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KEY FACTORS IN MONITORING INFORMATION SECURITY IN OPTICAL FIBERS

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Abstract: The article presents theoretical information about methods of extracting data from optical fibers. Among the analyzed methods, the simplest one is based on the bending of the optical fiber, which occurs when the conditions for total internal reflection are violated. The functional dependence of losses and the emitted power level is determined by the bending parameters and geometry of the optical fiber. In this case, the monitoring system controls the introduced losses in order to detect fiber bending. The structure and operating principles of monitoring systems, as well as development trends, are discussed. The main technical characteristics of optical radiation detection devices are also presented.

Keywords: optical fiber communication line, information protection, monitoring system, reflectometry, bending, unauthorized access, leakage channel.

Introduction

With scientific and technological advancement, the potential vulnerability of optical fiber networks increases. This is primarily due to the decreasing cost and increasing availability of the equipment and devices necessary for interfering with optical lines. There is also a downside to technological progress: more and more attackers are gaining the technical capability to carry out unauthorized access.

As in many other cases, the likelihood of unauthorized access is determined by economic feasibility – specifically, the cost-benefit ratio of the connection. For example, in home PON networks, unauthorized access could be used to gain free access to cable television, but this is rarely done because, in such cases, a regular subscription is cheaper for the average user. The situation is different when it comes to accessing data in corporate or institutional networks.

Such data is usually confidential and may be of significant importance to certain categories of individuals. In this case, the risk of unauthorized access cannot be ruled out.

In this regard, the development of identification algorithms and principles for creating monitoring systems to detect data leakage channels in optical fiber transmission systems is an important and relevant task.

Problem formulation

Monitoring information security in optical access networks involves identifying and addressing issues related to data leakage through technical channels. In many cases, the operating principles of data collection devices are based on pressure, macro bending, and the influence of temperature on the optical fiber.

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Alternative methods of extracting a portion of optical radiation from the surface of an optical fiber have several significant drawbacks, such as potential fiber damage and low levels of tapped power. Currently, there are devices capable of extracting information through fiber bending, which makes unauthorized access in optical access networks (OANs) technically feasible.

Methods based on monitoring have wide functional capabilities:

- does not require the communication to be closed;
- more cost-effective;
- allows for the application of networks with various hierarchical levels (local, subscriber, zone);
- enable monitoring of different information transmission technologies.

Methods for detecting unauthorized connection to optical fiber

The principle of monitoring unauthorized access is based on the fact that any external influence causes changes in both the local properties of the light guide and the overall parameters of the communication line. Changes in the above parameters serve as indicators for modern monitoring tools – specialized complexes. Such systems must ensure the following:

- automatic detection of unauthorized access and its precise location;
- remote control of unauthorized access to active fibers of optical cables;
- timely documentation and reporting;
- management and control of the alert process regarding unauthorized access to optical cables;
- manual control of unauthorized access in the operational mode.

Functionally, the monitoring system consists of three main components

- control module;
- module for correcting changes in the optical fiber transmission line state;
- module for analyzing changes in the optical fiber transmission line state.

The management module is responsible for synchronizing and controlling the operation of other modules, as well as interacting with the data transmission system.

The module for recording changes in the optical fiber transmission line state is based on the diagnostic system of the communication line (SDS). The SDS is implemented through the analysis of relay scattering, Fresnel reflection signals, as well as Brillouin–Mandelstam scattering spectra.

Advantages of SDS with signal analysis:

- ability to continuously measure optical radiation parameters;
- ability to measure any network of the transmission system.

Moreover, the system has a relatively simple device. The simplest SDS, based on the error coefficient analyzer, can be implemented using basic VOLS tools. Later, more complex variants are based on transmitting multiple signals through the system: information and control signals. Control signals are usually transmitted at a longer wavelength due to physical principles, which allows for increased sensitivity of the system.

The SDS based on impulse reflectometry is more complex and functional. It allows for determining the coordinates of unauthorized access according to the following formula:

$$L_X = \frac{\Delta t}{2} \cdot \frac{c_0}{n_g}, [km]$$

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where L_x – the measurable coordinate of unauthorized access;

Δt – time difference between the peaks of the initial and final pulses, in nanoseconds;

c_0 – speed of light in a vacuum, equal to 300,000 km/s;

n_g – refractive index of the core glass group.

The systems allow for measuring the losses introduced through unauthorized access with high accuracy. This is achieved through the use of regression analysis, by estimating the sections of the reflectogram before and after the connection. In the case of linear approximation:

$$Y = a + bx$$

where a and b are the coefficients calculated using the formulas:

$$a = \frac{\sum_{i=1}^{n} \hat{Y}_i \sum_{i=1}^{n} (\hat{X}_i)^2 - \sum_{i=1}^{n} \hat{X}_i \sum_{i=1}^{n} \hat{X}_i \hat{Y}_i}{n \sum_{i=1}^{n} (\hat{X}_i)^2 - (\sum_{i=1}^{n} \hat{X}_i)^2},$$

$$b = \frac{n \sum_{i=1}^{n} \hat{X}_i \hat{Y}_i - \sum_{i=1}^{n} \hat{X}_i \sum_{i=1}^{n} \hat{Y}_i}{n \sum_{i=1}^{n} (\hat{X}_i)^2 - (\sum_{i=1}^{n} \hat{X}_i)^2}, \quad (8)$$

Where: $\hat{X}_i$ – mathematical estimation of the measured L_i coordinates;

$\hat{Y}_i$ – mathematical estimation of the loss values measurable at the L_i coordinates;

n – number of samples in the estimated segment.

The maximum distance to the coordinates of unauthorized access can be calculated using the formula:

$$L_{\max C} = D / \alpha_{abs}$$

Where: D – dynamic range of the optical reflectometer,

α_{abs} – optical fiber's per-kilometer losses.

When the length of the optical fiber transmission line exceeds 20 km and high spatial resolution is required, the pulse detection sensitivity may not be sufficient. The metrological parameters of the monitoring system can be significantly improved by using frequency-modulated complex probing pulses. In this case, optical radiation is introduced into the monitored system along with the information signal, but its frequency changes according to the given modulation function at a different wavelength. The radiation passing through the optical fiber transmission line and reflected in the opposite direction is mixed with the probing signal. Information about the evolution of the probing optical signal is obtained from the frequency spectrum of the beats resulting from the mixing of the two signals. These are the promising trends for the development of monitoring principles.

An emerging trend for more accurate detection of unauthorized access is the analysis system based on neural networks. The computing network synthesizes and processes data obtained through various diagnostic methods, analyzes, identifies, and provides precise information about the causes of changes in the state of the VOLS and the most probable attacks for the model network. This allows for deeper analysis and reduces the likelihood of false positives, thereby enhancing the efficiency of the monitoring system.

Conclusion

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The results of the analysis of unauthorized access methods to fiber can be used in the design, construction, and technical operation of optical access networks. Research on the attenuation of optical signals and the increase in output power levels serves as the basis for developing an algorithm to detect unauthorized access in optical access networks. The functional dependence of radiation power loss through the side surface of the optical fiber, depending on the output coefficient, provides the foundation for justifying the required sensitivity of the photodetector. The diagnostic system based on pulse reflectometry is the most informative for assessing the state of optical fiber.

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