DESIGNING BROADBAND FIBER-OPTIC NETWORK INFRASTRUCTURE AND EVALUATING ITS EFFICIENCY

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Abstract: This article discusses the theoretical and practical foundations of designing broadband fiber-optic network infrastructure. It examines the role of fiber-optic communication networks in modern telecommunications systems, the selection of network architecture, planning of cable routes, placement of active and passive equipment, subscriber connection processes, and methods for evaluating the technical and economic efficiency of the network. In addition, important indicators such as optical signal loss, network bandwidth, transmission delay, reliability, quality of service, and energy consumption are analyzed. The article emphasizes the necessity of considering the number of subscribers, characteristics of the service area, expected future traffic volume, and possibilities for network expansion during the design of broadband optical networks.
Keywords: broadband communication, fiber-optic network, telecommunications infrastructure, optical cable, passive optical network, subscriber network, optical signal, bandwidth, network reliability, quality of service.

Today, information and communication technologies are deeply integrated into all areas of society. The level of digital technology use is increasing in public administration, education, healthcare, banking, industry, trade, transportation, agriculture, and service sectors. This process further increases the demand for high-speed, stable, and reliable Internet networks.

Distance learning systems, video conferencing, electronic document management, cloud computing services, digital television, online commerce, electronic payments, and artificial intelligence-based services require modern network infrastructure for their full operation. Under such conditions, traditional copper-based communication lines may not provide sufficient capacity for transmitting large volumes of data at high speeds.

Fiber-optic communication technology is based on transmitting information through light signals. This technology is distinguished by high transmission speed, large bandwidth, resistance to electromagnetic interference, the ability to transmit data over long distances, and long-term operational convenience. Therefore, broadband fiber-optic networks are considered one of the main technological infrastructures of the modern digital economy.

The development of broadband optical networks not only increases Internet speed but also enables the delivery of stable digital services to the population and organizations, supports the introduction of new electronic services, and contributes to the digital development of regions.

The main purpose of this article is to describe the process of designing broadband fiber-optic network infrastructure, analyze the main technical solutions, and explain the criteria used to evaluate network efficiency.

A broadband communication network is understood as a telecommunications system capable of transmitting large volumes of information within a short period of time. Such networks allow users to access high-speed Internet, digital television, Internet telephony, video surveillance, cloud services, and other modern information services.

Fiber-optic networks have several advantages over copper-based networks. First, fiber-optic cables can transmit very large volumes of information. Second, optical fiber does not conduct electrical current and is almost unaffected by electromagnetic interference. Third, because signal attenuation in optical fiber is relatively low, data can be transmitted over long distances without the need for additional signal amplification equipment.

Broadband optical networks are especially important in the following areas: organizing distance and blended learning in educational institutions; introducing telemedicine services in healthcare institutions; developing secure online services in the banking and financial sectors; improving electronic government services in public organizations; automating production processes in industrial enterprises; providing high-quality Internet and digital television services in residential areas; centrally managing video surveillance and security systems; developing data centers and cloud computing systems.

Therefore, designing and regularly modernizing fiber-optic networks is one of the key tasks in the development of a country's digital infrastructure.

A broadband fiber-optic network consists of several interconnected technical elements. The correct selection and placement of these elements directly affect the overall efficiency of the network.

The infrastructure of a fiber-optic network usually includes the following main devices and components:central communication node; optical line terminal; backbone optical cable; distribution optical cable; optical distribution boxes; optical signal splitters; optical cross-connect equipment; optical network terminal installed at the subscriber side; routers and switches; backup power supply systems; network monitoring and management tools.

The central communication node is considered the main control point of the network. This location contains the central active devices, servers, switches, data transmission equipment, and network management systems.

The optical line terminal is an important device installed at the central node. It establishes communication between the operator's network and subscriber networks. This device transmits and receives data in the form of optical signals.

At the subscriber side, an optical network terminal is installed. This device converts the optical signal into an electrical signal that can be used by the subscriber. As a result, the user can connect a router, computer, television, telephone, or other digital devices to the network.

During the network design process, selecting the appropriate architecture is extremely important. The architecture determines how far the optical cable is extended, how subscribers are connected, and where active and passive equipment is placed within the network.

In this approach, the optical cable is extended directly to the subscriber's apartment, house, or office. This method makes it possible to provide users with very high-speed Internet access and other digital services.

The main advantage of this architecture is that copper cable is not used between the subscriber and the network center. As a result, transmission speed is high, signal quality is stable, and future network expansion becomes easier.

In this architecture, the optical cable is extended to a multi-story building or institutional building. Users inside the building are then connected through copper cables, local area networks, or other internal communication systems.

This solution is convenient for apartment buildings, business centers, educational institutions, and enterprises. In this case, it is not necessary to extend fiber-optic cable to every subscriber apartment, but special attention must be paid to the quality of the internal building network.

This method is used to connect enterprises, organizations, banks, public institutions, and business centers to high-speed networks. In such infrastructure, data security, reliability, and uninterrupted operation are of particular importance.

In this architecture, the optical cable is extended to a specific area, street, or neighborhood node. Users are connected through other communication technologies in the remaining section. Although this approach can reduce initial costs, it may have limitations in meeting future demand for very high transmission speeds.

Passive optical network technology is widely used in the construction of broadband optical networks. A passive optical network refers to a network established between the central node and subscribers using passive optical devices, especially optical signal splitters that do not require electrical power.

In this technology, a single optical signal from the central communication node is distributed among several subscribers. The signal is divided through an optical splitter and delivered to different users. As a result, the need to install a separate optical cable for every subscriber is reduced.

The main advantages of a passive optical network include:efficient use of cable resources; reduction in electrical energy consumption; reduction in the number of active devices at intermediate points; lower maintenance costs; availability of network expansion opportunities; convenience in connecting subscribers located at long distances.

However, when designing a passive optical network, it is necessary to consider optical losses caused by signal splitting. As the number of subscribers increases, the loss in the optical splitter also increases. Therefore, the optical power reserve of the network must be carefully calculated in advance.

Designing a broadband fiber-optic network consists of several sequential stages.

At the first stage, the project area is studied. The geographical location of the area, population size, residential buildings, enterprises, social facilities, and expected number of subscribers are determined. In addition, existing power networks, communication channels, roads, underground utilities, and other engineering infrastructure elements are analyzed.

At the second stage, the technical requirements of the network are defined. This includes determining the Internet speed, digital television services, video surveillance, telephony services, and other services to be provided to users. It is also necessary to determine how many subscribers the network will serve and the level of future expansion required.

At the third stage, optical cable routes are selected. Cables can be installed through underground cable ducts, along aerial lines, or by using existing communication infrastructure. When selecting a cable route, safety, maintenance convenience, economic costs, and natural conditions of the area must be considered.

At the fourth stage, network equipment is selected. Optical line terminals, subscriber terminals, optical splitters, switches, routers, optical cross-connect devices, and other equipment are determined according to technical requirements.

At the fifth stage, the optical power budget of the network is calculated. This calculation helps identify all losses that occur from the transmitting device to the receiving device.

At the sixth stage, testing and commissioning activities are carried out. During testing, signal quality, transmission speed, delay time, packet loss, network load, and other indicators are checked.

Data transmission speed is one of the most important network performance indicators. It refers to the amount of information transmitted within a certain period of time. This indicator is usually measured in megabits per second, gigabits per second, or terabits per second.

High data transmission speed enables users to download large files quickly, watch high-quality video content, participate in video conferences, receive online education, and effectively use cloud-based systems.

Bandwidth refers to the amount of information that a network can transmit simultaneously. This indicator depends on the number of users in the network, traffic type, equipment capacity, and channel capacity.

When designing a network, it is necessary to consider not only the current number of subscribers but also potential future users and the expected growth of services. Otherwise, the network may become overloaded within a short period of time.

Transmission delay refers to the time required for a data packet to travel from the sender to the receiver. Since signals in optical networks travel at speeds close to the speed of light, delay is relatively low.

Transmission delay is particularly important for the following services:video conferencing; online gaming; remotely controlled equipment; telemedicine systems; video surveillance systems; online payment services; real-time monitoring systems.

Packet loss refers to a situation in which a portion of transmitted data does not reach its intended destination. If packet loss increases, video quality may deteriorate, voice communication may be interrupted, webpages may load slowly, and data may be transmitted incorrectly.

In fiber-optic networks, packet loss is usually very low. However, improperly configured devices, high network load, cable damage, or equipment failures may lead to an increase in packet loss.

Conclusion

Designing broadband fiber-optic network infrastructure is one of the important directions in the modern telecommunications sector. Such networks ensure the stable operation of high-speed Internet, digital television, distance education, cloud services, electronic government platforms, telemedicine, and other modern services.

Fiber-optic networks are distinguished by high bandwidth, low signal attenuation, resistance to electromagnetic interference, the ability to establish communication over long distances, and energy efficiency.

For successful network design, it is necessary to thoroughly study the service area, number of subscribers, traffic volume, cable routes, technical capabilities of equipment, optical power budget, and future expansion needs.

Network efficiency should be evaluated based on indicators such as data transmission speed, bandwidth, transmission delay, packet loss, network reliability, energy consumption, and economic profitability.

A properly designed, high-quality, and continuously monitored fiber-optic network serves as a strong technological foundation for the future development of digital services.

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