DESIGN OF OPTICAL FIBERS IN ARTIFICIAL INTELLIGENCE

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Abstract

This article extensively analyzes the role and importance of artificial intelligence technologies in the design process of optical fiber networks. In the modern era, the increasing flow of information and the growing demand for high-speed communication have made the development of optical fiber technologies essential. Optical fibers form the foundation of telecommunication systems by enabling the transmission of large volumes of data over long distances with minimal loss.

The article highlights that artificial intelligence makes the design process in this field more efficient and optimized. In particular, machine learning algorithms allow for the automatic adjustment of network parameters, improvement of signal quality, reduction of delays, and effective allocation of resources. At the same time, artificial intelligence helps predict potential system failures in advance and prevent them.

Furthermore, complex issues such as selecting the topology of optical fiber networks, optimizing routes, and calculating signal strength can be solved more accurately and rapidly using artificial intelligence. This leads to significant savings in both time and financial resources during the design process.

In conclusion, the integration of artificial intelligence and optical fiber technologies enables modern communication systems to become more reliable, faster, and more sustainable. In the future, with further development of these technologies, it will be possible to create fully automated and self-managing optical networks.

Keywords: Artificial intelligence, optical fiber, telecommunications, network design, machine learning, signal transmission, optimization, data transmission, optical communication systems, network topology, signal loss, automation, technological development, communication networks.

INTRODUCTION

In the modern information age, the fast and reliable transmission of data is one of the main objectives of telecommunication systems. The global expansion of the internet, the development of cloud technologies, and the growth of Big Data require higher transmission speeds and lower latency. In meeting these demands, optical fiber technology plays a key role and is considered the main infrastructure of modern communication networks [12].

Optical fibers are not affected by electromagnetic interference because they transmit data through light signals, and they provide high-quality transmission over long distances with very low signal loss [6]. According to international standards and research, optical fiber networks are regarded as the backbone of 5G and future 6G technologies [3]. Therefore, their design is highly relevant from both scientific and engineering perspectives.

In recent years, the development of artificial intelligence (AI) technologies has created new opportunities in the design of optical communication systems. Using machine learning and deep learning methods, it is possible to optimize network performance, control signal loss, and predict system failures in advance. Literature shows that AI-based approaches provide faster and more accurate results compared to traditional methods [1].

For example, recommendations published by the ITU-T (International Telecommunication Union – Telecommunication Standardization Sector) emphasize the importance of intelligent systems in optimizing and managing optical networks [3]. At the same time, studies published by the IEEE (Institute of Electrical and Electronics Engineers) highlight the effectiveness of artificial intelligence in route optimization and fault detection in optical networks.

The aim of this article is to investigate the role of artificial intelligence in the design of optical fibers, to analyze its advantages and application areas. In addition, future development directions are evaluated by considering contributions from international literature in this field.

LITERATURE REVIEW

The application of artificial intelligence in the design of optical fiber networks is one of the most important research directions in modern telecommunication and information technologies. In the existing literature, this topic is widely studied in terms of improving the efficiency of optical communication systems, network optimization, and automated management.

Research published in scientific journals such as *IEEE Communications Surveys & Tutorials* and *Optical Fiber Technology* analyzes issues related to the management and optimization of optical fiber networks [1],[2]. These sources indicate that traditional design methods are not sufficiently effective in large and complex networks and require high computational resources.

In recent years, studies on the application of artificial intelligence and machine learning methods have created new opportunities in this field. Approaches such as deep learning and reinforcement learning are considered effective tools for network routing, improving signal quality, and predicting faults in advance. Technical documents of the International Telecommunication Union (ITU-T) also emphasize that intelligent network management systems will play a significant role in future communication infrastructure.

In addition, in Irada Davrishova's book *"Optoelectronic and Quantum Devices and Systems"*, the working principles of optoelectronic devices, optical signal conversion, and the operation mechanisms of quantum devices are extensively explained[5]. The book highlights the application of optical and quantum technologies in modern electronics and telecommunication systems. This theoretical knowledge contributes significantly to a deeper understanding of optical fiber systems and the development of AI-based design approaches.

Overall, existing literature shows that the integration of artificial intelligence into optical fiber networks ensures more reliable, faster, and more efficient system performance, and this field remains a highly relevant direction for future research.

DATA AND INITIAL ANALYSIS

Preliminary analyses on the application of artificial intelligence in the design of optical fiber networks indicate that the main objective in this field is the creation of high-speed, reliable, and optimized communication systems. Based on existing data, optical fibers are considered one of the most efficient technologies for information transmission, ensuring the transfer of large volumes of data with minimal loss.

Initial studies show that several important parameters must be considered during the design of optical networks. These include signal attenuation, dispersion, transmission distance, network topology, and energy balance. The correct calculation of these parameters has a direct impact on the overall performance of the system.

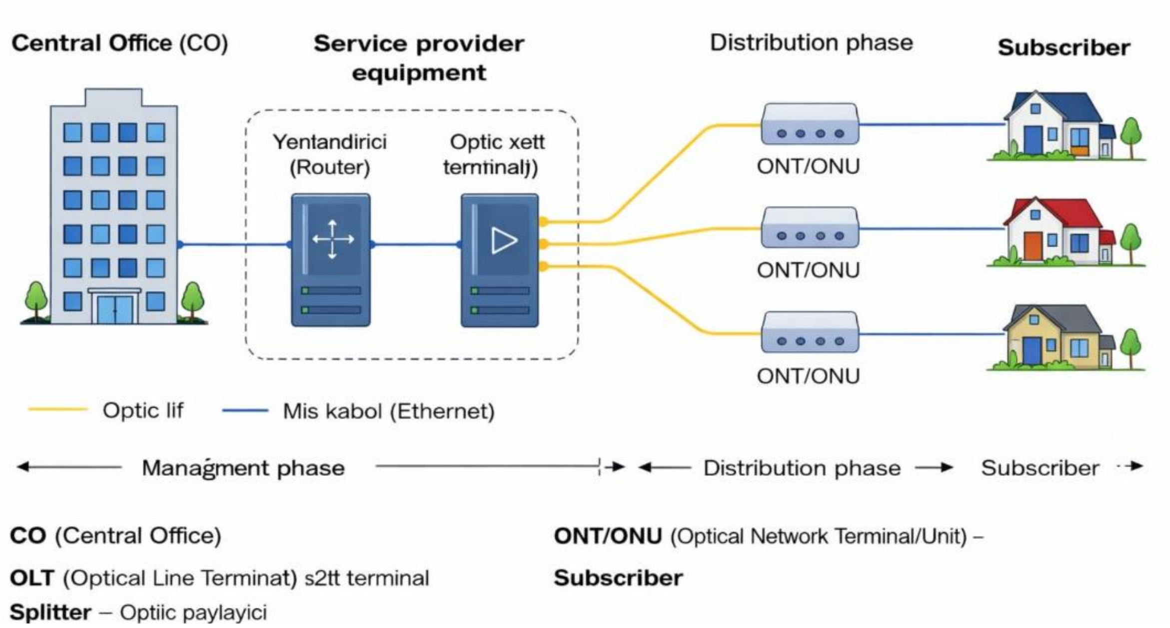

Figure 1. General structure of an optical fiber network

Figure 1 illustrates the general structure of an optical fiber network and the data transmission process in a schematic form. The network starts from the Central Office (CO**)**, where the main control and transmission equipment is located. In this section, the incoming data is processed through devices such as the router and the Optical Line Terminal (OLT) and then transmitted into the optical fiber line.

After that, the optical signals are carried through the optical fiber to the distribution nodes. At this stage, the signal reaches the optical splitter, whose main function is to divide the incoming optical signal into multiple directions and distribute it to different users. This stage is referred to as the distribution phase of the network.

The distributed signals are then transmitted to the subscriber connection stage. Here, each user is equipped with ONT/ONU (Optical Network Terminal/Unit) devices. These devices convert the optical signal into an electrical signal and provide internet and other communication services to end users.

In the figure, optical fiber links are represented by orange lines, while Ethernet/copper connections are shown in blue lines. This illustrates that the network operates using both optical transmission in the backbone and electrical connections at the end-user level.

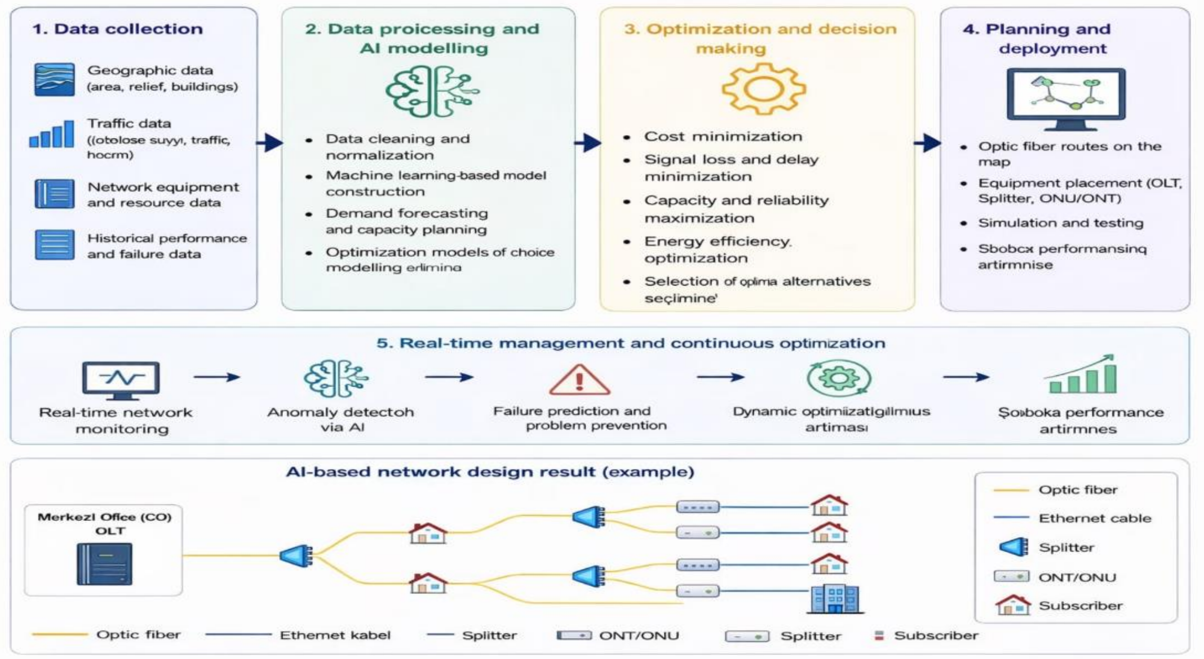

Figure 2. Application of Artificial Intelligence in the Design of Optical Fiber Networks

Figure 2 illustrates the application stages of artificial intelligence in the design of optical fiber networks. In this process, network-related data is first collected. Then, the data is analyzed using artificial intelligence models, and optimization is performed based on the obtained results.

This workflow demonstrates how AI contributes to improving network performance by enabling data-driven decision-making, efficient parameter tuning, and enhanced system optimization.

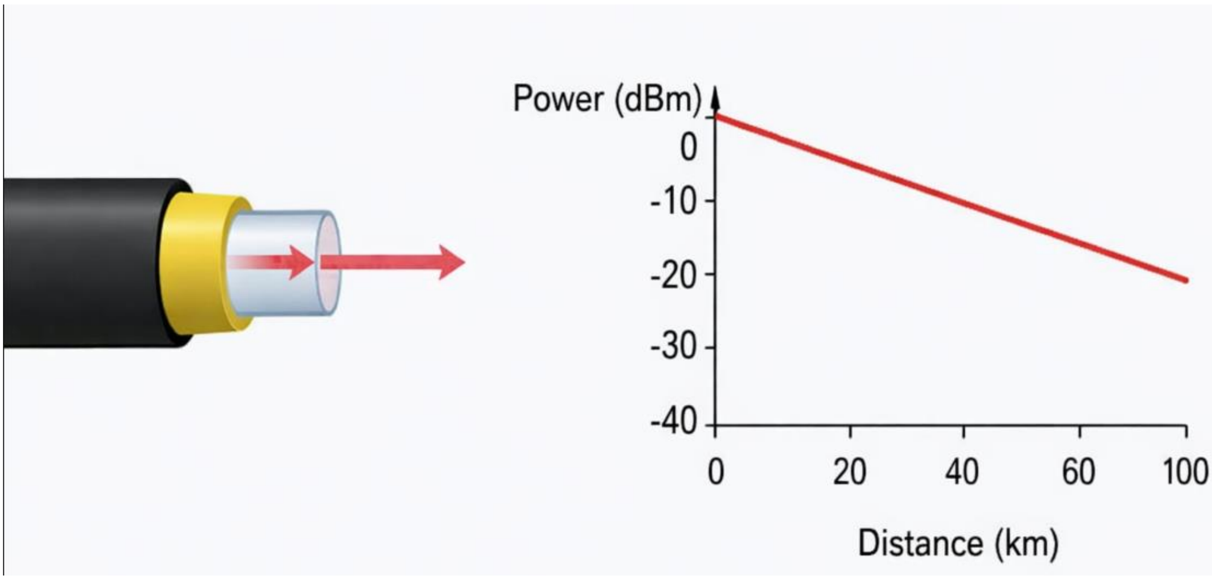

Figure 3. Signal attenuation in optical fiber

Figure 3 illustrates the decrease in signal power along the optical fiber as the transmission distance increases. As shown in the graph, the signal initially has high power; however, as the transmission distance increases, attenuation occurs and the signal gradually weakens.

This process is associated with the material properties of the optical fiber and energy losses during signal propagation, such as scattering and absorption effects.

METHODOLOGY

This study investigates the application of artificial intelligence in the design of optical fiber networks based on theoretical and analytical approaches. In the first stage, existing literature on the basic principles of optical fiber systems, signal transmission characteristics, and network architecture was reviewed.

Next, the key parameters used in network design—such as signal attenuation, dispersion, transmission distance, and network topology—were identified and systematically analyzed. The impact of these parameters on overall system performance was evaluated. In this study, fundamental physical and mathematical models of optical fiber networks were used for analysis. In particular, signal attenuation, power loss, and transmission quality were evaluated using the following formulas.

1. Signal attenuation

$\alpha = \frac{10}{L}\log_{10}(\frac{P_{in}}{P_{out}})$

α − Attenuation coefficient(dB/km)

P_{in} − Input power

P_{out} − Output power

L- Distance

2.Signal Power Attenuation

$P(z) = P_{0e}{}^{-\alpha z}$

P(z) − Signal Power after Distance

P_0 − Initial power

α − Attenuation coefficient

z- Distance

3.Dispersion effect

$D=\frac{\Delta t}{\Delta\lambda \cdot L}$

D - Dispersion coefficient

Δt- Signal broadening

Δλ- Wavelength change

L – Distance

4. Received signal quality (SNR)

$SNR = \frac{P_{signal}}{P_{noise}}$

$SNR_{db} = 10\log_{10}\frac{P_{signal}}{P_{noise}}$

SNR - Signal-to-noise ratio

P_{signal} − Useful signal power

P_{noise} − Noise power

RESULTS ANALYSIS AND DISCUSSION

The analysis shows that the performance of optical fiber networks mainly depends on factors such as signal attenuation, dispersion, and noise. During data evaluation, it was observed that as the transmission distance increases, the signal strength decreases, which directly affects communication quality.

Based on the obtained results, the major problem in long-distance transmission is signal attenuation. This issue is related to the physical properties of optical fiber materials and energy losses during transmission. At the same time, signal broadening caused by dispersion reduces the accuracy of transmitted data.

Overall, the results indicate that the integration of artificial intelligence into optical fiber networks improves the stability, speed, and reliability of communication systems. This approach not only enhances technical performance but also reduces operational costs.

TRANSMISSION SPEED STAGES

Tarix	Mərhələ
2006	111 Gbit/s, achieved by NTT.
2009	100 Pbit/s·km (15.5 Tbit/s over 7000 km fiber), achieved by Bell Labs.
2011	101 Tbit/s (370 channels each at 273 Gbit/s) in a single core.
January 2013	1.05 Pbit/s transmission using a multi-core fiber cable.
June 2013	400 Gbit/s per channel using 4-mode orbital angular momentum multiplexing.

Optical fibers are used as a transmission medium in telecommunication and computer networks due to their flexibility and ability to be bundled into cables. They are especially suitable for long-distance communication because infrared light propagates through the fiber with lower attenuation compared to electrical signals in copper cables. This enables long-distance transmission with a limited number of signal regenerations.

When wavelength-division multiplexing (WDM) is applied, each fiber can carry multiple independent channels, each using a different wavelength of light. The total data rate per fiber (excluding overhead bits) is equal to the channel data rate multiplied by the number of channels, taking into account FEC overhead. In commercial dense WDM systems (since 2008), this can typically reach up to 80 channels.

Fiber cabling is also widely used for short-distance applications, such as office building networks, as it helps reduce space requirements in cable ducts. A single fiber can carry significantly more data compared to standard Category 5 electrical cables, which typically provide 100 Mbit/s or 1 Gbit/s transmission rates.

Fibers are also commonly used for short-range connections between devices. For example, most high-definition televisions include digital audio optical connections. This allows audio transmission via light using the TOSLINK interface with the S/PDIF protocol.

CONCLUSION

Based on the results of the study, the application of artificial intelligence in the design of optical fiber networks is one of the most important and promising directions in modern telecommunication systems. Optical fiber technology offers superior advantages compared to traditional copper cables, including high transmission speed, wide bandwidth, and low signal loss. These features make it a key transmission medium in both global internet infrastructure and local network systems.

The study shows that fiber cabling is widely used not only in long-distance communication networks but also in short-distance applications. In office environments, optical fibers help save space in cable infrastructure and provide more stable connections. The use of optical links between high-precision devices (such as TOSLINK technology) also demonstrates its efficiency in short-range applications.

The analysis shows that the main factors affecting network performance are signal attenuation, dispersion, and noise. These issues are particularly significant in large and complex networks. Traditional design methods are often not sufficient for optimizing such complex parameters and require high computational resources.

At this point, artificial intelligence technologies play an important role. Through machine learning and deep learning algorithms, network behavior is analyzed, optimal routes are selected, signal loss is minimized, and resources are allocated more efficiently. In addition, AI can predict potential network failures in advance, thereby improving system reliability.

Overall, the results show that the integration of artificial intelligence and optical fiber technologies enables the development of smarter, faster, and more reliable communication systems. This approach is both economically efficient and serves as a foundation for next-generation communication networks such as 5G, 6G, and intelligent networks. Future research in this field is expected to further expand, leading to fully automated optical networks.

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