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OPTIMIZATION OF A BASIC NETWORK IN AUDIO ANALYTICS SYSTEMS

Abstract. **Relevance.** The sound is a source of data that provides information necessary for survival and warns of potential dangers. Audio analytics solutions allows detecting and responding in time to illegal actions and violations of the law, which are accompanied by appropriate sounds. Therefore, the problem of reducing delays in the transmission of audio streams in network-based systems of audio analytics becomes relevant. **The object of research** is the process of audio signals transmitting. **The subject of the research** is mathematical models of audio and video streams transmission in network systems. **The purpose of this paper** is to develop an approximate method for quickly solving optimization equations for a network of connecting links and to assess the adequacy of the developed method. **Research results.** A method for selecting the network structure of the audio analytics system is proposed. The optimization of the network structure of audio analytics system under non-ordinary Poisson load is presented. The optimization of the basic network of audio analytics system was studied according to the cost criterion. Comparisons of the optimization results shows that the given link distribution options are not significantly different from each other and are close in cost.

Keywords: audio analytics; sound event; audio stream; mathematical model; optimization.

Introduction

Relevance. Sound is a source of data; it helps to obtain information necessary for survival or warns of danger. Early response to dangerous sound events can help save lives. Loud events such as gunshots or glass breaking are very easy to detect precisely with the help of audio analytics solutions, and to transmit information about these events to the relevant authorities.

Low latency is an important factor that ensures reliable operation and high performance of multiservice networks. Audio and video analytics solutions are highly dependent on network latency. Increasing the delay by just a few milliseconds can result in distorted picture and sound, software failure, or loss of a life-saving opportunity. Therefore, the task of reducing delays in the transmission of audio streams in network systems of audio analytics becomes urgent.

An overview of scientific works. Many scientific works are devoted to the issues of audio signal transmission in network-based audio analytics systems and audio signal processing in general.

Thus, in [1] a mathematical model of audio signals transmission in network-based audio analytics systems was developed. Articles [2–5] present modern approaches to audio information processing and detection of sound events.

Article [6] discusses the issues of creating a data set for training an audio analytics system. Article [7] is devoted to audio codecs and the issue of audio compression.

Articles [8, 9] discuss the development of mathematical models in network systems. Article [10] is focused on the study of audio data transmission in multiservice networks.

Setting objectives. Therefore, it becomes necessary to optimize the corresponding mathematical models. Based on this, **the goal of this paper** is to optimize the mathematical model of audio signals transmission in network-based audio analytics systems. To do this, it is necessary to develop an approximate method for quickly solving optimization equations for a multiservice network.

The method of choosing network structure for an audio analytics system

Solving the optimization equations for the corresponding basic network structures makes it possible to determine optimal structural parameters of these network fragments under a given limitation on quality of service. However, iterative procedure for obtaining such a solution even for simplest 3-node structure is quite time-consuming, which leads to the need to use approximations that make it possible to reduce number of calculations and, at the same time, guarantee fairly reliable estimates of the considered network parameters.

The conducted studies [1] revealed that when solving optimization equations for basic structures, it is advisable to use the approximations proposed in [8] to optimize the link switching network of a hierarchical structure, because they make it possible to take into account modularity of transmission systems, structure of the switching field and the connection establishment algorithm, and, at the same time, significantly reduce number of calculations.

According to optimization equation for a unidirectional 3-node basic structure, the procedure for solving the algorithm for calculating the capacities of link bundles is iterative in nature and includes following operations:

1. Set initial values β_2 and β_3.
2. Calculate the value H_1 according to equation

$$H_1 = C_1 / \left(C_2 / \beta_2 + C_3 / \beta_3 \right).$$

3. Calculate the capacity of a direct bundle of links $V_1 = f\left(A_1, F_{d1}\right)$ for the value H_1, obtained in item 2 under condition

$$H_1 = -\left(\frac{\partial r_1^e\left(A_1 V_1\right)}{\partial V_1} \right)_{A=const,\, E_{d_1}=const} = -A_1 \frac{\partial E_{V_1}\left(A_1\right)}{\partial V_1},$$

since $V_2 \ \ r_1^e\left(A_1 V_1\right) = A_1 E_{V_1}\left(A\right)$.

4. Calculate: the parameters of excess load from the bundle of links of the first choice V_1, arriving at the first bypass direction – r_1^e, Z_1^e; load parameters received for service on the second connecting line: $r_2 = A_2 + r_1^e$, $Z_2 = \left(A_2 + r_1^e Z_1^e\right) / r_2$; the capacity of the bundle of links on the second connecting line V_2 provided that the losses on the bundle $V_2 : P_2 = P_{acc}$; average value of the load served on the link: $Y_2 = r_2 - r_2^e$ and parameters of the load coming to the third connecting line: $r_3 = A_3 + Y_2$, $Z_3 = \left(r_3 + Y_2 Z_1\right) / r_1^e$; the capacity of the bundle of links on the third connecting line V_3 provided that the losses on the bundle $V_3 : P_3 = P_{acc}$.

5. Calculate the value: $\beta_i = \left(\dfrac{\partial r_1^e}{\partial V_1}\right)_{\substack{Zi=const \\ F_{d_1}=const,\, i=2,3}}$.

6. Compare the value $\beta_i \; (i = 2,3)$ with the specified value ε: if $\beta_2 = \beta_3 \le \varepsilon$, then finish the calculation; if $\beta_2 = \beta_3 > \varepsilon$, then proceed to point 2.

Z-approximation is one of the most effective methods for calculating probability of loss in switching nodes with internal blockages in networks with bypass paths and determining the capacities of link bundles.

According to this approximation, the probability of connection losses on a bundle of links with capacity V and effective availability d_e which receives a load with parameters $\left(R_i, Z_i\right), Z_i > 0$, is defined as:

$$P = E\left(\frac{V}{Z_i}, \frac{R_i}{Z_i}, \frac{d_e}{Z_i}\right) = E\left(\frac{V}{Z_i}, \frac{R_i}{Z_i}, \frac{FdV}{Z_i}\right), \qquad (1)$$

where $E(\bullet,\bullet,\bullet)$ – the Erlang formula for an ideal inaccessible inclusion.

When solving network optimization problems, in the process of its design the availability coefficient F_d is assumed to be known, as well as the permissible amount of connection losses on the path of the last choice and the parameters of initial load (R, Z) are set.

The link bundles capacities of the last choice are calculated at fixed values of the loss values $P_{acc} = P_n$ for the path of the last choice and availability coefficient F_d during determination of the derivative:

$$\left(\frac{\partial Y}{\partial V}\right)_{P_H = const,\, F_d = const}. \qquad (2)$$

Given that the desired derivative (2) is calculated at a fixed value $P_H = const$, it is possible to write:

$$\frac{\partial Y}{\partial V} = \left(1 - P_H\right)\left[\frac{\partial R\left(P_H\right)}{\partial V}\right]_{F_d = const}, \qquad (3)$$

where $R\left(P_H\right)$ – incoming non-Poissonian load at the point P_H.

It follows from expression (3) that the derivative $\partial R / \partial V$ is defined at the point P_H, therefore, it can be assumed that

$$\frac{\partial R}{\partial V} \approx \frac{R\left(V + \Delta V\right)_{P_H = const} - R\left(V - \Delta V\right)_{P_H = const}}{2\Delta V},$$

where $R\left(V + \Delta V\right)$ і $R\left(V - \Delta V\right)$ – load value R in points $\left(V + \Delta V\right)$ and $\left(V - \Delta V\right)$ respectively, by condition $P_H = const$.

Given (1) and the fact that $P_H = const$, it is possible to write:

$$\sum_{x = VF_d / Z}^{V/Z} \left[x\right]_{V/Z} \cdot \sigma(x) = P_H, \qquad (4)$$

where $\left[x\right]_{\frac{V}{Z}}$ і $\left[x\right]_{\frac{V}{Z}}$ – functions *R* and *Z*.

On the basis of previously obtained relations, (4) can be represented as an equation of form $R = f(V)$, under the condition $F_d = const$, $Z = const$.

Equation (4) can be solved using an iterative procedure, which involves finding a derivative of the following form:

$$F'\left(R/Z\right) \approx -\frac{\partial\left(\sum_{x = VF_d / Z}^{V/Z} \left[x\right]_{V/Z} \cdot \sigma(x)\right)}{\partial\left(R/Z\right)}.$$

The definition of the derivative $\left(\dfrac{\partial Y}{\partial V}\right)_{\substack{A=const \\ F_d=const}}$ is reduced to the definition of the derivative $\left(-\dfrac{\partial P}{\partial V}\right)_{\substack{A=const \\ F_d=const}}$, since

$$\frac{\partial Y}{\partial V} = \frac{\partial\left[A\left(1 - P\right)\right]}{\partial V} = \frac{\partial A}{\partial V}(1 - P) = -A\frac{\partial P}{\partial V}.$$

Thus, for the desired derivative, only a numerical value can be found using the integral representation of this formula.

After determining the link bundles capacities of connecting lines, which constitute the path of the last choice, it is possible to calculate the marginal loads β_2 and β_3: $\beta_i = \left(\dfrac{\partial R_i}{\partial V_i}\right)$ by condition $Z_i = const$, $E_i = const$, $F_d = const$ and $i = 2,3$.

In this case, the derivative is calculated in the same way as described above for calculating the derivative given by expression (2).

When solving the optimization equation for a bidirectional three-node basic structure, problem is reduced to considering two 3-node basic structures, into which the considered structure is decomposed. Each of the basic structures is optimized independently, according to the algorithm discussed above.

Optimization of the network structure in an audio analytics system under non-ordinary Poisson load

When creating digital multi-service networks, the problem of optimal distribution of link bundles within such a network is particularly relevant. The application of accurate analytical models is complicated by the complex functional dependence between the probability of losses and structural parameters. In addition, the application of strict analytical models requires a large number of calculations, which limits the size of the analyzed network. Therefore, it seems most appropriate to use approximate models, advantages of which are the uniformity of characteristics calculation and high speed.

Considering a unidirectional three-node basic structure [1], assume that there is a set of K non-ordinary Poisson loads on the link between nodes 1 and 3, which will be replaced by equivalent recurrent loads, which are given by the pair (R_i, Z_i), $i = \overline{1,K}$. In this case, the recurrent load between nodes 1 and 3 is the following:

$$R_1 = \sum_{i=1}^{K} R_i,\ Z_1 = \frac{\sum_{i=1}^{K} R_i Z_i}{R_1}.$$

Thus, in such formulation, the load between nodes 1 and 3 will be the load generated by the recurrent flow and is given by the pair (R_1, Z_1). The nature of the self-loads between nodes 1-2 and 2-3 is not significant, since the resulting loads between these nodes are, as a rule, non-Poisson.

So, assume that there is a proper load between nodes 1 and 3 (R_1, Z_1), a proper Poisson load between nodes 1 and 2 (A_2), and a proper Poisson load between nodes 2 and 3 (A_3).

To optimize the scheme, modify the Pratt equation [9]. Previously, the marginal use was calculated using the formula, in which the incoming load A and the availability coefficient F_d were considered constant:

$$H = \left(\frac{\partial r^e}{\partial V}\right)_{A=const, F_d=const}.$$

Now, unlike this formula, the condition $A = const$ is replaced by the condition $R = const$, $Z = const$, i.e.:

$$H' = \left(\frac{\partial r^n}{\partial V}\right)_{R=const,\, Z=const,\, F_d=const}.$$

Thus, optimization equation in the case of a 3-node network will look like the following:

$$\frac{C_1}{H_1'} = \frac{C_2}{\beta_2} + \frac{C_3}{\beta_3}. \quad (5)$$

In the case of using the optimization equation (5), optimization algorithm of the 3-node network [1] generally coincides with the algorithm discussed above. The difference is only in the procedure for determining the links bundle capacity of the path of the first choice V_1 by the value of the derivative H_1'. Using relation (5) can obtain the following:

$$H' = \frac{C_1}{C_2/\beta_2 + C_3/\beta_3}. \quad (6)$$

On the other hand, the value of this derivative can be approximately determined using the formula:

$$H' = \frac{r_{1,2}^e - r_{1,1}^e}{2\vartriangle V}, \quad (7)$$

where $r_{1,1}^e = f\left((R_1, Z_1), V_1 + \vartriangle V\right)$ – the excess load occurring on the links bundle of the path of the first choice, the capacity of which is equal to $V_1 + \vartriangle V$;

$r_{1,2}^e = f\left((R_1, Z_1), V_1 - \vartriangle V\right)$ – excess load arising on the bundle by capacity $V_1 - \vartriangle V$.

The number of excess loads $r_{1,i}^e$, $i = 1, 2$ can be determined by the formula (1):

$$r_{1,1}^e = R_1 E\left(\frac{R_1}{Z_1}, \frac{V_1 + \vartriangle V}{Z_1}, \frac{F_d\,(V_1 + \vartriangle V)}{Z_1}\right);$$

$$r_{1,2}^e = R_1 E\left(\frac{R_1}{Z_1}, \frac{V_1 - \vartriangle V}{Z_1}, \frac{F_d\,(V_1 - \vartriangle V)}{Z_1}\right).$$

The value of the link capacity of the path of the first choice V_1 can be found iteratively from the solution of equation (7), which in this case will take the following form:

$$H_1' = \frac{R_1 \left[E\left(\frac{R_1}{Z_1}, \frac{V_1 - \vartriangle V}{Z_1}, \frac{F_d\,(V_1 - \vartriangle V)}{Z_1}\right) - E\left(\frac{R_1}{Z_1}, \frac{V_1 + \vartriangle V}{Z_1}, \frac{F_d\,(V_1 + \vartriangle V)}{Z_1}\right) \right]}{2\vartriangle V}, \quad (8)$$

where $\vartriangle V = const$ and is chosen according to the permissible calculation error.

The following iterative equation was used to determine the value V_1 from equation (8):

$$V_1^{[i+1]} = V_1^{[i]}\left(1 - \left(H_{11} - H_{12}\right)\right), \quad (9)$$

where $H_{11} = const$ is from (6), and H_{12} – from (8).

The considered algorithm was tested during the solution of the optimization problem of a unidirectional 3-node network structure [1], for which an exact solution was previously obtained. The influence of non-Poisson load on the nature of optimization will be compared using example of a 3-node network, for which: $A_2 = A_3 = 5$ Erlangs, $C_1 = 1$ and $C_2 = C_3 = 1.5$, $R_1 = 5$ Erlangs, and $Z_1 = 1, 2$ or 4.

The optimization results for three values Z_1 are summarized in the table 1, which shows the results of the network optimization, obtained by exhaustive enumeration.

Table 1 – **Verification of the considered algorithm**

	Load dispersion coefficient					
	$Z_1 = 1$		$Z_1 = 2$		$Z_1 = 4$	
	analyt.	acc.	analyt.	acc.	analyt.	acc.
V_1	7	7	9	10	13	16
V_2	13	12	12	12	14	12
V_3	12	12	13	12	13	12
C	425	430	440	460	510	520
σ,%	1.18		4.55		1.96	

During network optimization, link bundles of the path of the last choice were determined with a fixed weighted average loss of 1%.

The method, generalized to the case of non-Poisson loads, gives results close to optimal (error no more than 6%). Increasing the dispersion coefficient Z_1 causes the first-choice link bundle during optimization to have a higher capacity under the same conditions compared to the case where $Z_1 = 1$.

Optimization of the basic network of audio analytics system according to the cost criterion

The number of links in a switching network is usually calculated on the basis of minimum capital costs criterion with a fixed quality of connection service on the link bundles of the path of the last choice. In addition, it is necessary to comply with the multiplicity requirement of the total number of links in the output and input direct paths bundles to the number of primary module links of the transmission system. However, at the same time, there is some error in determining the capacity of bundles, which is quite difficult to estimate analytically. Search optimization methods can be used as methods for estimating such error, for example, the random search method, which is often effectively used during analysis of individual network fragments.

The objective function C is the total capital costs for organization of communication network:

$$C = \sum_{i \in N} C_i V_i , \tag{10}$$

where C_i – capital costs for organization of one link of the *i*-th direction; V_i – capacity of the bundle of links in the *i*-th direction; N_i – a multitude of all directions.

All bundles of links of the direct path are determined in such a way that the sum of the links in the outgoing and incoming bundles between each pair of nodes is a multiple of the primary group accepted module of the transmission system *M*:

$$V_{in.dp} + V_{out.dp} = kM , \tag{11}$$

where *k* – multiplicity factor ($k > 0$), and the distribution of links for each of these bundles is made on the basis of ensuring the minimum total redundancy of the load.

During the application of random search method, the objective function (10) must be refined by relating the capacity of the bundles $V_i \left(i \in N \right)$ to the parameters of load received on this bundle, the probability of an excess load and the structure of switching node. The influence of the structure of switching node on V_i, is taken into account using the formula:

$$P = E\left(\frac{R_i}{Z_i}, \frac{V_i}{Z_i}, \frac{d_{ei}}{Z_i} \right), \tag{12}$$

where $E\left(\bullet,\bullet,\bullet \right)$ – Erlang's third formula; *P* – probability of the occurrence of excess load; V_i – capacity of the links bundle; R_i – intensity of the load applied to this link; d_{ei} – effective accessibility in the search direction; Z_i – coefficient of dispersion of the incoming load.

To optimize the objective function, it is advisable to use the "algorithm with a return at an unsuccessful step", which belongs to the local methods of step search.

The peculiarity of this method is the reduced tendency to wander in target area. A successful step is a step in which the numerical value of the objective function is less than its value in the previous step. Let some random step be taken in the space of optimized parameters from a point characterized by a vector of links $\overline{V_i}$ and the value of the objective function $C\left(\overline{V_i} \right)$. In this case, new random point will be characterized by a vector $\overline{V}_{i+1}$ and a new value of the objective function $C\left(\overline{V}_{i+1} \right)$. If $C\left(\overline{V}_{i+1} \right) < C\left(\overline{V}_{i+1} \right)$, then the step taken is considered successful, if $C\left(\overline{V}_{i+1} \right) \geq C\left(\overline{V}_{i+1} \right)$ the step is considered unsuccessful and a return to the previous stage of optimization is made.

The formula of this algorithm is the following:

$$C\left(\overline{V}_{i+1} \right) = C\left(\overline{V} + \vartriangle \overline{V}_{i+1} \right), \tag{13}$$

where $$\vartriangle V_{i+1} = \begin{cases} \overline{\alpha \xi} \ if \ C\left(V_i \right) \leq C\left(V_{i-1} \right); \\ -\vartriangle \overline{V_i} \ if \ C\left(V_i \right) > C\left(V_{i-1} \right); \end{cases}$$

$\overline{\alpha}$ – scale vector, which is determined by the possible limits of the variable vector change; $\overline{\xi}$ – *L*-dimensional unit random vector.

Let's optimize the basic network of the audio analytics system (Fig. 1) according to the cost criterion using a random search algorithm.

The following routing algorithm was used: if it is necessary to establish a connection between two stations, use the shortest path principle. If the attempt is unsuccessful, then an attempt is made to establish the connection in a bypass way.

During optimization of the objective function, it is necessary to determine the number of independent variables. According to the requirements for the design of the long-distance communication network, for the *i*-th station, total number of input and output links forming direct path link used for communication with the *j*-th station should be chosen as a multiple of the compaction module (30 links); bundles of bypass intermediate paths are chosen with a multiplicity of one.

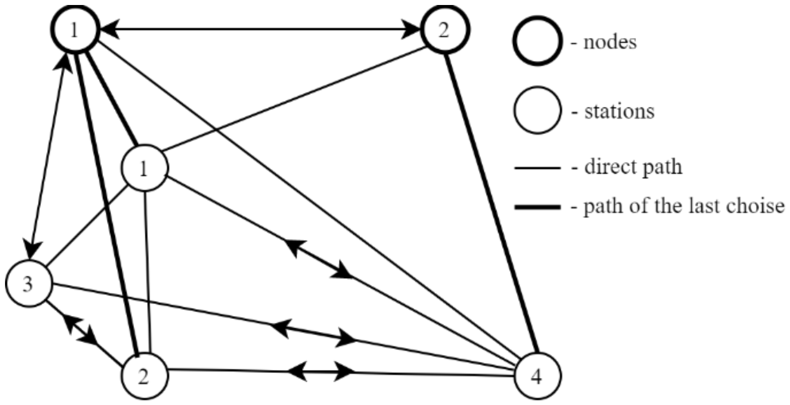

Fig. 1. Scheme of a 2-node network

An enlarged block diagram of the network optimization algorithm based on the cost criterion is shown in Fig. 2.

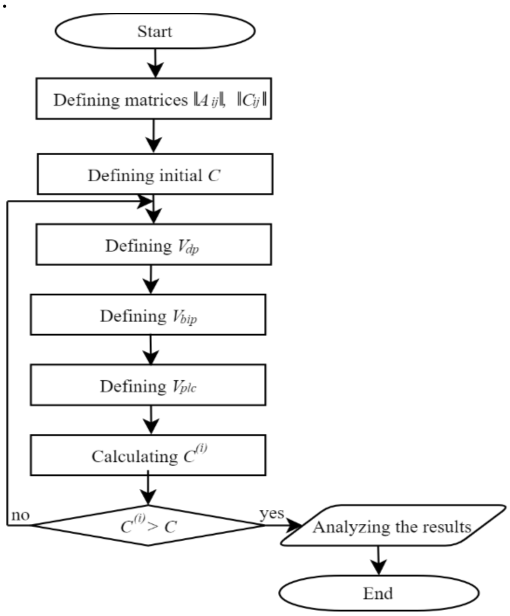

Fig. 2. An enlarged block diagram of the network optimization algorithm

The initial data for optimization were the following: matrix of loads $\left\| A_{ij} \right\|$ between stations (Table 2), matrix of costs of one link between nodes and stations of the network $\left\| C_{ij} \right\|$ (Table 3). It was assumed that all stations and nodes do not have internal blockages. The cost of optimization of this network is *1462,36* units.

The result of network optimization using the random search method is illustrated by the matrix (Table 5), which corresponds to 182 search steps. The capital costs of this variant of link distribution are C = 1451,96 units.

Table 2 – **Matrix of loads between stations**

i	j			
	C_1	C_2	C_3	C_4
C_1	0	49,2	1,5	0,6
C_2	6,1	0	95,2	13,2
C_3	1,9	14,1	0	0,9
C_4	0,4	79,8	0,7	0

Table 3 – **Matrix of costs of one link**

i	j					
	C_1	C_2	C_3	C_4	Y_1	Y_2
C_1	0	3426,5	2453,1	5321,8	3823,7	6502,5
C_2	3922,7	0	1437,4	4562,8	2752,3	5530,3
C_3	2680,1	1263,0	0	4208,5	1833,0	5987,5
C_4	4679,1	4232,0	3899,4	0	4005,4	3211,0
Y_1	3855,8	2600,3	1866,5	4682,0	0	6016,8
Y_2	7005,5	5226,9	6054,1	3022,4	6384,3	0

Table 4 – **Matrix of link bundles**

i	j					
	C_1	C_2	C_3	C_4	Y_1	Y_2
C_1	0	54	4	0	11	0
C_2	8	0	112	14	12	0
C_3	3	18	0	0	8	0
C_4	0	78	0	0	7	6
Y_1	8	17	11	0	0	9
Y_2	0	0	0	10	7	0

Table 5 – **The result of network optimization**

i	j					
	C_1	C_2	C_3	C_4	Y_1	Y_2
C_1	0	59	0	0	10	0
C_2	13	0	106	14	16	0
C_3	0	30	0	0	10	0
C_4	0	81	0	0	8	3
Y_1	8	16	9	0	0	12
Y_2	0	0	0	12	5	0

Table 6 – **The results with internal blockages**

i	j					
	C_1	C_2	C_3	C_4	Y_1	Y_2
C_1	0	59	4	0	9	0
C_2	13	0	115	11	24	0
C_3	4	31	0	0	21	0
C_4	0	72	0	0	17	4
Y_1	7	15	8	0	0	7
Y_2	0	0	0	7	5	0

As it can be seen from the comparison of the optimization results, the link distribution options are not significantly different from each other and are close in cost.

This makes it possible to conclude that the assumptions adopted during the development of the mathematical model of audio signals transmission in network-based audio analytics systems are quite acceptable and do not lead to a significant error when calculating link bundles in the network.

For the above-mentioned conditions, network optimization was also made by the method of random search, assuming that internal blockages are allowed at all stations and nodes (Table 6). Analysis of the table shows that the transition from fully accessible bundles of links in the network o bundles with blocking increases costs by approximately 7% (*C = 1 551,92* units).

Conclusions

The following results were obtained in this paper:

1. A method for selecting the network structure of an audio analytics system was proposed.

2. The case of optimizing the network structure of an audio analytics system under non-ordinary Poisson load was considered.

3. The optimization of the basic network of an audio analytics system was conducted according to the cost criterion, and the optimization results were analyzed.

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Оптимізація базової мережі системи аудіоаналітики

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Анотація. Актуальність. Звук є джерелом даних, він допомагає здобувати інформацію необхідну для виживання або застерігає про небезпеку. Рішення аудіоаналітики дозволяють виявляти та вчасно реагувати на протиправні дії та порушення закону, що супроводжуються відповідними звуками. Тому стає актуальним завдання зменшення затримок у мережних системах аудіоаналітики. **Об’єкт дослідження** – процес передавання аудіосигналів. **Предмет дослідження** – математичні моделі проходження аудіо- і відеопотоків у мережних системах. **Метою даної статті** є розроблення наближеного методу швидкого розв’язання оптимізаційних рівнянь для мережі з’єднувальних ліній та оцінка адекватності розробленого методу. **Результати дослідження.** Запропоновано метод вибору мережної структури системи аудіоаналітики. Виконана оптимізація мережної структури системи аудіоаналітики при неординарному пуасонівському навантаженні. Досліджено оптимізацію базової мережі системи аудіоаналітики за критерієм вартості. Проведені зіставлення результатів оптимізації показують, що наведені варіанти розподілу каналів несуттєво відрізняються один від одного.

Ключові слова: аудіоаналітика; звукова подія; аудіопотік; математична модель; оптимізація.