac{2 \cdot m(t_k) \cdot M(t_k)}{m(t_k)^2 + (t_k)^2} \tag{10}$$

where, t_k - the k-th moment of traffic control;

$m(t_k)$ is the mathematical expectation of the reference traffic;

$M(t_k$ is the mathematical expectation of the model traffic.

For the discrete case, we introduce the average value of the concordance criterion of the model and reference traffic:

$$p_0(Z_1, Zn) = \sum_{t_k=0}^{1} \frac{2 \cdot m(t_k) \cdot M(t_k)}{m(t_k)^2 + M(t_k)^2}$$

where Z_1, $Z_n$are the optimal quantized values of the traffic model of dimension n .

For the continuous case, we introduce the integral criterion for the concordance of the model of the non-stationary traffic standard:

$$p_0(Z1, Zn) = \int_0^1 \frac{2 \cdot m(t_k) \cdot M(t_k)}{m(t_k)^2 + M(t_k)^2} dt_k$$

The value of the coefficient of concordance varies from 0 to 1. Research and observation of the work of computer networks carried out by the author that their condition can be considered satisfactory if the value of the coefficient of concordance is greater than or equal to 0.9. Thus, summing up the results, we can draw the following conclusions on this section.

In order to select the most optimal and effective mathematical apparatus for modeling the distribution and control of traffic in wireless computer networks, the problems causing delay in information transmission have been analyzed. Based on the results obtained, the necessity and expediency of using queue management algorithms and cluster reconfiguration methods are substantiated. The possibility of using the concordance coefficient to compare the value of the model traffic with the reference value has been substantiated.

3. FEATURES OF THE USE OF WIRELESS NETWORKS IN EDUCATIONAL INSTITUTIONS

The introduction of distance learning technologies into the educational process involves the creation of new types of educational content that supplements or replaces traditional educational materials, and the organization of new ways of delivering this content to consumers of educational services. The spread of local and global computer networks provides wide accessibility and ease of use of electronic educational resources. This is a new stage on the way to the widespread dissemination of distance learning technologies using computer networks. Currently, an increasing number of educational institutions of various levels are actively introducing in the process of mastering educational programs information resources located both in the local network of the institution itself and on the Internet. This is due to the fact that, although each organization carrying out educational activities seeks to select and place in its local network the educational resources required for its students to master the corresponding educational programs, the Internet has a significantly greater educational and informational potential.

All this leads to the fact that educational institutions strive not only to provide students with access to electronic resources during working hours from specially equipped classrooms and libraries, but also to make this possible at any time using wireless access (often called a Wi-Fi network) to their local network, and through it to the Internet.

At present, there is a wide range of equipment designed for organizing Wi-Fi networks, which is advertised in such a way that it is not uncommon to get the impression that for the implementation of such a network only the purchase of equipment, its correct connection and the implementation of the software settings given in the attached instructions are sufficient. However, to organize the safe and highly efficient operation of such networks, when designing them, one should take into account certain features inherent in both the equipment and the space in which the network is deployed, therefore, a detailed technical analysis and calculation of the network are mandatory conditions for the successful operation of the network in the course of its further operation taking into account the specified features.

In the simplest case, data exchange in a Wi-Fi network requires two devices, which together with the distribution medium form a communication channel between the switched device and the local network. One of them is, as a rule, a mobile device (for example, a laptop, a tablet computer, a smartphone, etc.), in modern models of which the function of forming a radio channel of a Wi-Fi network is provided. The second is a conventional stationary hardware and software device (base station), which includes a transceiver that exchanges radio signals with a mobile device connected to this wireless network, as well as devices for processing exchanging data and connecting to a local network. A base station (often referred to as a wireless access point) is installed in the premises of an educational institution, and through it, users can use their mobile devices to access the institution's local network and the Internet.

One of the essential features of the operation of such equipment is the emission of electromagnetic oscillations of the super-high-frequency range both by the base station and by the switched device. The amount of such radiation is determined by the propagation medium of the signal between this equipment and can reach values that exceed those established by hygienic requirements for the level of electromagnetic fields.

Currently, the most common data exchange in Wi-Fi networks occurs using radio signals, the frequency of which is in the 2.4 GHz band. The levels of electromagnetic radiation in this radio frequency range are regulated by sanitary and epidemiological rules and regulations.

The first of them establishes that the permissible level of electromagnetic radiation in the radio frequency range 300 MHz ... 300 GHz in residential premises is 10 μW / cm^2 [8]; the second regulates the level of electromagnetic fields in the frequency range 300 MHz ... 2400 MHz generated by base station antennas on the territory of residential buildings, inside residential, public and industrial premises, which should also not exceed 10 μW / cm^2. In accordance with the documents of title, sanitary and epidemiological requirements for residential buildings and premises apply to educational institutions, culture, sports, etc., therefore, this norm is mandatory for use when designing a Wi-Fi network in educational institutions.

The currently available equipment for the implementation of such networks, as a rule, is universal and is intended not only for combining several nearby devices into a common network segment, but also for connecting a switched device to a remote network, the base station of which is located at a distance of several kilometers. Such equipment provides a significant output power of the transmitter (up to 1 ... 2 W), is completed with antennas with increased values of the gain, which means that a Wi-Fi network organized with its help in the premises of an educational institution can form an electromagnetic field level in the antenna of a base station that is significantly higher regulated.

The propagation of electromagnetic waves in the considered range has its own characteristics: the obstacles that arise during their passage depend on the material and thickness of the walls of buildings, the presence of reinforcement in them, the presence in the room of various metal surfaces and structures that reflect microwave waves well. Therefore, when choosing a location for the base station, it is necessary to take into account the features of the building structure. In particular, the signal from an access point installed in an auditorium may be significantly weakened in neighboring auditoriums, which narrows the range of the Wi-Fi network. At the same time, taking into account the propagation of the reflected signal, for example, from the walls of the corridor, can expand the coverage area of the network. Therefore, when developing design solutions, a thorough analysis of the specific conditions of the network location is required, which allows determining the optimal location of the base station.

Another reason for the decrease in the signal received from the base station may be an increase in the radiation level of the mobile device operating in this location with the base station of the network and seeking to maintain stable error-free data transmission. Such a change in the amount of radiation is typical for modern communication mobile devices and largely depends on their specific models. In them, in the event of a decrease in the level of the received signal, the amount of radiation of the mobile device may increase and, under certain conditions, exceed the value of the regulated permissible level of electromagnetic radiation.

To experimentally evaluate the real values of the radiation levels of the equipment intended for use in the Wi-Fi network, their values were measured for two samples of equipment used as base stations and three samples of mobile devices. The measurements were carried out using an SRM-3006 selective radiation meter and a matched antenna included in the meter set in the mode of continuous exchange of information packets between the devices, generated by the Ping program. In the course of measurements, to reduce the level of the received signal, the device was shielded, which did not interrupt the exchange of information packets.

The values of the measured power fluxes were: for the TL-WR542G wireless router operating with a standard antenna with a gain of 5 dB - 396.6 μW / cm^2 ; ASUS Wireless Router WL-520g - 223 μW / cm^2; tablet computer Samsung GT-P7500 - 196 μW / cm^2; smartphone ZTE V970 - 91 μW / cm^2; smartphone Samsung GT-I7500 - 287 μW / cm^2. Thus, it can be considered proven that the observed readings of the radiation levels of the equipment can significantly exceed the limit values established by sanitary standards [9].

Each of the users can indirectly control the radiation intensity of their mobile devices independently by the indicator of the received signal level, choosing the place of entry into the network in which the reception will be the best, which means that the radiation will be the least.

At the same time, the location of the base station when organizing a Wi-Fi network in closed rooms (classrooms, halls) of educational institutions cannot be chosen arbitrarily. This applies not only to the room in which the base station will be installed, but also to the place of its installation in this room. For example, it seems appropriate to use wall and ceiling mount antennas, or devices with built-in antennas; do not place them in the immediate vicinity of workplaces; use equipment with an adjustable output power, and also do not place the equipment near equipment, the reflection from which can direct the radiation flux to the user.

Despite the obvious expediency of applying the results of mathematical modeling at the design stage of wireless networks, the practical implementation of this idea is limited, as noted above, by the lack of realistic models brought to specific design schemes. This prompts the search for ways to objectify heuristic and intuitive decisions made in the design process.

One of the possible options for achieving the formulated goal is the method of expert assessments. It is successfully applied in solving multicriteria optimization problems, when a quantitative assessment of one or several criteria is difficult or does not exist at all. This method is also often used in the absence of a generally accepted mathematical description, when the existing framework concept allows for various interpretations that do not substantially coincide with each other in details [12].

The method of expert assessments is based on the hypothesis that the cumulative experience accumulated in a certain area by practicing professionals, positive results obtained by trial and error, empirically found methods of work, not being identical to exact knowledge, in some cases can replace it. Under certain conditions, intuitive guesses and stable relationships revealed in the process of solving applied problems can become the core of a new theory, give an impetus to the creation of scientifically grounded representations of models and algorithms [10, 11].

To conduct this study, eight specialists with significant (at least three years) experience in the design, implementation and operation of wireless networks, including in educational institutions (figure 6). Each of them was asked to independently evaluate, on a ten-point scale, the technical, economic and operational characteristics of a wireless computer network designed for an institution of higher professional education. Six indicators were selected for assessment, which are the coordinates of the Kiwiata diagrams shown in figure 1 - 4, namely: cost, amount of equipment, performance, network scalability, network security, implementation complexity.

The results of the experts' work and the values of the averaged estimates are presented in Table 1.

Table 1: Summary Map Of Expert Assessments

Network characteristics	Experts								Mean
	1	2	3	4	5	6	7	8	
The cost	8	8	7	8	8	7	9	8	7,875
Number of equipment	9	9	10	9	9	9	10	9	9,25
Performance	7	8	8	8	7	9	8	8	7,875
Network scalability	9	9	8	9	8	9	9	9	8,75
Network security	6	6	5	7	6	5	5	7	5,75
Complexity of implementation	10	9	10	10	9	10	10	9	9,625

Before starting the procedure for statistical processing of the examination data, a round table was organized, where specialists familiarized themselves with each other's assessment sheets. During the resulting discussion, they were given the opportunity to motivate the grades and share their views on the problem as a whole.

Below is a brief summary of the discussion in the part that deals with only assessed indicators.

1) Cost. Average score 7.875. Since “Equipment Quantity” was included in the questionnaire as a separate indicator, the cost was estimated at the existing prices for the main and auxiliary equipment and the special requirements of the customer for the organization of the network. According to experts, standard equipment that meets the requirements of sanitary and hygienic standards is sufficient to create a wireless computer network in a higher educational institution. Temporary failure of a separate access point will not lead to irreversible loss of important information or disruption of the educational process, therefore, additional costs for solving backup problems are not provided. There are also no special requirements for network security, which could significantly increase the cost of the project. Thus, the cost of creating a network will be

higher than average, but not prohibitively high.

2) The number of equipment. Average score 9.25. This parameter depends, of course, on the areas available to the educational institution and the number of students. However, if the priority is a high degree of user comfort and a high threshold value of the signal, then the amount of equipment that ensures the operation of the network should be large. An attempt to save money on this can result in unacceptable traffic disruptions, and lead to systematic failures of the educational process.

3) Performance. Average mark 7.875. Most experts are of the opinion that high performance of a network operating in an educational institution is not required. They rightly point out that in order to increase productivity, the installation of additional equipment will certainly be required. And this, in turn, will entail a rise in the cost of the project. Justice this conclusion is supported by the same average scores for cost and performance.

4) Network scalability. Average score 8.75. Most experts, especially those whose professional activities are related to the operation of wireless networks, consider scalability to be a very important factor, which is of particular importance in the aspect of future planning and development of the network. Indeed: the rapid development of information technologies, the active penetration of their organization of the educational process, the emergence of new electronic aids, the growing interest in distance education - all this presupposes the expansion of the network and such an opportunity must necessarily be provided at the stage of design solutions.

5) Network security. Average score 5.75. In assessing this indicator, the opinion of the experts was absolutely unanimous. No special security measures related to the conditions of storage and transmission of information are required for wireless computer networks serving the educational process in higher educational institutions.

6) The complexity of the implementation. Average score 9.625. On this issue, the unanimity of the members of the expert group was again almost complete. The need to take into account the structural features of the building, attenuation of the signal by reinforcement elements, the material of walls and ceilings, the obligatory fulfillment of sanitary and hygienic requirements for the placement of access points inside the premises makes the implementation of design solutions very difficult.

According to Table 1, a Kiwiata diagram for a wireless network of a higher educational institution is built in the same coordinates as the diagrams in figures. 1 - 4.

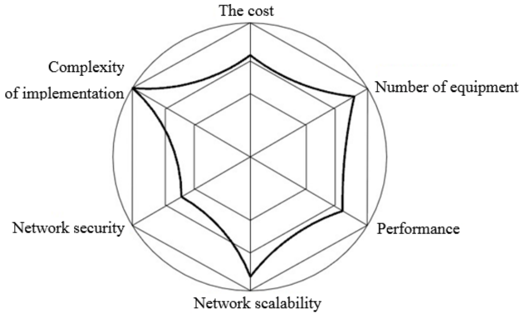

Figure 6: Kiviata diagram of the wireless network of the institution of higher education

The results of the work of the expert group, obtained during the questionnaire, must undergo a mandatory check for consistency. If the opinions of the experts turn out to be inconsistent, that is, significantly different within the group, the results are recognized as unsuitable for making meaningful judgments about the subject of the examination, and the examination itself did not take place. A similar situation may arise either due to significant differences in the level of qualifications of invited experts, or due to the lack of generally accepted criteria for assessing the problem under discussion in the community of specialists. In the first case, the difficulty is easily overcome by forming a new group of experts, while in the second it is recognized that the problem is ripe only for discussion, but not for examination.

The generally accepted method for checking the consistency of opinions is the method based on calculating the Kendall-Smith multiple rank correlation coefficient and checking its statistical significance.

For the verification procedure, the assessments put down by the experts are ranked: the highest grade is assigned rank 1, the next - 2, etc. The same grades are assigned the same ranks equal to the arithmetic mean of their ordinal numbers. These ranks are called linked.

Let's consider the order of ranking by the example of the estimates of the first expert. The highest score, equal to 10 points, was given to them for the indicator “complexity of implementation. It is assigned a rank of 1. The two metrics "hardware quantity" and "scalability" have a score of 9. In order, they are numbered 2 and 3, so both of these indicators are assigned a rank of 2.5. This is followed by the “cost” indicator with an estimate of 8. It is given a rank 4. And, similarly, the “performance” indicator gets a rank of 5, and “network security” a rank of 6.

The summary results of the ranking are presented in Table 2.

TABLE 2: SUMMARY MAP OF RANK ESTIMATES

Network characteristics	Experts								Sum of ranks
	1	2	3	4	5	6	7	8	
The cost	4	4,5	5	4,5	3,5	5	3,5	4,5	34,5
Number of equipment	2,5	2	1,5	2,5	1,5	3	1,5	2	16,5
Performance	5	4,5	3,5	4,5	5	3	5	4,5	35
Network scalability	2,5	2	3,5	2,5	3,5	3	3,5	2	22,5
Network security	6	6	6	6	6	6	6	6	48
Complexity of implementation	1	2	1,5	1	1,5	1	1,5	2	11,5

To calculate the Kendall-Smith coefficient K, we use the well-known relation

$$K = \frac{\sum_{i=1}^{n}(\sum_{j=1}^{m} r_{ij} - \bar{r})^2}{\frac{1}{12}\left(m^2(n^3-n) - m\sum_{j=1}^{m} T_j\right)} \qquad (11)$$

where r_{ij} is the rank of the i - th indicator of the j - th expert;

$$\bar{r} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} r_{ji}}{n}$$

n is the number of assessed indicators; m is the number of experts in the group;

$$T_j = V_j^3 - T_j$$

where V_j is the number of the same related ranks set by the j-th expert.

Using the calculated relation (11), we obtain

$$K = \frac{926}{\frac{1}{12}(64{,}210 - 8{,}90)} = 0{,}874$$

A high value of the coefficient indicates a good consistency of expert estimates. Nevertheless, let us be convinced of this by checking the hypothesis of consistency statistically using the x^2 criterion. For this purpose, we find the value of the criterion for the rank array of Table 2 by the formula

$$x^2 = \frac{\sum_{i=1}^{n}(\sum_{j=1}^{m} r_{ij} - \bar{r})}{\frac{1}{12}\cdot(mn\cdot(n+1) - \frac{1}{n-1}\sum_{j=1}^{m} T_j)} \qquad (12)$$

Using this formula, we get $x^2 = 34.9$. Let us compare this value with the table value of the criterion for the significance level α = 0.05 and the number of degrees of freedom $f = n$ - 1 (see, for example, [164]) $x^2 = 11.1$. Since the calculated value of the criterion exceeds the tabular value, the hypothesis of the consistency of expert assessments can be considered confirmed. And use the results obtained to develop technical requirements for the design of a wireless computer network of a higher educational institution.

4. CONCLUSIONS

A mathematical model of traffic control in wireless networks is proposed.

Algorithms for managing queues and methods for reconfiguring clusters were used.

The traffic of wireless data transmission in computer networks was modeled using the queue control algorithm - parametric identification, which allows identifying the parameters of the mathematical model of a wireless computer network using only the value of the data transmission window.

The features of the design of wireless networks designed to ensure the educational process in institutions of higher professional education are considered in detail.

The necessity and expediency of using queue management algorithms and cluster reconfiguration methods are substantiated.

The possibility of using the concordance coefficient for comparing the value of the model traffic with the reference value has been substantiated.

The objectification of heuristic and intuitive decisions made in the design process has been carried out.

The work of a group of independent experts on the assessment of the technical and economic characteristics of wireless networks was organized, the results were verified using well-known statistical procedures.

The hypothesis of the consistency of expert assessments was confirmed, with the help of which technical requirements for the design of a wireless computer network of a higher educational institution were developed.

Recommendations and prospects for further development of the topic.

The development of the topic in the future consists in the development of mathematical models that adequately reflect the behavior of queuing systems for the purpose of their effective administration and management using artificial intelligence, as well as mixed flows with limited service time.

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