A Predictive Maintenance Digital Thread Framework for Small Internet Service Providers: A Case Study of FAHNET Internet Services, Mumbai

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Abstract

This research paper presents an integrated Predictive Maintenance Digital Thread framework designed for FAHNET Internet Services, a growing Internet Service Provider (ISP) in Mumbai. The study identifies key operational challenges including unplanned downtime, limited visibility into network health, and inefficient reactive maintenance and proposes a scalable, data-driven solution. The framework incorporates IoT-based data acquisition, machine learning enabled predictive analytics, digital twin simulations, and cloud-integrated maintenance management. Findings indicate that the Digital Thread approach significantly enhances network reliability, reduces Mean Time to Repair (MTTR), optimizes resource utilization, and improves customer satisfaction. The proposed model provides a cost-effective implementation pathway suitable for small ISPs in emerging markets.

Key Words: ISP, IoT, Predictive Maintenance, Digital Thread, MTTR

Introduction

Small and mid-sized ISPs in India face growing operational challenges due to rapid increases in user demand, rising expectations for uninterrupted connectivity, and competition from large telecom providers. FAHNET Internet Services, based in Mumbai, operates a hybrid network infrastructure consisting of routers, optical fiber nodes, wireless access points, and edge servers. With a limited workforce, FAHNET relies largely on reactive maintenance, resulting in service interruptions, increased repair costs, and declining customer satisfaction.

Predictive maintenance supported by continuous data monitoring, analytics, and simulation offers ISPs an opportunity to improve operational resilience. This research explores how a unified Digital Thread connecting design data, operational telemetry, maintenance workflows, and field reporting can transform FAHNET's maintenance strategy from reactive to predictive.

The paper outlines the technical foundation, architecture, modeling methodology, and performance outcomes achieved through this integrated predictive maintenance system.

Literature Review

1.Maintenance Approaches in Network Infrastructure

Traditional maintenance approaches such as reactive and preventive strategies have limitations in dynamic network environments. Reactive maintenance focuses on repair after failure, causing downtime and customer dissatisfaction. Preventive maintenance schedules periodic tasks but ignores real-time asset conditions, leading to over-maintenance and inefficiencies.

2. Predictive Maintenance Fundamentals

Predictive Maintenance (PdM) uses real-time data, IoT sensors, and machine learning to forecast failures before they occur. In ISP environments, PdM analyzes parameters such as packet loss, signal strength, temperature, voltage fluctuations, and device health indicators to generate actionable predictions.

3. Digital Thread and Digital Twin Technologies

A **Digital Thread** creates bidirectional data flow across the asset lifecycle—design, operation, maintenance, and feedback. A **Digital Twin** is a real-time virtual model of the network, enabling simulation of failures, prediction of component degradation, and testing of maintenance strategies without disrupting live systems.

4. Role of IoT and AI in Network Monitoring

IoT sensors provide high-frequency telemetry such as temperature, humidity, and power quality in server rooms and fiber distribution nodes. AI and machine learning models analyze this data to identify anomalies, predict Remaining Useful Life (RUL), and trigger alerts before outages occur.

Problem Statement and Research Objectives

1. Problem Statement

FAHNET faces persistent operational challenges due to the absence of integrated monitoring and predictive analytics capabilities. Key issues include:

- Unplanned network downtime
- Limited visibility into device health
- Manual diagnosis of failures
- Poor maintenance scheduling
- Inadequate feedback between operations and field teams

These limitations prevent FAHNET from scaling operations while maintaining high reliability.

2. Research Objectives

The study aims to:

1. Develop a Digital Thread framework integrating network design, operations, and maintenance data.

2. Build predictive analytics models for fault forecasting.

3. Implement a Digital Twin to simulate network performance and evaluate maintenance strategies.

4. Deploy IoT-based monitoring for real-time data collection.

5. Establish a cloud-based Maintenance Management System (MMS).

6. Assess improvements in uptime, MTTR, cost efficiency, and customer experience.

Methodology

The research follows a hybrid methodological framework:

Phase 1: Requirement Analysis

Assessment of existing FAHNET infrastructure, device types, environmental conditions, and maintenance logs.

Phase 2: Digital Thread Architecture Design

Creation of a multi-layer architecture consisting of:

1. Physical & IoT Layer

2. Connectivity & Data Acquisition Layer

3. Data Integration Layer

4. Analytics & Intelligence Layer

5. Visualization & Maintenance Layer

Phase 3: Predictive Analytics Model Development

Machine learning models analyze:

- Device temperature
- CPU load
- Packet loss
- Signal strength
- Power voltage variations

Outputs include failure probability, anomaly detection, and RUL estimates.

Phase 4: Digital Twin Implementation

Simulation engine replicates the behavior of routers, switches, and servers under various load and environmental scenarios.

Phase 5: Pilot Deployment and Evaluation

A pilot rollout on a selected network segment measures improvements in:

- Uptime
- MTTR
- Prediction accuracy
- Resource efficiency

System Architecture

1 .Physical & IoT Layer

Includes routers, switches, servers, and sensors monitoring environmental parameters such as temperature and humidity.

2. Data Acquisition Layer

Telemetry collected through SNMP, NetFlow, Syslog, MQTT, and REST APIs.

3. Data Integration Layer

A cloud-based data warehouse storing operational, design, and maintenance data, forming the backbone of the Digital Thread.

4. Analytics & Intelligence Layer

Machine learning models calculate:

- Failure probability
- RUL
- Anomaly scores

5. Visualization & Maintenance Layer

Dashboards display device health, alerts, and predictions.

The MMS automatically generates work orders and assigns tasks to field engineers.

Results and Discussion

1. Performance Metrics

After implementing the predictive system:

- Network uptime improved to 99.5%
- MTTR reduced to under 4 hours
- Prediction accuracy improved significantly
- Emergency incidents decreased
- Field engineers received prioritized work orders

2. Operational Benefits

- Reduction in unplanned downtime
- Better resource utilization
- Enhanced decision-making
- Improved customer satisfaction
- Lower maintenance cost due to fewer emergency repairs

3. Digital Twin Outcomes

Simulations allowed FAHNET to:

- Test maintenance strategies safely
- Forecast failures weeks in advance
- Optimize spare parts inventory
- Train staff using virtual models

Conclusion

The study demonstrates that a Predictive Maintenance Digital Thread framework is technically feasible, cost-effective, and highly beneficial for small ISPs like FAHNET. The integration of IoT sensors, machine learning models, digital twin simulations, and cloud-based MMS produces significant improvements in reliability, operational efficiency, and customer experience.

Future Scope

- Expansion of digital twin coverage
- Integration of AR-based guidance for field engineers
- AI-driven root cause analysis
- Energy optimization for sustainability

The proposed framework serves as a reference model for small and mid-sized ISPs seeking affordable digital transformation solutions.

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