Advances in Artificial Intelligence and Machine Learning; Research 5 (4) 4631-4644 Received 22-08-2025; Accepted 22-11-2025; Published online 29-11-2025

# AI-Based OTDR Event Detection, Classification and Localization in Optical Communication Networks

**Islambek Saymanov** islambeksaymanov@gmail.com
*National University of Uzbekistan*
*Uzbekistan*

**Rikhsi Isaev** ceoatetm@gmail.com
*Tashkent University of Information Technologies*
*Uzbekistan*

**Saparniyaz Tursimuratov** s.salavatovich@tuit.uz
*Tashkent University of Information Technologies*
*Uzbekistan*

**Avazbek Jurabekov** avazbek.zhurabekov@gmail.com
*Tashkent University of Information Technologies*
*Uzbekistan*

**Kholisakhon Davletova** holisa23459@gmail.com
*Tashkent University of Information Technologies*
*Uzbekistan*

**Corresponding Author:** Islambek Saymanov

## Abstract

The article describes the research on the assessment of the operational state of fiber-optic communication lines in operation in the sharply continental climate of the Republic of Karakalpakstan. The study analyzed the operational state of the fiber-optic communication line by processing the OTDR trace curves obtained from the OTDR (Optical Time Domain Reflectometer) device. The MATLAB program was used as an environment for processing the OTDR trace curves obtained from the OTDR device. In this case, the OTDR trace curve was converted from the SOR format to the CSV format and processed. In order to improve the quality of the initial return signal to the OTDR trace curves, filtering and noise were reduced, and events on the line were identified. At the next stage, artificial intelligence tools were used. The k-means clustering algorithm was used for analysis. In fiber-optic communication lines, line segments are divided into groups as normal, faulty or anomalous depending on the attenuation and loss of the optical signal power. Also, signal drops above the average level were detected using the threshold method. This increased the efficiency of early fault detection. The research results showed that the proposed methods are effective in processing large volumes of OTDR data. They also increase the accuracy of fault detection and localization. This research method is convenient and easy to use in conditions where initial data for analysis and research are scarce, that is, difficult to control. In addition, this

**Citation:** Islambek Saymanov et al. AI-Based OTDR Event Detection, Classification and Localization in Optical Communication Networks. **Advances in Artificial Intelligence and Machine Learning**. 2025;5(4):257. https://dx.doi.org/10.54364/AAIML.2025.54257

approach can be used as an effective tool for continuous monitoring of the condition of fiber optic communication lines and for detecting anomalies.

**Keywords:** OTDR, Optical networks, Event detection, Fault localization, AI, Karakalpakstan, K-means clustering, Threshold-based method.

## 1. INTRODUCTION

Fiber-optic communication systems are the main link of the modern information and communication infrastructure, ensuring reliable information exchange in all spheres of the economy and society. Reliable and uninterrupted operation of such systems is of strategic importance. In recent years, the construction of infrastructure based on fiber-optic communication lines has been rapidly expanding in the world. Therefore, ensuring stability during the operation of TOAL has become an urgent problem.

This problem is especially clearly observed in the territory of the Republic of Karakalpakstan, located in the north-west of Uzbekistan on the shores of the Aral Sea. The territory has sharply continental climate characteristics and falls into the IVG climate classification. Due to sharp temperature changes, dry air and proximity of salty groundwater to the surface, TOAL elements wear out quickly. This leads to frequent malfunctions during operation. Therefore, it is very important to assess the operational condition of the line in such climatic conditions using modern research methods. In practice, for this purpose, initial control measurements are made using an OTDR device, and OTDR trace curves are analyzed as initial data for assessing the condition. However, in harsh continental climates, OTDR signals undergo changes due to various noise and external influences, which complicates the analysis process. Therefore, researchers are conducting research to increase the accuracy of OTDR measurement analysis by introducing modern signal processing methods (See Figure 1).

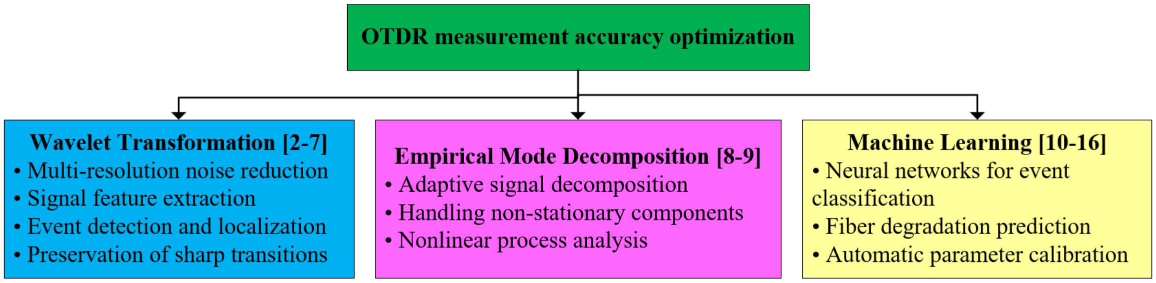


Figure 1: Modern methods for improving the accuracy of OTDR measurements [1]

As compared to WT where its localization characteristics in both time and frequency domains offer great capabilities, the OTDR signals using the wavelet transforms (WT) has been step by step decomposed in detail for each frequency component, which can be extracted independently for further study. Early studies have reported in Ref. [2] that the WT application for OTDR signal processing has been investigated in particular for Morlet wavelet. Through theoretical and numerical analysis, they have shown that the event detection and the corresponding device performance can be largely improved. While in recent studies [3–8] emphasized the extensive use of WT for OTDR signal analysis. The improved algorithms can reject the interference more reliably, detect the weak or non-reflective signal and more accurate localization of the faults. To some extent, the new approach of optical wavelet reflectometry (OWDR) has been proposed to solve some of the limitations of traditional OTDR and OFDR. Besides, discrete wavelet transforms (DWT), biorthogonal wavelet, entropy-based method and hybrid WT+CA-CFAR method has widely been used in OTDR and their performance were verified to be very high in suppressing noises [9]. Certainly, these methods can also be used in mountainous areas or in extreme climatic conditions to improve the reliability and stability of OTDR.

Empirical mode decomposition (EMD) has been used to suppress noises in the OTDR traces. OTDR signals are usually polluted by transient interference. It has been proved that EMD is an effective tool to suppress noises in these signals. Some hybrid methods combining EMD and WT have been proposed. The event detection and localization accuracy were improved by combining the advantages of EMD adaptability and WT advantages of localization [10]. However, EMD is still a method without strict mathematics foundation. Another strategy to improve the OTDR measurement is to apply intelligent monitoring system by combining OTDR data and external environment information. The multi-parameter analysis enables the real-time monitoring of the fiber optic communication link. It is expected to expand the dynamic range of measurements while preserving spatial resolution. The strategy based on EMD has been used in the optical network fault diagnosis and analysis.

In recent years, there has been an increasing interest in using OTDR data and machine learning (ML) algorithms for fault detection and prediction in optical networks. For instance, in [11], a multi-task LSTM framework was proposed and applied in fiber link to detect reflectivity defects such as splice and connector with up to 93% accuracy and provide accurate fault localization. Results show that ML-based methods significantly outperform traditional OTDR trace analysis. In [12], an intelligent monitoring system was proposed by combining both OTDR data and external environment information such as temperature and soil moisture. The multi-parameter analysis enables the early fault detection and enhances the efficiency of preventive maintenance, which in turn leads to a reduction of the unplanned outage. In addition, in [13], a CNN combined with ensemble learning was proposed to classify eight different types of fiber optic faults. The achieved accuracy was an exceptionally high 99,3% (F1=0.99) and high robustness to noises and data imbalance.

The problem of accurate fault localization in underground networks is particularly challenging. In [14] an ML model that localizes faults based on OTDR data and also provides information on the cost of repair or replacement of fiber sections was presented. Similarly, in [15] a machine learning based event detection strategy for differential signal processing was presented, which attained 95% splice detection accuracy under noisy conditions. Similarly, in [16] it was shown that application of CNN to low-SNR OTDR signals can greatly enhance the reliability of event detection.

As a result, the synergy between OTDR readings and machine learning methods results in quicker, more precise and less expensive fault detection, setting the stage for operation monitoring in real-time and immensely increasing the reliability of fiber optic networks in operation.

## 2. MATERIALS AND METHODS

### 2.1 OTDR Testing Principles.

OTDR is a widely used device for testing, diagnosing and monitoring optical fibers and fiber optic communication lines [17]. The operating principle of OTDR is similar to the operating principle of radar: a short light pulse sent to one end of the optical fiber is introduced through a light source, and the reflected optical signal is received through a photodetector. The amplitude of the returned signal, recorded as a function of the propagation time of the light pulse, shows the characteristics of the attenuation levels at each point in the optical fiber. These characteristics are described using Rayleigh and Fresnel reflections.

In fiber optic communication, Rayleigh reflection is one of the most important linear effects in single-mode optical fiber, which is important in determining the main limit of optical signal power loss. At the same time, Rayleigh reflections are also used to distribute the attenuation of optical signal power in the optical fiber [14].

Fresnel reflection is very important for detecting the boundaries of these two media, i.e., the locations of detachable connectors and faults. This effect is characterized by a sharp change in the characteristics of the optical signal propagation medium, unlike Rayleigh reflection.

Figure 2 below shows the general structure of the OTDR device. In this case, a laser diode probes optical signals for testing the fiber optic communication line. The laser diode generates a sequence of short optical signal pulses and is controlled by an electrical pulse generator. The reflected optical signal is received by a photodetector. The waveform of the recorded optical signal is amplified and converted into a digital signal by an analog-to-digital converter. At the next stage, the digital signal is analyzed in the processing unit.

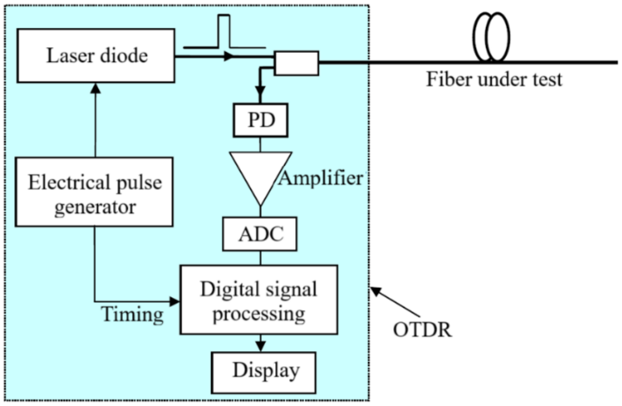


Figure 2: Basic block diagram of OTDR

The OTDR trace defines the attenuation distribution function along the cable length and can also be used to locate sections and causes of transmission quality degradation. For example, splice points and scattering areas appear on the OTDR trace as regions of increased attenuation without a power spike of the reflected signal. This indicates that these areas are points of Rayleigh scattering ($P_{rs}$)

without Fresnel reflection. At the same time, points of poor connections, fiber breaks, or significant cable damage appear as reflection points with characteristic spikes in the reflected signal power.

The study of reflectometric traces allows the detection of numerous events or malfunctions that arise mainly due to specific optical phenomena, each of which has a characteristic effect on the trace. Rayleigh backscatter is one of the most basic types of backscatters. This natural result in the fiber comes from microscopic imperfections and impurities manufactured into it. This phenomenon is the main mechanism of signal attenuation, and ultimately reduces the optical power along the fiber's length in a linear fashion, or seen on an OTDR trace in terms of dB/km. Fresnel reflection is caused from a pulse of light reflecting off a discontinuity in the fiber, such as breaks, couplers, attenuators, and splices. At this localized point, some of the light reflects back toward the OTDR detector and creates a distinct and clear peak on the trace.

Discrete losses are manifested on the OTDR trace curve as sudden reductions in signal level, typically caused by optical components such as splices, couplers, or attenuators that reduce the level of optical power reflected (See Figure 3). If two discontinuities are close together, reflection or scattering from the first can mask the second. The industrial junction causes dead-space in the trace that places the instrument in a zone where it is unable to resolve individual events.

The optical conditions are responsible for generating optical events that inform the diagnostic and supervision of the fiber link. The optical events are then interpreted by optical engineers or specialized software. For our study, we have recognized four categories of events:

- face-plate this incident occurs at the beginning of the span where the OTDR tool injects the pulses;
- pass-through the coupling of two FOCL occurs mechanically;
- fiber-end this incident occurred because a connector was inserted into a far-end device that cut physics of the FOCL;
- fiber-cut this incident occurred and was a cut that cuts the fiber and consequently the transmission.

The recommended values for event thresholds are responsible for accurate analysis of fiber-optic links and therefore provide a reasonable compromise between detection sensitivity and the amount of nuisance alarms we collect. In adverse conditions (e.g., high-noise networks) those thresholds can be adjusted using OTDR's automated threshold calculations in TABLE 1.

In practice, unknown phenomena may also occur that cannot be observed in any of the above categories. In addition, there are several types of events, such as a very rare bulk attenuator, so it is not possible to collect a sufficiently large number of training examples. Solutions for detecting unknown phenomena are very valuable, as they can also report rare phenomena that are not represented in the training set.

OTDR uses Rayleigh scattering and Fresnel reflection to describe optical properties [1]. When light is transmitted in an optical fiber, Rayleigh scattering is caused by a slight fluctuation in the refractive index of the fiber, while Fresnel reflection is associated with a sharp change in the refractive index

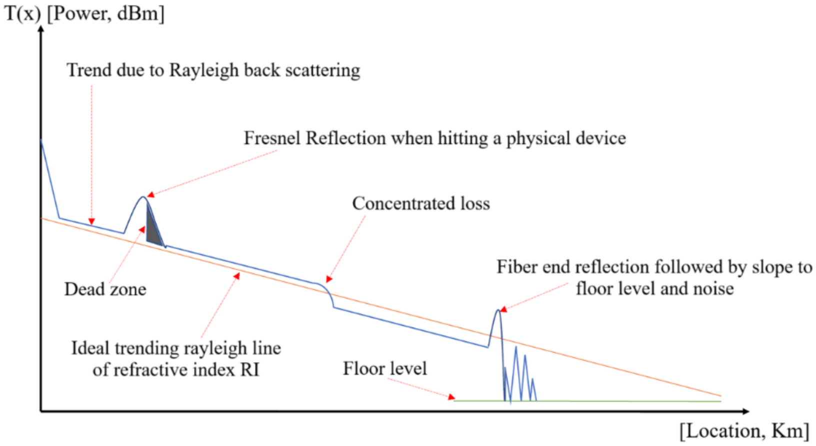


Figure 3: Example of an OTDR trace curve with multiple events

Table 1: OTDR event threshold settings

| Events | Recommended range (dB) | Default value | Standards | Practical guidelines |
|---|---|---|---|---|
| Fusion splice | 0,01…1,99 | All events | ITU-T G.650.1<br>(Max 0,3 dB loss per splice) | SM fiber: 0,05–0,3 dB |
| Reflections (connectors, breaks) | −98…−11 | All events | IEC 61280-4<br>(Typical reflections −40...−14 dB) | Good connectors: −45...−55 dBFaulty connections: > −35 dB |
| Fiber end | 3…20 | Auto-detection | ITU-T L.41<br>(Detection threshold 4–15 dB) | Clean end: 8–14 dBContaminated: 3–6 dB |
| Bend losses | 0,1…5 | 0,5 | ITU-T G.657<br>(Max 0,5 dB for macrobend) | Critical bends: >1 dB |
| Noise floor | −90…−70 | −75 | IEC 61746-1<br>(OTDR dynamic range) | Wavelength-dependent (1550nm: −80...−85 dB) |

at the end face or at a defect point of the fiber. discrete reflection. It is worth noting that Rayleigh scattering is determined by the specific properties of the fiber material, while Fresnel reflection is related to the actual operation and condition of each fiber and reflects a “point” phenomenon in the fiber.

The Rayleigh scattering signal produced by the OTDR is a slowly descending curve, which decreases as the laser beam travels a large distance through the fiber. According to the scattering principle, the optical power of the Rayleigh backscattering is proportional to the pulse width of the incident laser beam when the signal wavelength is determined. In particular, the longer the pulse width, the stronger the Rayleigh backscattering. The Rayleigh scattering signal produced by the OTDR is a slowly descending curve, which decreases as the laser beam travels a large distance through the fiber. According to the scattering principle, the optical power of the Rayleigh backscattering is proportional to the pulse width of the incident laser beam when the signal wavelength is determined. In particular, the longer the pulse width, the stronger the Rayleigh backscattering. The power reflected from the fiber, that is, the Rayleigh backscattering power received by the OTDR optical receiver Prs, can be calculated by equation (1).

$$P_{rs}\left(L\right) = \frac{1}{2} S c \alpha_S \tau P_0 e^{\left(-2\alpha L\right)}. \tag{1}$$

where $L = V_f t/2$ is the distance from the fiber injection tip; $c$ represents the speed of light in vacuum; $V_f$ the propagation velocity of light in the fiber; $P_0$ the pulse power at the injection tip of the optical fiber at $t = 0$, that is, the peak power of the optical pulse injected into the optical fiber; $\tau = l_p/V_f$ represents the incident laser pulse width; $l_p$ represents the pulse spacing; $\alpha_S = 2P_{TS}/l_p P_0$ represents the Rayleigh excitation attenuation coefficient; $P_{TS}$ the total Rayleigh excitation power; $\alpha$ represents the fiber attenuation coefficient; $S$ represents the ratio of the back Rayleigh scattering power, also known as the rebound coefficient, to the total Rayleigh scattering power. For a single-mode fiber,

$$S_{SM} = \frac{3}{2}\left(\frac{\omega_0}{r}\right)^2 \frac{1}{V^2}\left(\frac{NA}{n_1}\right)^2, \tag{2}$$

where $NA = \sqrt{n_1^2 - n_2^2}$ denotes the numerical aperture of the optical fiber; $n_1$ and $n_2$ are the refractive indices of the core and cladding, respectively; $r$ is the radius of the fiber core; and $\omega_0$ represents the spot size. In addition, the normalized frequency $V$, which is a structural parameter of the fiber proportional to the frequency of the optical wave, can be defined as in equation (3).

$$V = k_0 r \sqrt{n_1^2 - n_2^2}, \tag{3}$$

where $k_0 = 2\pi/\lambda$ denotes the phase constant and $\lambda$ is the operating wavelength.

Fresnel Reflections are produced by localized discontinuities along the optical fiber. This discontinuity can be caused by splicing, extreme geometric distortion caused by sharp bends, or broken or disconnected fiber. At these locations of discontinuity, the refractive index changes abruptly rather than a smooth change of conditions affecting backscatter coefficient. The abrupt changes create reflected signals back to the OTDR, which in turn detects the reflections to identify faults, breaks, and anomalies along the fiber. It is important to note that the laser pulses produced by the OTDR and the corresponding emission duration, also known as emission period, can be set by the user (the emission duration period can be determined based on equation (4)).

$$t = 2\frac{Ln}{c}, \tag{4}$$

where $t$ denotes the total propagation time of the signal from the transmitter to the receiver, and n is the effective refractive index of the optical medium.

Let the power reflection coefficient of the optical fiber be denoted as $\beta_f$. Accordingly, the power returned by the optical fiber, i.e., the Fresnel reflected optical power received by the OTDR photodetector, $P_{fr}$, can be expressed as equation (5).

$$P_{fr}\left(L\right) = \beta_f P_0 e^{\left(-2\alpha L\right)}. \tag{5}$$

Equations (1) and (5) have indicated that Rayleigh scattered power and Fresnel reflected power are both proportional to backscatter coefficients, and both follow an exponential decrease according to the attenuation coefficient in the fiber. As such, it follows that a lower backscatter coefficient indicates less reflected power, and that a higher coefficient would indicate greater reflected power. Additionally, equation (2) indicates that in single mode fibers, the backscatter coefficient is inversely proportional to the fiber core diameter, the spot size, and the operating wavelength. Rayleigh scattering and Fresnel reflections can both be used by an OTDR to characterize the optical properties of fibers. Rayleigh scattering occurs when microscopic changes to the refractive index along the fiber, and causes the propagating light to be scattered in an uneven manner. An OTDR compares this backscattered light to the strength of the backscattered light which diminishes with distance because backscattered light produces a decay trace that must decay exponentially from the attenuation of the fiber. Fresnel reflections occur when there is an instantaneous change in the refractive index at a finite location on the fiber, e.g., at glass-air interfaces, connectors, or breaks in the fiber. These are strong localized reflections and can be used to segments the trace and provide the OTDR with information where splices, breaks, or faults may occur.

## 2.2 Clustering (AI – K-means).

Visual inspection of only OTDR traces curve may not be adequate because different kinds of distortion–such as coupling loss, micro bending, or signal attenuation–can render very similar values, making them almost impossible to differentiate. In this case, AI methods, specifically clustering algorithms such as K-means, are an excellent way to collect and classify OTDR data.

The K-means algorithm is performed as follows:

- Decide on a number of clusters $k$ (for example, good signal, average signal, and bad signal);
- Randomly choose initial cluster centers $c_j$; ;

Assign each data point $x_i$ to the nearest cluster center as follows:

$$\arg\min_{c_j} \sum_{i=1}^{N} \left\| x_i - c_j \right\|^2 , \tag{6}$$

- Update each cluster centroid $c_j$ to equal the average of the set of points assigned to it;
- Repeat the process of assignment and updating until convergence, i.e., until centroid positions no longer change.

Clustering can be conducted using, for example, loss and attenuation as characteristics on OTDR measurements, with various characteristics helping to feature distinguish a normal point from a defective one, even when they are too close to distinguish by eye.

In the k-means algorithm for the study, the number of clusters was obtained with *k=3*. This value indicates normal, abnormal, and faulty segments of the line ear condition.

### 2.3 Fault Detection (Threshold Method).

Clustering emphasizes a shared categorization of OTDR data, while the thresholding technique offers a straightforward approach to identify specific faults. The idea is simple; if the loss measurement at time t is a significant departure from the average loss, we deem that measurement a fault.

The fault condition can then be mathematically described as follows:

$$Fault = \begin{cases} 1, & L > t \\ 0, & L \leq t \end{cases}, \tag{7}$$

where $L$ is the measured signal loss and $t$ is the value of the threshold.

The threshold value is usually defined with respect to the average loss value like so:

$$T = 1,5L_{mean}, \tag{8}$$

This definition means that any measure with a loss greater than 1.5 times the average loss is marked as faulty.

In the study, when analyzing optical signal power losses, the threshold value was taken as 1,5 for the normal state, 2 for the faulty state, and 1,2 for the anomalous state.

## 3. RESULTS AND DISCUSSION

A study to assess the operational condition of fiber-optic communication lines was conducted on directly buried lines in the Khujaili district of the Republic of Karakalpakstan. The Khujaili district is located in the lower part of the Amu Darya River delta and is characterized by a sharply continental climate, especially the proximity of groundwater to the surface. Anritsu MT9083C2-053 reflectometer was used to diagnose the fiber-optic communication lines. The technical parameters and specifications of this device can be referenced in TABLE 2, and the directivity diagram of the reflectometer that was obtained during the measurements presented in FIGURE 4, provides the relevant information for future analysis and evaluation of line performance.

Table 2: OTDR MT9083C2-053 Specifications

| Wavelength | Fiber type | Pulse width | Dynamic range | Fresnel) | Rayleigh |
|---|---|---|---|---|---|
| 1310/1550 nm | SMF ITU-T G.652 | 3, 10, 20, 50, 100, 200, 500, 1000, 2000, 4000, 10000, 20000 ns | 46/46 dB<br>25/25 dB m Pulse: 100 ns | =1 m,<br>=80 cm | =3,8/4.3 m |

The FOCL status is retained in SOR format by the reflectometer device employed. The FastReporter 3 software was used in this study to process the SOR file with subsequent conversion to CSV file format so that it could be analyzed and analyzed in MATLAB. Main data extracted from the CSV file is presented in TABLE 3.

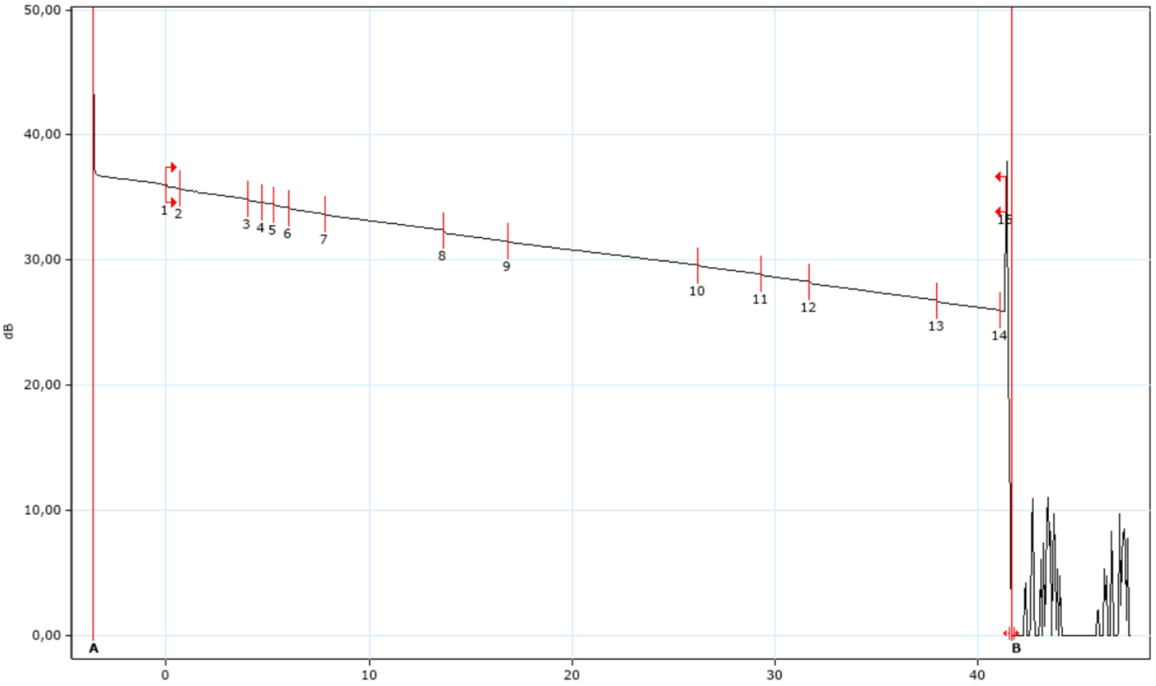
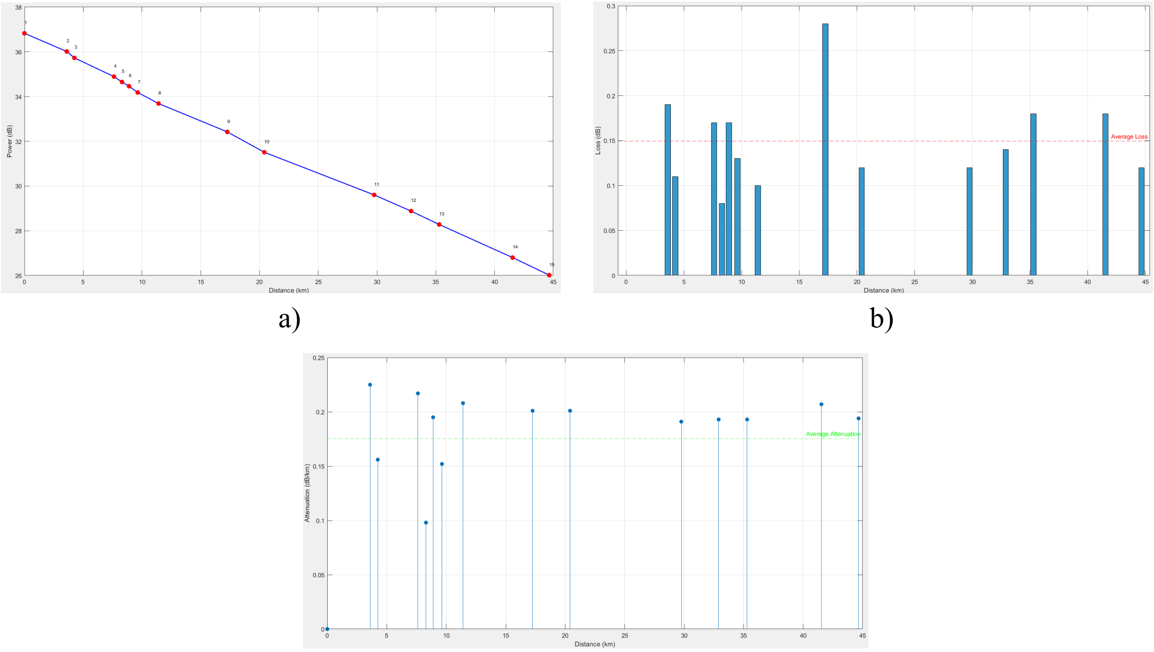


Figure 4: The research OTDR trace

Table 3: OTDR event data

| Distance (km) | OTDR (dB) | Event Type | Loss (dB) | Attenuation (dB/km) |
|---|---|---|---|---|
| 0,00 | 36,829 | Start | 0,00 | 0,000 |
| 3,60 | 36,017 | Loss | 0,19 | 0,225 |
| 4,25 | 35,729 | Loss | 0,11 | 0,156 |
| 7,62 | 34,893 | Loss | 0,17 | 0,217 |
| 8,30 | 34,653 | Loss | 0,08 | 0,098 |
| 8,90 | 34,462 | Loss | 0,17 | 0,195 |
| 9,64 | 34,183 | Loss | 0,13 | 0,152 |
| 11,41 | 33,689 | Loss | 0,10 | 0,208 |
| 17,26 | 32,421 | Loss | 0,28 | 0,201 |
| 20,41 | 31,511 | Loss | 0,12 | 0,201 |
| 29,76 | 29,603 | Loss | 0,12 | 0,191 |
| 32,90 | 28,880 | Loss | 0,14 | 0,193 |
| 35,29 | 28,281 | Loss | 0,18 | 0,193 |
| 41,54 | 26,801 | Loss | 0,18 | 0,207 |
| 44,66 | 26,016 | Loss | 0,12 | 0,194 |
| 44,96 | 25,878 | End | 25,83 | 0,080 |

The investigated optical fiber link has a total length of 44,983 km. For the reflectometer measurements, a probing optical signal with a pulse duration of 500 ns, a wavelength of 1550 nm and a refractive index of 1,4682 was selected. The attenuation threshold of 0,05 dB and the reflection threshold of -60 dB allow for the detection of minor weak points, as well as macro- and microbends in the fiber. Figure 5 presents the main results obtained based on the reflectometer measurement data. The reflectometer radiation pattern (a) shows the distributed backscattered signal power along the optical fiber, indicating the presence of scanning events including splices, connectors and possible faults. (b) shows connection loss values at various distance points along the fiber, with the average loss value indicated for the purpose of estimating the amount of abnormal degradation at the fiber link. (c) the next assessment is to look at the amount of attenuation per kilometer, this samples both the overall quality and stability of the transmission link. When analyzed together, these three images show valuable diagnostic information gained from standard OTDR measurements, intercoupling degradation, periodic localized loss, and averaged fiber performance.



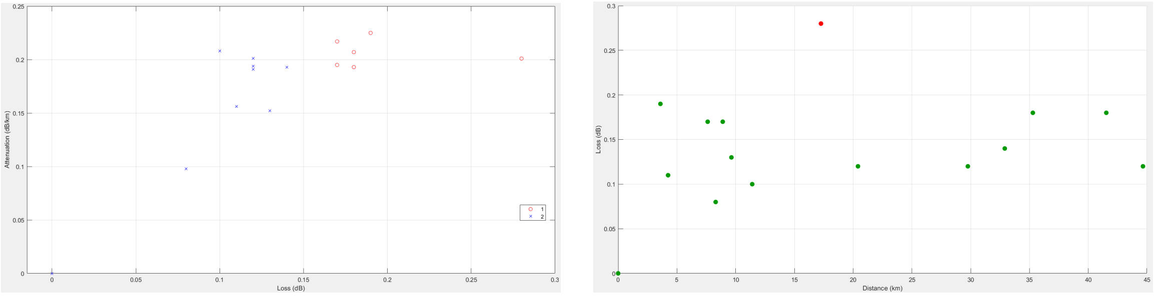
a) b)

c)

Figure 5: Fundamental results obtained from OTDR measurement data. a) OTDR Trace b) Connection Losses in Optical Fiber c) Attenuation along the Fiber

FIGURE 6 shows the application of AI methods to event classification and fault detection (a) shows a k-means clustering algorithm that classifies events into normal and faulty classes by loss and attenuation features. This unsupervised method produces more objective, data led classifications than a manual method analysis. (b) A threshold-based method is used to label events with losses that exceed 1.5X the mean as bad. The rule-based method is more straightforward and quicker, but the clustering approach is much more robust to noise and variability. All this suggest that AI-supported analysis can improve the value of OTDR-based networks monitoring.

The study tested 44,983 kilometers of fiber optic links in the Khujaili district of the Republic of Karakalpakstan. Faults were semi-naturalistically induced using controlled coupling losses, thereby bending fiber segments at important junctions, and breaking the connectors using normative stress tests (See TABLE 4). Faults were assessed using OTDR measures both before and after the faults were induced. The data reports were evaluated using the proposed AI-based model against the traditional detection pattern detection algorithm, which identifies the existence of faults based on a database of pre-defined loss thresholds.



a) b)

Figure 6: AI improved event classification and fault detection. a) k-means clustering of fiber events b) fault detection using threshold method

Table 4: Results of field experiments

| **Parameter** | **Classic threshold value** | **Developed model of AI** |
|---|---|---|
| Accuracy | 78,6% | 90,4% |
| False Detection Rate | 15,4% | 9,1% |
| Mean Localization Error | 4,4 m | 2,3 m |
| Mean time to detect a fault | 14,5 s | 8,4 s |

The AI model demonstrated high efficiency in correctly classifying and localizing subtle signal distortions even in sharply continental conditions and topological interference. CNN, LSTM, and hybrid EMD-WT models have high accuracy (93-99%) but require a large fixed dataset and significant computational resources (See TABLE 5). The proposed k-means + threshold approach, on the other hand, is simpler than complex neural networks, providing a convenient solution for working with real OTDR data in the field.

Table 5: Results of field experiments

| **Parameter** | **Classic threshold value** | **Developed model of AI** |
|---|---|---|
| Accuracy | 78,6% | 90,4% |
| False Detection Rate | 15,4% | 9,1% |
| Mean Localization Error | 4,4 m | 2,3 m |
| Mean time to detect a fault | 14,5 s | 8,4 s |

## 4. CONCLUSION

In this article, modern research methods for processing initial data obtained from the OTDR device for assessing the operational state of FOCL were analyzed. In this issue, emphasis was placed on research methods using wavelet transformations and artificial intelligence tools. The MATLAB program was used to process the initial data, and the results were obtained using k-means and statistic methods for fault detection. A fiber optic communication line with an operational life of more than 20 years in a sharply continental climate was selected as the object of research, and its operational indicators were compared with the proposed research method and traditional methods. The comparison results showed that the assessment of the operational state of FOCL based on artificial intelligence tools is superior in its accuracy and efficiency in detecting and localizing faults. However, by further improving these methods, it is possible to more accurately assess the state of communication lines in complex operational conditions. The method used and the results obtained are unique in that they are used to process large volumes and quantities of OTDR data used in operational condition assessment.

## References

[1] Liu H, Zhao T, Zhang M. OTDR Development Based on Single-Mode Fiber Fault Detection. Sensors. 2025;25:4284.

[2] Gu X, Sablatash M. Estimation and Detection in Otdr Using Analyzing Wavelets. Proceedings of IEEE-SP International Symposium on Time- Frequency and Time-Scale Analysis. IEEE. 1994:353-356.

[3] Kabulov A, Baizhumanov A, Saymanov I. Synthesis of Optimal Correction Functions in the Class of Disjunctive Normal Forms. Mathematics. 2024;12:2120.

[4] Kabulov A, Baizhumanov A, Berdimurodov M. On the Minimization of K-Valued Logic Functions in the Class of Disjunctive Normal Forms. J Math Mech Comput Sci. 2024;121:37-45.

[5] Kabulov A, Saymanov I, Babadjanov A, Babadzhanov A. Algebraic Recognition Approach in IoT Ecosystem. Mathematics. 2024;12:1086.

[6] Saymanov I. Logical Automatic Implementation of Steganographic Coding Algorithms. J Math Mech Comput Sci. 2024;121:122-131.

[7] Kabulov A, Normatov I, Saymanov I, Baizhumanov A. On the Completeness of Classes of Correcting Functions of Heuristic Algorithms. Azerbaijan J Math. 2025;15:51.

[8] Saymanov I, Babadzhanov A, Varisov A, Urinov N, Madjidov A. Numerical Methods of Synthesis of a Correct Algorithm for Solving Recognition Problems. Adv Artif Intell Mach Learn. 2025;5:3534-3547.

[9] Qiang H, Zhihui Z, Dongsheng W, Lei L, Xibao H. An OTDR Event Analysis Algorithm Based on EMD-Based Denoising and Wavelet Transform. 12th IEEE International Conference on Electronic Measurement & Instruments (ICEMI). IEEE. 2015:1034-1038.

[10] Shangguan Y, Du J, Yang T, Shi S, Fan X. A Correlation OTDR Based In-Service Fiber Links Monitoring Using Flexible Frame Switching and EMD Denoising. Asia Communications and Photonics Conference (ACP) and International Conference on Information Photonics and Optical Communications (IPOC). IEEE. 2020:1-3.

[11] Abdelli K, Grießer H, Ehrle P, Tropschug C, Pachnicke S. Reflective Fiber Fault Detection and Characterization Using Long Short-Term Memory. J Opt Commun Netw. 2021;13:E32-E41.

[12] Kasem A, Tolba H. Fiber Monitoring and Fault Prediction System for Telecom Networks: Integrating Mixed Trace Analysis with Machine Learning. 2025. Available at SSRN: https://ssrn.com/abstract=5376484

[13] Titouni S, Messaoudene I, Himeur Y, Alnaseri O, Chetouah F, et al. Hybrid CNN- Ensemble Framework for Intelligent Optical Fiber Fault Detection and Diagnosis. IEEE Open J Commun Soc. 2025;6:5626-5638.

[14] Asok A, Pournami SS. Using Machine Learning Technique, Tracing the Actual Location of Faults in Underground Optical Networks. 9th International Conference on Smart Computing and Communications (ICSCC). IEEE. 2023:45-49.

[15] Yang Z, Hong D, Feng X, Xie J. A Novel Event Detection Method for OTDR Trace With High Sensitivity Based on Machine Learning. 2nd Information Communication Technologies Conference (ICTC). IEEE. 2021:265-269.

[16] Abdelli K, Griesser H, Pachnicke S. Convolutional Neural Networks for Reflective Event Detection and Characterization in Fiber Optical Links Given Noisy OTDR Signals. Photonic networks; 22th ITG Symposium. IEEE. 2021:1-5.

[17] Barnoski MK, Jensen SM. Fiber Waveguides: A Novel Technique for Investigating Attenuation Characteristics. Appl Opt. 1976;15:2112-2115.