РАДІОТЕХНІКА, ТЕЛЕКОМУНІКАЦІЯ ТА ЕЛЕКТРОНІКА

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INTRODUCTION INTO THE GENERAL THEORY OF INFOCOMMUNICATIONS

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ВСТУП У ЗАГАЛЬНУ ТЕОРІЮ ІНФОКОМУНІКАЦІЙ

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ВВЕДЕНИЕ В ОБЩУЮ ТЕОРИЮ ИНФОКОММУНИКАЦИЙ

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Abstract. Further development of telecommunications and the desire to improve the efficiency of communication systems led to the creation of a new theory - the theory of electrical communication, the core of which is the theory of signal transmission. Both electromagnetic oscillations and information were already the focus of this theory. The notion of a "signal" appeared as an electromagnetic oscillation carrying information. The next step in the progressive development of telecommunications was caused by the growth of a communication network. This was due to a sharp increase in the number of users and the need to establish connections between any subscribers, regardless of their location. There was a need to switch information flows. Thus, the theory of mass service was applied, and the theory of information distribution arose. These theories no longer used the notion of an oscillation-signal. They considered information without a relative physical carrier. Based on the laws of the evolution of sciences, a conclusion has been made about the need for the general theory of infocommunications. Two definitions of infocommunications are given, both as of a branch of the economy and as a technical and technological system. A mathematical model of the open systems interaction was used to describe the functioning of infocommunication systems. The problem of analysis and synthesis of the infocommunication system has been formulated in a general way.

Key words: theory, infocommunications, open system, interaction, service, operator, probability of an error, delay, reliability.

Анотація. Подальший розвиток телекомунікацій та прагнення підвищити ефективність систем зв'язку привели до створення нової теорії - теорії електричного зв'язку, стрижнем якої є теорія передачі сигналу. І електромагнітні коливання, і інформація вже були в центрі уваги цієї теорії. Поняття "сигнал" постало як електромагнітне коливання, що несе інформацію. Наступний крок у прогресивному розвитку телекомунікацій був викликаний зростанням мережі зв'язку. Це було пов'язано з різким збільшенням кількості користувачів та необхідністю встановлення зв'язків між будь-якими абонентами, незалежно від їх місцезнаходження. Виникла необхідність перемикати інформаційні потоки. Таким чином, була застосована теорія масового обслуговування, і виникла теорія поширення інформації. Ці теорії більше не використовували поняття сигналу коливань. Вони розглядали інформацію без відносно фізичного носія. На основі законів еволюції наук зроблено висновок про необхідність загальної теорії інфокомунікацій. Дано два визначення інфокомунікацій - як для галузі економіки, так і для техніко-технологічної системи. Для опису функціонування інфокомунікаційних систем була використана математична модель взаємодії відкритих систем. Задача аналізу та синтезу інфокомунікаційної системи була сформульована у загальному виді.

Ключові слова: теорія, інфокомунікації, відкрита система, взаємодія, сервіс, оператор, ймовірність помилки, затримка, надійність.

Аннотация. Дальнейшее развитие телекоммуникаций и стремление повысить эффективность систем связи привели к созданию новой теории - теории электрических коммуникаций, ядром которой является теория передачи сигналов. И электромагнитные колебания, и информация уже были в центре внимания этой теории. Понятие «сигнал» появилось как электромагнитное колебание, несущее информацию. Следующий шаг в прогрессивном развитии телекоммуникаций был вызван ростом сети связи. Это было связано с резким увеличением количества пользователей и необходимостью устанавливать соединения между любыми абонентами, независимо от их местоположения. Возникла необходимость переключения информационных потоков. Таким образом, была применена теория массового обслуживания, и возникла теория распространения информации. Эти теории больше не использовали понятие колебательного сигнала. Они считали информацию без относительно физического носителя. На основании законов эволюции наук сделан вывод о необходимости общей теории инфокоммуникаций. Дается два определения инфокоммуникаций – как для отрасли экономики, так и для технической и технологической системы. Математическая модель взаимодействия открытых систем была использована для описания функционирования инфокоммуникационных систем. Задача анализа и синтеза инфокоммуникационной системы сформулирована в общем виде.

Ключевые слова: теория, инфокоммуникации, открытая система, взаимодействие, сервис, оператор, вероятность ошибки, задержка, надежность.

In recent decades, scientific and technological progress has significantly changed society, which transformed from industrial to informational. In the process of this transformation, new knowledge was created that was the driving force in scientific and technological progress. The process of the formation of sciences, scientific directions and theories is a monotonically increasing function with discontinuities of the first kind, i.e. in the beginning there is an accumulation of knowledge and at some point, in time there comes the realization of the need to make communication in the form of a new theory. Genetics, cybernetics, and computer science have come into being not long ago. Let us first consider the process of the formation of theories within the framework of the "Telecommunications".

A brief look into the past shows that the invention of the telegraph, telephone, radio and their scientific justification started in physics. There was a need to develop more sophisticated equipment and a more sophisticated element base due to the need to transfer more and more information. It was impossible to solve this problem based on previous theory. Therefore, physics gave start to electronics (micro- and nanoelectronics), the theory of electrical circuits, and the theory of the electromagnetic field. The object of their study was electromagnetic oscillations.

Further development of telecommunications and the desire to improve the efficiency of communication systems led to the creation of a new theory - the theory of electrical communication, the core of which is the theory of signal transmission. Both electromagnetic oscillations and information was already the focus of this theory. The notion of a "signal" appeared as an electromagnetic oscillation carrying information. The next step in the progressive development of telecommunications was caused by the growth of a communication network. This was due to a sharp increase in the number of users and the need to establish connections between any subscribers, regardless of their location. There was a need to switch information flows. Thus, the theory of mass service was applied, and the theory of information distribution arose. These theories no longer used the notion of an oscillation-signal. They considered information without a relative physical carrier.

The next transformation in telecommunications was caused by the emergence of computers, especially personal computers. There was a breakthrough in data processing, modelling, programming, management, etc. However, in the beginning, computers were not interconnected. Remember that the first databases were local. That is, they were kept on the same computer and were not accessible to other computers. Thus, information and telecommunication technologies (telecommunications) were separated from each other.

Today, these technologies are closely interconnected, so that they cannot function at full capacity without each other. Quantitative changes in computer technology, software and telecommunications led to the appearance of a qualitatively new phenomenon. At the same time, new problems emerged that could not be solved within the framework of the aforementioned theories, for example, providing open system interactions, flow management, cyber security, etc.

The final result of the study is not the calculation of fields, currents, voltages, and signals. At present, the final result of the study is the quantity and quality of service delivery. At the same time, the overwhelming volume of traffic falls in information services: video on demand, distance learning, access to data banks, telemedicine, etc. The development of the Internet of Things (IoT) has led to the need to provide tele-automatic services (for example, switching on or off household appliances from a distance). It should be noted, however, that the old theories continue to develop successfully and fruitfully, solving increasingly complex problems. The emergence of new theories puts ever-increasing demands on the already traditional theories that were mentioned above. This has been well-illustrated in numerous publications [1-5].

Naturally, there is new terminology. First of all is **infocommunications**, which is widely used in literature (unfortunately, the definition of the term "infocommunication" is not standardized).

The influence of these transformations on all the aspects of human activity is so great that infocommunications have become the cause of the third and fourth industrial revolutions [6,7]. Therefore, there was a need to comprehend the ongoing processes of knowledge accumulation at the present stage and make relevant conclusions and generalizations.

Considering such an important role of infocommunications, it is necessary to develop a corresponding theory.

Therefore, the goal was set: to formulate the basic principles of the general theory of infocommunications.

The purpose of this work is to work out the proposals for the creation of a basis for a new theory reflecting the present state and level of accumulated knowledge – the general theory of infocommunications.

Main definitions, the subject and the purpose of the theory of infocommunications. The theory begins with definitions. The emergence of a new theory always takes place in the existing ones. The forefront of "Infocommunications" were "Telecommunications" and "Information". Several definitions are directly or indirectly linked to them: telecommunication and information systems and networks, telecommunication facilities, services (information and telecommunication), global information infrastructure, and others. It is clear, the same or similar definitions should exist in the theory of infocommunications.

In the literature there is a whole range of definitions of infocommunications. Let us divide these definitions into two types. One type reflects the economic aspects of infocommunications, and the other is techno-technological one. Summarizing the relevant information in literary sources, we formulate the definition of the "Infocommunications" concept for each type:

- Infocommunications as a branch of the economy.
- Infocommunication is a new branch of the economy which creates an information space for the effective functioning of other sectors of the economy, science, education, the state and global society, in general.
- Infocommunication as a technical and technological system.
- Infocommunication as a technical and technological system. Infocommunication is a system-forming set of telecommunication and information resources united into a single system for the provision of information, telecommunication, and other services inherent to the information society.

- Infocommunication service is what is offered by the infocommunication system to the consumer in order to meet their needs that are connected with the information transmission and processing.
- The infocommunication system is the aggregate of all the means (telecommunication systems, telecontrol and automation, information resources, robotics, artificial intelligence), that provide information-communication services.

The subject of the general theory of infocommunication is a set of methods and means providing information and communication services.

Classification of services.

There is a classification of services in accordance with various attributes. However, as for the quality of the services provided, it is suggested to divide the services into groups regarding their sensitivity to errors and delays. Considering this attribute, there are four types of services:

1. Sensitive to errors and not very sensitive to delay.
2. Sensitive to delays and not very sensitive to errors.
3. Sensitive to both errors and delays.
4. Not sensitive to errors or delays.

As in any theory, the general tasks of the GTIC (General Theory of Infocommunications) are the analysis and synthesis of infocommunication systems.

The task of the analysis is to find indicators of the quality of service (service delivery) based on the given infocommunication system and the traffic of applications.

The task of synthesis is to build an infocommunication system that is optimal to the chosen criterion, based on the specified range of services and quality of service indicators. It goes without saying that the task of analysis is explicit, and synthesis is multivalent.

Mathematical description of the open system interaction model. These problems are too complex, so they need to be structured. In cybernetics, the process of structuring is called the "decomposition problem".

It is suggested to perform such a structuring with the help of the generalizations of the open system interaction model, which consists, in a general case, of a certain number of levels (sublevels) and planes (subplans) (Fig. 1) [8,9]. The front face of the parallelepiped is the standard image of the Open System Interconnection (OSI/ISO) reference model.

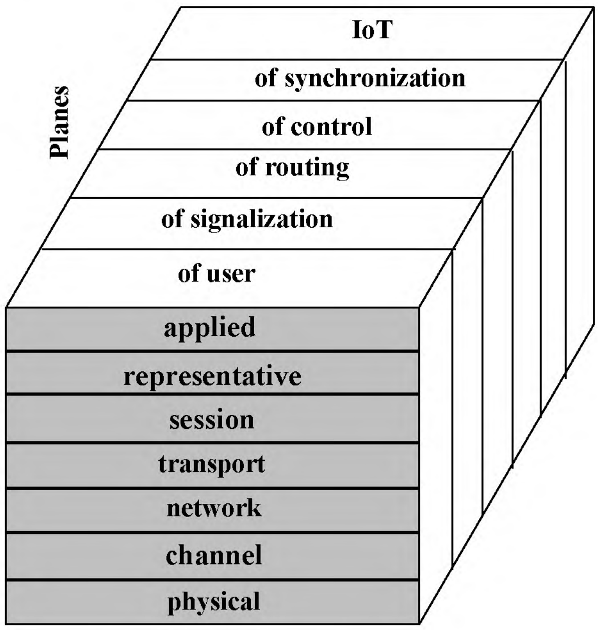

Figure 1 – Graphical image of the verbal generalized sample OSI model

Fig. 2 shows the same model, but in a different, more constructive form.

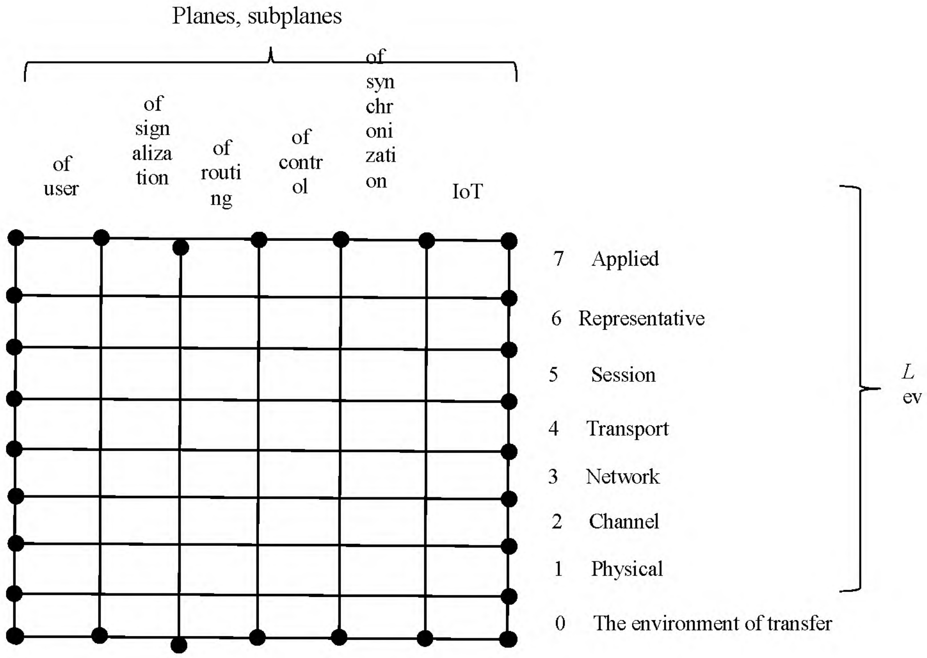

Figure 2 – Two-dimensional generalized EM OSI

Carrying out similar trains of thought, we can write the signal at the output of the k^{th} level of the i^{th} plane.

$$S_k^{(i)\downarrow} = \mathrm{A}_{ik}^{\downarrow}[\mathrm{A}_{i,k-1}^{\downarrow}[\mathrm{A}_{i,k-2}^{\downarrow}\dots\mathrm{A}_{i2}^{\downarrow}[S_1^{(i)\downarrow}]]. \qquad (1)$$

The connection between the data streams at the input and output of the second level of the S-model is expressed by the matrix equation.

$$\begin{bmatrix} S_2^{(1)\downarrow} \\ S_2^{(2)\downarrow} \\ \dots \\ S_2^{(i)\downarrow} \\ \dots \\ S_2^{(M)\downarrow} \end{bmatrix} = \begin{bmatrix} \mathrm{A}_{12}^{\downarrow} & 0 & \dots & 0 & \dots & 0 \\ 0 & \mathrm{A}_{22}^{\downarrow} & \dots & 0 & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & \mathrm{A}_{i2}^{\downarrow} & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & .. \\ 0 & 0 & \dots & 0 & \dots & \mathrm{A}_{M2}^{\downarrow} \end{bmatrix} \begin{bmatrix} S_1^{(1)\downarrow} \\ S_1^{(2)\downarrow} \\ \dots \\ S_1^{(i)\downarrow} \\ \dots \\ S_1^{(M)\downarrow} \end{bmatrix}. \qquad (2)$$

This equation establishes a relationship between the applied-level vector of all planes and the transformed signal vector at the input of the second level.

The transformation of the signal vector by any level is described by the following equation:

$$\begin{bmatrix} S_k^{(1)\downarrow} \\ S_k^{(2)\downarrow} \\ \dots \\ S_k^{(i)\downarrow} \\ \dots \\ S_k^{(M)\downarrow} \end{bmatrix} = \begin{bmatrix} \mathrm{A}_{1k}^{\downarrow} & 0 & \dots & 0 & \dots & 0 \\ 0 & \mathrm{A}_{2k}^{\downarrow} & \dots & 0 & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & \mathrm{A}_{ik}^{\downarrow} & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & .. \\ 0 & 0 & \dots & 0 & \dots & \mathrm{A}_{Mk}^{\downarrow} \end{bmatrix} \begin{bmatrix} S_{k-1}^{(1)\downarrow} \\ S_{k-1}^{(2)\downarrow} \\ \dots \\ S_{k-1}^{(i)\downarrow} \\ \dots \\ S_{k-1}^{(M)\downarrow} \end{bmatrix}. \quad (3)$$

Let us determine the relationship between the signals at the input and output of the transmission medium. It is obvious that the signals of any plane are transformed by the same transfer function, which characterizes the transmission medium. This transformation is described by the matrix equation

$$\mathbf{S}^{\uparrow} = \mathbf{H}\mathbf{S}^{\downarrow}, \quad (4)$$

where $\mathbf{S}^{\uparrow}$ – is the matrix-column of signals of all planes at the output of the transmission medium (input of the first level of the [OS model of the receiving system);

$\mathbf{S}^{\downarrow}$ – the matrix-column of signals of all planes at the output of the N-level of the transmission medium of the model;

H – is a diagonal matrix, all elements of which are the operator $\mathbf{H}_{ii}$,where i = 1, M. In this case, $H_{11} = H_{22} = H_{MM}$.

This operator can be a complex function of an imaginary or complex variable or a convolution integral.

The second I-model is described by the same equations and symbols. It is enough to replace *S* by *I*, A by α.

$$I_k^{(i)\downarrow} = \alpha_{ik}^{\downarrow}[\alpha_{i,k-1}^{\downarrow}[\alpha_{i,k-2}^{\downarrow} \dots \alpha_{i2}^{\downarrow}[I_1^{(i)\downarrow}]], \quad (5)$$

$$\begin{bmatrix} \mathrm{I}_2^{(1)\downarrow} \\ \mathrm{I}_2^{(2)\downarrow} \\ \dots \\ \mathrm{I}_2^{(i)\downarrow} \\ \dots \\ \mathrm{I}_2^{(M)\downarrow} \end{bmatrix} = \begin{bmatrix} \alpha_{12}^{\downarrow} & 0 & \dots & 0 & \dots & 0 \\ 0 & \alpha_{22}^{\downarrow} & \dots & 0 & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & \alpha_{i2}^{\downarrow} & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & .. \\ 0 & 0 & \dots & 0 & \dots & \alpha_{M2}^{\downarrow} \end{bmatrix} \begin{bmatrix} \mathrm{I}_1^{(1)\downarrow} \\ \mathrm{I}_1^{(2)\downarrow} \\ \dots \\ \mathrm{I}_1^{(i)\downarrow} \\ \dots \\ \mathrm{I}_1^{(M)\downarrow} \end{bmatrix}; \quad (6)$$

$$\begin{bmatrix} \mathrm{I}_k^{(1)\downarrow} \\ \mathrm{I}_k^{(2)\downarrow} \\ \dots \\ \mathrm{I}_k^{(i)\downarrow} \\ \dots \\ \mathrm{I}_k^{(M)\downarrow} \end{bmatrix} = \begin{bmatrix} \alpha_{1k}^{\downarrow} & 0 & \dots & 0 & \dots & 0 \\ 0 & \alpha_{2k}^{\downarrow} & \dots & 0 & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & \alpha_{ik}^{\downarrow} & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & .. \\ 0 & 0 & \dots & 0 & \dots & \alpha_{Mk}^{\downarrow} \end{bmatrix} \begin{bmatrix} \mathrm{I}_{k-1}^{(1)\downarrow} \\ \mathrm{I}_{k-1}^{(2)\downarrow} \\ \dots \\ \mathrm{I}_{k-1}^{(i)\downarrow} \\ \dots \\ \mathrm{I}_{k-1}^{(M)\downarrow} \end{bmatrix} \quad (7)$$

It should be noted that there are OSI models with a different number of levels. The reference model of the OSI has seven layers, the Internet model - four layers. The problem is to choose the number of layers of the model. Generally speaking, the number of layers can be quite big and everything depends on the task to be solved and the developer's aim.

The minimum number of layers is determined by the number of basic tasks solved by the infocommunication system. Let's list these tasks:

1. Formation of a service - application layer.
2. Information distribution - network layer.
3. The formation of a signal transmission and the reception of a signal – the physical layer.

Such a model was first described in [10].

Mathematical model of the infocommunication system. In accordance with the classification, the quality of services is determined mainly by the probability of error and delay. The error probability is a function of a vector ξ_{ik} whose elements are input signals, matrix-functions, and interference vectors as well.

$$P_{\text{ош}} = \Phi_1[\mathbf{A}_{ik}, \alpha_{ik}, S_{\text{вх}}, \xi_{ik}], \tag{8}$$

The signal delay depends on the same functions as the error probability. So,

$$\tau(t) = \Phi_2[\mathbf{A}_{ik}, \alpha_{ik}, S_{\text{вх}}, \xi_{ik}]. \tag{9}$$

Consequently, the analysis problem is to determine $P_{\text{ош}}$,and $\tau(t)$ from the given matrices by the functions $\mathbf{A}_{ik}$ and α_{ik}, the noise vectors ξ_{ik}, and also the functionals Φ_1 and Φ_2.

Besides, it is necessary to calculate several additional, but very important parameters. For example, indicators of reliability, cybersecurity, cost of services, risks, etc.

Equations (3) and (4) are a mathematical description of the infocommunication system.

Let us state here that, the problems (3) and (4) describing the infocommunication system are fundamentally different from the description of the cybernetic system that connects input and output signals. In the infocommunication system, a connection is established between the input signals and the system quality indicator.

The synthesis problem is inverse to the analysis problem, and in this case it is in finding matrix functions $\mathbf{A}_{ik}$ and α_{ik}, and which, under certain constraints, minimizes the probability of error and the delay time, which will ensure the given quality of infocommunication system functioning the at minimum costs i.e.

$$P_{\text{ош}} \le P_{\text{ошз}} \qquad \tau(t) \le \tau(t)_{з}, \tag{10}$$

where the letter "z" ("з" in Ukrainian) means the given values.

In this case, additional requirements for reliability, safety, etc. should be met.

Between two end systems, an arbitrary number of switching nodes is possible. The obtained results can easily be generalized to an arbitrary number of switching nodes. Fig. 3 shows a communication system consisting of two end systems ES1 and ES2 (End System Switching) and K switching nodes. The end systems and the switching nodes are connected by the transmission medium.

Consecutive application of formulas (1–10) to each pair (ES1-SN1); (SN2-SN3); ... (SNk-ES2) will allow to solve the tasks of analysis and synthesis.

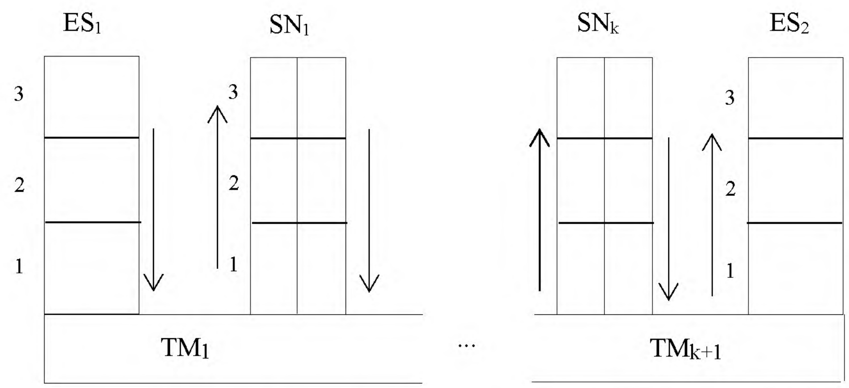

Figure 3 – Communication system consisting of two end systems ES1 and ES2

Conclusions:

1. The basic definitions of the theory of infocommunications, as well as the problems of analysis and synthesis, are formulated.

2. Based on the two-dimensional model of interaction of open systems, a mathematical model of two interacting infocommunication systems is designed to solve the problem of analysis and synthesis.

3. The possibility of a mathematical model generalization to an infocommunication network of any complexity is shown.

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