Proactive Network Maintenance for Customer Premise Issues in DOCSIS Network

A technical paper prepared for presentation at SCTE TechExpo24

Vikram Karwal
Senior Data Scientist
Rogers Communications
vikram.karwal@rci.rogers.ca

Jenny Panman
Manager, Data Science
Rogers Communications
jenny.panman@rci.rogers.ca

Table of Contents

Title **Page Number**

List of Figures

Title **Page Number**

List of Tables

Title **Page Number**

1. Introduction

The need to guarantee Quality of Service (QoS) in modern telecommunication networks is more important than ever before with near-real time sensitive applications relying on low-latency DOCSIS® networks as backhaul. Proactive network maintenance (PNM) approach needs to be emphasized for DOCSIS networks with technology's supporting virtual reality, online gaming, health care and trading use cases.

This paper proposes to group the major issues faced by the customer in group of symptoms. Thereafter, the impaired network KPIs that flag for each of these symptoms may be identified. These network KPIs can be tracked for the entire base of customers. When the identifying KPIs fall below the threshold it can be predicted that the customer is going to experience the symptom. Network Health Prediction for DOCSIS networks can be divided into two major parts comprising of head-end, access layer, node and tap taken care by maintenance technicians and the other part south of drop till customer equipment maintained by service technicians.

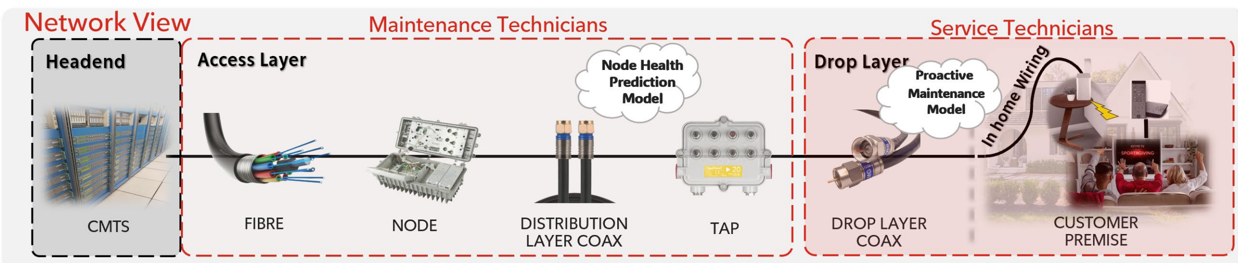

Figure 1: Last mile issues addressed by Proactive Modem Model

In this work we introduce a comprehensive predictive framework that identifies issues south of Drop to the Customer Modem. Performance measures will be taken from data sources like Internet Protocol Detail Record (IPDR) and Comcast Reference Design Kit (RDK). Customer modem (CM) service impacting symptoms are identified using the Network KPIs. These KPIs are tracked for the entire base of customers. Once the symptoms are identified, the subset of customers that are known to face these issues may be analyzed.

Proactive monitoring of DOCSIS (Data Over Cable Service Interface Specification) for the last mile is critical in maintaining high service quality for broadband networks. The last mile refers to the final leg of the telecommunications network that delivers services to end users. In DOCSIS networks, this involves the segment from the Cable Modem Termination System (CMTS) at the service provider's end to the customer premises equipment (CPE), a cable modem in this case.

Key Components for Proactive Monitoring:

1. **Signal Quality Metrics:**
   - **SNR (Signal-to-Noise Ratio):** Monitoring SNR levels helps in detecting noise issues that can lead to degraded service.
   - **MER (Modulation Error Ratio):** High MER values indicate better signal quality and fewer errors, so proactive monitoring of MER can prevent degradation.
   - **BER (Bit Error Rate):** Monitoring BER helps in identifying errors in data transmission, indicating potential issues in the network.
2. **RF Signal Levels:**
   - **Downstream and Upstream Power Levels:** Ensure these are within acceptable ranges to prevent service degradation.

o **Ingress Noise Monitoring:** Identifying and mitigating ingress noise is essential to maintaining signal integrity.

3. **Service Utilization and Bandwidth Monitoring:**
    - **Traffic Load:** Monitoring network traffic helps in identifying congestion points that may degrade service quality.
    - **Channel Utilization:** High utilization of DOCSIS channels can lead to service degradation, so monitoring and managing channel allocation is crucial.
4. **Error Logs and Alarms:**
    - Monitoring error logs data helps identify areas where errors are being corrected and potential service issues.
    - **CMTS and Modem Alarms:** Tracking alarms and events reported by CMTS, and modems can indicate impending issues.
5. **Latency and Jitter:**
    - Monitoring round-trip latency and jitter ensures that latency-sensitive service like video streaming maintain quality.
6. **Proactive Diagnostics Tools:**
    - **Spectrum Analysis:** Using spectrum analyzers to detect RF interference that can affect service.
    - **Remote Modem Diagnostics:** Utilize the remote diagnostic capabilities of cable modems to check signal levels and performance metrics.

Implementing Proactive Monitoring:

- **Automated Threshold-Based Alerts:** Set thresholds for key metrics (e.g., SNR, MER) and automate alerts when they are breached, allowing for immediate investigation and remediation.
- **Historical Data Analysis:** Use historical data trends to predict potential issues before they become service-affecting.
- **AI/ML for Predictive Maintenance:** Implement AI/ML models to predict and prevent potential service degradation based on historical performance data.

Benefits:

- **Improved Customer Satisfaction:** By preventing service degradation before it impacts customers, proactive monitoring enhances user experience.
- **Reduced Operational Costs:** Early detection and resolution of issues can reduce the need for costly truck rolls and repairs.
- **Higher Network Reliability:** Consistent monitoring and quick response to potential issues maintain overall network performance and reliability.

The proactive network maintenance approach outlined in this paper, enables timely identification and resolution of customer service impacting issues in DOCSIS networks. By leveraging data from various sources, service technicians can have a holistic insight and address potential faults before they impact service quality, leading to higher customer satisfaction, reduced churn rates, reduced Customer calls and Service truck rolls. This proactive strategy ensures a high standard of service delivery and strengthens the company's reputation and competitiveness in the market.

2. Literature Review

Researchers have proposed several proactive techniques to detect the Network impairments in DOCSIS network. Ranging from DOCSIS pre-equalization techniques to use of deep learning algorithms. Researchers in [5] proposed monitoring pre-equalization data for Network Monitoring and maintenance. By analyzing trends in pre-equalization metrics, operators can take preventive maintenance actions to avoid network degradation.

In [8] the problem of localizing and classifying anomalies on 1-dimensional time series data using Deep Convolutional Neural Networks is proposed. The algorithm uses custom feature aggregation layers and prediction layers to perform localizations and classification in a single step, this significantly improves the localization accuracy and classification [8].

In [6] researchers have presented state-of-the-art deep learning based multivariate time series Long Short Term Memory (LSTM) model which can forecast KPIs based on historical data and predicts anomalies. Proactive anomaly detection of the Key Performance Indicators (KPIs) is of paramount important for consistent end-user experience. This approach efficiently predicts KPIs by learning patterns from the time series data along with the seasonality behavior.

With evolution of cable systems and ever-increasing need for more bandwidth continues, high split systems are deployed. This creates new challenges for leakage measurements which are more predominant in downstream direction. Taking care of these leakage is more important than ever before. Researchers in [11] have proposed OUDP (OFDMA upstream data profile) technique in DOCSIS 3.1 to detect leakage issues. OUDP test burst can be generated that serves as ideal signal for leakage measurement.

In [4] researches have presented a comprehensive preprocessing framework for full-band capture (FBC) downstream spectrum data for impairment detection. Clustering algorithm is used for diverse FBC downstream spectrum datasets. The approach includes selecting optimal clustering algorithms and analyzing within-cluster outliers to better identify and categorize network issues, ultimately leading to more efficient network maintenance and improved service reliability.

Recent research [2] lists gaps in PNM needed for DOCSIS 4.0 technology with two important changes in specifications namely extended spectrum and full duplex transmission.

3. Model Overview

Major network KPIs that have been proven to measure user experience include Packet Error Rate, Partial Service OFDM/OFDMA/SCQAM, Downstream and Upstream Utilization, SNR, Tx and Rx. Network KPIs are computed for each CM and historical KPIs information is maintained. It is proposed to work on CM that are not connected to impaired node (a aggregation point serving several different devices) issues. i.e. customers not facing network impairments due to issues north of drop.

Network KPI that is used to identify each of the major symptom can be determined and correlation with other Network KPIs can be computed. These network KPIs can be tracked and a list of customers falling in these symptoms can be identified. Machine Learning Clustering algorithm can be used to identify the threshold of each of the Network KPIs falling in each symptom. The Network KPIs information will help Service technicians address the potential problems that customers are facing. Data cleaning for duplicate and missing data have to be addressed and aggregations for each of the Network KPIs has to be catered before applying Clustering algorithm to determine thresholds.

Proactive DOCSIS last-mile degraded service monitoring involves a combination of signal quality metrics, RF signal level checks, bandwidth utilization tracking, error log monitoring, and the use of advanced diagnostic tools. Implementing these practices can significantly reduce service degradation and enhance the quality of service provided to end users.

The model goal is to provide a tool that will identify when the service technician is needed instead of field maintenance. Time and resource saving for the network maintenance team.

The idea of our model is concluded in conducting the following:

1. Collecting widest possible base of DOCSIS network and service related KPI for the entire customer base. The data will be collected on the 15 minute basis which will allow to monitor behaviors in granular data sections and as close as possible to the service degradation event.

2. Excluding from the analysis modems that are identified on degraded nodes based on the Node Targeting Tool [12]

3. Establishing groups of network and service symptoms that are recognized as indicators of service impact, and identifying modems that fall into each of these symptomatic categories.

4. Creating groups of identifying KPIs ("identifiers") for each one of the symptomatic categories. These identifiers are the direct data pointers to detect list of modems in each symptomatic category. The rest of the KPIs ("contributors") will be analyzed by the created machine learning algorithm.

5. Identifying relationships between individual contributing KPIs and groups of similarly behaving KPIs for each symptomatic category.

   Tree Based Algorithms – Random Forest, Gradient Boosting or XGBoost

   Clustering Algorithms – K-Means

   Regression based Algorithm

6. Based on the findings, if correlations and clusters of KPIs were detected, extrapolate the detection method to the entire customer base on non-degraded nodes, by creating thresholds and flags.

7. Model validation by POC, comparing to the historical data. The list of impaired customers in each symptom to be validated with POC.

8. Feedback- loop and model maintenance. The inputs received from service technicians will be used to weight the Network KPI and can be tuned accordingly.

9. Create a tool that will provide last mile service department with visibility of the customers flagging in the model and detailed list of the affected KPIs. This list will provide service technicians overview of other failing KPIs that may be addressed while the service technician is at customer premise.

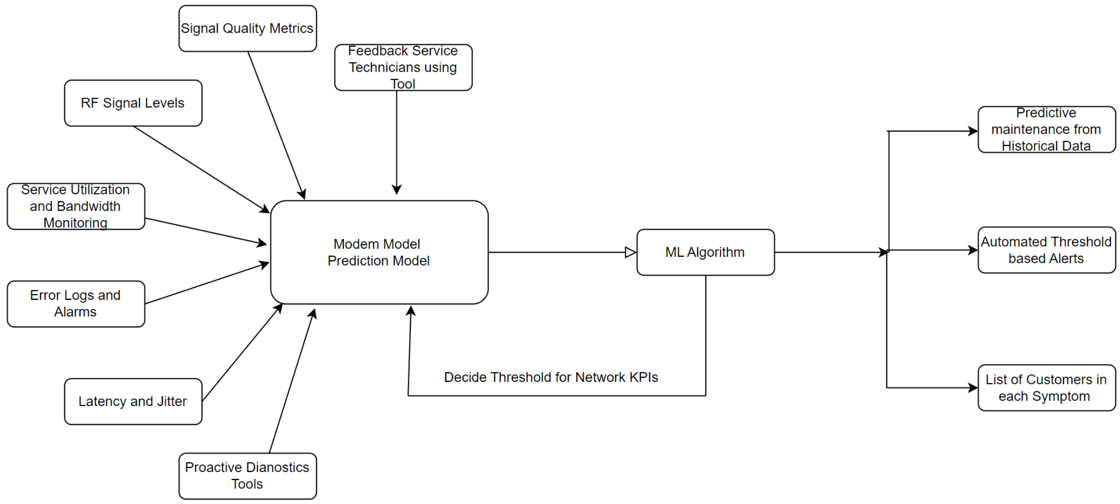

Figure 2: Schematic View of Proactive Modem Model

4. Network KPIs

In this section, Network KPI's used to measure the customer service experience are listed in Table 1. Each of these network KPIs are computed using the feeds collected from several sources of data. Data is cleaned and aggregated at daily level. DOCSIS 3.0 and DOCSIS 3.1 recommended thresholds are proposed to be used in this model.

DS RxMER: Downstream Received Modulation Error Rate

US Tx Power: Upstream Transmit Power

US MER: Upstream Modulation Error Rate

Signal to Noise Ratio: Signal to noise Ratio

Packet Error Rate: Refers to the percentage of packets that are received with errors out of the total number of packets transmitted over a DOCSIS network. Not only the information about un-correctable codewords important but the codewords that were corrected can also be used to measure performance.

Partial Service OFDM/SCQAM: Customers with imputed channels and undergoing partial service for each of for OFDM/ OFDMA and SCQAM channels are computed.

Reboots: Number of times the modem reboots outside maintenance window (window used for software upgrades or other maintenance work)

DS/US Utilization: Customers exceeding Utilization in Downstream/Upstream

Bit-rate-shift: Percentage of sessions facing Modulation bit rates shift in the duration when customer is watching video channel

Latency: Percentage of sessions experiencing Latency while customer is watching video channel.

LTE Ingress: The high frequency LTE signal can interfere with the cable and mute some channels.

Accessibility: Percentage of total time the modem is online

Re-registrations: Number of times CM re-establishes its registration with the Cable Modem Termination System (CMTS)

5. Symptoms

In this work, we identified five major symptoms that would indicate to us that the customers are facing some sort of network impairments. We analyzed the Network KPIs mentioned in Section 4 corresponding to each of these symptoms.

For each of these symptoms Network KPIs that have the highest correlation based on importance are derived. For Symptom 1 i.e. customers either calling for service-related issues or for which truck was rolled the Network KPIs that were flagging in the bucket of these customers are SNR, Downstream Utilization and US Modulation Error Rate. In future work, we propose to track each of these Network KPI namely SNR, DS Utilization and US MER and find set of CM's where each of these KPIs are degrading. This list can be used to determine proactive list of customers that might face this symptom in future. This will help increase customer satisfaction and improve quality of service.

(i) Repeated Customer calls for Tech issues and STRs
(ii) Customer Churn
(iii) Customers experiencing Black Screen Issues
(iv) Video Streaming Impairments
(v) Accessibility degradation/Modem Rebooting

Table 1: Symptoms and their description

Symptoms	Description
Customer Calls	Customers that call regarding technical issue 3 times last week
Truck Rolls	Service Truck Rolls more than 2 times in a week
Accessibility outside maintenance window	Percentage of time modem is online outside maintenance window
Reboots	Modem rebooting more than 3 times in last 2 days
Number of speed tests	More than 2 speed tests in a day
Video Streaming Impairments	Latency issues resulting in black screen/video impairments
Churned Customers	Customer who disconnected their service due to service issue

6. Correlation with Network KPIs

Machine Learning clustering algorithm was used to find the Network KPIs that were flagging in each of these symptoms. Some of the early results for each of these customer symptoms are listed in Table 2. This list of CM can be used as Proactive Network Maintenance and help address service impairments before the customers sees the issue. The table below lists the summary of the symptoms analyzed in this work:

Table 2: Symptoms, identified KPIs, Major Network KPIs flagging for the symptom

S. No.	Symptom	Identifying impacted KPIs	Major flagging KPIs for symptom
1	Repeated Customer calls for tech issues/STR booked	Customers who called regarding tech issue or had truck-roll	SNR DS Utilization US MER
2	Increased number of speed test compared to previous period	Number of GWST tests carried out	US Partial Service US TX DS Utilization
3	Customer experiencing Video Streaming Impairments	Count of Bit-rate Shifts	Latency Perc US TX DS Utilization
4	Customer churn	List of Customers Churned due to technical reasons	PER US TX, RX Partial Service
5	Modem Rebooting/Accessibility issues	Utilization DS and US	PER US MER Partial Service

List of Customers for which Network KPIs identified in Table 2 are flagging can be proactively used to identify the prospective list of customers that are facing issues due to network impairments.

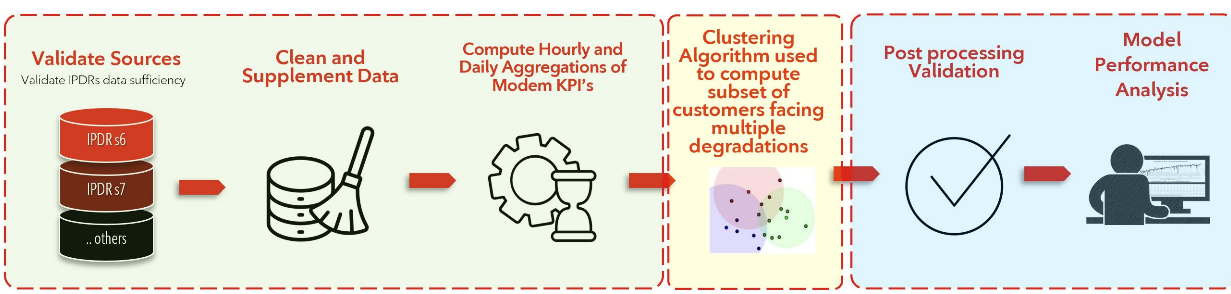

Figure 3: Data Flow for Proactive Modem Model

Figure 3 lists the Data flow diagram for proactive modem model and Figure 4 lists the major components.

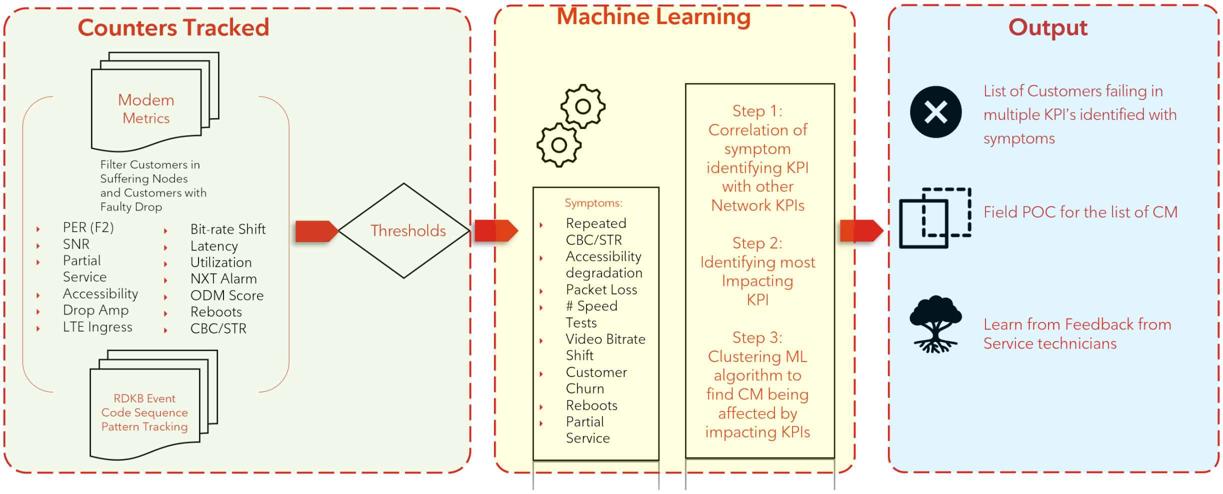

Figure 4: Major components of proactive modem model

7. Conclusion

In this work a Proactive Network Maintenance framework is proposed based on different symptoms for DOCSIS customers. Network KPIs flagging for each of the symptoms can be determined. These network KPI's can be tracked for the entire base of customers and the model provides us with a proactive list of customers for which these KPIs are degrading and might face that particular symptom is prepared. This information can be effectively used by service technicians to proactive action of customers service impairments. The model also provides service technicians access to the Network KPIs and help them address the issue holistically. Applications with low latency requirement and near real-time will greatly benefit from this predictive model. This will help increase customer happiness and reduce customer churn as customers issues will be delt with in time. With increasing network complexity it is useful to address customer issues at early stage to proactively action customers service issues and will improve customer experience.

Abbreviations

DOCSIS	Data Over Cable System Interface Specification
CMTS	Cable Modem Termination System
HFC	Hybrid fiber coaxial
KPI	Key performance indicator
SNR	Signal-to-noise ratio
Tap	Passive device containing directional coupler and splitter
Upstream	The direction from the subscriber location towards head-end
PNM	proactive network maintenance
CM	cable modem
FMECA	failure mode, effect, and criticality analysis
DS	downstream
US	upstream
FBC	full band capture
dB	decibel
OUDP	OFDMA upstream data profile

Bibliography & References

[1] Ghorbel MB, Bedeer E, Hossain MJ, Howlett C, Berscheid B, Cheng J. A clustering-based approach for low-complexity adaptive profile selection in DOCSIS 3.1. In Proc. 28th Biennial Symp. Commun.(BSC) 2016 Jun (pp. 1-6).

[2] Hranac R. and Rupe J., “How Will Proactive Network Maintenance Change Under DOCSIS® 4.0?” in SCTE TECHNICAL. 2023 Feb:5.

[3] Hamzeh B., Toy M., Fu Y. and Martin J., "DOCSIS 3.1: scaling broadband cable to Gigabit speeds," in IEEE Communications Magazine, vol. 53, no. 3, pp. 108-113, March 2015, doi: 10.1109/MCOM.2015.7060490.

[4] Cassandro R., Rupe J. and Li Z. S., "Enhancing Impairment Detection in Full-Band Capture (FBC) Downstream Spectrum Data Using Unsupervised Learning Methods," 2023 Global Reliability and Prognostics and Health Management Conference, Hangzhou, China, 2023, pp. 1-7, doi: 10.1109/PHM-Hangzhou58797.2023.10482620.

[5] Volpe B., “DOCSIS Pre-Equalization: Vastly Powerful, Often Undervalued” Cable-Tec Expo, SCTE 2014.

[6] Sinha R.R., Kolli S.K., Soman S. and Maddala K.P., “Efficient Throughput Degradation Prediction in Telco Networks using Anomaly Detection” in 2023 Fourteenth International Conference on Ubiquitous and Future Networks (ICUFN) 2023 Jul 4 (pp. 515-520). IEEE.

[7] Berscheid B. and Howlett C., "Full Duplex DOCSIS: Opportunities and Challenges," in IEEE Communications Magazine, vol. 57, no. 8, pp. 28-33, August 2019, doi: 10.1109/MCOM.2019.1800851.

[8] Zhu J., Sundaresan K. and Rupe J., "Proactive Network Maintenance using Fast, Accurate Anomaly Localization and Classification on 1-D Data Series," 2020 IEEE International Conference on Prognostics and Health Management (ICPHM), Detroit, MI, USA, 2020, pp. 1-11, doi: 10.1109/ICPHM49022.2020.9187045.

[9] Hu J, Zhou Z, Yang X, Malone J, Williams JW. {CableMon}: Improving the Reliability of Cable Broadband Networks via Proactive Network Maintenance. In17th USENIX Symposium on Networked Systems Design and Implementation (NSDI 20) 2020 (pp. 619-632).

[10] Simakovic M, Cica Z. Detection and localization of failures in hybrid fiber–coaxial network using big data platform. Electronics. 2021 Nov 24;10(23):2906.

[11] Chrostowski, J. et al, "Leakage in a High Split World: Detecting and Measuring Upstream Leakage Levels in a One Gpbs Symmetrical High Split Hybrid Fiber Coax Network." Proceedings of SCTE CableTec Expo 2020.

[12] Sahar M. et al. "Predictive Framework for Enhanced Wireline Network Reliability", Accepted for publication in SCTE CableTec Expo 2024.