The Public Communication Network Development as the Process of Complex System Evolution

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Abstract—**The Public Communication Network (PCN) serves users on all continents of the globe. Providing the main and additional services to subscribers is carried out through the use of modern hardware and software. These circumstances stimulate research of the PCN as a complex system. This article discusses some aspects peculiar to complex systems in the context of actual tasks related to PCN development. Two perspective applications of the proposed approach are considered. First example deals with rural areas development. Second example is devoted to the solution supporting the telecommunications, the electric power transmission, and no gasoline transport systems. This solution is presented as triad "M+E+I" (Matter plus Energy plus Information). The proposed triad can be seen as a new facility for further research and development.**

I. THE MAIN FEATURES AND CHARACTERISTICS OF THE COMPLEX SYSTEM

The terms listed below were taken mostly from several monographs [1 – 4], but have been adapted to notions accepted in the telecommunication thesaurus. Considering issues addressed in the article, it is appropriate to introduce five definitions:

1) The element. PCN equipment with no need to allocate smaller components (in the context of the object of study).

2) The system. A totality of elements, interacting with each other to perform assigned tasks.

3) The complex system. A set of large (but countable) number of elements, with mainly non-trivial relationship between them.

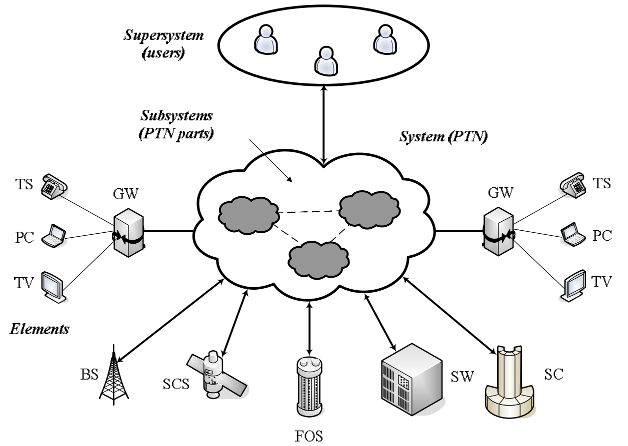
4) The supersystem. An object, standing one level above in the accepted classification hierarchy.

5) The subsystem. A subset of the elements associated with each other (it can be viewed as a system due to having all relevant properties).

Fig. 1 shows a model that allows specifying the terms given above. The PCN development level supposed to be consistent with the concept of Next Generation Network (NGN) [5]. This network carries the traffic of voice, data and video.

The supersystem is appropriate to be considered as the totality of PCN users. Under the latter we understand not only human subscribers, but also a variety of devices using PCN resources without human intervention. The set of tasks to be solved by PCN are formed by communication and information demands of users.

In general, PCN carries out the functions of the system. There is no doubt that the PCN should be taken as a complex system. This statement can be found in a number of monographs on the theory of complex systems. Previously, a telephone network was a typical example of a complex system. In recent years, the term "complex system" has been frequently used when mentioning the World Wide Web. Among others, PCN includes both of these networks.



TS – telephone set, PC – personal computer, TV – television receiver, BS – base station, SCS – satellite communication system, FOS – fiber optic system, SW – switch, SC – supercomputer, GW – gateway.

Fig. 1. The Supersystem – System – Subsystem – Element model

The PCN has a hierarchical structure [5]. At each level of the hierarchy there are parts of PCN, which are a set of subsystems. They, in turn, include a totality of elements, as shown on Fig. 1. Some elements are rather simple. In particular, the old but still operated types of the stationary telephones are not as sophisticated as today's mobile terminals. In several cases some elements to be regarded as a complex logical system. An example of such element is a supercomputer.

In modern scientific literature authors identify a set of properties peculiar to complex systems. For the solution most of the theoretical and practical problems of PCN development, this set can be limited to seven following properties:

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1) purposefulness;
2) functionality;
3) integrity;
4) openness;
5) hierarchy;
6) variability over time;
7) the existence in a constantly changing environment.

The five important features of the complex systems were formulated in [6]. They are listed below with some brief comments.

1) The lack of adequate mathematical description. Mathematical description in [6] is interpreted as the presence of the algorithm F, which allows one to calculate the state of the object Y, according to observations of its managed and unmanaged inputs U and X, respectively. In other words, it is impossible to determine the complex system function Y=F(X, U).

2) Noisiness. This feature of the complex systems is determined not much by the presence of objectively existing sources of random noise, but by the nature of the object. In a complex system the secondary processes inevitably arise, being unexpected during its creation and development process. Similar phenomena could be conveniently considered as random factors, manifesting themselves in the form of random noise.

3) Intolerance to management. This feature of the complex system is explained in [6], as it was created not to be managed. Apparently, these statements are true in cases where a human being becomes a part of the system or even groups of people do. In relation to PCN the other point of view is admissible. It is important that one of the PCN evolution directions is to provide a control system, which should be close to optimal.

4) Non-stationarity. This feature of PCN, as a complex system, is well known by the nature of the served traffic [7]. There are other examples of its non-stationary behavior [1].

5) Experiment soleness. This feature is not fully inherent to PCN. The soleness of experiments could be related to features II and IV [6]. It is observed, for instance, when measuring multiservice traffic in PCN, but completely absent under testing conditions, which are not of stochastic nature.

The properties and characteristics of the complex systems should be considered in the case of long-term scenarios of development. These scenarios are based on the prognostics, taking into account also the processes, related to the field of interdisciplinary research.

II. PCN DEVELOPMENT DIRECTIONS

In this section we outline our subjective considerations on connection of PCN development strategies with the first three properties of a complex system, given above. The four rest properties need no comments. The purposefulness is determined by the supersystem requirements. These requirements can be divided into three groups. The first group includes communication demands [8], implemented in the form of human communication via telecommunications networks. Informational demands [9], provided by the means of telecommunications, form a second group. The third group is appropriate to include requirements that either directly or indirectly improve the living level of the individual and the society in general. To satisfy most of the needs the concepts of IoT - Internet of Things [10] and M2M - Machine-to-Machine [11] were developed.

The strategic objectives of the PCN evolution will be determined by the three requirement groups briefly discussed above. It is expected that the major changes will be stimulated by the requirements of the latter group.

The term functionality is described by dictionaries and encyclopedias in a number of ways. In terms of the issues discussed in this article, the most appropriate definition is that given in Russian Wikipedia: "a set of the features (functions), provided by the system." As the system we understand here the PCN system. The main functions of PCN, as well as any other network, can be represented in the form of algorithm, based on a set of simple Pick-and-Drop tasks [12]. What one needs to "pick" can be interpreted as a set of bits that should be "dropped", considering given parameters.

Statistics and prognostic estimates indicate that the PCN functionality develops in the three main directions. First, the improving of opportunities to gain the quality of the services provided to users. Second, the constantly expanding range of the services supported by PCN. Third, the increasing PCN intelligence regardless of the location of appropriate hardware and software.

The PCN integrity as its required property is defined in the Russian Federal Communications law. Considering PCN as a complex system, it is possible to slightly change its interpretation. The conventional model of the generic telecommunication network is the graph [1], for which one of the most important parameters is connectivity [13]. Therefore, the PCN integrity should be associated with its ability to preserve the connectivity in the case of failure and external destructive influences.

III. THE PCN EFFICIENCY

An important characteristic of most of the technical systems, not only complex ones, is the efficiency. It is not always possible to express it with some simple parameters. However, from theoretical and practical points of view it is interesting to evaluate the efficiency of PCN at least on a qualitative level. A number of publications give an illustration reproduced on Fig. 2. Its form corresponds to the structure proposed by the Technology Business Research Company.

It is possible that the trends in traffic and income can be taken for granted. This statement is based on the analysis of similar relationships for the complex systems of some different kinds. The discussing of the curves shown in Fig. 2 is advisable to be continued after an analysis of changes in the volume of information that passes through the PCN.

Fig. 3 shows two functions. The upper curve actually repeats *Traffic* curve from the previous illustration. Its features are not contrary to the results given in the fundamental works of A. Kharkevich [14] and L. Varakin [15]. At the point t_1 it adjoins a function called *Volume of useful data*. It grows more slowly than the upper one. This function is built on the basis of intuitive considerations. For this reason, its behavior may be different and requires further study.

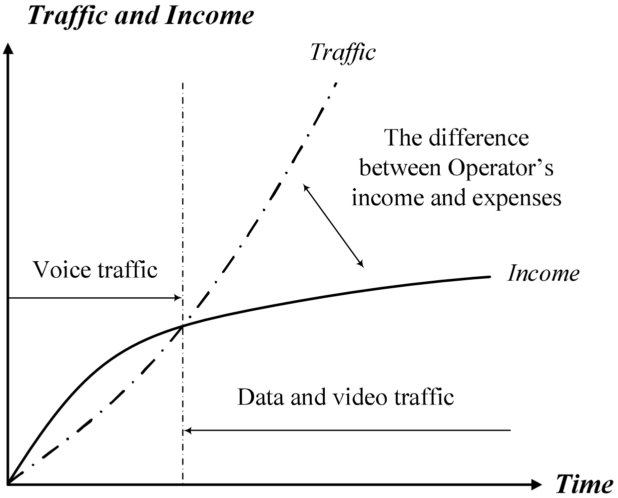


Fig. 2. The PCN efficiency as the difference between traffic and income trends

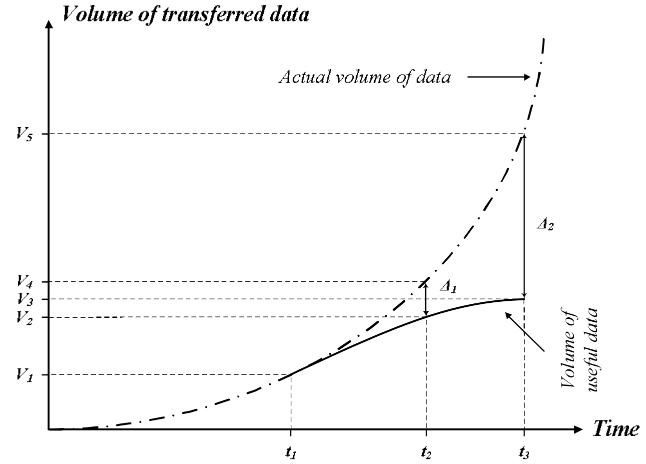


Fig. 3. Two kinds of Traffic volume function

Apparently, the point t_1 is appropriate to be considered as the end of monopoly of telegraph communications, for which the volume of data is designated as V_1. For the telegraph networks the volume of useless information was minimal. The notion is used below to refer to that part of the sent and received messages, which is formed by various participants of the infocommunication market for their own goals, artificially and without tangible benefits for the PCN subscribers. One of these goals is the creation of so-called voracious consumer [16].

At point t_2 the difference between volumes of data V_2 and V_4, equal to Δ_1, becomes noticeable. Such a difference in the point t3 becomes so significant that can be expressed as $\Delta_2 >> \Delta_1$.

The estimates of changes of the data exchange rate in the access network [17] indicate that in the next years, the values of the Δ_i will grow.

Back to Fig. 2, it should be emphasized that the *Traffic* curve can be regarded as the sum of two components. Moreover, these components are inherently directed as the vectors in the opposite directions, but acting together they generate a significant increase in traffic level. We are talking about the consequences of simultaneous processes, which can be regarded as a *development and degradation* pair. The *Income* curve reflects the value that users assign to the information of all kinds. Apparently, the explanation of the progress of this function can be obtained by detailed analysis of the pyramid of needs, proposed by Abraham Maslow [18, 19].

Continuing the same reasoning approach to Fig. 3, we can hypothesize the following statements:

- *The actual amount of data* curve reflects the result of collaborative impact of the pair of processes such as *the development and degradation* on PCN system.
- *The volume of useful data* curve is determined by the result of the evolution of PCN.

Justification of the hypothesis is the subject of a separate research. It is appropriate to perform it using the principles of interdisciplinary approach [20].

IV. ONE NETWORK OR SOME NETWORKS

Theoretically, the NGN concept is based on combining existing networks into a single network. This idea is illustrated in Fig. 4. Cloud titled NGN is shown by a thick line.

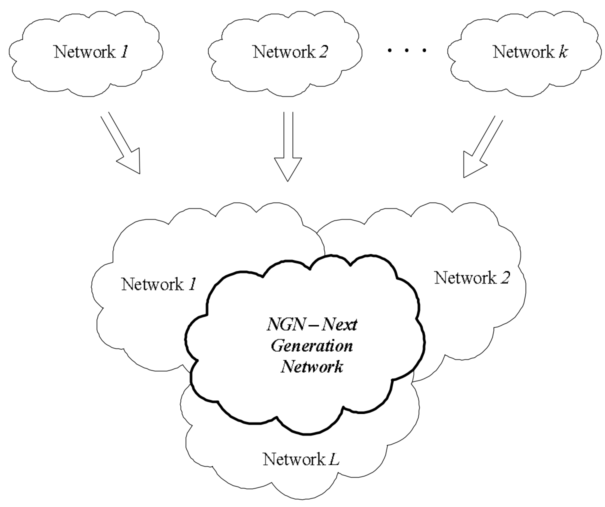


Fig. 4. Transition to the Next Generation Networks

It should be noted that the commonality of fixed and mobile communications is stated in the definition of Next Generation Network (NGN) in ITU documents. Moreover, NGN is able to integrate a lot of networks operated today. The Fig. 4 shows the integration of *K* networks using the concept of NGN. A number of networks (it is assumed that their number is equal to L) can be integrated onto the NGN only partially. It's obvious that $L < K$.

This simple model (in a slightly different form) can be found in the publications devoted to the evolution of telecommunications. It allows us to start the analysis of three important processes of telecommunications networks development: convergence, integration and consolidation.

V. Processes of convergence

This section of the article examines the convergence according to the classical interpretation of the term. A definition closer to the language of professional communicators would be the process of convergence in the telecommunications system is the appearance of similarities in the structure of the networks, in their use of hardware and software, and in the set of services provided to subscribers. This definition highlights three aspects:

- structure of the network;
- technical means of its construction;
- services provided to subscribers.

It is expedient to give three examples that illustrate these aspects of convergence. It will also help with investigating other issue related to the differences between the convergence and integration. The first example of convergence is associated with the structure of the transport network.

In the past, the structure of the urban transport networks mostly consisted of communication nodes connected using "everyone with everyone" principle. Mathematicians call such structure a fully connected graph. The intercity and rural transport networks usually implemented the structure of "tree" and "star". The introduction of Synchronous Digital Hierarchy (SDH) systems led to the unification of the structure of the transport network at all levels of the hierarchy. Transport networks began to be built on the basis of a ring topology. In turn, an aggregate of rings can be considered as a cellular topology. In other words, the structures of transport networks of fixed and mobile communications in the course of their evolution have acquired the maximum similarity.

A second example of convergence is derived from the history of the development of variety of exchanges for different hierarchical levels in Public Switched Telephone Network. In the first half of the XX century in the networks of long-distance and international communications manual switches were mostly used. At the same time, many urban telephone networks have used automatic switching equipment. They are strikingly different from the switches which have been developed for rural communication. Digital equipment and software ensure the unification of all types of switching equipment used in the telephone network. Leading manufacturers of switching equipment have developed a set of hardware and software that allows us to produce international, long distance, urban and rural stations. This switching equipment with some adaptation is suitable to serve the traffic of mobile communication.

The third example illustrates the convergence of functionality of fixed and mobile communications in terms of the services that can be provided to subscribers. In the past, fixed-line terminal limited "mobility range" by length of telephone cord. The development of text messaging like SMS wasn’t even considered. In recent years, fixed networks subscribers have been actively using cordless terminals, which significantly expand the range within which subscribers can move. In addition, there are phones that support the exchange of SMS. Mobile communication terminals, in turn, were unable to transmit data at the speed which was available for fixed network subscribers. The advent of technologies GPRS, EDGE and others helped significantly bring together the functionality of fixed and mobile communications which is just typical of the initial process of convergence. Similar trends can be found in services related to video.

VI. Processes of integration

The purpose of the majority of the integration processes is to reduce capital and/or operating expenditures of Operators. In addition, the construction of integrated networks and systems often reduces the risks that inevitably arise in the Operator's activity. Reasoning that subscribers are also interested in construction of integrated network is likely to be one of the myths that always accompany the evolution of the telecommunications system. Most users are not interested in the way a network is constructed and technical means that the Operator selected. Subscribers typically impose requirements on service attributes and prices.

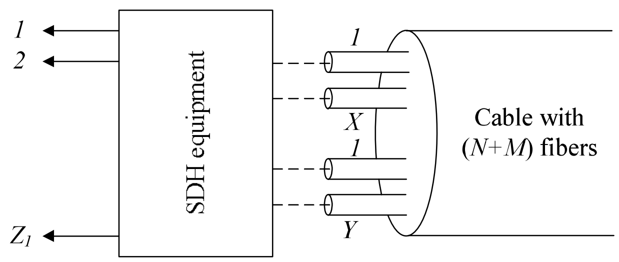
NGN as a financial project can be considered as the second (after the fiasco of the Integrated Services Digital Network – ISDN) attempt to implement an integrated network. However, the ideology and the network, and the list of technologies used in the NGN are significantly different from the solutions developed for ISDN. Nevertheless, the basic idea of NGN is to create a network to serve all types of traffic. It is considered that the capital expenditures on a single multi-service network will be less than the investment in the creation of several networks each of which supports a limited set of services. This statement is confirmed by creation of the network technology known as a IP/MPLS [5].

Given that the networks, providing a "limited services" have already been created, the hypothesis about capital cost savings may be incorrect. Techno-economic calculations which have been carried out by a number of design organizations show that the radical reduction of investments in the construction of NGN does not occur contrary to the promises of some developers.

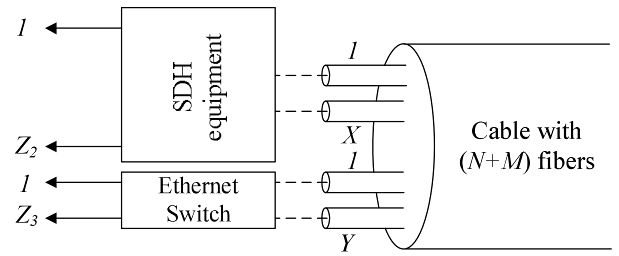
The situation is different with savings in operating expenditures. The corresponding estimates show that the reduction in Operator expenditures for NGN can be significant. From this perspective, the relevance of the strategy of transition to NGN is undeniable.

VII. Processes of consolidation

The main difference of the consolidation from the integration can be formulated in the form of the slogan "sacrifice a portion of the profits but reduce the level of risk." A typical example of the consolidation process is the organization of transport resources for the different switching technologies. The Fig. 5 shows two possible solutions for this problem. On the upper fragment of the figure there is a variant of construction of transport network, based on integration. The solution of the same problem which is based on consolidation is shown on the bottom fragment of the model. It should be noted that this example represents the initial stage of development of the Internet. At present, Operators create Optical Transport Networks using different WDM (Wavelength Division Multiplexing) technologies. However the authors consider this solution as useful model to illustrate the nature of integration processes.



a) Integration (E1 links only)



b) Consolidation (E1 links and Ethernet)

Fig. 5. Examples of the integration and consolidation

Integral solution is based on the fact that all of the optical fibers in cable are used in SDH transmission system. As a result, transport resources, which amount can be estimated by number of E1 channels, with the capacity of 2048 kbit/s are created. The estimated value is designated as Z_1. It can be argued that the unit cost of transport resources C_1 will be minimal compared to any other options for the network, which is also focused on creating E1 channels.

A consolidated solution takes into account the fact that part of the resources of the transport network in the long term should be able to support the Ethernet interface. In that case only X optical fibers are used for SDH transmission system. Y optical fibers are plugged to the Ethernet switch. For E1 channels, the number of which equals Z_2, the unit cost of transport resources C_2 will be higher than C_1. This disadvantage is offset by a decrease in the risk caused by the fact that the implementation of Ethernet interfaces is simpler in comparison with the option, based on the integrated solution.

Consolidation in the considered example involves the use of a cable with optical fibers which are utilized by different transmission systems. Interesting examples of consolidation can be found in the analysis of processes of outsourcing but such considerations are beyond the scope of this article.

More interesting process in the future is the consolidation of the telecommunications network and the electric power transmission one. Typically, these networks are based on the geographically closest tracks. Sometimes the optical fibers are embedded in ground wire of power lines.

Such an approach provides the reduction of the capital expenditure needed for creation of telecommunication networks. However, the processes of consolidation is not limited by this decision. In particular, in [20], the number of perspective scenarios related to consolidation of telecommunication networks and electric power transmission ones are discussed. One of these scenarios is described in the next section of article.

VIII. First Example. Rural Area Development

Simplified model of telecommunication network is given in Fig. 6. This model is based on Recommendation ITU-T [21]. It consists of the four clouds. The arrows emphasize the mutual influence of adjacent elements of the model.

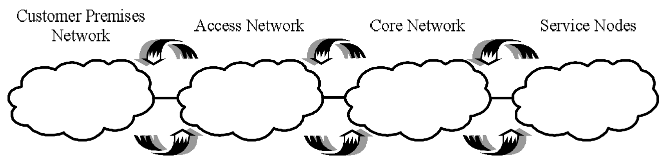


Fig. 6. Model of telecommunication network

It was well known [22, 23] that the cost of connecting to the telecommunications network in rural areas is very high. Currently, the situation has not changed [24]. In the foreseeable future, a significant reduce of access cost in rural areas is not expected. Major investments are needed to create two components:

- access network,
- part of core network that is outside toll exchange.

Reduction of the needed investment can be achieved by combining elements of infrastructures of the electric power transmission system and telecommunication one. Fig. 7 shows fragment of rural area with combination of two infrastructure elements.

Power line with fibers in ground wire is installed between district center and rural settlement. This site is located within the boundaries of the core network. For considered model, star structure of core network is depicted. Undoubtedly ring topology is preferred for high-reliability network.

New kind of cable is used within distribution area of access network. Such cable consists of fibers and copper pairs for electric power transmission. In Russia, the standard 220/380 V is used.

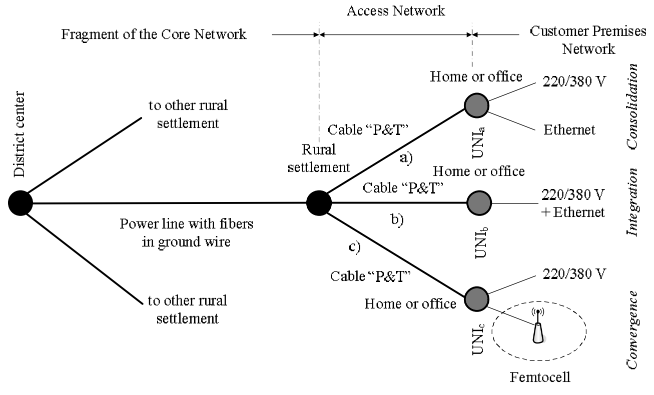


Fig. 7. Fragment of rural area

There are three main scenarios for creation of the customer premises network. Three types of user-network interface (UNI) are shown for the model:

a) Different medias for electric power transmission and telecommunication services are used. This scenario can be considered as consolidation.

b) Single new jack is elaborated as the combination of plug for electric power transmission and for Ethernet connector. This scenario can be considered as integration.

c) Copper wires are used for electric power transmission. All telecommunication services are supported by wireless technologies. Femtocell is created within each home or office. This scenario can be considered as convergence.

Currently, these scenarios are studied in detail for the development of equipment and typical project solutions.

IX. Second example. Triad "M+E+I"

In recent years, experts are discussing the possibility of a smooth transition to new types of vehicles. These cars will use the powerful battery instead of gasoline. The topologies of roads, power lines and cable ones are located close to each other. In this case, unified infrastructure can be built. Example of such solution is shown in Fig. 8. Corresponding model is named as "M+E+I". Three letters in proposed name are matter, energy, and information respectively.

Considered model is the next step in the development of the previous example. However, complexity of the emerging tasks increases substantially. A preliminary analysis showed that the most difficult problems will arise from the maintenance of a unified infrastructure. Nevertheless, the economic efficiency will be very high. On the other hand, growth of risks should be taken into account.

X. Conclusion

For the industrial science the research of the PCN evolution directions as a complex system is of great theoretical and practical interest due to at least three reasons. First, the interpretation of the results obtained for complex systems will enhance the level of research conducted by the specialists in telecommunications. Second, a number of a novel evolutionary trends inherent to PCN, are hard (or sometimes impossible) to explain by the set of methodologies, which are peculiar for industrial science. Third, the processes of applying the results obtained by specialists in other disciplines are intensified in the field of telecommunications. From this perspective, an interdisciplinary approach [20, 25, 26] should be considered as a key tool for future research directions.

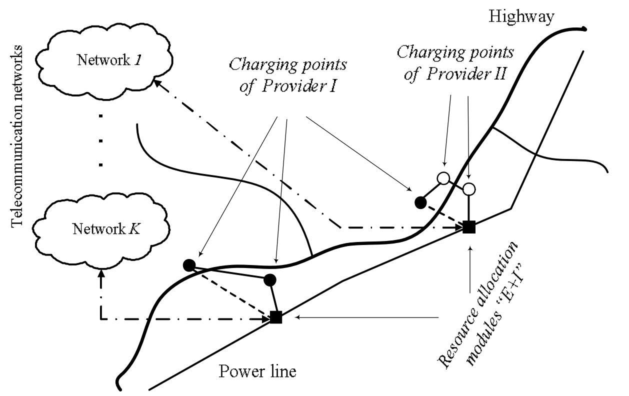


Fig. 8. Examples of triad "M+E+I"

References

[1] Davydov G.B., Roginsky V.N., Tolchan A.Y. Seti electrosvyazi (*Telecommunication Networks*). Moscow: Svyaz, 1977.

[2] Novoseltsev V.I., Tarasov B.V. Teoreticheskie osnovy systemnogo analyza (*Theoretical Basements of System Analysis*). Moscow: Mayor Osipenko, 2013.

[3] Tarasenko F.P. Prikladnoy systemnyi analyz (*Applied System Analyzis*). Moscow: Knorus, 2010.

[4] Norenkov I.P. Osnovy avtomatizirovannogo proektirovaniya (*Fundamentals of Automated Programming*). Moscow: MGTU Bauman, 2002.

[5] Goldstein B.S., Sokolov N.A., Yanovsky G.G. Seti svyazi (*Telecommunication Networks*). St. Petersburg: BHW, 2010.

[6] Rastrigyn L.A. Adaptatsiya slozhenyh system. Metody i prilozheniya (*Adaptation of Complex Systems. Methods and Applications*). Riga: Zinatne, 1981.

[7] Sokolov N.A. Zadachi planirovaniya setey electrosvyazi (*Telecommunication Networks Planning Tasks)*. St. Petersburg: Technika Svyazi, 2012.

[8] Maslow A.H. Motivation and Personality. NY: Addison-Wesley, 1987.

[9] Case D.O. Looking for Information: A Survey of Research on Information Seeking, Needs and Behavior. San Diego: Academic Press, 2002.

[10] Hersent O., Boswarthick D., Elloumi O. The Internet of Thinks. Wiley, 2012.

[11] Boswarthick D., Hersent O., Elloumi O. M2M Communications. Wiley, 2012.

[12] Rekimoto J. Pick-and-drop: a direct manipulation technique for multiple compute environments // Proceedings of the 10th annual ACM symposium of User interface software and technology, 1997.

[13] Popkov V.K. Matematicheskiye modely svyaznosty (*Mathematical*

Models of Connectivity). Novosibirsk: IVMiMG SO RAN, 2006.
[14] Kharkhevich A.A. Informatsiya i technika (*Information and Technica) //* Communist Magazine, 1962, № 12.
[15] Varakin L.E. Informatsionno-economitcheskiy zakon (*Informational economy law*). Moscow: MAS, 2006.
[16] Ilyin V.I. Obschestvo potrebleniya: teoretitcheskaya model i rossiyskaya realnost (*Consumption Society: Theoretical Model and Russian Reality*) // Mir Rossii, 2005, №2.
[17] Sokolov N.A. Evolutsiya setey dostupa. Tri aspekta (*Access Networks Evolution. The Three Aspects*) // Pervaya Milya, 2015, №2.
[18] Maslow A.H. Motivation and Personality. NY: Addison-Wesley, 1987.
[19] Sokolov N.A. Tarify na uslugi svyazi i pyramida potrebnostey (Network Services Tax Rates and the Demands Pyramid) // Infocom: Proceedings of MAS, 2004, №2.
[20] Komashinskij V., Sokolov N. Koncepcija 2E: novyj podhod k modernizacii sistemy sel'skoj svjazi (2E Concept: new approach for the modernisation of the rural communication) // Connect! Mir svjazi, №9, 2011.
[21] ITU-T. Recommendation Y.130. Information communication architecture. – Geneva, 2000.
[22] Mosher R.E. Bell and Rural Telecom in U.S. – Telephony, March 12, 1979.
[23] CCITT. Supplement to the Handbook on Rural Telecommunications, Vol. II. – Geneva, 1990.
[24] ITU-D. Telecommunications for rural and remote areas. Final Report. Geneva, 2010.
[25] Kuperin U.A. Teoriya slozhnyh system i mezhdistsiplinarniye issledovaniya (*Complex System Theory and Interdisciplinary Studies*). http://www.nadprof.ru/library/books/kuperin.shtml (available on 17 March 2015).
[26] Augsburg T. Becoming Interdisciplinary: An Introduction to Interdisciplinary Studies. New York: Kendall Hunt Publishing Company, 2006.