Formation of methodological approaches to increasing the efficiency of optical networks

Hassan Ali Al-Ababneh[1,*], *Eman* Ahmad Shudaydat[2], and *Mahmud* Agel Abu Dalbouh[1]

[1]Department of Administrative and Financial Sciences - E - Marketing and Social Communication, Irbid National University, Amman, Jordan
[2]Department of Creative media, Luminus Technical University College, Amman, Jordan

Abstract. In modern conditions of organizing the work of IT infrastructure, the issue of increasing the efficiency of the optical network is relevant and in demand. In this regard, to formalize methodological approaches and argue the theoretical prerequisites for increasing the efficiency of optical networks, an in-depth analysis of the main methods and directions was carried out. The advantages of using the method of transforming the architecture and topology of the network are argued. The main types of optical networks are stated: passive, hybrid, elastic, followed by highlighting key technologies and identifying promising options for increasing efficiency. Optimization opportunities highlighted operation of an optical network using PoF cable and super coherent technologies. Aspects of a software solution to improve the efficiency of an optical network are touched upon. The use of redundancy is justified as one of the promising methods to improve the efficiency of an optical network. Methodological approaches to increasing the efficiency of optical networks have been formed and can be applied in practice when organizing information architecture using the main results of the study.

1 Introduction

The intensification of processes of maximum digitalization of all sectors of the global economy has led to a dramatic increase in traffic volumes in all architectural and information and telecommunication networks. The rapid growth in traffic volumes is due to the formation and creation of new types of digital services, which are caused by increased requirements for the quality of existing services and an increase in the number of users. The dynamically variable intensification of the load in the functioning of optical networks necessitates a qualitative improvement in the process of distribution and data transmission capacity between architectural systems and information and telecommunication flows with the effective use of optical networks. It should be noted that existing wavelength routing techniques are not adapted and are not suitable for transmitting and switching information and telecommunication flows with a high level of discrete bandwidth distribution. Explicit methods of packet switching of information and telecommunication flows do not ensure efficient use of the capacity of optical communication networks, taking into account the

* Corresponding author: Hassan_ababneh@inu.edu.jo

peculiarities of modern operation, and require separate packet services, which leads to an extension of the transmission cycle and signal propagation along optical communication lines. Arguing the presented, it should be stated that in modern conditions of operation and use of technologies for optical communication of blocks, which mainly includes the structuring of load flows by class and destination nodes when combined, this determines the key prerequisites for increasing the efficiency of the process. Since efficiency and rationality under current conditions are important indicators that ensure the transfer of information in communication nodes, in order to improve the performance of the entire optical network, it is necessary to take a more in-depth look at the features and modifications in this area.

2 Research methodology

As part of the intensification of the digital development of the global economy and a significant increase in the role and share of information and telecommunications technologies in various segments of world-class companies, the issue of the efficiency of the functioning of optical networks is acute. The basic goal of the study is to argue the theoretical premises and formulate basic methodological approaches to improving the efficiency of optical networks. To achieve the stated goal of the research in the work: an analysis of existing literature was carried out to determine the main aspects of the functioning of optical networks and the features of the organization of their activities; structured basic types of optical networks with unification of the network architecture of each type; the basic technologies and approaches to organizing the specifics of the functioning of optical networks are constructively described depending on the type of optical networks; the main scientific approaches and methods of organizing the effective operation of optical networks are classified; methods for determining the efficiency of organizing the functioning of optical networks are argued and presented, and the need to calculate ring redundancy by replacement using an unloaded reserve is stated; It was proved that to increase the efficiency of the optical network, super coherent technologies should be used. Theoretical premises have been substantiated and methodological approaches to increasing the efficiency of optical networks have been formed and can be applied in practice as a basic approach to determining the main aspects of the functioning and selection of key approaches to increasing the efficiency of optical networks as a whole.

3 Research results

The modern realities of the functioning of modern companies and their information and telecommunications architecture cannot be imagined without optical networks, which have a significant role and task in transferring information and volumes of data. Based on this, it is important to highlight the main scientific views in the field of research into the characteristics of the organization and functioning of optical networks. Attention is focused on the consideration of issues of ensuring energy efficiency of telecommunication optical networks in scientific works [1-4], and the need to improve the operation of optical networks through energy saving is revealed. It should be noted that this is one of many options for ensuring the efficiency of companies at the modern level, however, this does not affect the performance of optical networks, which requires further consideration and improvement. The specifics and modifications of approaches to the throughput of optical networks within the framework of the development of modern architecture are discussed in [5]. The elastic distribution of bandwidth in flexible optical networks based on OFDM is argued, which is relevant and important in modern realities, but does not solve the issue of ensuring the efficiency of optical networks, which needs to be researched.

Optical networks today ensure the transmission of large volumes of information, which are provided by digital channels and digital services, which have their application in almost all areas of the global economy, generating traffic that needs to be managed and ensure its resiliency. Based on this, attention should be paid to scientific approaches [6-8], which consider the need for dynamic traffic control in elastic optical networks, argue for the use of traffic regulation taking into account fragmentation and lane changes in spectral-spatially flexible optical networks, as well as digital subcarrier multiplexing: creation software-defined optical networks. These views are fundamental in the field of studying the specifics and modification of the functioning of optical networks and traffic management, which served as the basis for research with further improvement. The creation of any information and telecommunication system is impossible without infrastructure and the formation of an optical network architecture. The structural features of the architecture of optical networks are highlighted in scientific work [9], which argues for the features of organizing switching of optical networks based on a single-level architecture, which does not quite correspond to the modern conditions of the IT segment and requires improvement and further research. Based on what has been presented, in view of the fact that there is no general concept regarding increasing the efficiency of optical networks, there is an urgent need to study this direction and formulate the main methodological aspects. It is important to state that the innovation regarding technological and software coding of information flow within fiber-optic communications in order to increase the efficiency of their throughput was promising and worthy of discussion. Based on the Australian Center for the Study of Ultra-High-Bandwidth Devices Provided in Optical Systems, it was concluded that existing networks transmit data streams with significant “gaps”, creating normal downtime situations in the potentially active fiber optic environment. The practical solution to this problem was the optimization of selective switching of light waves based on LCoS technology with a subsequent change in the order of sent information packets [4]. Clearly, the method of increasing the efficiency of an optical network is the method of transforming the architecture and topology of the network. Such a method, in the current conditions of large volumes of traffic and available bandwidth, allows us to achieve results with segmental exponential growth. The classification of a unified network architecture in the form of a passive optical network (Fig. 1.), which acquires its own qualitative development in the form of hybrid (Fig. 2.), and elastic (Fig. 3.), types of construction, is shown in Fig. 1.

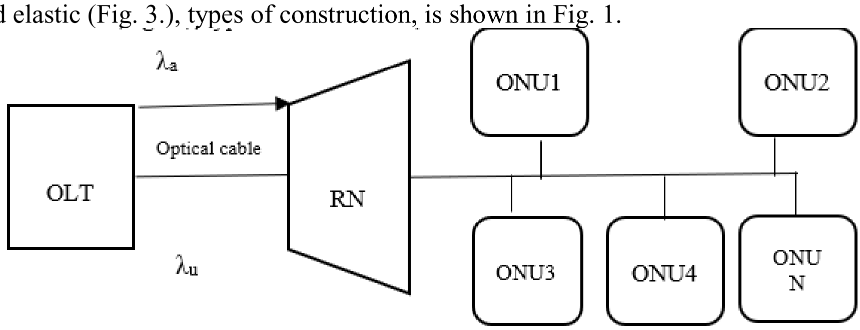

Fig. 1. Network architecture in the form of a passive optical network.

Where: λa is the optical wavelength of the shipment; λu is the loading optical wavelength; *OL*T - PON switch (optical line terminal); *RN*—remote node; *ONU*—subscriber receiving device.

Passive optical network (PON) is represented by a number of technologies on the market, among which the iconic ones are: APON, BPON, EPON, GEPON, GPON and the promising 10GEPON. From the point of view of commercial efficiency, such diversity is quite imaginary, taking into account the technological obsolescence of APON and BPON technologies, as well as the low comparable throughput of EPON technology (at the level of 100Mbps) in conditions of close range in prices for network equipment.

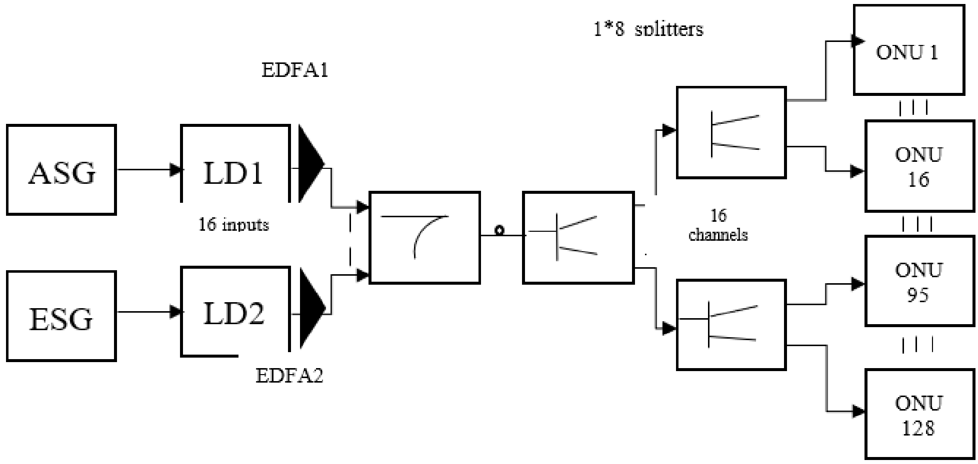

Fig. 2. Network architecture in the form of a hybrid optical network.

Where: *ASG* – analog signal generator; *ESG* – electrical signal generator; *LD* – laser diode; *EDFA* - fiber optic amplifier based on optical fiber doped with erbium ions; *WDM MUX* – spectrum multiplexer; *WDM DEMUX* – spectral demultiplexer; *RN* – remote node; *ONU* - subscriber terminal.

Thus, the most relevant technologies within Ukraine are GEPON and GPON. The main differences between the two above technologies are: double packing of packets into GEM and GTC frames (in GPON technology) and high-performance network switching and packet multiplexing technology (for GPON). Standardization of GEPON technology within the 1310nm wavelength significantly reduces the commercial load when forming client infrastructure and increases the energy efficiency of the entire system. The most powerful ONU and OLTGEPON systems allow you to flexibly increase the effective radiation range up to a margin of 37 dB [7].

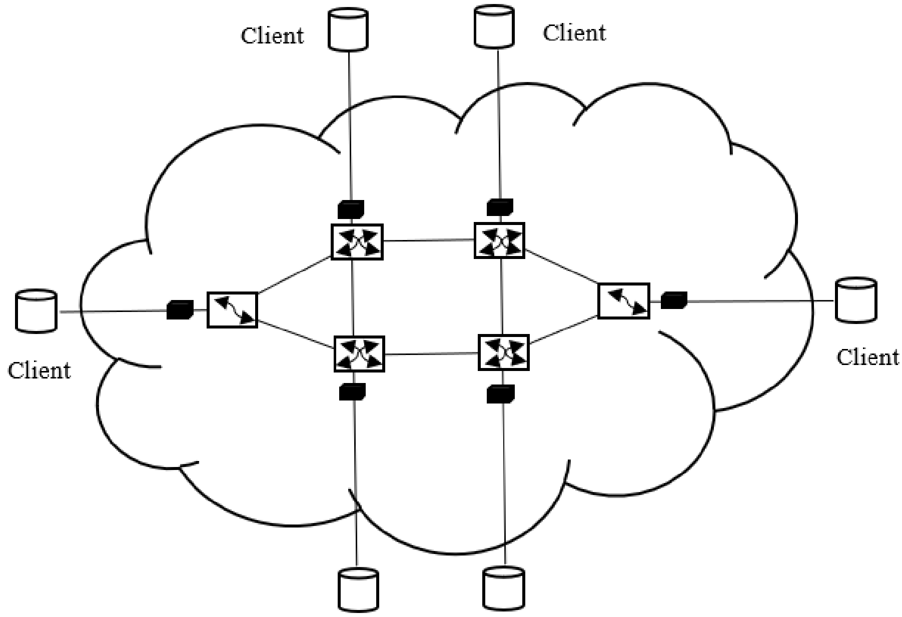

Fig. 3. Network architecture in the form of a elastic optical network.

Where, there is a transponder with variable bandwidth and an operational switch with variable bandwidth [5].

It should be noted that a separate branch of the alternative growth in the efficiency of a fiber-optic network can be called the developments of Titus Appel, Steve Sanders and Motohara Matsura in the context of the practical application of their PoF cable (power-over-fiber). This cable allows us to solve the problem of providing remote galvanic isolation, which gives it an alternative functional load. At this stage of development, the level of transmitted energy allows only powering medium-power sensors, however, in the near future there are plans to increase the transmission capacity up to the possibility of powering amplifying and relaying network devices, which will solve a number of problems with organizing an alternative energy network [3, 5].

The development of NEC Corporation and Netcracker Technology called Netro Sphere Concept is one of the promising software solutions for optimizing the operation of a fiber-optic network. This software allows the functionality of CPE equipment (client) to increase the efficiency of its work/information exchange with the network through the network virtualization system – Network Functions Virtualization. This system allows you to perform network analytics at all levels and manage network throughput due to adaptive flexibility, which involves adaptive spectral allocation of bandwidth for the optical path, basing calculations on traffic volumes and path length. In fact, this system saves optical network resources due to the calculated narrowing of the bandwidth for each client, taking into account its needs [6].

Elastic optical networks make it possible to offload IP traffic through the use of multi-stream optical transponders. This reduces the number of router interfaces while keeping cross-connections simple. The static-dynamic approach to assessing the efficiency of an optical network invariably leads to the need to specify the issues of uninterrupted operation of the network, and therefore its operational maintainability and degree of redundancy. Speaking about the technological aspects of redundancy, it is advisable to touch upon three basic aspects: the design diagram, the software and technological aspect and the method of mathematical individualization. The optical network redundancy scheme in its basic meaning is limited to linear, ring and system technologies. From the point of view of implementation, linear redundancy technology is extensive and involves increasing the number of optical fibers above the minimum required value, predominantly in a loaded form [8]. In other words, an overly large network organized according to a pure ring topology will invariably critically increase the potential for segmental disintegration in the event of a number of local breakdowns, which makes such solutions ineffective. System topology is a transformation of linear views, taking into account its construction not according to an active-passive scenario, but exclusively according to an active one.

This approach is invariably more expensive, but also provides greater autonomy in the event of damage to the primary relay nodes. The next topology goes beyond the extensive scenario provided by the synchronous digital hierarchy and is already based on spectral multiplexing of channels. The potential for implementing backup routes in the same optical fiber, without the use of additional fibers, makes it possible to reduce their number in the cable without reducing the exchange and transmission speed, reducing the spectrum of the operated waves, etc. At the same time, it should be understood that the implementation of spectral multiplexing technologies within linear structures without equipment optimization brings both positive (releasing 50% of network capacity) and negative consequences (decreased reliability and a critical reduction in availability factor) - in other words, a high-quality transition is possible only with attracting new material resources, which should be calculated using a unified formula:

$$K_g = \frac{T_s}{T_s + T_p} \tag{1}$$

where: K_g - the availability coefficient directly mediates the commercial efficiency of the network, increasing its significance with the growth of the analyzed temporal segment; T_s is the total time of correct operation, and T_p is the total downtime.

The reflected differentiation of methods for constructing an optical network significantly mathematically complicates the calculation of treated elements, strictly linking their display with the analyzed topology and the format of its implementation. To do this, you should describe a mathematical expression in the form of a formula for calculating ring reservation by replacement using an unloaded reserve:

$$P(t)_p = P(t)\sum_{i=0}^{m}\left(\frac{t_p}{\bar{T}}\right)^i \frac{1}{i!} = P(t)\left[1 + \frac{t_p}{\bar{T}} + \frac{1}{2!}\left(\frac{t_p}{\bar{T}}\right)^2 + \cdots + \frac{1}{m!}\left(\frac{t_p}{\bar{T}}\right)^m\right] \tag{2}$$

where: $P(t)_p$ - is the probability of failure-free operation of the redundant system; $P(t)$ - probability of failure-free operation of a non-redundant system; m -reservation ratio.

Based on the provided mathematical expression for the relationship between redundancy and mean time between failures, we obtain a nonlinear dependent structure that receives the following values for:

- fully loaded single reserve - K_g= <0.85;
- linear single waiting reserve - K_g= 1.1-1.5;
- linear single cold reserve - K_g= >2; etc. [9].

It should be understood that the value of this coefficient is considered under conditions of equivalence of the elementary structure of the system, in the same case when there is no such equality - its value will have less impact on the cumulative efficiency indicator of the optical network (example: the use of cold reserve in a linear structure for all elements will increase the value of the availability factor, but due to commercially unjustified implementation costs it may lose its significance in the final result). Another vector for increasing the efficiency of an optical network is super coherent technologies, the development of which can be divided into the following areas:

a) balance of multi-modulation capacity and power - aspects of square amplitude modulation are directly related to issues of qualitative indicators of the throughput efficiency of an optical network. QPSK modulation allows you to transmit 2 bits per symbol, while 64QAM modulation allows you to transmit 6 bits per symbol. However, from a technological point of view, increased modulation not only has increased data transmission speed characteristics, but also pays for this in inversely proportional to the value of noise immunity. Thus, from the point of view of building a fiber-optic network, the following modulations are considered optimal: 16QAM – for operational localization facilities (for example: metro); 8QAM – for objects of regional localization (for example: city district); QPSK – for objects at a high distance (for example: inter-city communications) [10-11].

b) dynamic transformation of the baud stream – actually reflects the speed characteristics of information transmission, while modulation is the density of the stream. In the case of determining the throughput potential of a channel under noise load conditions, the use of the baud category will be more preferable than other units of measurement. Increasing the speed of information transmission faces the opposition of noise present in the system to the channel width and signal power. These patterns are most fully outlined in the Shannon-Hartley theorem and make it possible to calculate the peak practical, rather than regulatory, potential of an optical network. Such “noise individualization” of the designed network allows not only to assess the degree of satisfaction of the design needs, but also to practically determine the required characteristics of the “receiving” equipment, in particular digital signal processors [12].

c) leveling out reflection losses from the receiver - in fact, lies in the search for providers of technologies and opportunities to reduce signal power and its subsequent distortion. The influence of this moment becomes more significant the more voluminous and wide the analyzed optical network. It should be noted that the formulas proposed by Augusta Fresnel for calculating the amplitude and intensity, refracted and reflected electromagnetic waves when passing through a flat interface between two media with different refractive indices, to a large extent, inversely correlate with the correctness and quality of installation of a fiber-optic network - the greater the installation error - the lower the validity of the results obtained [13]. Thus, it should be emphasized that the polarization for which the vector of the electric field strength of an electromagnetic wave is perpendicular to the plane of incidence is calculated using the following mathematical expressions and formulas:

$$\left\{\begin{matrix} S = \frac{2}{1+\frac{\mu_1 \tan\alpha}{\mu_2 \tan\beta}} P \Leftrightarrow S = \frac{2\cos\alpha\ \sin\beta}{\sin(\alpha+\beta)} P \Leftrightarrow S = \frac{2n_1 \cos\alpha}{n_1\cos\alpha + n_2\cos\beta} P \\ Q = \frac{1-\frac{\mu_1 \tan\alpha}{\mu_2 \tan\beta}}{1+\frac{\mu_1 \tan\alpha}{\mu_2 \tan\beta}} P \Leftrightarrow Q = -\frac{\sin(\alpha-\beta)}{\sin(\alpha+\beta)} P \Leftrightarrow Q = \frac{n_1\cos\alpha - n_2\cos\beta}{n_1\cos\alpha + n_2\cos\beta} \end{matrix}\right\} \quad (3)$$

where: α -is the angle of incidence, β - is the angle of refraction, μ_1 - is the magnetic permeability of the medium from which the wave falls, μ_2 -is the magnetic permeability of the medium into which the wave passes, *P* - is the amplitude of the wave that falls on the interface, *Q* - is the amplitude of the reflected wave, *S* - is the amplitude of the refracted wave.

d) advanced coding – advanced technologies and coding techniques in fiber optic networks can significantly increase their efficiency. Among the most common technologies, the system of forward error correction (FEC) should be highlighted in three available forms: soft decision (Softdecision), hard decision (Harddecision) and forced decision (Ultradecision). Thus, the value of the OpticalSNR (Signal-to-noiseratio) indicators is of great significance, implying the relationship between the signal power and the noise power in a given bandwidth. As the name implies, FEC technology not only encodes/decodes, but also creates a software mechanism for error anticipation by detecting and correcting the received signal. Conceptualizing the presented, it should be noted that one of the most modified techniques of the first generation FEC -Reed-Solomon provides the ability to increase the quality signal by 7% at the control point, in contrast to optical networks, where these technologies are absent and allow increasing the signal strength by 6 dB, which in turn makes it possible to achieve efficiency in data transmission and is presented in Fig. 4.

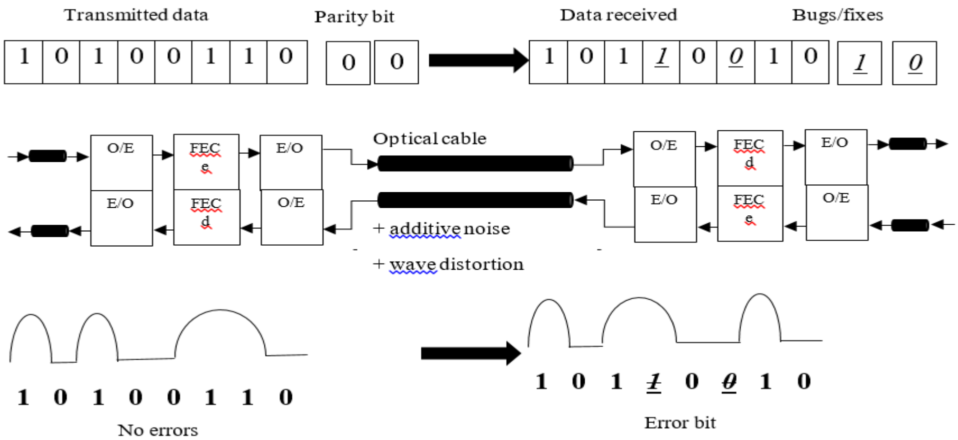

Fig. 4. Network architecture in the form of a elastic optical network.

where: FECe–forward error correction system encoder; FECd–decoder of the forward error correction system.

In practice, this technology allows you to add up to 15 km of effective data transmission with a signal in a 100 Gbit system, overcoming its natural OSNR threshold of 40 km. The use of a more stringent approach in organizing the activity of an optical network makes it possible to further increase intermediate control procedures due to the fact that the decoder not only determines the value of the binary signal, but also guarantees the reliability of the decision made [12-13].

Having stated what has been presented, it should be noted that the presented approaches and methods for increasing efficiency are not final and unique and can be supplemented and expanded depending on the purpose and objectives of the study. It should be noted that in modern conditions of intensive development, the following approaches are emerging to increase the efficiency of optical networks: multiple over-modulation; ultra-high-speed baud technologies; construction of Txpulses (with the aim of identifying new channels of limited operating frequencies and leveling the factor of negative interference of multipath signal reflections); super channels; advanced coding technologies. Ensuring the efficient operation of optical networks is important and requires constant modernization and revision of existing approaches, since the interchange and receipt of data depends on this.

4 The discussion of the results

The intensity of development of information and telecommunications technologies leads to an expansion of the range of services in the online environment, which in many ways makes it possible to optimize many business processes in companies, however, an increase in the online segment will lead to a colossal increase in traffic that is transmitted through optical networks that need to be supported , scale and modify. Based on this, it is important to note that the issue of ensuring the efficiency of optical networks is widely known and requires detailed study and development of the main methodological aspects for organizing the process of operation and increasing efficiency. The existing approaches to the study of optical networks, the specifics and features of the organization of their work discussed in the article are not exhaustive and can be supplemented depending on the direction of research. Regarding the considered approaches and the proposed methodology for increasing the efficiency of optical networks based on the expression of the relationship between redundancy and time between failures, which results in a nonlinear dependent structure, it is not exhaustive and can be improved by expanding the factors of influence or taking into account specific elements of the company's activities. which may be developed in subsequent works. The unambiguity of the need to improve efficiency is confirmed by the growth of the online segment of the global economy and the increase in traffic, which once again proves the relevance of this research and the need to find new approaches and solutions.

5 Conclusions

Realities are characterized by the fact that in all sectors of the global economy it is necessary to carry out modernization and constant modification of existing ones and the search for new approaches to management in different segments and types of activities. In this regard, the article substantiates the growth of information and telecommunication technologies in the global economy, which causes a dramatic increase in traffic that needs to be quickly and efficiently transmitted by optical networks. However, the organization and operation of optical networks requires a serious approach to the design and architecture with the expectation of increasing power and increasing efficiency. The article argues the main approaches in the field of construction and management of optical networks, highlighting the most significant and interesting approaches. It is argued and demonstrated that any system and organization of its effectiveness is an important and priority factor. The work examines the main types of optical networks, highlighting their architecture and specific organization. It has been proven that the optical network is acquiring a special complex significance, the differentiation of which is possible both according to unified and expanded vectors, which ensure the rational development of architecture and organization of functioning. Unification of the content of the desired category leads to a narrowing of the validity of its results down to a narrow target specified sector, thereby limiting its application.

The complex meaning is the broadest and includes not only intensive-extensive parameters of equipment and software, but also the external market environment - from spatial topology to economic feasibility. The proposed approaches to determining the quality of operation and increasing the efficiency of an optical network can be applied in practice as a theoretical toolkit that will serve as a basis for building an information and telecommunications architecture. The widest segment of actors in the field of building optical networks - the business environment - will always use the complex category of efficiency in the logic of their own development, while some state networks may ignore the factors of economic validity of their practical decisions. It is precisely in connection with the factors outlined above that there are no universal solutions in building effective optical networks, that is, the external environment and surroundings have priority in choosing optimal solutions.

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