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CHOOSING A STRATEGY FOR THE LONG-TERM DEVELOPMENT OF THE COMMUNICATION SYSTEM FOR RURAL AREAS

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ABSTRACT

Strategies that include communication systems for rural development as a significant aspect of rural development are utterly needed. The article proposes a strategy of a long-term development of communication system for rural areas, used to solve a number of actual problems including improving economy and social aspect of people's life. Depending on specific scenario different methods of organization of access are proposed for rural areas. A model of multiservice network is described in the form of a random graph and a multiphase teletraffic system, including crucial aspects of modernization of infrastructure in country area.

Keywords: *Communication System; Multiservice Network; Rural Area; Multiphase Teletraffic System;*

1. INTRODUCTION

The 2030 Agenda for Sustainable Development, adopted by the United Nations General Assembly on September 25, 2015, recognizes the enormous potential of ICT to improve socio-economic development in developing countries.

The world is moving faster and faster towards a digital society. The International Telecommunication Union is committed to build a bold new development agenda, placing digital technologies at the core of every nation's future growth and prosperity.

According to the ITU, out of the 2.9 billion people who still not connected to communication networks, about 96% live in developing countries. Globally, urban residents are twice as likely to use the Internet than rural residents.

The level of development of the rural communication system largely determines the possibilities for improving the economy and the social sphere of the population's life. For these reasons, the choice of a strategy for the long-term development of the rural communication system remains an urgent task. Its solution is complicated by a number of circumstances. Among them, it is appropriate to distinguish two factors. Investments per household, which usually has several users are significantly higher than in urban areas. The number of factors that determine the principles of building a telecommunications network significantly also exceeds the one inherent in cities.

Rural areas are usually classified according to economic, geographic, climatic and demo-graphic characteristics. These indicators are important when choosing a strategy for the long-term development of the communication system. Nevertheless, some universality of the strategy for the development of the rural communication system is possible. Recently, there has been a need to create a new network concept. This need was caused by the continuous change in the requirements for telecommunication networks, which are moving into the category of infocommunication. Fundamentally new technologies are emerging, such as Internet of

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Things (IoT), self-organizing sensor networks, cloud computing, Big Data and other infocommunication applications. These technologies will reduce the digital divide between urban and rural areas, especially in developing countries. The authors chose the Republic of Kazakhstan as the object of research, which does not limit the generality of the proposed solutions.

The tasks of infrastructure development are multivariate, decisions are made in conditions of high data uncertainty, which is also associated with the actions of alternative telecom operators. The infrastructure development market is located in a competitive environment of many telecom operators, as well as possible technologies. In this article, more preference is given to the use of optical communication cables, as the most stable and having the potential to increase bandwidth. At the same time, the authors do not exclude the possibility of using radio technologies.

Rural settlements with a population of above 250 people began to receive access to broadband Internet as part of the task set by the state program "Digital Kazakhstan" in the Republic Kazakhstan.

In the process of writing this article, publications of specialists dealing with various aspects of rural communication were used. An important contribution to the methodology for solving the problems under consideration was made by the works carried out by experts from the ITU Telecommunication Development Sector (ITU-D). Suffice it to mention the publications [1, 2].

2. FEATURES OF THE RESEARCH OBJECT

The Republic of Kazakhstan, the map of which is shown in Figure 1, is located on an area of 2.7 million square kilometers. The population of the Republic of Kazakhstan is approximately 19 million people.

Thus, the population density is estimated at about 7 people per square kilometer. This value is characterized by a large variance. For example, in the most densely populated rural area, with the total number of them at 168, the population density is 115 people per square kilometer. In the most sparsely populated rural area, this figure is only 0.1 people per square kilometer.

If we compare these indicators with Western Europe (according to the classification of the United Nations Statistics Division), then with a superiority in occupied area by more than 2 times, the Republic of Kazakhstan is inferior in population by about 10 times. The population density in the Republic of Kazakhstan is 23 times less than in the countries of Western Europe.

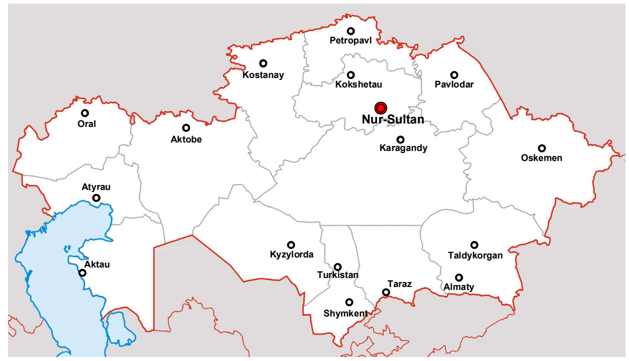

Figure 1: Administrative map of the Republic of Kazakhstan

It should also be mentioned that approximately 40% of the population of the Republic of Kazakhstan live in rural areas, which emphasizes the relevance of the issues discussed in this article. The territory within which the Republic of Kazakhstan is located includes plains, steppes, rocky canyons, hills, deltas, snow-capped mountains and deserts. The range of temperatures in several rural areas is very significant. Suffice to cite such indicators: in winter, frosts were recorded with a temperature of minus 57 degrees (on the Celsius scale), and in summer the heat can reach plus 42 degrees. These factors significantly complicate the choice of the strategy for the development of the rural communication system.

Of particular importance for the development of the communication system as a whole is the gross national product per capita based on purchasing power parity (GDP based on purchasing-power-parity per capita). According to the list of the IMF (International Monetary Fund, IMF) in 2020, the Republic of Kazakhstan was on the 52nd place in the world for this indicator.

3. ANALYSIS OF THE BASIC REQUIREMENTS FOR THE RURAL COMMUNICATION SYSTEM

Users' requirements for a communication system in rural areas practically coincide with those of urban residents. This statement reflects one of the aspects of convergence of living conditions of people in cities and in rural areas. However, the possibilities for creating a promising communication system in rural areas, as a rule, are inferior to the realities characteristic of most cities, due to the already

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mentioned economic, geographic, demographic, and climatic factors.

It is appropriate to analyze the basic requirements for the rural communication system taking into account the goals determined by the participants in the process of its development. It is enough to single out three such participants, also called players of the info communication market:

- ✓ Potential users of telecommunication and information services;
- ✓ Telecom Operators and Service Providers (telecommunications and information services);
- ✓ Communication administration, public administration body, which, among other things, coordinate the work of the law enforcement system, medical institutions, schools, and other social institutions of the Republic of Kazakhstan.

These participants in the development of the rural communication system are depicted on the sides of the cube, which is shown in Figure 1. The goals of the listed participants in the process under discussion coincide only partially. This circumstance should be remembered when solving technical, financial and organizational problems.

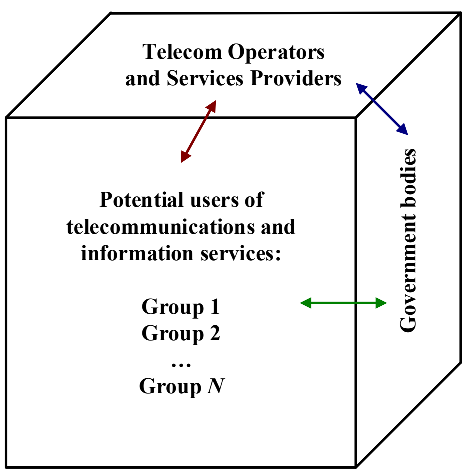

Figure 2: Three participants in the development of the rural communication system

The division of users into groups can be done in different ways. One of them is to use Sturges' rule [3]. If the total number of potential users N is known, then the sought value n is calculated by the following formula [3]:

$$n = 1 + [\log_2 N] \approx 1 + 3.322[\ln N]. \quad (1)$$

In this formula, the parentheses "[ ]" indicate the fact that the whole part of the result of the logarithm of x is taken. Sometimes the notation E (x) is used, derived from the French word "entier", translated as "whole". If, for example, the number of potential users is 500, then n = 20. In practice, such number of user groups is redundant. It is possible to choose the value of n, based on following list of types of services:

- ✓ group "A" – only telephone communication;
- ✓ group "B" – telephone communication and Internet access;
- ✓ group "C" – telephony and television broadcasting services;
- ✓ group "D" – television broadcasting services and Internet access;
- ✓ group "E" – telephony, Internet access and television broadcasting.

Such a classification is more logical than the grading based on Sturges' rule from the point of view of users, Carriers and Service Providers. For Telecommunications Operators and Service Providers (and partly for Government authorities), a classification in which n ≡ 5 is also useful. It allows distinguishing five groups of users, each of which generates 20% of revenues. An example of such a classification is shown in the left part of Figure 3. It allows us to estimate the number of users Xi that generates such income - the right part of the same figure.

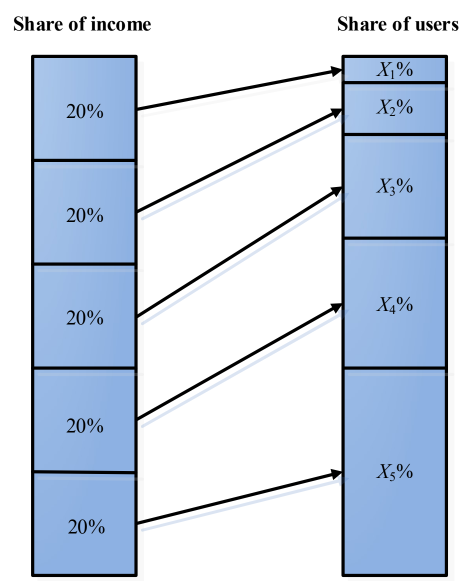

Figure 3: Identifying Five Groups Of Potential Users

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Government bodies are interested in supporting technologies of this kind: E-health, E-education, E-administration, E-business, E-banking and the like. Other participants in the development of the rural communications system are also interested in these services. With some assumptions, such technologies can be combined into a single class of E-services [4].

The study of trends in changes in the key requirements formulated by all participants in the development of the rural communication system allows us to conclude that in the foreseeable future the following rule should be followed: "Triple Play + E-services". The "Triple Play" service [5] is typical for users belonging to the "E" group.

In addition to the proposed "Triple Play + E-services" formula, the basic requirements for the rural communications system should also include following fundamental provisions:

- ✓ ensuring the same level of basic attributes that are typical for urban users with some time shift, the value of which will constantly decrease;
- ✓ minimization of the investments required for the creation and development of the applied technical means;
- ✓ reducing the cost of the operation system, considering the objective conditions inherent in rural areas.

These provisions stimulate the use of a methodological approach to the planning of the process aimed at the development of the rural communication system, which is known by the name Design for Excellence [6]. However, for a rural communication system, such an approach is characterized by some features. They can be reduced to three provisions. First, it is appropriate to consider this approach as a search for a solution that is aimed at minimizing investment, and not at maximizing income, since rural communications usually require subsidies. The ITU model for subsidizing universal communication services can be used to increase the investment attractiveness in rural networks. This model makes it possible to provide universal service to both rural and hard-to-reach regions. Secondly, the proposed concept for the development of the rural communication system should be very flexible, considering possible changes in economic and demographic indicators. Third, it is necessary to keep in mind the accelerating emergence of new paradigms for the modernization of telecommunications networks and ways to support the demand for information services.

Considering the above provisions, it is necessary to develop a long-term forecast of the requirements for the rural communication system. Such a task seems to be very difficult due to a number of objective and subjective reasons that do not allow obtaining results with high accuracy. Nevertheless, the task of forecasting remains very relevant.

3. DEVELOPMENT OF A LONG-TERM FORECAST OF REQUIREMENTS FOR THE RURAL COMMUNICATION SYSTEM

The requirements for a rural communication system can be divided into two classes. The first class usually includes requirements that are identical for all countries but are implemented at different times and at a speed determined mainly by the economic capabilities of the investor. The second class consists of requirements specific either for the country as a whole or for the territory under consideration.

The requirements of the first class allow us to use predictive estimates obtained for developed countries. In [7], a forecasting technique is proposed based on the fact that the nature of the processes describing the development of communication systems in different countries largely coincides. This conclusion was based on an analysis of available statistics for developed countries, one of which was chosen as a reference. The differences between the studied process Qj(t) and the reference, denoted for the considered rural area as Sj(t), can be found in three indicators:

- absolute values of the maximum (amplitude);
- development rate (frequency);
- shift of the starting point on the "Time" axis (phase).

These factors can be counted by modifying the known properties of the Qj(t) function obtained for the reference, although such an artificial technique somewhat reduces the reliability of predictive estimates. An example of the behavior of the functions Qj(t) and Sj(t) is shown in Figure 4. It is assumed that the process under study in a developing country begins with a "delay" by the value of τ. For randomly selected two time points, the extensions of the functions Qj(t) and Sj(t), denoted as hQ and hS, are also not identical: hQ > hS .

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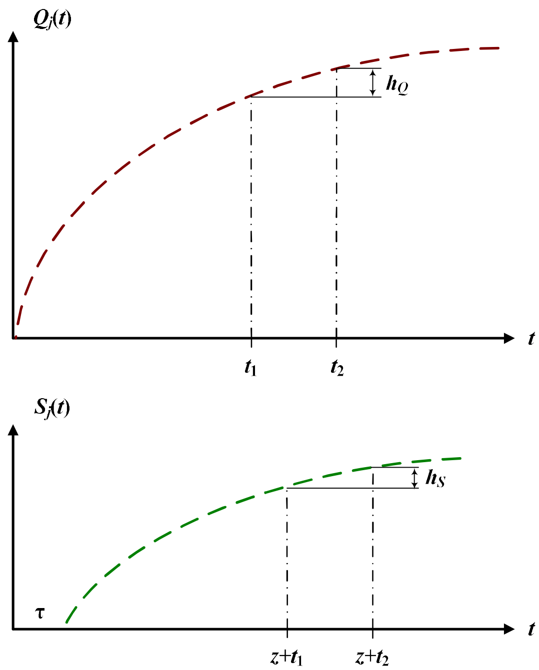

Figure 4: An Example Of The Behavior Of The Forecast Curves Qj(T) And Sj(T)

The change in amplitude can be calculated by multiplying the functions Qj(t) by the coefficient kA. The calculation of this coefficient can be carried out according to the formula, which includes the values of GDP per capita for the standard and the studied area - GR and GX, respectively [7]:

$$k_A = \frac{G_X}{G_R}\,. \qquad (2)$$

The change in frequency can be considered by replacing the variable t in the formula Qj(t) with the value tF. For this operation, it is necessary to know the values of the tariffs established for the reference territory HR and for the considered territory in the rural area HX. If necessary, you can enter a correction factor ξ, that takes into account the regional specifics. If the calculation of this coefficient is not possible, then it is assumed to be equal to one. The new variable tF is defined as follows:

$$t_F = \xi \frac{H_R}{H_X} t \qquad (3)$$

The phase change is reduced to the shift of the Qj(t) graph to the right along the "Time" axis by the value of τ. The value of this quantity is determined in an elementary way. To do this, it is necessary to find the date of the beginning of the process under study in the country, which is chosen as an analogue, and compare it with the plans for the modernization of the considered fragment of the rural communication system. Then you can get a predictive estimate of Sj(t) based on the following approximate formula:

$$S_j(t) \approx \frac{G_X}{G_R} Q_j\left(\xi \frac{H_R}{H_X} t - \tau\right). \qquad (4)$$

Relation (4) can be considered as an example of solving an applied problem related to the set of problems set forth in the theory developed by Alexander Gerschenkron. This theory is commonly referred to as "the advantage of economic backwardness" [8]. By studying the experience of leaders, you can not only use their achievements, but also avoid the mistakes they made.

Predicting requirements related to the second class usually does not allow the use of mathematical methods. In this case, one must resort to expert assessments or use artificial intelligence tools [9]. Useful information can be found in monographs devoted to research objects that are close in nature to the issues under consideration [10].

5. CHOOSING A SCENARIO FOR THE LONG-TERM DEVELOPMENT OF THE RURAL COMMUNICATION SYSTEM

The variety of options for placing potential users within the service boundaries of the local switching node (SN), as well as differences in geographic, climatic and demographic nature, stimulate the use of a scenario approach [11], which makes it possible to choose a set of solutions for the development of a rural communication system for a long-time perspective. These solutions represent a scenario that in rare cases will be optimal from a theoretical point of view. [12]. In most cases, one should look for a rational solution [13], which allows choosing a scenario that is resistant to changes in those external and internal factors that can significantly affect the development of the rural communications system.

The principles of placing potential users within the local SN service boundaries have historical, geographic, ethnic and economic roots. These principles in some regions have remained unchanged for tens and even hundreds of years. In other regions, they can change radically within a few years.

Figure 5 shows four models showing a range of user placement options within the local SN service boundary. These boundaries outline a rectangular area. Model (a) assumes that potential users are located in apartment buildings, which, in turn, are

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evenly distributed within the boundaries of the area under consideration. If apartment buildings are unevenly distributed, then model (b) should be used. Model (c) illustrates the even distribution of private households, each with one family. The variant of the placement of potential users, the most valuable for most practical purposes is displayed by the model (d). The model includes fragments of three previous models.

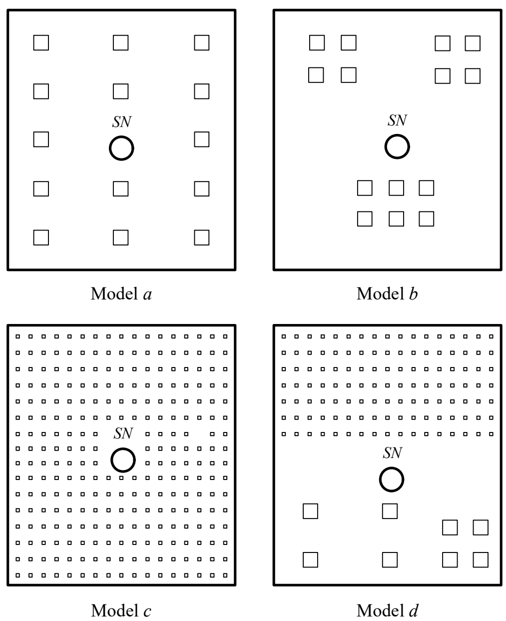

Figure 5: Differences In User Placement Within The Service Boundaries Of The Switching Node

Obviously, selecting of an adequate model will reduce the number of analyzed alternatives, relying on the experience of specialists in the planning of telecommunications networks. The analysis of the function NPV (t) - Net Present Value can serve as a tool for choosing a scenario that is implemented for the long-term development of the rural communication system. If L alternative scenarios are considered, then it is necessary to calculate the series of functions NPV (i, t); where i = 1, 2, ..., L. For each scenario, you need to know Cash Flow at time k - C (i, k) and discount rate expressed as decimal r(i). Then, by the time period t, the function NPV (i, t) is defined as follows [14]:

$$NPV(i,t) = \sum_{k=1}^{t} \frac{C(i,k)}{[1+r(i)]^k}. \quad (5)$$

In this case, all the technical characteristics of each scenario must meet the accepted standards, usually given in the form of equalities or inequalities. Then the choice of the best-case scenario is carried out according to the maximum value of NPV(i,t). It should be considered that in some cases, even in the best-case scenario, the value of NPV(t) might be negative. These are the realities of the rural communication system. Nevertheless, increasing the value of the NPV(t) function remains an urgent task. One way to solve it is to create a joint infrastructure with companies involved in transport and energy systems. Another possibility lies in the application of RF resource sharing technology. This will reduce the investment burden on mobile operators.

The results of the analysis of alternative solutions made it possible to develop a scenario that will be used in many rural areas of the Republic of Kazakhstan. The corresponding model of a fragment of a multiservice network is shown in Figure 6. For the considered territory of a rural area, the local switching node is the SN2 hardware and software. This switching node is included in the ring that forms a multi-service network of a higher hierarchy level. The use of a ring topology ensures high communication reliability for SN2.

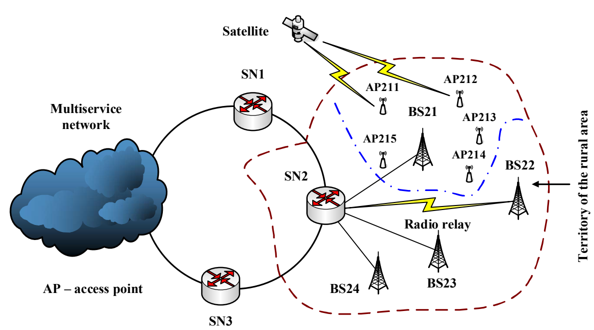

Figure 6: A Model Of A Multiservice Network Fragment In A Rural Area

Communication of potential users ' equipment with SN2 is carried out through the use of wireless technologies. Apparently, 5G and 6G mobile communication standards will be good solutions for the long term [15]. The connection of base stations (BS) to SN2 can be carried out using cables with optical fibers or with radio relay lines. The communication of the BS with the access points (AP), where the users' equipment is located, is implemented through wireless technologies. Two access points can use a backup path to access the multiservice network via satellite. The geostationary communication satellites "KazSat" are used in the Republic of Kazakhstan. Such solutions are used for particularly important access points, which, for

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example, must have access to a multiservice network in the event of emergency situations accompanied by destructive impacts [16].

The definition of service boundaries for each BS is carried out according to well-known network planning methods. For the model under consideration, the boundaries of user service by means of BS2 are indicated by a dash-dotted line. Network planning methods should be improved and supplemented with new functionality to obtain effective solutions and automate the development of project documentation. To analyze the advantages and disadvantages of the decisions taken, which may appear after a certain time, it is appropriate to use a network of digital twins [17]. The creation of such a network is an urgent scientific task.

6. ORGANIZATION OF ACCESS FOR REMOTE AND HARD-TO-REACH SETTLEMENTS

A special difficulty in the development of the rural communication system is assigned to the tasks of organizing access for remote and hard-to-reach settlements [2, 18]. One of the effective solutions for such rural objects is satellite communication systems. The current level of development of satellite communication systems allows us to economically solve emerging problems [19], which does not cancel the consideration of other options based, for the most part, on wireless technologies.

For a significant part of remote and hard-to-reach settlements in rural areas, one can not rely on reliable energy supply. For this reason, the options for organizing communication using therminal equipment with minimal energy consumption are especially important. In addition, it is necessary to analyze the possibility of applying alternative energy sources. Solar panels and wind power plants will play an important role for the conditions inherent in the Republic of Kazakhstan.

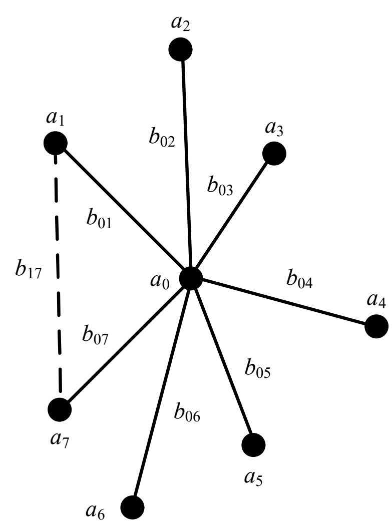
In most remote and hard-to-reach settlements, it is very difficult to carry out the functions of technical operation. For this reason, it is necessary to use highly reliable equipment that has the ability to self-diagnose. A special role in remote and hard-to-reach settlements belongs to the Internet [20] in terms of transmitting information about emergency situations and predicting adverse events of a natural and man-made nature

7. A MODEL OF A MULTISERVICE NETWORK IN THE FORM OF A RANDOM GRAPH

To solve the emerging problems of planning a multiservice network, it is necessary to develop a mathematical model that is adequate to the object under study. Moreover, the proposed model should describe the state of the object under study in dynamics, taking into account its possible changes. For rural areas, a random graph can serve as such a model [21].

Usually, a random graph is used to analyze situations caused by the appearance or disappearance of edges. For the rural communication system, events related to the occurrence or elimination of vertices are also of interest. From a practical point of view, such events mean the development of new territories (for example, for the construction of a cottage settlement) or the liquidation of unpromising rural settlements.

An example of a random graph that changes its state at times t1 and t2 is shown in Figure 7. Initially, the random graph includes eight vertices ai and eight edges bij. The dotted line at time t1 illustrates a variant of organizing a direct connection between localities, the models of which are the vertices of the random graph a1 and a7.



a) Graph at a moment in time t_1

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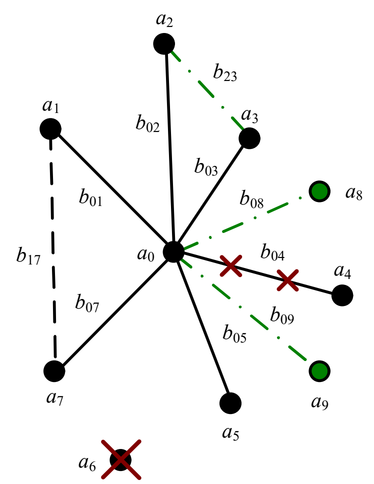

b) Graph at a moment in time t_2

Figure 7: A Model Of A Multiservice Network Fragment In The Form Of A Random Graph

Let's assume that the situation has changed by time t2. First, two new vertices appeared – a8 and a9. Secondly, the vertex a6 has been eliminated. Third, a new edge has been created between the vertices a2 and a3, which in practice means the organization of a direct connection between two localities. In addition, the edge b04 is marked with "crosses". This designation is used to emphasize the fact of the failure of linear structures, which leads to the temporary isolation of the vertex a4 until the malfunction of technical means or software is eliminated.

The considered example allows us to emphasize the effectiveness of the use of wireless technologies for the rural communication system. The resources previously used to create edge b06 can be used to organize edges b08 and b09. If the b06 edge had been implemented by laying a cable line, then financial losses would have become inevitable.

The model of a telecommunications network in the form of a random graph is very useful for conducting applied research. For a number of tasks, it may be useful to use models in the form of hypernetworks, which allow expanding the list of studied problems [22].

Analysis of the reliability characteristics of a telecommunication network remains an urgent problem solved by the methods of graph theory. For example, the probability of connectivity between vertices a2 and a5, denoted as R25, is also determined by the states of vertex a0, as well as the edges b02 and b05. If we denote the probabilities of finding these elements in a working state (replacing the letters "a" and "b" with "p" and "q", respectively) as p0, p2, p5, q02 and q05, then the probability of connectivity of the vertices a2 and a5 is calculated by a product of this type:

$$R_{25} = p_2 \times q_{02} \times p_0 \times q_{05} \times p_5. \qquad (6)$$

Expression (6), using a simple mathematical relation, illustrates the well-known thesis: star-shaped structures have low reliability. Unfortunately, in rural areas, the implementation of fault-tolerant structures is carried out very rarely due to the high costs of a set of technical means.

8. MODEL OF A MULTISERVICE NETWORK IN THE FORM OF A MULTIPHASE TELETRAFFIC SYSTEM

A multiservice network has specific quality of service (QoS) metrics. They are normalized between user-network interfaces [23]. For this reason, a multiphase teletraffic system is usually used as a model for examining QoS characteristics. An example of a model that includes M phases of service is shown in Figure 8. To study the characteristics of QoS, the methods of teletraffic theory are used [24].

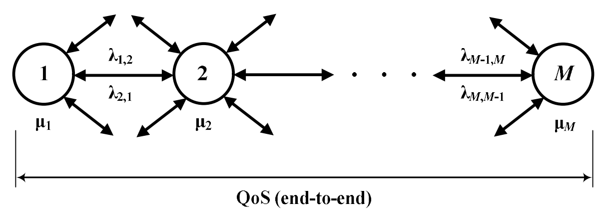

Figure 8. Model Of A Multiservice Network As A Multiphase Teletraffic System

For each phase in the model, it is necessary to estimate the intensity of the incoming traffic λk,l, as well as a number of other characteristics [24]. In the process of designing a multiservice network, the task of choosing such values of the intensity of service μj, (j = 1, 2, ..., M) which will ensure the established norms for the QoS indicators is usually solved.

The study of multiphase teletraffic systems is a complex process. The scope of analytical methods is limited to the simplest models. A few useful relations are given, particularly, in [23]. Usually, the search for solutions is based on the use of simulation methods.

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9. ASPECTS OF MODERNIZATION OF INFRASTRUCTURE IN RURAL AREA

In recent years, the term "infrastructure" is sometimes used, to put it mildly, not quite correctly. Using dictionaries and authoritative publications, it is appropriate to define the infrastructure as follows: "A complex of interconnected service structures that form and / or provide the basis for solving the problem." This definition is in good agreement with the classical interpretation of infrastructure used in the technical literature on telecommunications systems. Their infrastructure includes buildings, cable sewers, structures that house the equipment of cellular network base stations, and similar facilities.

Typically, the traces of some networks of a very different nature coincide or run close to each other. This stimulates the search for solutions to create common infrastructural objects [25].

The idea of building a common infrastructure for several networks that are different in their essence is not new. The features of the practical implementation of the common infrastructure at the present time are that the technologies of building networks are changing significantly, as well as the requirements of an economic and, which is very important, of an organizational nature. In a number of countries, the requirement to "dig the ground once" (dig-once requirements) is enforced at the legislative level. Relevant information concerning the USA, South Korea, India and other countries is easy to find on the Internet.

Infrastructure installations can be located both above the "surface" of the earth (means of placing base stations), and below it (collectors of public utilities). From a functional point of view, regardless of the location, infrastructure facilities play a kind of role as a foundation for networks of various purposes.

Figure 9 shows an example of a common infrastructure for two networks - telecommunications and electricity. The lower part of the illustration shows the infrastructure communication routes forming a ring topology, which is characterized by high reliability indicators.

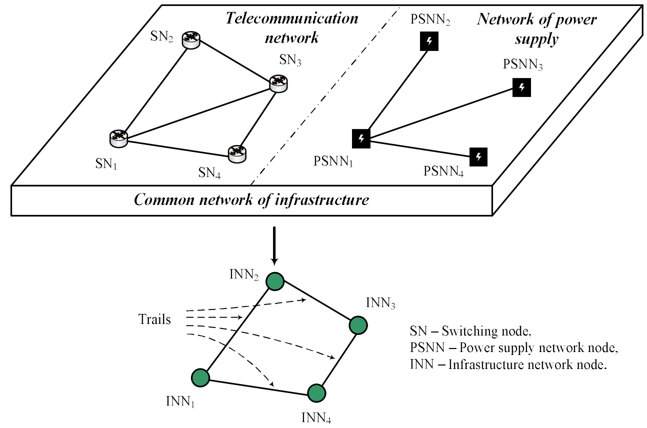

Figure 9: Representation Of Two Infrastructures As A Foundation For Networks.

The ring topology of communication routes allows you to create networks with different structures. For a telecommunication network, the top left of Figure 9 shows a ring structure with a chord. The star structure is chosen as the topology model for the power supply network. INN, SN and PSNN equipment sites are located nearby. Trails connecting nodes of the same name usually run in parallel.

Ring topologies can be formed incrementally if required to reduce capital costs. An example of the formation of rings at one of the subsequent stages of infrastructure modernization is shown in Figure 10 for four communication routes. These routes contain transit points of the INN class. The communication routes at the previous stage of infrastructure development are shown on the left side of the illustration under consideration. On the right, two traces are shown (between INN 4 – INN 6 and INN 9 – INN11), the construction of which allows the implementation of ring topologies.

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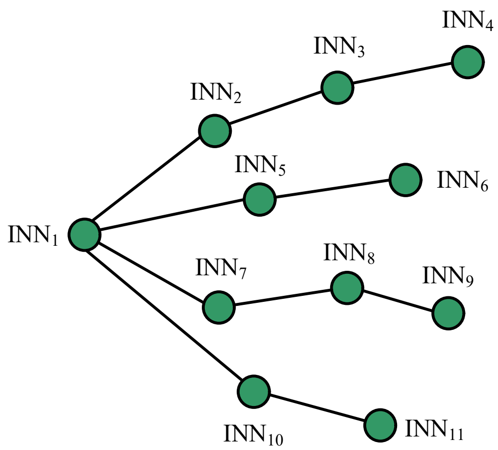
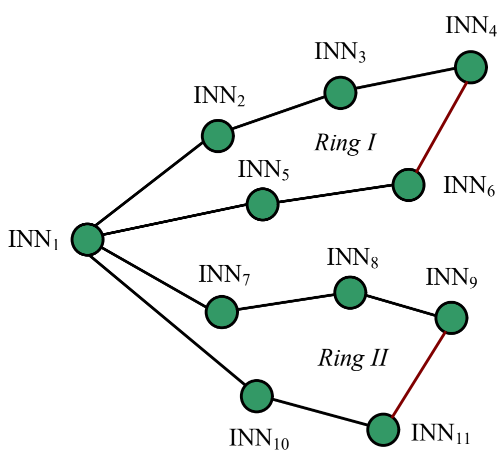


a) The first stage of infrastructure creation



b) The second stage of infrastructure creation

Figure 10: An Example Of The Step-By-Step Formation Of Two Ring Topologies

An important systemic aspect of building a common infrastructure is the organization of those processes of technical operation of equipment that can potentially disrupt the operation of other networks. The emerging tasks require separate interdisciplinary research.

Currently, the main advantages and disadvantages of the concept implying the construction of a common infrastructure can be assessed by means of a SWOT analysis [26]. This name is formed from the first letters of four words: Strengths, Weaknesses, Opportunities, and Threats. Economists, using SWOT analysis, as a rule, correlate the strengths and weaknesses of the object or process under study with internal factors. Opportunities and threats are viewed as external factors.

It should be noted that SWOT analysis was not initially used in economics. It was used to streamline information about the current situation and likely trends in the development of complex systems. This article uses the original purpose of SWOT analysis as an effective tool for the qualitative investigation of problems inherent in complex systems. The results obtained can be represented by the following examples:

- ✓ Strengths – almost complete coincidence of the topologies of the operated networks, the presence of highly qualified specialists;
- ✓ Weaknesses – the need to solve complex organizational and financial issues, lack of clarity with the division of responsibility in the event of large-scale accidents and with the rules for their elimination;
- ✓ Opportunities – significant economic effect, favorable conditions for the use of new technologies;
- ✓ Threats – functional reliability of an integrated system, the complexity of planning infrastructure modernization processes in the event of radical changes in the composition of any network.

All formulated provisions can be analyzed at a qualitative level - without the use of mathematical methods. Moreover, there are no generally accepted and tested economic and mathematical methods for studying a number of the above-mentioned factors of SWOT analysis. Perhaps only the characteristics of reliability and survivability can be estimated with acceptable accuracy through the use of the appropriate mathematical apparatus.

The difficulty of obtaining economic assessments, first of all, lies in the fact that the objects under consideration, as a rule, are at different levels of development and in a wide range of the infrastructure life cycle. Their further development is carried out with a difference in the goals set and in not always coinciding conditions of an economic, geographic, climatic, demographic and historical nature.

For example, experts involved in the creation of India's National Optical Fiber Network (NOFN) estimate the cost of excavating (digging trenches) for cable ducts at 60-70% of the total project investment. Apparently, this estimate is quite correct for the conditions of India, but it may turn out to be very overestimated for a similar project in most cities in other countries or underestimated when solving a similar problem in some rural regions.

With these considerations in mind, the numerical estimates below should be treated with caution. They allow, as some mathematicians say, to "estimate the

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order" of the quantities under consideration. Available estimates are in different currencies. For this reason, to compare the results, it is appropriate to use their normalized values, which are obtained since the maximum estimate is taken as one or 100%. For example, data from several projects implemented in the UK revealed the following pattern:

- ✓ maximum capital costs per unit length of cable duct are 100%;
- ✓ the minimum capital costs per unit of cable duct length do not exceed 43%;
- ✓ the average value of capital costs per unit length of cable duct is 64%.

These estimates indicate that the distribution of capital costs for the projects under consideration does not obey uniform distribution law. It is curious that infrastructure costs differ noticeably for a relatively short access section in telecommunication networks built using FTTH (Fiber to The Home) technology. The minimum capital expenditures do not exceed 38% of the maximum, and the average value is 63%. The distribution of capital costs for the investigated fragment of the infrastructure also does not obey uniform distribution law.

The data available for the four neighboring Asian countries, shown in Figure 11, illustrate the differences in capital expenditures for infrastructure, which is primarily intended for optical fiber cabling, but will be used for other purposes. The required investments, except for country I, are close to each other. It is significant that for all four countries the reduction in capital expenditures, in comparison with projects for the implementation of separate infrastructural structures, is practically identical. It ranges from 54% to 57%.

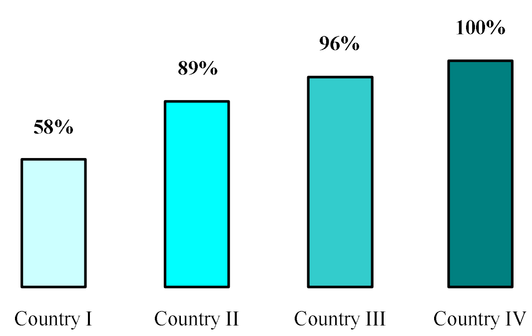

Figure 11: Infrastructure Capital Cost Differences

Thus, the construction of a common infrastructure allows you to get a tangible economic effect. More precise estimation of this effect can be achieved if the damage caused by the blocking of transport routes during construction work is evaluated in economic terms.

The formation of a unified infrastructure for networks of various purposes will provide a significant economic effect, but it generates complex tasks in terms of the implementation of relevant projects and in the organization of technical operation processes. The emerging tasks can be successfully solved if there is an agreed technical policy of network owners who are ready to create and develop a common infrastructure.

A single infrastructure has several additional benefits that are not discussed in this article. It economically ensures the practical implementation of the scenario of sustainable development of the telecommunications system. Some advantages related to networks for other purposes can only be formulated by specialists from other fields of knowledge that do not relate to telecommunication systems. It is possible that they will also point out the risks that the authors "missed", since they are not professionals in the construction and operation of networks for other purposes (not related to the "Telecommunication" industry).

Further work is appropriate to carry out as interdisciplinary research. This will make it possible to formulate key principles for building a common infrastructure, draw up scientifically grounded requirements for a set of new technical means, and develop the necessary regulatory framework.

10. RESULTS OF THE PROJECT FOR THE CONSTRUCTION OF FIBER-OPTIC COMMUNICATION LINES TO RURAL SETTLEMENTS OF THE REPUBLIC OF KAZAKHSTAN

In December 2020, two large telecom operators, Kazakhtelecom JSC and Transtelecom JSC, completed the implementation of the first stage of the largest project in the field of information communications "Providing broadband access to rural localities of the Republic of Kazakhstan using fiber-optic communication lines technologies" within the framework of the state program "Digital Kazakhstan", created through the mechanism of public-private partnerships [27].

This project made it possible to provide access to high-speed Internet to almost 3700 government agencies in 1249 remote villages of the country. The project has a social orientation, its main goal is to eliminate the digital divide between the city and the countryside.

This project, named "FOCL SNP 250+", is a fundamental project, since with the help of the infrastructure built within its framework,

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Kazakhtelecom JSC, Transtelecom JSC and other telecom operators were able to provide the entire range of telecommunication services in the country.

It should be noted that the widespread use of telecom operators of the mechanisms for sharing the infocommunication infrastructure and radio frequency resource made it possible to increase the investment attractiveness and early implementation of the project.

These achieved results allowed Kazakhstan to start the implementation of another project in the summer of 2020, which provided the rural population of the country with high-quality mobile Internet. Mobile operators that are included in the group of such companies as Kazakhtelecom JSC, Kcell JSC and MTS LLP, built their networks in villages with a population of 250 or more.

The Tele2/Altel operator (Mobile Telecom Service LLP) installed and put into operation 238 base stations in 2020 as part of the FOCL SNP 250+ program.

11. CONCLUSION

Choosing a strategy for the long-term development of the rural communications system is a very difficult process and this choice rests with the Decision Makers [25, 28]. The success of the choice of strategy depends on the depth of analysis of alternative scenarios. Suppose that three alternative solutions were considered, assessed by some integral indicator Vi (i = 1, 2, 3). Let's say that we managed to rank three scenarios in terms of the following preferences:

$$V_2 \succ V_1 \succ V_3. \qquad (7)$$

Then Decision Makers receive well-grounded arguments for choosing a strategy for the long-term development of the rural communications system. However, preferences of the form (7) cannot always be formulated properly. This statement is illustrated in Figure 9. It contains an outer square with a side length equal to one. This square corresponds to an ideal scenario with the four attributes of the communication system listed near the nodes of the square. The area of this square is equal to one. The real values of the estimated attributes, denoted as Wi, are usually less than one. For this reason, the area of the quadrangle formed by connecting the vertices Wi is also less than one.

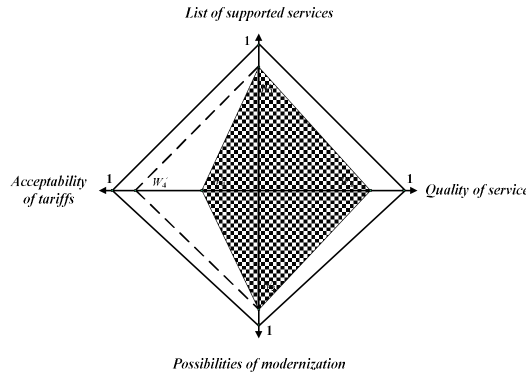

Figure 12: A Method For Assessing Scenarios For The Rural Communication System Development

For the considered construction, the "Acceptability of tariffs" indicator, in contrast to the other three attributes, is defined by two values – W4 and W4'. A similar situation may arise due to differences in the points of view of potential users. Then, when drawing up preferences of the form (7), one should use not only the values of the areas of the quadrangles, but also the values of their variance.

This is just one of the new tasks related to the particular problem of choosing the best strategy for the long-term development of the rural communications system. In fact, the list of tasks requiring study and development of solutions is quite extensive. In the most general form, such tasks are formulated in the ITU-D materials [1, 2, 18], as well as in a number of monographs and articles directly or indirectly devoted to the development of communications in rural areas.

12. FUTURE WORK

The World Telecommunication/ICT Policy Forum (WTPF-21) was hosted virtually by the International Telecommunication Union (ITU) in December 2021. At this forum, more than 400 of the world's leading representatives of the public and private sectors confirmed the need to align new technologies and ICT with global sustainable development priorities.

The rapid development of low-orbit satellite technologies is one of the promising strategies for providing rural communities and hard-to-reach regions of developing countries with infocommunication networks. Research of business models that provides information and communication services, and issues of improving the national regulatory framework of countries chosen by these global technologies still remain relevant.

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