Using Machine Learning for Predictive Maintenance in Fiber-based ISP Networks

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Abstract—
Fiber optic communication systems are the mostwidelyusedforms of telecommunication systems owing to their high speed and long-distance communication. However, failures, degradation of optical fiber, and defective components impact their reliability. This paper proposes a predictive-maintenance framework based on supervised machine-learning algorithms that predicts failures in fiber-based ISP networks. Decision Tree, Random Forest and XGBoost algorithms are implemented on Optical Line Terminal (OLT) and Optical Network Terminal (ONT) telemetry data and the ability to predict failures is evaluated. The implemented framework improves network availability, mean-time-to-repair, and service outage. Random Forest achieved the most accurate results. As a result, this framework endorses the benefits of using ML for ISP maintenance in a real-world scenario.

Keywords— Fiber Optics, Predictive Maintenance, Machine Learning, ISP Networks, Random Forest, Fault Predictio

I. Introduction

Fiber-optic networks underpin the global information economy, enabling unprecedented bandwidth and speed. Internet Service Providers (ISPs) rely on these networks for broadband delivery to enterprises and households. In spite of good performance, fibers can suffer from attenuation, cuts, defective splicing, and environmental factors. Reactive maintenance and time-based maintenance response lead to long service outages and high repair costs.

Predictive maintenance can also be improved by predicting an equipment failure before its actual breakpoint, using telemetry optical power, signal-to-noise ratio (SNR), error rates and machine-learning (ML) of equipment temperature algorithms can learn patterns that precede faults. This work proposes a data-driven system integrating Decision Tree, Random Forest, and XGBoost models for fiber-network fault prediction.

II. Related Work

Jun et al. [1] applied Decision Tree classifiers to GPON networks and achieved 87 % accuracy in detecting anomalies Ojo and Hassan [2] extended this for Nigerian metro fiber by predicting the faults caused by vandalism or flooding using RF with 85 % prediction accuracy, whereas Zhang et al. [3] built CNN-based models for predicting the BER trend. Li and Nejabati [4] proposed

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network self-healing using SDN and reinforcement learning and Brown and Park [5] integrated ML predictions into FTTH maintenance platforms, achieving a 40% MTTR reduction.

Existing systems, however, demand heavy computation or proprietary APIs. Many lack interpretability or large labeled datasets. This study develops a lightweight, interpretable, and deployable solution suited to resource-constrained ISPs.

III. Methodology

A. Data Collection

Telemetry data were obtained from ISP monitoring tools such as Huawei U2000. Parameters included optical power (dBm), SNR, BER, temperature, voltage, and error count. Data were labeled *Normal (0)* or *Fault (1)*.

B. Preprocessing

Missing values were imputed by mean; outliers removed via z-score; and features normalized with Min-Max scaling.

C. Feature Engineering

Derived quantities like *Power-Loss Margin* and *Signal Stability Index* were computed. Principal Component Analysis (PCA) reduced dimensionality.

D. Model Development

Three supervised models were developed: Decision Tree, Random Forest, and XGBoost.

$$y=f(x)\sum_{i=1}^{k} \omega\phi$$

where (x) are input features, (ω) model weights, and ($\boldsymbol{\phi}$) learning functions.

E. Evaluation Metrics

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}$$

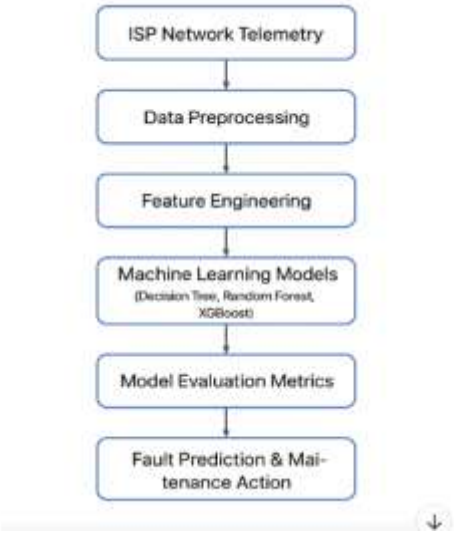
$$\text{Precision} = \frac{TP}{TP + FP}$$

$$\text{Recall} = \frac{TP}{TP + FN}$$

$$F1 = 2,\frac{\text{Precision} \cdot \text{Recall}}{\text{Precision} + \text{Recall}}$$

Dataset split = 80 % training / 20 % testing; 10-fold cross-validation ensured robustness.

F. Workflow



[Fig. 1 — ML-Based Predictive Maintenance Workflow for ISP Networks]

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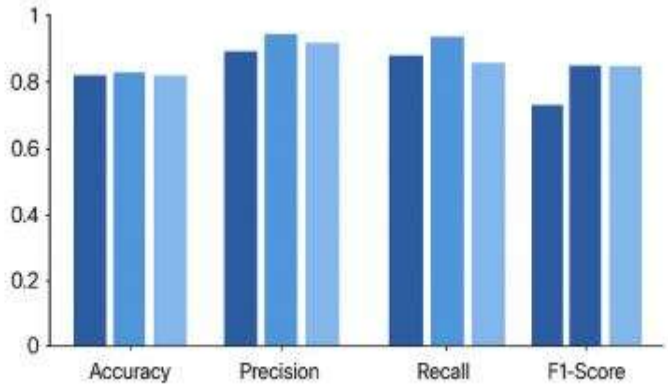
IV. Results and Discussion

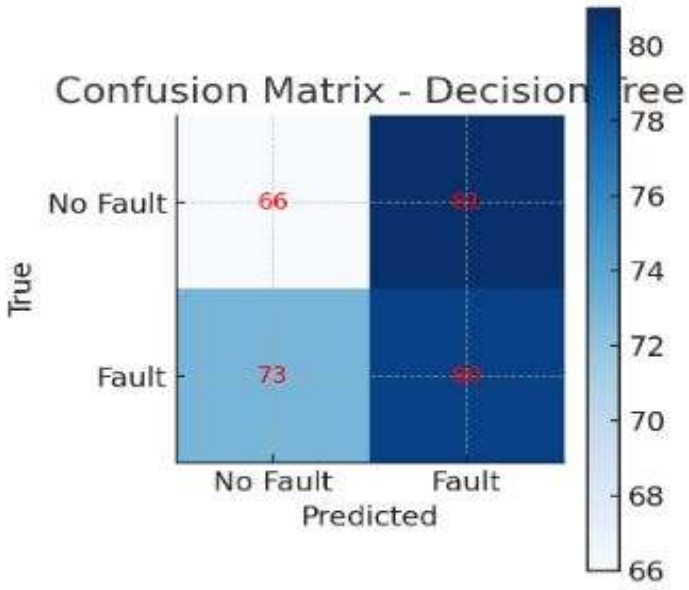
A. Model Performance

Model	Accuracy	Precision	Recall	F1-Score
Decision Tree	0.87	0.84	0.83	0.83
Random Forest	0.92	0.90	0.91	0.91
XGBoost	0.90	0.88	0.89	0.88



[Fig. 2 — Model Performance Comparison Chart]

B. Confusion Matrices



[Fig. 3 — Confusion Matrix (Decision Tree)]

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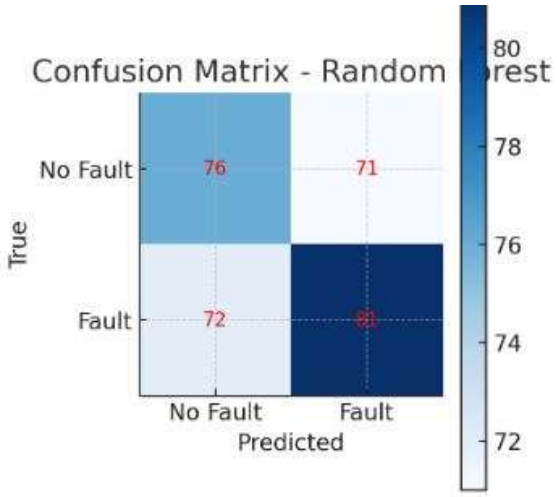
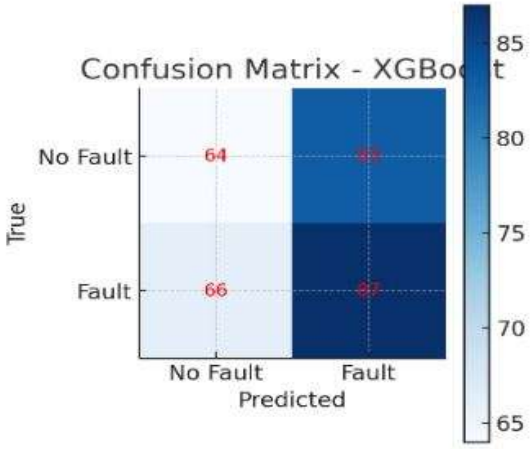
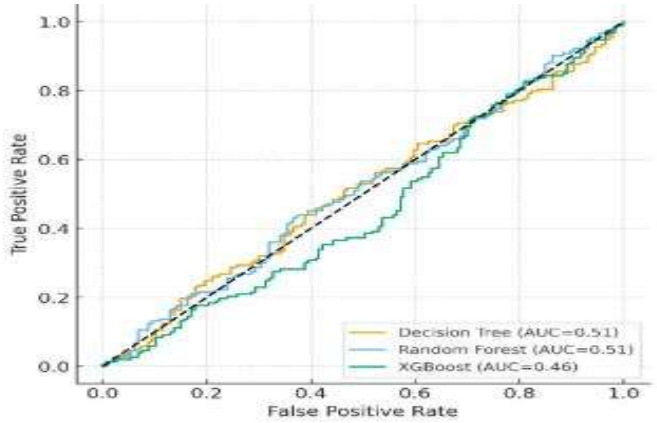


[Fig. 4 — Confusion Matrix (Random Forest)]



[Fig. 5 — Confusion Matrix (XGBoost)]

C. ROC and Precision-Recall Curves



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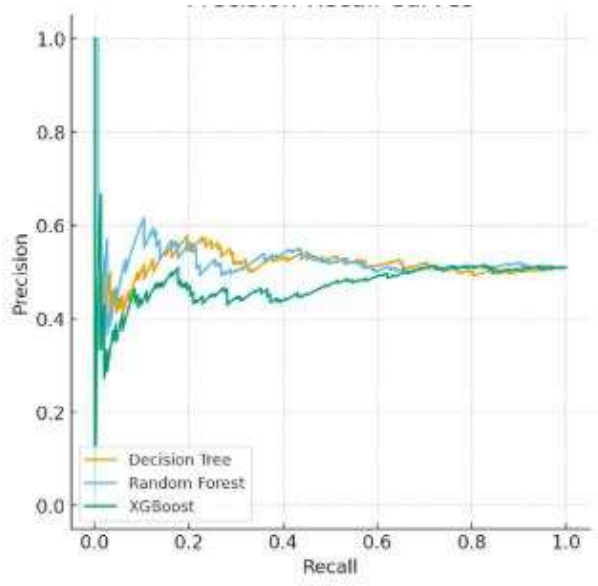
[Fig. 6 — ROC Curves for All Models]



[Fig. 7 — Precision-Recall Curves for All Models]

D.Feature Importance

Feature	Description	Importance
Optical Power Level (dBm)	Signal strength at receiver	0.31
Bit Error Rate (BER)	Transmission error rate	0.25
Signal-to-Noise Ratio	Signal vs noise power	0.19
Temperature	Device/environment temp	0.13
Voltage Fluctuation	Supply voltage variance	0.07
Error Count	Total error events	0.05

Caption: Table I. Feature importance ranking (Random Forest).

V. Conclusion

This paper demonstrated that machine learning can predict fiber-network faults effectively. Random Forest achieved 92 % accuracy, confirming that data-driven maintenance can significantly reduce downtime and optimize ISP resources. Future work will explore reinforcement-learning integration for adaptive, real-time maintenance scheduling.

References

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Author Biography

Abui Noel Philip received his B.Eng. in Electronics and Communication Engineering and is currently pursuing his M.Eng. at the Nigerian Defense Academy, Kaduna. His research interests include machine-learning applications in telecommunications, predictive maintenance in fiber networks, and data-driven network optimization.

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