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Implementation of Underground optical fiber fault localization using multi-point photodetectors

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***Abstract*—In modern communication systems the underground optical fiber networks constitute the backbone but they are highly vulnerable to faults which are caused by digging, bending stress, moisture, rodent attacks which are caused by rats, mice, Squirrels, and physical damage. Conventional fault detection modes such as Optical Time Domain Reflectometry (OTDR) require costly equipment and manual work, limiting their suitability for monitoring continuously. This paper presents a low-cost distributed fault localization system using multi-point photodetector nodes deployed along the fiber route. Each node measures local optical power through a tap coupler and transmits data to a central server via an IOT module. A differential attenuation algorithm detects abnormal losses and identifies the fault segment. Experimental results show detection sensitivity of 0.5dB and localization accuracy of 5-20meters depending on mode spacing. The proposed system enables real-time monitoring, cloud-based alerts, and energy-efficient operation suitable for telecom and smart city deployments.**

***Keywords*— Underground optical fiber, fault localization, distributed monitoring, IoT, photodetector nodes, real-time monitoring.**

I. INTRODUCTION

Due to its low signal attenuation, large bandwidth, and resilience to electromagnetic interference [1], underground optical fiber transmission is important to contemporary telecommunication networks. Despite all these benefits, underground optical fibers are vulnerable to some problems which are including bending losses, cable breaks, and signal attenuation are born on by climatic and mechanical conditions [2]. It is difficult, and costly to point the precise sites of such problems. Due to the need of an expensive things and experienced labor, traditional fault detection techniques are causes service restoration to be delayed and observe the rise in maintenance [3]. This suggests a DFS based on multi-point photodetectors placed at certain intervals along the fiber link [4]. Unusual signal losses or interruptions can be quickly detected by constant monitoring of optical signal intensity. The technology can accurately identify the problem while reducing manual testing methods [5] by observing changes in optical power between subsequent monitoring locations. The suggested architecture improves the dependability and operational effectiveness of underground optical fiber networks [6].

A. Overview

The goal of Implementation of Underground Optical Fiber Fault Localization Using Multi-Point Photodetectors is to effectively and precisely identify and locate faults in underground optical fiber cables. High-speed data transmission frequently uses optical fibers, but once the cable is damages underground, it can be challenging to detect defects like fractures, bends, or signal attenuation. This technology leads to increase network reliability and decrease fault detection time [7].

This method continuously monitors light intensity by positioning several photodetectors at various locations along the optical fiber. Fault information can be processed, displayed, or broadcast as alerts for prompt maintenance. When the fault occurs, the optical signal level lowers at a particular photodetector, aiding in the identification of the approximate fault location [8].

The technology offers an affordable and useful way to monitor underground optical fiber networks in real time. It is appropriate for industrial and telecommunication communication systems [9] because it minimizes manual inspection, decreases downtime, improves fault localization efficiency.

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B. Related Work

The aim of this project is to use multi-point photodetectors to locate and identify problems in the underground optical fiber cables. To find the flaws like cable breaks, bending loss, signal loss with conventional methods is challenging and time-consuming since optical fibers are damaged below. This project continuously monitors the light signals which are placed at different locations [10].

In this the light intensity lowers at a specific point to find the location. So, this can increase the dependability [11] of underground optical fiber communication systems, limited networks, reduce the maintenance costs and also reduce the fault detection times [12],[13].

C. History and evolution of optical fiber communication

The semiconductor light sources and low-loss optical fibers in the last 20th century is the beginning of optical fiber communication [14]. Due to its larger bandwidth, longer transmission distances, and optical fibers swiftly conventional copper connections. The problem detection and maintenance techniques became more important as fiber networks grew in particularly underground.

Optical fiber fault detection mostly depended on labor intensive and simple signal testing and human inspections. OTDR systems are costly, need expert operators [15], and aren't always applicable for continuous real-time monitoring, despite over these effective. Modern fault localization techniques have developed in automated and distributed monitoring systems in order to overcome these problems.

Faults can be identified and more precise localized with low expense and complex by placing the photodetectors at different positions [16]. In present communication infrastructure, this can facilitate real-time monitoring, quick maintenance, and the dependability increases optical fiber networks [17].

II. LITERATURE SURVEY

R. S. Kaler and R. S. Kamal (2019) was published the paper "Optical Fiber Fault Detection Using OTDR Method" in the International Journal of Engineering Research & Technology (IJERT). Their project focuses mainly using Optical Time Domain Reflectometer (OTDR) to locate and finding problems in optical fiber communication systems. To detect the faults in Optical cables such fiber breaks, bends, and attenuation losses, the OTDR method measures echo signal and reflected light signals. This method detects significant disadvantages, such as the high cost of equipment and the need for specialized individuals for operation, even if the OTDR method offers high accuracy in determining fault location and distance [18].

S. Prakash and R. Kannam (2020) was proposed an "Underground Optical Fiber Fault Detection Using Microcontroller" and published in the International Journal of Advanced Research in Electrical, Electronics, and Instrumentation Engineering (JAREEIE). To identify the problems a microcontroller-based technique which can change the tracks in light intensity along the optical fiber connection was proposed by the scientists. This method can delete the manual testing by identifying the damaged portion and displaying the location of the fault when a fault occurs in the optical cable. This technique is appropriate for underground cable monitoring applications since it provides faster fault identification and less human need and interaction than conventional optical fiber fault detection methods [19].

P. Venkatesh and M. Arjun in 2021 was proposed "Optical Fiber Fault Monitoring System Using Photodetectors" and published in the International Journal of Innovative Technology and Exploring Engineering (IJITEE). Their study presents a fault monitoring system that can measures optical signal intensity using photodetectors which are positioned at various places along the optical fiber. The disrupt of a problem is indicated by a significant decrease in light intensity. In fault localization, especially in underground optical fiber networks, the suggested technology offers an low-cost and consistent alternative. Additionally, it supports to monitor continuously and also enabling faster maintenance response and improved network reliability [20].

K. Suresh and Dr. N. Balaji in 2023 was proposed a "IOT Based Underground Optical Fiber Fault Detection System" in the International Journal of Scientific Research in Engineering and Management (USREM). To track changes in optical signals in underground fiber cables, their study merges photodetectors and sensors with an Internet of Things. Rapid fault alarms and remote monitoring are feasible by the IoT network's real-time transmission of problem identification. By enabling service providers to react swiftly to issues without requiring on-site inspection, this technique greatly lowers network downtime and increases system reliability [21].

Ravi Kumar and S. Harshini in 2024 was proposed "Fault Localization in Optical Fiber Network Using Multi-Point Detection" published in the International Research Journal of Engineering and Technology (IRJET). The multi-point photodetector-based detection techniques are to increase fault localization accuracy is the main significance of the work. Compared to single-point detection techniques, the system may have precise determine the approximate fault site by examining signal loss patterns over several sensing locations. The finding shows that multi-point detection is extremely appropriate for contemporary underground optical fiber networks since it provides faster fault identification, increased accuracy, and lower cost maintenance [22].

A. Overview of Literature Survey

The optical fiber detection research has always increased from conventional techniques to real-time monitoring systems. Optical Time Domain Reflectometer techniques which can offer both detection and measuring but these techniques are not ideal for continuous monitoring in underground networks although they are costly, heavy, and require trained staff [23]. These techniques were developed for continuous monitoring and changes in optical signal strengths to get these restrictions. It increases the localization accuracy as well as it provides scalable and affordable underground fiber fault solution. Optical Time Domain Reflectometer will also provide faster detection and measuring in underground optical networks which are costly and heavy which required trained off.

This faster defect identification is possible by these technologies, which reduces the lower implementation costs and manual handling. For remote monitoring systems recent developments combine IOT platforms with multi-point

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detection techniques. By detection signal lo the photodetector systems increase localization accuracy and provide scalable and affordable underground fiber fault management solutions. This method will also improve the efficiency which are not provide efficient location under the optical fiber networks and they can develop for the continuous monitoring and the changes in the optical signal strengths to get rid of these restrictions which are essential [24].

III. EXISTING SYSTEM

Modern systems depend on optical fiber networks but they are damaged and also difficult to detect. In traditional technique, optical signals are sent through the underground cable by a laser source. The photodetectors at the receiving end track the optical power is decreased by any disruptions, such as cable cut, bending loss, or attenuation [25].

ADC and a microcontroller used to process the optical signals are has been transformed into an electrical signal. To determine the fault defects, the controller compares the signal with the predetermined threshold values. For fault information the remote transmission allows the wireless modules which is shown on LCD. For improved monitoring, a GPS module might additionally offer information of the location.

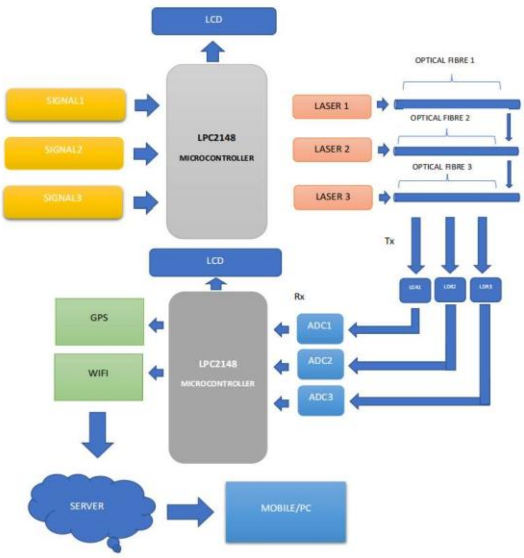


Fig 1: Fiber fault detection block diagram

This system initially uses threshold-based analysis and end-point intensity measurement, although supporting remote fault indication and real-time monitoring. This makes it more difficult to locate faults accurately, particularly in extensive or crowded underground fiber networks [26].

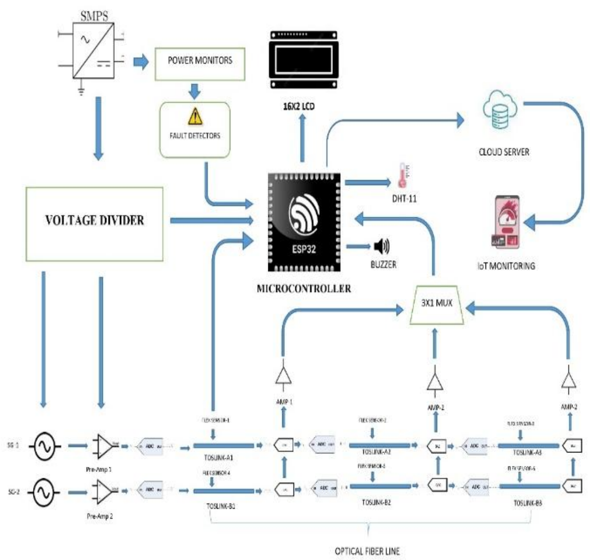
A. *Working Principle of Existing System*

The system locates and diagnoses problems in subterranean optical fiber connections by using multi-point photodetectors and an LPC2148 microcontroller configuration. At the transmitter side the NXP Semiconductors LPC2148 microcontroller initiates several laser sources to introduce optical signals into different fiber lines. The multi-point photodetectors are used to continuously monitor these signals as they pass at the several intermediate sites through the underground cables. All photodetectors receive adequate light intensity under typical circumstances. The light intensity drops at a particular sensing point in the event of a fault, such as, bending loss, fiber break, or attenuation, which aims to locate the fault between two photodetectors [27].

The photodetectors convert optical signals into electrical signals, which are insert into ADC channels of the receiver-side LPC2148 microcontroller. The ADC converts analog signals into digital form, and the controller analyzes signal levels to determine the fault position. The fault condition is displayed locally on an LCD. A GPS module provides geographical coordinates of the fault location, and a Wi-Fi module transmits the information to a remote server for monitoring via mobile or PC [28].

B. *Limitations*

- Existing fault detection methods are time-consuming and delay fault identification in underground optical fiber cables.
- Traditional systems such as OTDR require expensive equipment, increasing overall maintenance cost.
- Fault localization accuracy is limited, especially in long underground fiber links.
- Single-point monitoring makes it difficult to pinpoint the exact fault location.
- Manual inspection often leads to unnecessary digging and cable damage.
- Lack of automation increases network downtime and service interruptions.
- Existing systems are not easily scalable for large or complex fiber networks.
- They need skilled technical personnel for operation



and analysis.
- Most systems do not support real-time or continuous monitoring.

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IV. PROPOSED SYSTEM

The proposed system introduces an IoT-based underground optical fiber fault localization framework that uses multi-point photodetector nodes to detect and identify faults in optical fiber communication cables, fault detection in underground cables is also often challenging due to limited accessibility and delayed manual inspection. To address this issue, the proposed system introduces a distributed monitoring architecture capable of detecting cable faults such as cuts, signal attenuation, and physical bending in real time. In this system, multiple sensor nodes are deployed at different locations along the optical fiber route.

Fig 2: Fiber fault detection proposed system block diagram

Each node consists of a photodetector, flex sensor, environmental sensor (DHT11), ADC interface, and an ESP32 microcontroller. The photodetector continuously monitors the optical signal intensity passing through the fiber cable. Optical signal indicates a possible fiber cut or bending, attenuation fault. To ensure accurate signal monitoring, using an Analog-to-Digital Converter (ADC) the analog output from the photodetector is converted into digital data allowing the ESP32 controller to process the signal values efficiently. Additionally, a Digital-to-Analog Converter (DAC) can be utilized to generate test signals or simulate optical signal conditions for testing purposes.

Apart from signal loss detection, the system prefers a flex sensor to monitor mechanical stress or bending in the optical fiber cable. Excessive bending in cables often leads to micro-bending losses that reduce signal quality. By continuously monitoring the bending conditions, the system can detect potential faults before a complete failure occurs. Environmental conditions such as temperature and humidity are also monitored using a DHT11 sensor, as underground environmental factors can influence cable performance and reliability. These parameters help in understanding each monitoring node processes the sensor data and communicates with a central monitoring system through the ESP32's built-in Wi-Fi capability [29]. When an abnormal signal drop, cable bending, or environmental anomaly is detected, the system generates an alert and identifies the approximate fault location based on the node where the signal loss occurs. By comparing the signal strength across multiple nodes along the fiber path, the system can estimate the distance of the fault from the transmission point, enabling faster maintenance and repair operations.

A. Advantages

- Real-Time Monitoring
- IOT integration
- Accurate fault localization
- Low cost and Compact Design
- Automated Alerts
- Scalable System
- Energy efficient.

B. Disadvantages

- Dependence on Internet Connectivity
- Limited Range of Sensors
- Complex Circuit Design
- Maintenance Requirement
- Security Concerns

C. Applications

- Telecommunication Networks
- Power Transmission Systems
- Smart Cities
- Industrial Automations
- Defense and Security Systems
- Railway and Transportation System
- Internet Service Providers

V. CONCLUSION

IoT-based optical fiber fault detection and monitoring system provides an effective and dependable solution for maintaining modern communication networks. Integrating sensors, multiplexing techniques, and the ESP32 microcontroller with cloud connectivity, the system can permit real-time monitoring and precise fault localization. This technique reduces manual intervention, reduces time and improves overall system performance. Although challenges such as network dependency and security concerns exist, the advantages of remote usability, scalability, and cost-effectiveness make the system highly suitable for practical applications in telecommunications and smart infrastructure [30].

Moreover, the proposed system monitors significant potential for future advancements by incorporating advanced data analytics and machine learning techniques for predictive fault detection. This would permit the system not only to identify existing faults but also to predict potential failures before they occur, thereby improving reliability and reducing maintenance costs [31]. Further improvements in sensor accuracy, the system can progress into an intelligent monitoring solution, making it highly relevant for next-generation communication networks and smart grid applications [32].

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