Management of the Internet of Things System Based on Decision-Making and Optimization Approaches

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Abstract— **In this paper we consider the problem of managing the Internet of things system. Such a system is presented in the form of two subsystems: basic and telecommunication. The structure of the decision-making system in the management of the Internet of things is given. The procedure of formation the optimization problem of multi-alternative aggregation Internet of things subsystems is given. The scheme of distribution a permissible resource for two subsystems is considered.**

I. Introduction

The basis for managing the objects system the Internet of things (IoT) at the strategic level is the decision-making system.

We can structure it by outlining the introduction of control actions, providing the achievement of the set indicators and the level of resource provision, the procedures for constructing the optimization problems of multialternative aggregation of objects of the IoT [1], [2] and a multi-algorithmic procedures of selection variant of rational control.

At the same time, it is necessary to assess the degree of influence of subsystem parameters on the basic indicators of the main IoT system [3], [4]. As one of the systems such a basic system is considered.

The level of formation it is determined by the readiness index putting into service. The achievement of an appropriate intensity threshold by the system contributes to the development of other systems.

The dual nature of the impact of the parameters of the IoT system on the readiness index and indicators of the main system development in the optimization model is reflected by the division into criteria and limitations. The possibility of optimal choice of components of the IoT system is achieved by introducing alternative variables so that a certain set of their values corresponds to a certain set of parameters [5].

The multistage nature of the dependence of the optimization criterion and constraints on the optimized variables requires the construction of mathematical models based on expert information, taking into account the peculiarities of its appearance. After the identification of the mathematical description of these dependencies, the formed multi-alternative optimization model makes it possible to organize the search for a rational variant of the development of facilitating systems of the IoT and management of the development of the basic system [6], [7].

II. Structure of the Decision-Making System and Particularly Components of Its Mathematical Software

Decision-making system is considered as the main tool for managing the IoT system at the strategic level using formalized and expert information (Fig.1).

The first group of procedures included in the mathematical support of the decision support system is associated with the use of calculation algorithms for determining indicators $F_{i_l} = F_{i_l}\left(U_n(w), U_n(r_q)\right), i = \overline{1, I}$, for the main system and subsystems of known algorithms.

Then two groups of basic optimization problems are formed on their basis.

However, the direct solution of these optimization problems with the use of known randomized search algorithms does not take into account the multi-alternative choice of all control components associated with the simultaneous variation of variants of development directions and boundary conditions for the distribution of financial resources.

In this regard, the second group includes multimodule algorithmic procedures for choosing a rational control option [8], [9]. They include a preliminary module for the transformation of basic optimization problems and a final module for making a final decision using expert information, in addition to the known module for the formation of a set of promising options based on the results of randomized search.

The procedures for the formation of basic optimization problems of the IoT system management are specified for the case when we consider telecommunication components as subsystems, the effectiveness of their influence on the main IoT system is determined by the readiness index putting into service [10].

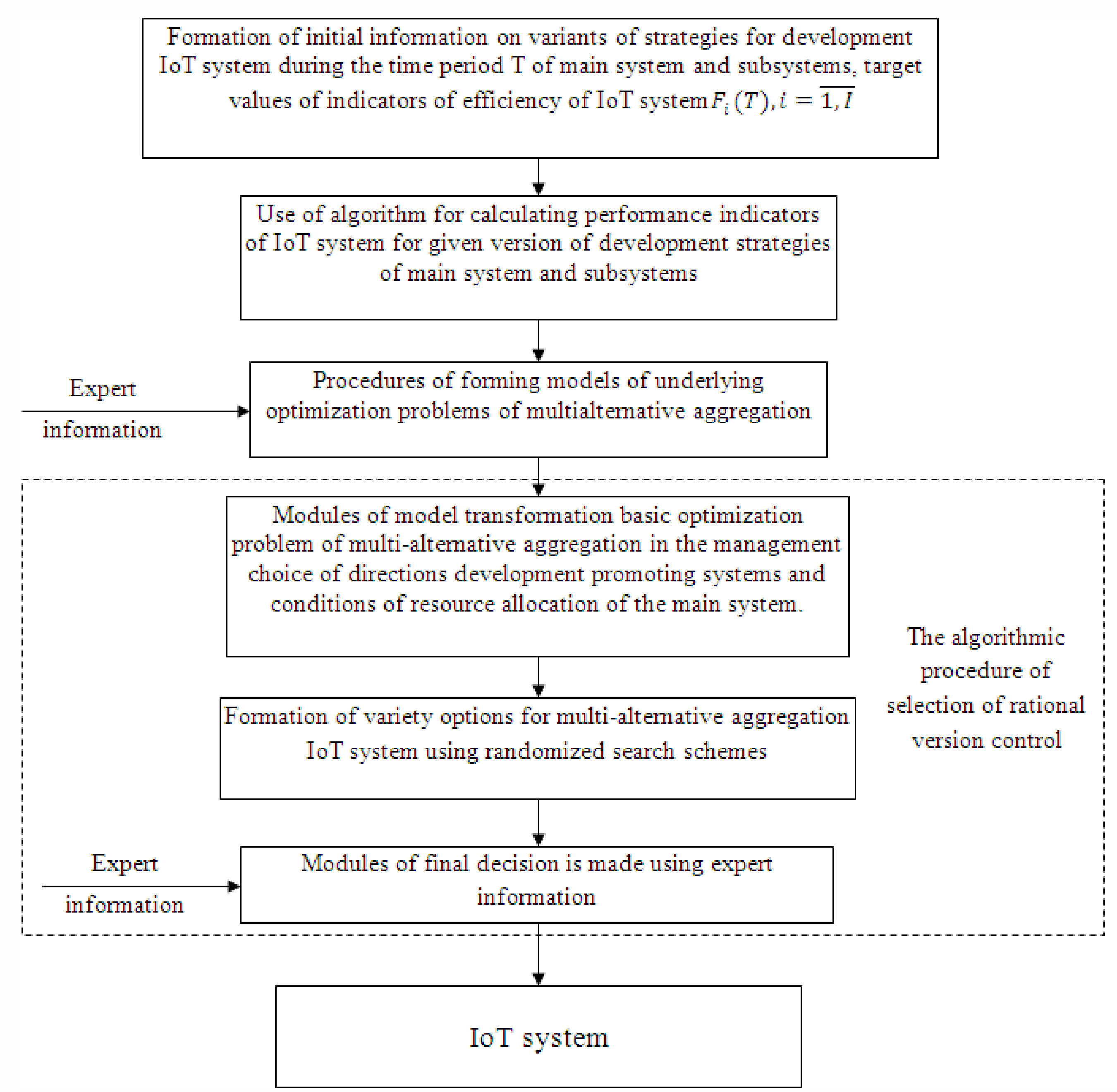

Fig. 1 Structure of the decision-making system in the management of IoT

III. PROCEDURE OF FORMATION OPTIMIZATION PROBLEM OF MULTIALTERNATIVE AGGREGATION SUBSYSTEMS OF IOT

The block diagram of IoT system at the first stage of mathematical support construction requires formalization of problem of optimal decision-making on the choice of perspective directions of system development.

Under optimal decision-making we understand a three-stage procedure, including the analysis of initial information, preparation for decision-making, selection of the optimal solution [11], [12]. Below we look at each of the steps in more detail.

The readiness index putting into service is used as a key criterion of the degree of readiness for complex system of vital activity for large-scale use the telecommunication component. The scheme of construction of readiness index putting into service is shown in Fig. 2.

The index is built on the basis of aggregation values of indicators, and aggregation occurs at several levels, allowing to build regions ratings in separate directions and factors development with various degree of detail [13], [14].

The rankings use complete data sets for all indicators, the reliability of which we consider based on the analysis of the features of the system.

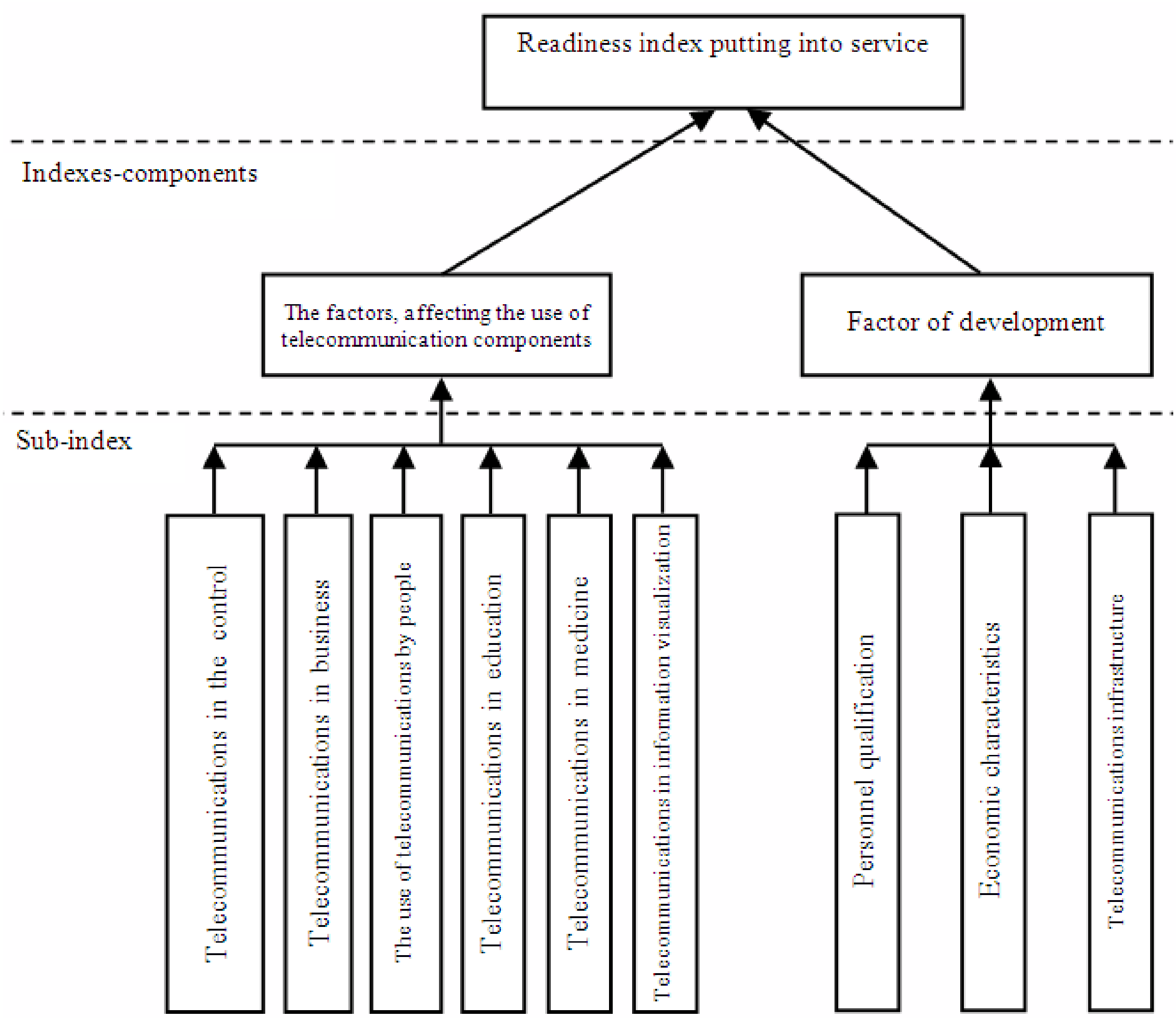

Fig. 2. Structure of the readiness index of the IoT for putting into service

We will formalize the method of calculating the readiness index for putting into service commissioning in the following sequence: sub indexes, index components, readiness index.

At the first stage, the sub indexes $d_{l_1}, l_1 = \overline{1, L_1}$, $d_{l_2}, l_2 = \overline{1, L_2}$, are determined which are calculated on the basis of quantitative parameters characterizing the use of Internet, computer equipment, local area networks, telephony:

$$d_{l_1} = \psi_{l_1}(U_n), l_1 = \overline{1, L_1},\ d_{l_2} = \psi_{l_2}(U_n), l_2 = \overline{1, L_2},$$

where d_{l_1} - sub index related to factors of system development, d_{l_2} - sub indexes related to use of telecommunication components for main system development, $U_n, n = \overline{1, N}$ - quantitative parameters of used telecommunication components, $\psi_{l_1}(\cdot), \psi_{l_2}(\cdot)$ - functions that describe the relationship between values in the sub indexes and values in the parameters.

The next step is to define the index components $d_1 = \varphi_1(d_{l_1})$, $d_2 = \varphi_2(d_{l_2})$, where d_2 - index characterizing the system development, d_2 - index characterizing the use of telecommunication components for main system development, $\varphi_1(\cdot), \varphi_2(\cdot)$ - functions that describe the relationship between index values-component and values of the sub indexes. Finally, readiness index putting into service is determined $d = \varphi(d_1, d_2)$, where $\varphi(\cdot)$ is the function that describes the relationship between index values and values of indices component.

Parameters of telecommunication components [15], [16] $U_n, n = \overline{1, N}$, have a direct impact on the change towards improvement of a number of indicators of the main system development: $F_i = f_i(U_n)$ where $F_i, i = \overline{1,I}$ - the development indicators of the system, $F(\cdot), i = \overline{1,I}$ - functions describing the relationship between values of indicators in main system and values of telecommunication components parameters.

The dependencies $\psi_{l_1}(\cdot), \psi_{l2}(\cdot), \varphi_1(\cdot), \varphi_2(\cdot), \varphi_1(\cdot), F_i(\cdot)$ are set according to the calculation method.

The next stage of decision-making is the formation of a set of criteria and constraints for the optimization problem [17], [18]. As a criterion, the maximization of readiness index putting into service d is proposed. The main limitation serves is resource providing telecommunication component.

$$Z = \sum_{m=1}^{M} \sum_{j=1}^{J} z_{jm}\left(U_{nj}\right) \leq Z^{add},$$

where Z-total costs, $j = \overline{1,J}$ - numbering indices of perspective telecommunication components,

$z_{jm}(\cdot)$ - functions that describe the relationship between the cost values for the implementation of j-th telecommunication component in m-th subsystem of the main system and values of telecommunication component parameters that determine the j-th quality parameter $\left(U_{nj}\right)$,

Z^{add} – necessary resources.

Another group of limitations is related to impact of the use of telecommunication components on the dynamics of development indicators and their achievement of the specified program values $F_i^{np}, i = \overline{1,I}$:

$$F_i = F_i(U_n) \leq F_i^{np}.$$

The set of alternatives on which the choice of the optimal solution is carried out includes a set of perspective telecommunication components. In this case, the choice is formalized by the introduction of alternative variables:

$$\mathrm{x_j} = \begin{cases} 1, \text{if the j-th strategy is used to} \\ \text{develop the telecommunications component} \\ 0, \text{otherwise} \end{cases}$$

where $j = \overline{1,J}$.

The final objective of choice directions development of information and communication component is reduced to the

$$\varphi\left(\varphi_1\left(\psi_{l_1}\left(U_n\left(x_j\right)\right)\right), \varphi_2\left(\psi_{l_2}\left(U_n\left(x_j\right)\right)\right)\right) \to \max, \quad (1)$$

multialternative optimization models:

$$Z = \sum_{m=1}^{M} \sum_{j=1}^{J} z_{jm}\left(U_n\left(x_j\right)\right) \leq Z^{add}, \quad (2)$$

$$F_i\left(U_n\left(x_j\right)\right) \leq F_i^{np}, i = \overline{1,I}, \quad (3)$$

$$\mathrm{x_j} = \begin{cases} 1, \text{if } \mathrm{j} = \overline{1,\mathrm{J}}. \\ \\ 0, \text{otherwise} \end{cases} \quad (4)$$

The block diagram of the formation of the optimization model is shown in Fig. 3.

IV. PROCEDURE OF FORMATION THE OPTIMIZATION PROBLEM MULTI-ALTERNATIVE AGGREGATION IN DEVELOPING SYSTEM

We will consider the development of two subsystems $r_1 \in \overline{1,R_1}$ and $r_2 \in \overline{1,R_2}$.

The first subsystem acts as the main one, the requirements to the performance indicators $F_i^{np}, i = \overline{1,I}$ and the required resource Z^{add} allocated for its development are defined for it.

The second subsystem includes telecommunication components [19], [20].

These components under consideration develop according to their laws.

Management of such a system is based on the optimization model, in which, along with the limiting conditions F_i^{np}, Z^{add}, the optimization criterion d is defined.

To carry out the analysis for the two specified subsystems, we must use a two-stage optimization modeling [21]:

at the first stage, it is necessary to optimally distribute the resource Z^{add} between and into two components $\mathrm{Z_1^{add}}$ and $\mathrm{Z_2^{add}}$;

the second is connected with choosing perspective directions of development r_2, on the basis of and limitations $\mathrm{Z_2^{add}}$ on program indicators $F_{2i}^{np}, i = \overline{1,I}$.

The optimal model of the first stage is based on the resource allocation Z^{add} in accordance with the scheme shown in Fig. 4.

In this scheme, υ_1 and υ_2 are control actions that determine the part of the required resource Z^{add} which is used for promotional systems r_1 and r_2 development. The following restrictions during simulation are imposed on the values υ_1 and υ_2:

$$\upsilon_1 + \upsilon_2 = 1,$$

$$\upsilon_1 = \upsilon_{11}, \ldots, \upsilon_{1s}, \ldots, \upsilon_{1S},$$

$$\upsilon_2 = \upsilon_{21}, \ldots, \upsilon_{2s}, \ldots, \upsilon_{2S},$$

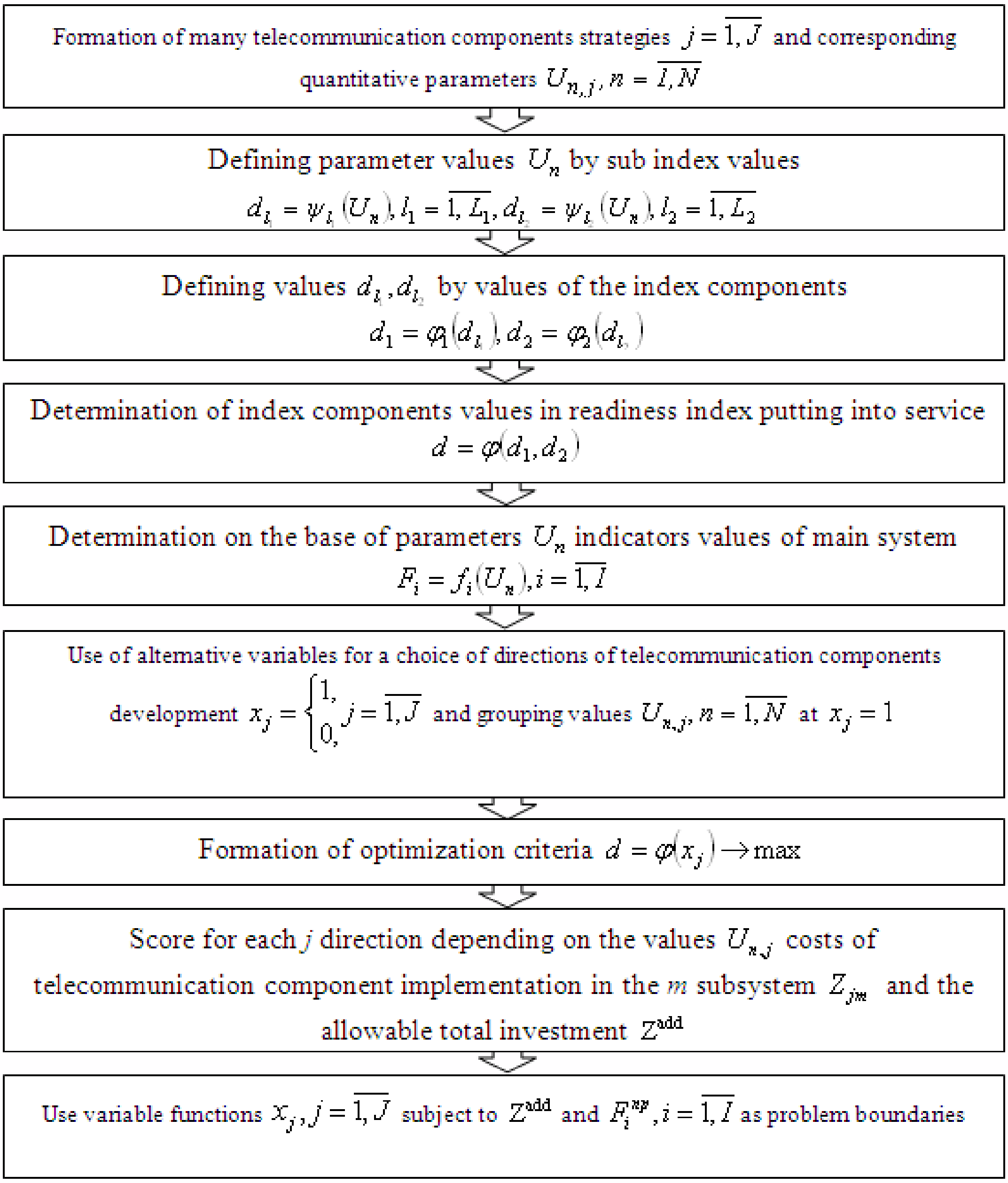

Fig. 3. Block diagram of optimization model formation for telecommunication system components

where υ_1 and υ_2 - a set of discrete values that can take control actions. The choice of a particular impact υ_2, completely determines the value $\upsilon_{1s}=1-\upsilon_2$.

Since the system is switched on at the time interval of the system development r_1, for optimization modeling [21] we will keep the criterion d of the first system, which in this case will depend on two groups of alternative variables $x_{1j}, j=\overline{1,J_1}$ and $\upsilon_s, S=\overline{1,S}$:

$$d=\varphi_1(\psi_l(U_{1n}(x_{1j},\upsilon_s))),\varphi_2(\psi_l(U_{1n}(x_{1j},\upsilon_s))),$$

where U_{1n} -parameters of the first subsystem r_1.

At the same time, the second subsystem should be allocated a resource that will exceed the threshold of intensity of use, after which the development of the subsystem begins:

$$Z^{add}\upsilon_{2s}(\upsilon_s)\geq Z^{lim},$$

where Z^{add} -the threshold level of the developing resource, the record $\upsilon_{2s}(\upsilon_s)$ means the dependence of the control action υ_{2s} on the value of the alternative variable υ_s.

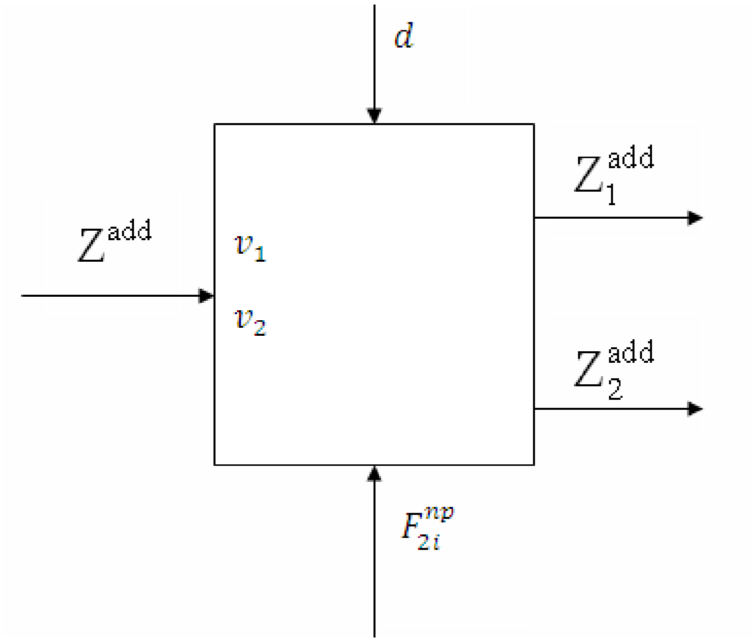

Fig. 4. The block diagram of admissible resource distribution for two subsystems

The final multi-alternative optimization model has the form

$$\varphi\left(\varphi_1\left(\psi_l\left(U_{1n}\left(x_{1j},\upsilon_s\right)\right)\right),\varphi_2\left(\psi_l\left(U_{1n}\left(x_{1j},\upsilon_s\right)\right)\right)\right)\to \max,$$

$$Z^{add}\upsilon_{2s}(\upsilon_s)\geq Z^{lim}$$

$$F_i(U_{1n}(x_{1j}))\leq F_i^{np}, i=\overline{1,I},$$

$$\sum_{m=1}^{M}\sum_{j=1}^{J} z_{jm}\left(U_{1n}\left(x_{1j}\right)\right)\leq Z^{add}\left(1-\upsilon_{2s}\left(\upsilon_s\right)\right)$$

$$F_i(U_{1n}(x_{1j}))\leq F_i^{np}, i=\overline{1,I},$$

$$x_{1j}=\begin{cases}1, \text{if } j=\overline{1,J}\\ 0, \text{otherwise}\end{cases},$$

$$\upsilon_s=\begin{cases}1, \text{if } s=\overline{1,S}.\\ 0, \text{otherwise}\end{cases}.$$

At the second stage, under certain conditions $x_{1j}^*, j=\overline{1,J_1}$ and $\upsilon_s^*, s=\overline{1,S}$, a multi-alternative optimization model of the choice of perspective directions (strategies) of the r_2 subsystem development during simulation is formed .

In this case, an indicator d similar to the intensity of the use of telecommunication components is used as an optimization criterion, and the limitations are similar to (2) and (3).

The indicator d_2 has the structure as d, multi-alternative optimization model on a set of variables is used

$$x_{2j}=\begin{cases}1, \text{if } j-\text{th direction}\\ \text{(strategy) development}\\ \text{of subsystem } r_2\\ 0, \text{otherwise}\end{cases}, j=\overline{1,J_2}$$

it is written as follows

$$d_2=\varphi\left(U_{2n}\left(x_{2j}\right)\right)\to \max,$$

$$\sum_{m=1}^{M}\sum_{j=1}^{J} z_{jm}\left(U_{2n}\left(x_{2j}\right)\right)\leq \upsilon_s^* Z^{add},$$

$$F_i U_{2n}\left(x_{2j}\right)\leq F_i^{np}$$

$$x_{1j}=\begin{cases}1, \text{if } j=\overline{1,J},\\ 0, \text{otherwise}\end{cases},$$

where U_{2n}-parameters of the second subsystem r_2.

The block diagram of two-stage optimization modeling of system that consisting of two subsystems is shown in Fig. 5.

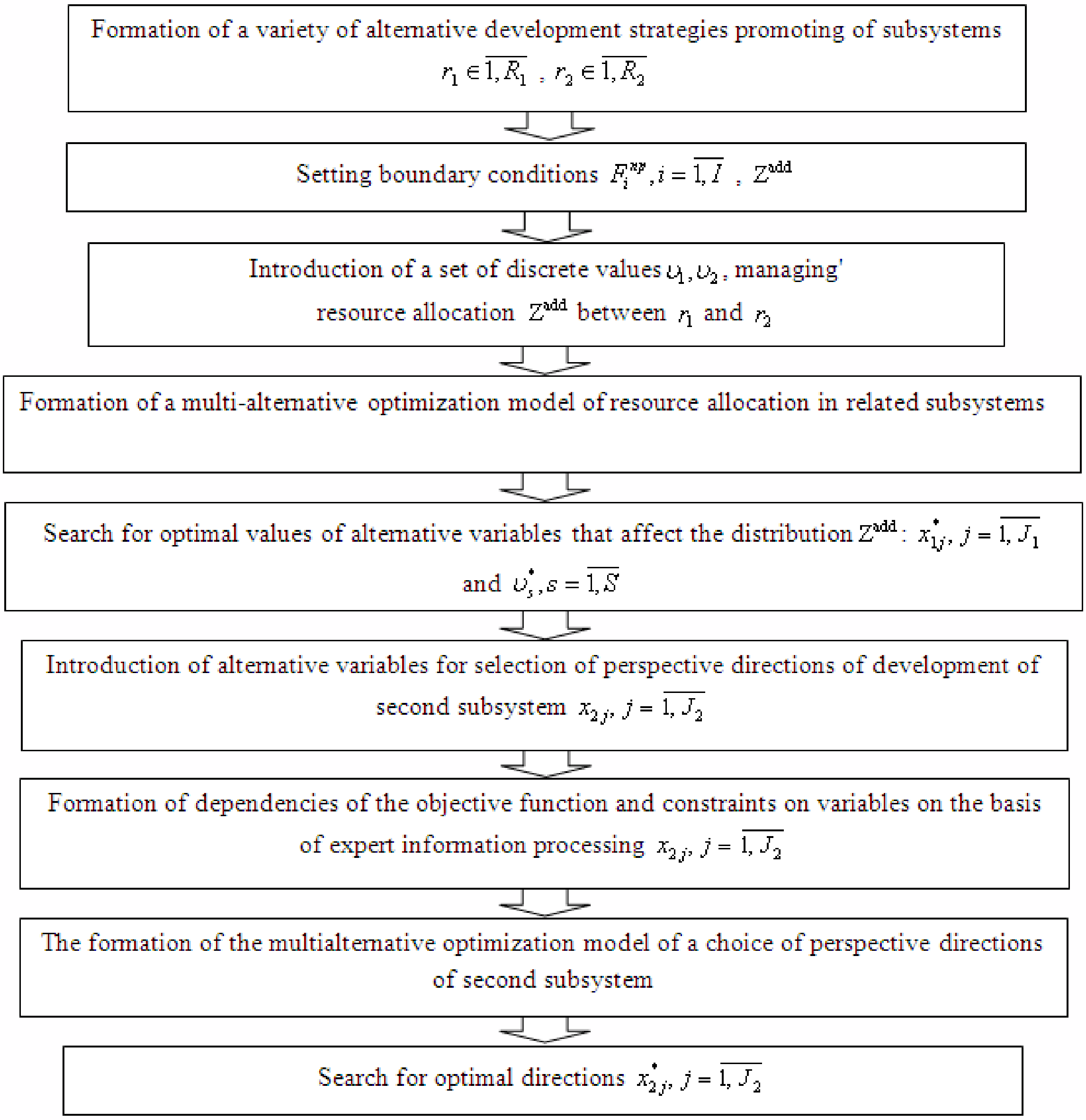

Fig. 5. Block diagram of two-stage optimization modeling of two subsystems.

V. RESULTS

Based on the analysis of the two subsystems, the basic requirements for planning within the organization, which employs 1800 people, you can implement a strategy to stimulate the development according technology.

During simulation by use of algorithm, based on two-stage optimization modeling of two subsystems we obtain some results.

On Fig. 6 the growing number of components that belong to first (1 – without optimization, 2 – with optimization) and second subsystem (3 – without optimization, 4 – with optimization) in organization are shown.

You can see that the gain due to optimization was more than 5 %.

As the main trends of scientific and technical development of the infocommunication system in the planning horizon of about 10 years some technologies are projected:

- cloud computing, reducing consumer spending on it due to the lack of need to build and maintain their own infrastructure and applications, and also due to economies of scale with providing the user of the equipment and software;

- mechanisms of collection, storage, processing and analysis of huge amounts of data, for the implementation of which there is not enough capacity of database systems available to the customer, with the receipt of information to ensure the adoption of the necessary decisions;

- M2M technology (from machine to machine), IOT, ensuring the implementation and development of complex Autonomous systems that interact with the surrounding reality

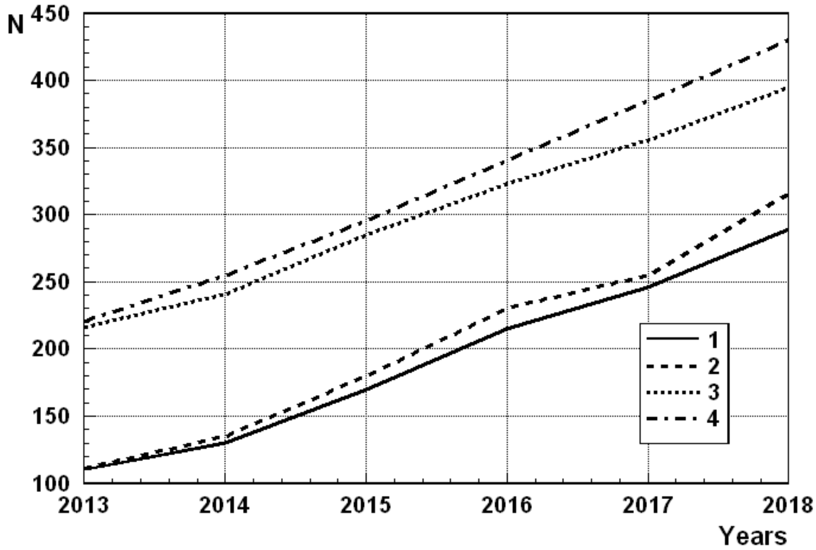

Fig. 6. Growing number of components that belong to first and second subsystem in organization

in all spheres of life support, in production, by including in the network infrastructure with the equipment sensors and actuators of various material objects;

- increase production efficiency through the use of intelligent devices and technologies;

- cybersecurity as a set of measures to achieve and maintain the security properties of cyber resources, including a set of tools, strategies, security principles, security guarantees, guidelines, approaches to risk management, actions, training, practical experience, insurance and technologies that can be used to protect the cyber environment, organization and user resources;

- further development of communication technologies with a data transfer rate of more than 1 Gbit/s and the introduction of a standard of universal electronic communications platform for the transmission of multimedia 3D content and virtual reality applications, combining the capabilities of satellite, terrestrial and fiber ICT technologies after acquiring a new quality, due to convergent NBIC technologies - convergence (NBIC=Nano+Bio+Info+Cognitive).

Within the framework of the above it is planned to develop a number of specific technologies:

- data mining class methods: association rule learning, classification (new data categorization methods based on principles previously applied to already existing data), cluster analysis, regression analysis;

- data mixing and integration - a set of techniques to integrate heterogeneous data from a variety of sources for deep analysis, as examples of such techniques that make up this class of methods, are digital signal processing and natural language processing;

- artificial neural networks, network analysis, optimization, including genetic algorithms;

- pattern recognition;

- predictive analytics;

- simulation modeling;

- spatial analysis-a class of methods that use topological, geometric, and geographic information in the data;

- statistical analysis;

- visualization of analytical data-presentation of information in the form of figures, diagrams, using interactive features and animations for both results and for use as input data for further analysis.

- identification (RFID, bar codes, Data Matrix, QR codes, means of determining location in real time etc.);

- measurements (from sensors (e.g. temperature, pressure, light, smart meters) to complex integrated measurement systems);

- human-object artificial intelligence interfaces, including recognition and reaction systems;

- artificial intelligence;

- service information technologies based on high-performance systems with elements of artificial intelligence operating in all spheres of human activity;

- robots and nanorobots, bio-and quantum computing systems

- software that allows to implement new production and business processes, including:

- organization and systematization of content;

- content delivery and tracking;

- parallel and distributed data processing;

- conducting regulated processes on the Internet;

- organization of joint work (collaboration) and virtual communities (community);

- modelings.

VI. CONCLUSION

In this paper we have developed an algorithm for multi-alternative optimization of the IoT system. The main conclusions that can be drawn from the investigation:

1. The procedures of formation of optimization problems of multi-alternative aggregation of IoT subsystems differ in the way of introduction of alternative variables through multi-stage dependence of criteria and restrictions and allow to pass to algorithmization of search of the maximum efficiency of development of system at accomplishment of boundary conditions of distribution of the used resource.

2. At the first stage of optimization modeling, it is advisable to carry out a meaningful description of the impact of the telecommunication component management of the development of the main subsystem by including in the structure of management decision-making optimal choice of telecommunication components, taking into account their impact on the indicators of the development program, and the index of readiness for implementation.

3. When constructing an optimization model for the selection of telecommunication components focused on the management of a complex system, it is effective to move from multi-stage dependencies between the indicators highlighted in the content description and the parameters of telecommunication components to the corresponding dependencies on alternative variables that determine the selection of components directly.

4. For optimization modeling of two subsystems of the IoT it is expedient to pass to two-stage procedure of a multi-alternative choice of operating influences on distribution of a necessary resource between subsystems.

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