Data Collection, Interpretation Methodologies, and Challenges for Proactive Network Maintenance

A Technical Paper prepared for SCTE by

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1. Introduction

Proactive network maintenance (PNM) measurements have been a part of DOCSIS® specifications for over a decade now, but data collection and interpretation are still a challenge for many, both vendors and operators. The DOCSIS specifications define how to request measurement data and the format within which it is to be returned but stop short of properly outlining their use. Furthermore, vendor implementations vary, and newer DOCSIS architectures have added their own challenges to this problem. As PNM tools evolve, we have learnt that our ability to gather the data can be impacted by the collection mechanism in ways we as an industry are unable to qualify in documentation without defining use cases.

The PNM Working Group (PNM-WG) at CableLabs, in conjunction with SCTE Network Operations Subcommittee Working Group 7 (NOS WG7) on PNM, continues to evolve the recommended best practices for this data to assist with troubleshooting network issues. As the network ecosystems are further investigated, gaps are identified that create additional concerns to be addressed. One such gap is that all the information available does not guarantee network equipment behaves as designed when faults occur. Some uses for this data require more than has been specified or described.

To help the industry take full advantage of PNM data, the PNM-WG at CableLabs continuously develops use cases, guiding interested parties in the capture and utilization of PNM data to the benefit of both vendors and operators alike.

In this paper we review the available data collection methods and discuss several PNM use cases to help the reader understand how PNM data can be used in the real world, identify challenges based on current implementations, and propose improvements to the collection methods and PNM data where needed.

2. Data Sources and Protocols

PNM was originally developed to derive in-channel frequency response (ICFR) using upstream pre-equalization coefficient data to identify response impairments. The pre-equalization coefficient data is collected for upstream channels from the cable modems and CMTS using SNMP and then processed by a PNM server. For more information on PNM's use of pre-equalization data see the PNM Best Practices document [4].

A few years after the launch of DOCSIS 3.0 technology, support for cable modem spectrum capture was added to the PNM data available from cable modems, providing a downstream spectrum capture capability.[1] For more information in the use of cable modem spectrum capture see SCTE 280 2022 Understanding and Troubleshooting RF Spectrum [4].

The development of DOCSIS 3.1 added more PNM data, based on tests that can be executed on the cable modem and CMTS. The primary PNM tests supported and in use today provide RxMER per subcarrier data for OFDM and OFDMA channels, and upstream triggered spectrum capture data providing return path spectrum data. Additional tests and data are defined, and more details can be found in the PNM sections of CM-OSSIv31 [1], CCAP-OSSIv31 [2], and CM-SP-PHY3.1 [9]. Unfortunately, not all the defined tests and data are available yet. As the data becomes generally available, additional uses are expected to be developed but are not discussed in this paper which is focused on data readily available in today's network.

[1] Cable modem spectrum analysis functionality was first defined in version I20 of the DOCSIS 3.0 Operations Support System Interface Specification (CM-SP-OSSIv3.0-I20-121113) in November 2012

Table 1 details the primary PNM data, its source, and collection protocol for commonly collected PNM data types.

Table 1 – Data, Sources and Protocols

Data Type	Source	Protocol
Pre-Eq	CM & CMTS	SNMP
Spectrum Capture (D3.0)	CM	SNMP
Spectrum Capture (D3.1)	CM	TFTP
OFDM RxMER	CM	TFTP
OFDMA RxMER	CMTS	TFTP[2]
OFDMA RxPower	CMTS	TFTP
UTSC	CMTS	TFTP or L2TP pseudowire from RPD

3. Data Collection

3.1. Overview

One of the first challenges in developing PNM applications is the collection of data from a potentially large number of sources in the network. CableLabs developed a DOCSIS Common Collection Framework (DCCF), part of a common collection framework [7], that can be used as a starting point for operators to build their own collection application. Several vendors have also developed and provide their own collection frameworks as part of commercially available PNM applications.

Developing scalable SNMP collection applications has been fundamental to network management platforms for decades. DOCSIS 3.1 introduced a new bulk-data transfer mechanism that uses TFTP to upload PNM data to a destination TFTP server. A PNM application first uses SNMP to configure the data being requested and configures the destination TFTP server where the data is sent. This configuration interface is defined in the DOCSIS OSSIv3.1 specifications [1], [2].

Figure 1 shows an SNMP configuration and TFTP transfer sequence diagram for the retrieval of OFDM RxMER data from a cable modem. A similar sequence would be used to request other types of PNM data.

[2] At least one CMTS implementation implements a Kafka bus streaming telemetry mechanism for bulk upload of OFDMA RxMER data.

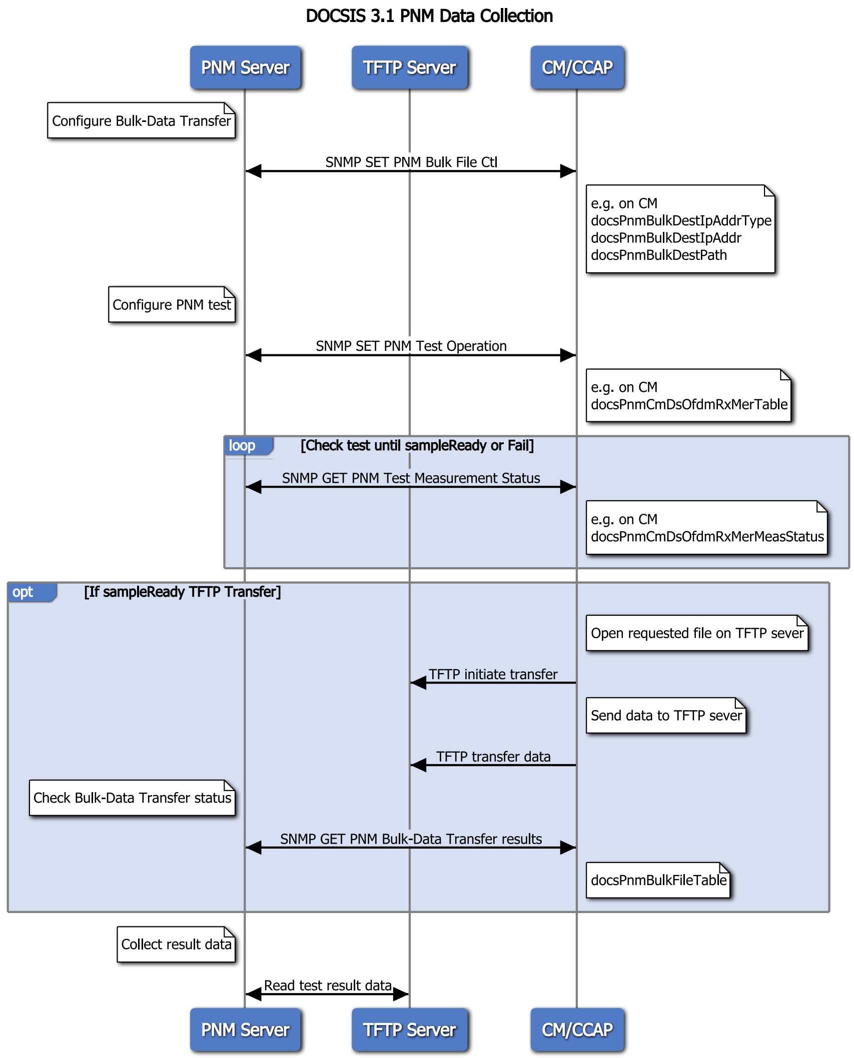

Figure 1: DOCSIS 3.1 PNM data collection sequence diagram (from [3])

3.2. Cable Modem Data Collection

When scaling the collection of PNM data from cable modems for pre-equalization, cable modem spectrum capture, and OFDM RxMER data, we are collecting small amounts of data from many individual endpoints. This allows the creation of a collection framework that scales horizontally, by adding compute resources that handle multiple groups of devices simultaneously. This scaling provides multiple parallel threads within a single compute resource and allows resources to be added as needed. In today's virtualized compute environment, it is also possible to dynamically add, modify, and delete compute resources as required to handle the workload. By implementing a multi-threaded, and multi-compute engine approach, it is possible to scale the data collection of cable modem PNM data from thousands to millions of devices, multiple times a day without creating undue risks or impacting the network negatively.

For DOCSIS 3.1 data such as OFDM RxMER per subcarrier, the cable modem pushes data via TFTP. The same multi-threaded, multi-compute engine environment will also work. However, consideration of system level resources to handle the incoming TFTP requests is required. Because each compute engine has a limited ability to handle multiple incoming TFTP requests, a larger number may be required to support this functionality. However, an individual CM cannot run the test for RxMER per subcarrier and spectrum capture at the same time.

3.3. CMTS Data Collection

Scaling PNM data collection from CMTSs presents a different challenge as we are now collecting a large amount of data from a small number of endpoints. The collection framework must be cognizant of CMTS resources, and CMTS implementations put limits on the number of requests and/or data types that can be retrieved simultaneously.

For OFDMA RxMER per minislot or subcarrier data, the DOCSIS OSSI configuration interface is defined such that data is requested for a single cable modem on an OFDMA interface at a time, by specifying the MAC address of the modem. This means that, for the OFDMA channel, a PNM application must serially request and wait for the data for each cable modem. Depending on the number of cable modems on the channel, this may take a significant amount of time. It may be possible to request the data for cable modems on different channels in parallel, but different CMTS implementations may limit the ability to do this, or require requests be from channels on different line cards.

As described later in this paper, RxMER data used for performance analysis and PMA applications requires the collection of data on common channels to be collected as closely as possible chronologically, so that the results can be compared at nearly the same time, under the same conditions. In this case, the CMTS becomes a bottleneck which a PNM application cannot directly mitigate to scale its data collection. To alleviate this limitation, alternative streaming telemetry mechanisms are being investigated by some CMTS vendors to provide substantially more data at an increased frequency.

For upstream triggered spectrum capture (UTSC) data, the PNM section of the CCAP-OSSIv3.1 specifications defines a configuration interface that allows a PNM application to request upstream spectrum data from an upstream port which is then pushed via TFTP to a PNM server. Based on available resources, the CMTS restricts how many simultaneous captures can run on both a line card and the overall chassis. As with OFDMA RxMER per subcarrier data, and based on constraints around the number of simultaneous requests active on the CMTS, the load and requirements on the PNM application infrastructure are easily managed. If required, additional compute engines can be deployed to handle groups of CMTSs, receiving the UTSC capture files for requested data.

While the CCAP-OSSIv3.1 specification does not distinguish between ports on integrated line cards and RPDs from a configuration perspective, the R-PHY specification does describe an alternate delivery mechanism for RPD upstream ports. For RPDs, the specification defines use of a dynamic pseudowire directly to transfer data from the RPD to the PNM application using an L2TP protocol. The L2TP data stream can result in a data transfer rate of 100 Mbps to 120 Mbps per actively monitored port. As a result, the PNM application, and the data links between the application and the RPDs, must be engineered to handle the aggregate rate from multiple L2TP data streams. For this specific use case, multiple compute engines across a DAA network may be required to effectively receive and process the data.

4. Downstream Data Use Cases

4.1. Cable Modem Spectrum Capture

Cable modem spectrum capture allows operators to capture and analyze the downstream RF spectrum at the cable modem. A spectrum capture capable modem provides the equivalent of a spectrum analyzer in every home, a powerful tool which allows remote RF power measurement without deploying a technician or requiring access to the cable modem's physical location.

Figure 2 shows how spectrum capture data may be displayed, and common elements typically seen in a downstream spectrum.

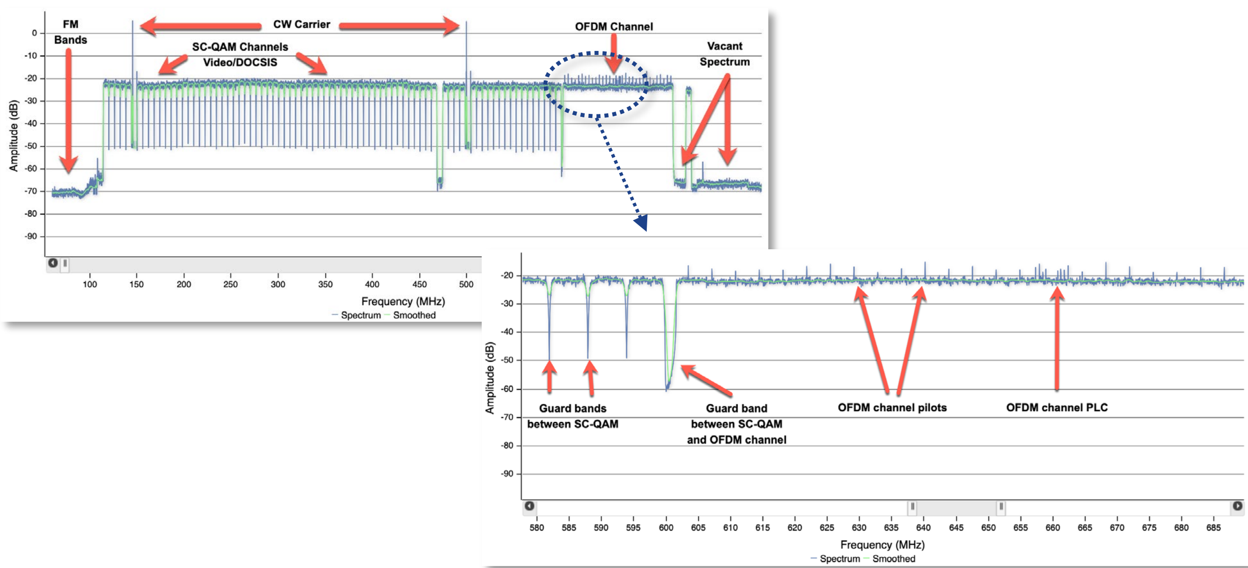

Figure 2: Example of spectrum capture display and common elements (courtesy Akleza)

Within the CableLabs PNM-WG, some members have collaborated on a software library that automatically detects common RF impairments. Additionally, some PNM application vendors have developed their own libraries and techniques offered as part of their commercial PNM applications. Commonly, this software is known as spectral impairment detection (SID) and can assist field technicians in identifying the type and potential cause of impairments impacting the downstream spectrum.

Figure 3 shows several common impairments and how they appear in a spectrum capture trace.

SCTE's NOS WG7 has developed an industry reference, SCTE 280 2022, Understanding and Troubleshooting RF Spectrum [8], that discusses the fundamentals of cable RF spectrum and provides an in-depth analysis of these common cable impairment types and their typical causes and resolution.

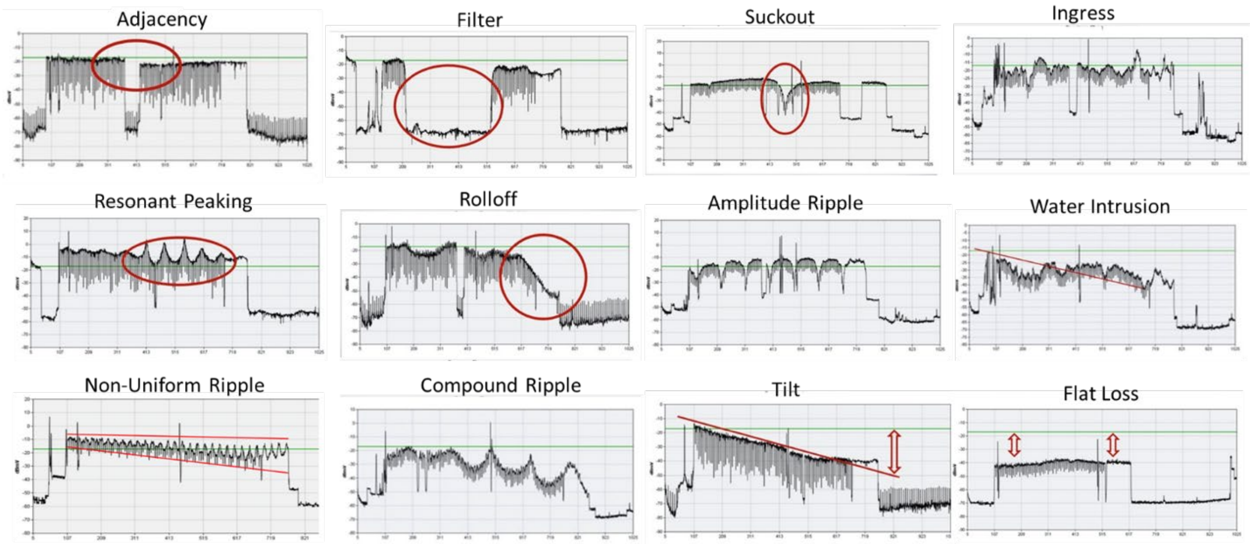

Figure 3: Examples of RF spectral impairments

4.2. OFDM RxMER per Subcarrier

With the release of the DOCSIS 3.1 specifications, there were many useful PNM tests added. One very powerful test added for OFDM (and OFDMA) is called RxMER per subcarrier. RxMER per subcarrier, provides a modulation error ratio measurement for each subcarrier in the OFDM or OFDMA channel. This means if an OFDM channel has 7600 subcarriers, data collectors will receive 7600 RxMER results estimating the signal quality of each subcarrier. When plotted, it creates a visualization like that of a spectrum analyzer but has a different meaning. See Figure 4 for an example graph of OFDM RxMER per subcarrier.

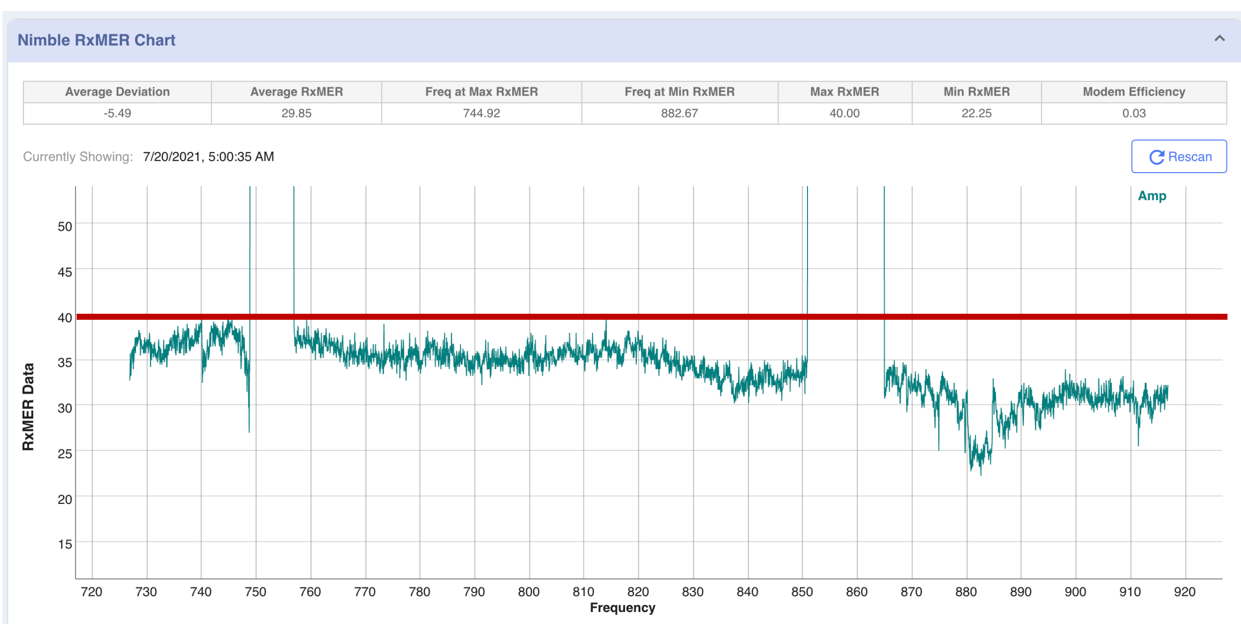

Figure 4: OFDM RxMER per subcarrier channel from a live plant (courtesy Nimble This)

In Figure 4, there are a couple of unique observations one can make.

First, the average RxMER is 29.85 dB, as shown in the top of the chart. A red line is added at 39 dB RxMER, which is the minimum threshold for 4096-QAM. Ideally, all RxMER per subcarrier datapoints should be above the red line to provide the highest level of data speed to the subscriber. If the CMTS was configured to provide 4096-QAM, this modem would not be able to receive any data. See Table 2 for the mapping of RxMER per subcarrier to OFDM modulation order.

Secondly, there are two sections of the RxMER per subcarrier plot where the chart goes above 50 dB. One is from 749 MHz to 757 MHz and the other between 851 MHz and 865 MHz. These are called exclusion bands which have been configured by the operator to exclude use of areas of the spectrum that may have interference or poor performance.

RxMER per subcarrier can be directly mapped to the modulation order which can be supported by a receiving cable modem. These mappings are defined in [PHYv3.1] (*see Table 46 - CM Minimum CNR Performance in AWGN Channel*) and [1] (*see Table 72 - CmDsOfdmRequiredQamMer Object*).

Table 2 shows these mappings up to 16384-QAM, but field testing has indicated that these values are conservative. As indicated in Figure 4, 39 dB is often used as the lower RxMER limit for 4096-QAM rather than the CableLabs recommendation of 41 dB for 4096-QAM.

Table 2 – Mapping downstream RxMER to supported QAM modulation order

Constellation/Bit Loading	CNR/MER (dB)
16-QAM	15.0
64-QAM	21.0
128-QAM	24.0
256-QAM	27.0
512-QAM	30.5
1024-QAM	34.0
2048-QAM	37.0
4096-QAM	41.0
8192-QAM	46.0
16384-QAM	52.0

4.2.1. LTE/5G Ingress Detection

While it is possible to deploy one or more OFDM channels anywhere within the downstream frequency spectrum, it is common for at least one OFDM channel to be located at the higher end of the spectrum, typically above 600 MHz. This frequency range is also where cellular LTE and 5G signals are transmitted over-the-air, so any cable shielding integrity faults may result in interference on the OFDM channel from the cellular signals.

Like cable modem spectrum capture impairment detection, it is possible to identify impairments in RxMER per subcarrier data, including the presence of interference caused by LTE or 5G ingress.

Figure 5 shows an example of a cellular 5G signal that is leaking into the cable network and reducing the RxMER for an approximately 20 MHz span of the OFDM channel, reducing these subcarriers' RxMER and their ability to utilize higher modulation orders.

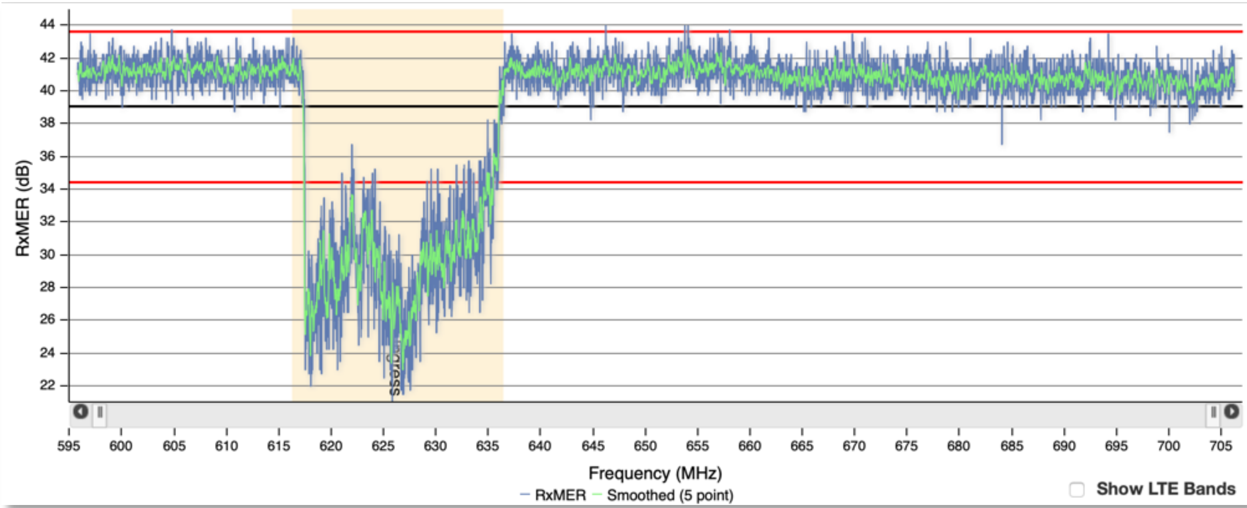

Figure 5: LTE/5G interference impacting OFDM RxMER per subcarrier (courtesy Akleza)

To isolate the location of the ingress further, RxMER per subcarrier data can be examined from several cable modems.

Figure 6 shows an example where RxMER per subcarrier data was analyzed from several cable modems, working upstream from where the ingress was detected.

When an upstream cable modem unaffected by the ingress is identified, the fault can be isolated to the segment of plant between this cable modem and the first cable modem downstream that is impacted. In this example, the ingress was caused by an amplifier housing issue that allowed LTE to leak into the downstream signal path.

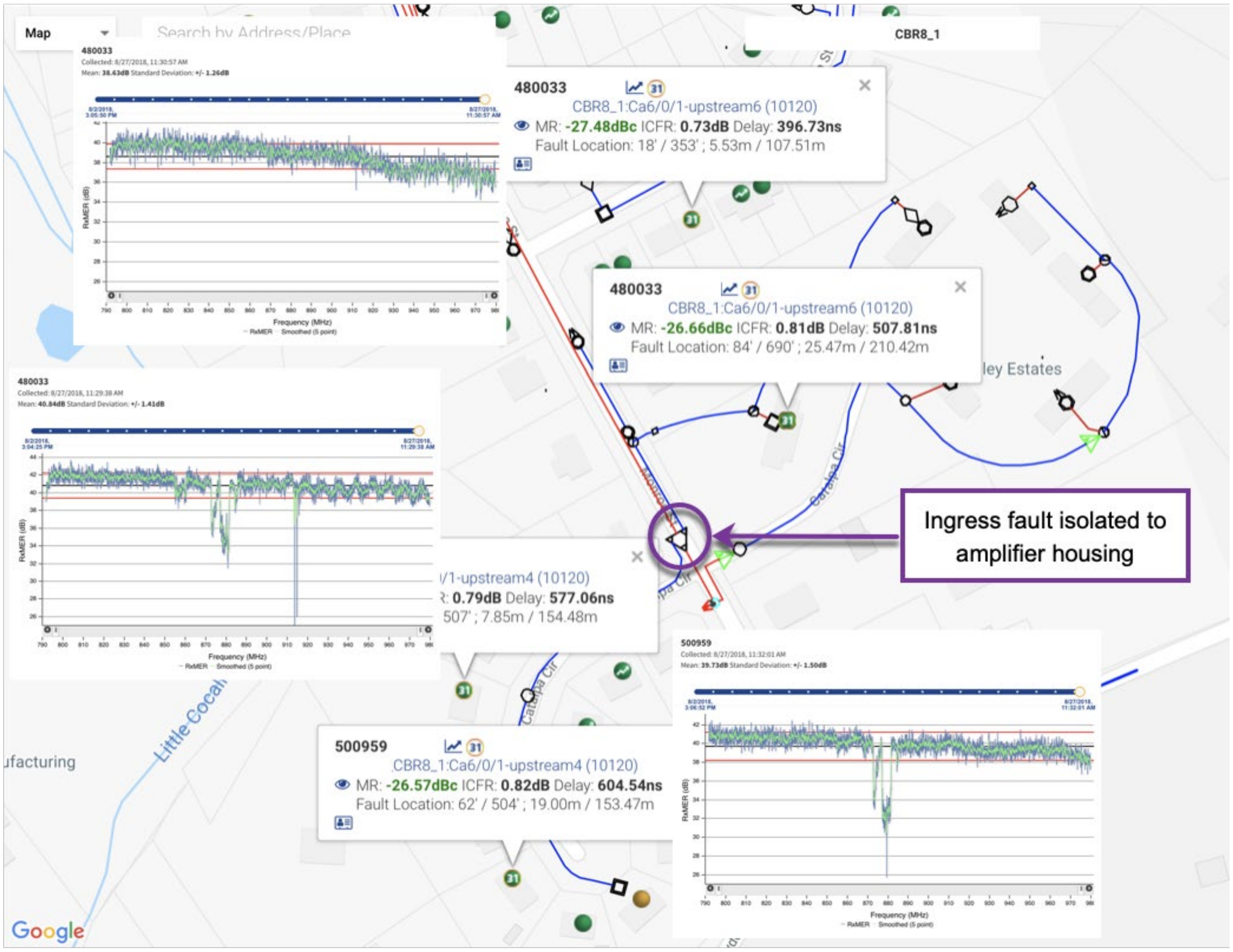

Figure 6: Localizing ingress faults using RxMER per subcarrier data (courtesy Akleza)

4.2.2. Profile Management Application

A profile management application (PMA) typically functions by ingesting RxMER per subcarrier data from a designated node's service area, conducts a detailed analysis of the data, and generates an optimal modulation profile for each cable modem. This procedure aims to augment both the capacity and the robustness of the network.

The improvement in network capacity and robustness is achieved by selectively reducing the modulation order in impaired regions of the OFDM channel, while maintaining higher modulation order(s) within the rest of the channel. This adjustment facilitates cable modems to consistently synchronize with the OFDM channel (contributing to robustness) and to utilize the highest order modulation profiles whenever feasible (boosting capacity).

With this approach, cable operators employing PMA discover a significant increase in the usage of the OFDM channel by DOCSIS 3.1 modems compared to systems not utilizing PMA. This results in the liberation of capacity on the SC-QAM channels for non-DOCSIS 3.1 modems. Subscribers equipped with DOCSIS 3.1 modems often report significantly enhanced download speeds, typically in concordance with their provided speed tiers.

PMA is a processing engine which analyzes the RxMER data from every cable modem in each node. After analyzing the RxMER data, the PMA engine will provide the optimal modulation profile for each subcarrier and the optimal frequency location for the PLC. This takes the guess work out of determining which profiles and PLC location each node's service area requires. Further, PMA can be fully automated, so that every node's service area can be optimized multiple times per day to compensate for the ever-changing nature of plant conditions and RF impairments.

Figure 7 shows a representation of an RxMER per subcarrier of a downstream OFDM channel starting at 853 MHz and ending at 994.495 MHz. One can observe there are lower frequency RF impairments and a high frequency rolloff as indicated by the light yellow and reddish lines. The more frequent the subcarrier dB reading, the darker the color. These lines represent nine cable modems which have been clustered together, having similar downstream RxMER per subcarrier values.

The PMA engine analyzes this data and creates a near-ideal profile given the impairments observed. This profile is indicated by the purple line, which has a stepped profile. Each step in the profile can be used to generate a command which will be run on the CMTS either manually or automatically to compensate for the impairments.

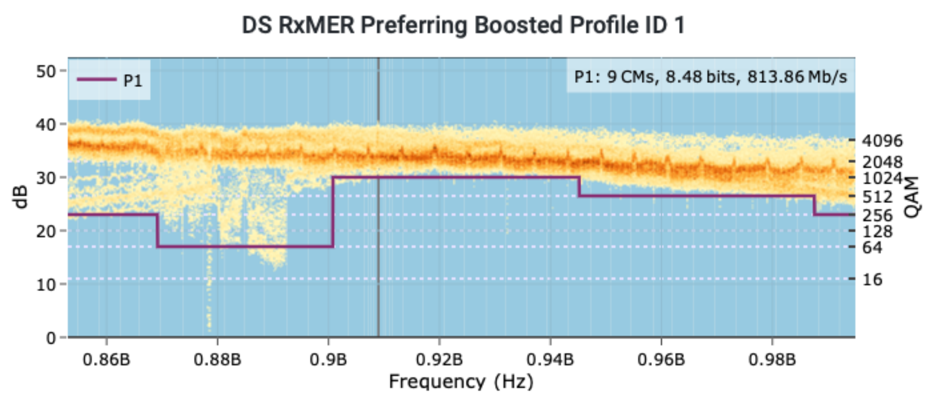

Figure 7: Downstream RxMER per subcarrier of OFDM channel with suggested PMA profile (purple line) (courtesy: OpenVault)[3]

The challenge of modifying OFDM and OFDMA profiles on a CMTS during the PMA process is three-fold, however.

There's a lack of a standardized protocol for carrying out these modifications using SNMP commands, meaning we must use Secure Shell (SSH) to access the CMTS command line interface (CLI). While SSH usage brings certain security considerations, it isn't the core issue.

Each make and model of CMTS often has vendor specific CLI commands for updating the OFDM and OFDMA profiles. This lack of uniformity demands a detailed understanding of the individual commands and procedures for each system. With the necessary SSH credentials in hand, vendors and cable operators face the daunting task of learning the unique syntax and command structure of each respective CMTS.

Once these hurdles have been cleared, an additional challenge emerges. The entire system must be automated to create a closed loop method of operation. In this approach, the PMA engine generates optimal profile recommendations, and the CMTS is then automatically updated with these profiles via the

[3] These charts are heat maps of the RxMER subcarriers for a 24-hour period with multiple poll cycles. The darker the color (red) the more frequent the reading. If there were no variations over time, this would result a straight dark red line.

CLI. This involves careful scripting, thorough testing, and continuous monitoring to ensure the loop operates flawlessly, further enhancing the complexity of the entire process.

As an initial step and until CMTS technicians are comfortable with the changes that will be made, a PMA can make recommendations which would then be manually applied by the CMTS technician.

PMA has several benefits, which are immediately realizable as follows:

- PMA will provide the optimal profile for a node:
    - PMA even provides modulations on a subcarrier level, though this is not yet supported by CMTS vendors.
- Through profile optimization per node, each node's service area will always see the maximum data throughput:
    - Many cable operators run OFDM conservatively, meaning they may not use 4096-QAM or even 2048-QAM and opt for lower order modulation orders to ensure data throughput to their subscribers. PMA will allow operators to run at the highest modulation possible with confidence.
- PMA can provide PLC placement recommendations to ensure the PLC is not operating in an area with impairments:
    - This is often overlooked as a critical feature of PMA. If the PLC is placed in a region where impairments exist (think about a suckout or LTE ingress), this will result in an outage. PMA will aid in preventing such instances from occurring.

These immediate benefits may seem obvious and exciting, but they have a bottom-line impact to total system capacity, which results in OPEX savings and preventive CAPEX investment.

In 2019, Comcast developed a PMA system for generating and transacting DOCSIS 3.1 downstream profiles tailored to the conditions of each OFDM channel in its network. Some point-in-time metrics from Comcast's deployment of PMA which indicates its realized value [5]:

- 34.3% capacity gain in OFDM profiles (Division A)
- Raw gain of 6020 Gbps for Division A
- 91.0% CM success rate (percent of CMTSs that were successfully configured with updated profiles)

Comcast considered PMA a huge success and subsequently issued a public press release [5].

5. Upstream Data Use Cases

5.1. Pre-equalization

PNM was originally developed based on the availability of pre-equalization coefficient data and the ability to detect and localize frequency response impairments in the return path signal by analyzing this data. The PNM Best Practices document [4] covers the use of pre-equalization in detail including data collection, analysis, and fault localization.

In contrast to SC-QAM channels, an OFDMA channel utilizes a separate pre-equalization coefficient for each subcarrier. Using OFDMA pre-equalization coefficients in conjunction with PNM active/quite probe PNM tests, allows applications to better estimate transmission line characteristics.

The pre-equalization coefficient data available consists of two sets: actual pre-equalization coefficients, and the latest updates as received by the cable modem. Actual pre-equalization coefficients are used by the cable modems adaptive pre-equalizer to adjust the transmitted signal, so it will be received by the CMTS in nearly optimal conditions. For more details see section 6.2 of [3].

Significant changes in the latest update data indicate adjustments to the pre-equalization coefficients instructed by the CMTS. This may be an indication of rapid changes in the transmission line characteristics and may indicate significant noise, ingress interference or cable defects caused by environmental factors (wind, precipitation, vibrations, etc.).

Support for the collection and analysis of OFDMA pre-equalization coefficient data still has some challenges.

First, not all vendors implement this in all firmware versions so coverage can be inconsistent.

Second, requests for the data may be blocked due to other outstanding PNM data requests, such as RxMER per subcarrier and spectrum capture data. It is therefore important for the PNM application to manage these data requests and schedule appropriately to minimize any conflict.

5.2. UTSC

5.2.1. Overview

Return path spectrum monitoring and analysis are important tools that cable operators rely on to troubleshoot RF interference in the upstream spectrum. However, the return funnel[4] effect in cable networks means that locating ingress sources continues to be a challenge, and is largely inference-based, which is manual and tedious. Locating the source of interference is still typically achieved through a "divide and conquer" technique, where return paths are isolated while validating if the interference is still visible.

Traditional return path monitoring platforms have also been hardware based, located in headend facilities, and measuring the RF signal split out using an RF switch or similar. As distributed access architectures (DAAs) are deployed, the RF connection back to the headend has been replaced by a digital fiber connection and therefore no RF signal is available to be measured.

UTSC provides a software solution for monitoring the return path and operates across both traditional RF and DAA environments.

A UTSC application provides a wideband spectrum analyzer function using the burst receiver within the CMTS or RPD to capture the RF signal. Since the receiver has knowledge of the scheduler it can be triggered to examine desired upstream transmissions as well as underlying noise and interference during a quiet period when no devices are scheduled to transmit. It can also be triggered to capture on specific timestamps or time slots granted to a specific MAC address. To date, availability of these trigger capture modes is not consistently implemented across all CMTS vendors for UTSC, but support is being rapidly developed and deployed based on operator and PNM application vendor priorities and requests.

[4] Also referred to as noise funneling. Downstream signal transmission in a cable network is point to multipoint (headend or hub site to multiple subscribers); upstream transmission is the opposite, multipoint to a single point. Upstream interference such as noise or ingress can enter the network at one or more locations and "funnel" back to the headend or hub, hence the reverse funnel effect.

5.2.2. freeRunning Mode of Operation

Currently all CMTS vendors implementing UTSC support the “freeRunning” trigger mode. This mode provides a continuous spectrum capture across a specified frequency range and resolution like that of existing visualizations provided by hardware-based platforms and field meters. Using this trigger mode, a UTSC application can support a real-time, live, spectrum analyzer function updating several times per second.

In addition to having scheduler information available, the CMTS also has demodulators that run continuously on active upstream channels. These demodulators can provide additional information for each of the channels to the UTSC application, such as RxMER and FEC statistics. This is useful for determining the impact of impairments and for troubleshooting.

Figure 8 shows an example trace from a UTSC application in a sub-split node. In this example you can clearly see the presence of common path distortion (CPD) with a raised noise floor across the entire spectrum. By integrating the channel metrics from the burst receiver, RxMER, total codewords, correctable codewords, and uncorrectable codewords, we can see the impact the impairment is having on the upstream transmissions.

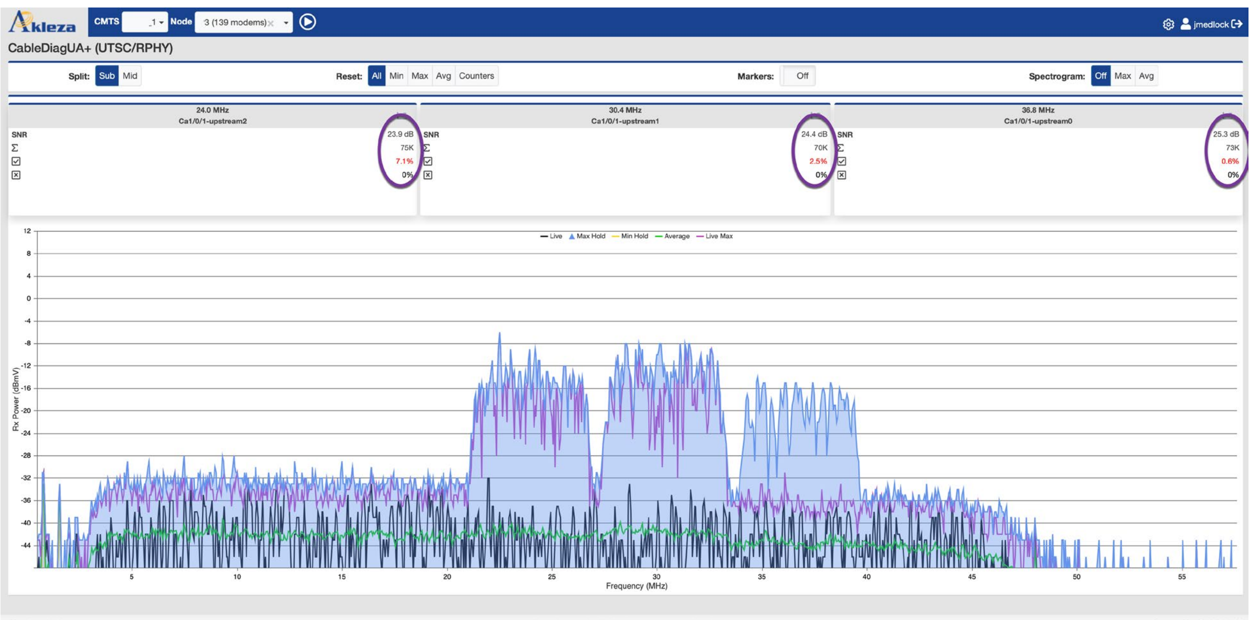

Figure 8: Example UTSC spectrum trace (courtesy Akleza)

5.2.3. idleSID Mode of Operation

While not available from all CMTS vendors, some implementations do support the “idleSID” or quiet time trigger mode. This captures the configured frequency range during a period when a channel is not transmitting which allows you to see any potential noise or interference under a carrier.

Figure 9 shows a UTSC example during a quiet time for the first channel. As is highlighted, this ability allows us to see the ingress under the carrier and again the burst receiver metrics highlight the impact the ingress is having on the channel transmission.

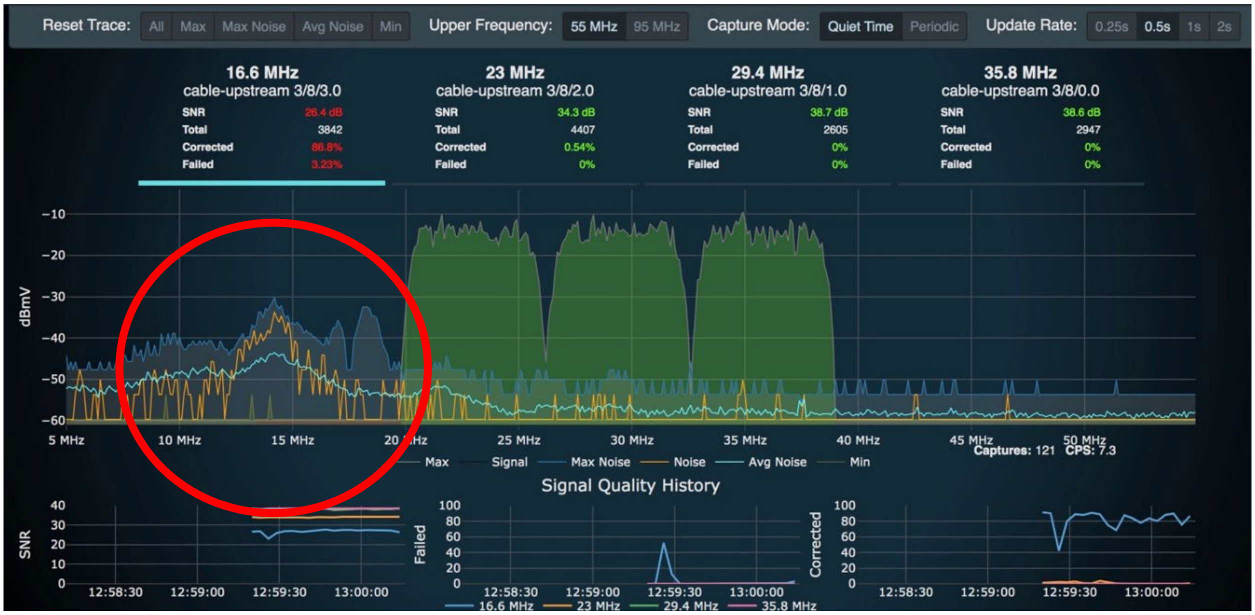

Figure 9: UTSC during channel quiet time (courtesy Comcast)

As a companion to the SCTE 280 2022, Understanding and Troubleshooting RF Spectrum informational report, SCTE NOS WG7 is developing another informational report focused on understanding and troubleshooting upstream impairments. This is expected to be released later this year.

5.2.4. Dynamic Triggers

UTSC can be triggered based on several different factors. Automation and orchestration are key to triggering, capturing, and analyzing upstream spectrum data and making intelligent decisions about the impairments and deployment of resources to repair them. Some options for triggering UTSC captures include:

- Periodic time-based captures as a proactive measurement tool during peak usage times to validate that service level agreements are being met.
- Quality of Service (QoS) metrics-based triggers including but not limited to latency spikes, SNR/MER degradation, cumulative packet loss increases, jitter variations, bandwidth utilization and congestion.

Implementation of these trigger mechanisms requires the necessary compute and data storage infrastructure along with the testing and optimization to make them truly effective. Other considerations include communication protocols available, hardware and software compatibility, security and privacy, error handling, and user feedback, all to consistently improve the algorithms being used to identify and investigate upstream impairments.

5.2.5. Smart Amplifiers

Smart amplifiers, also known as adaptive or intelligent amplifiers, are relatively new to the industry. They utilize advanced technologies and techniques to optimize performance in ever changing environments. They are designed to provide efficient and high-quality amplification while adapting to changing RF conditions, interference, and other factors that can affect signal quality.

Smart amplifiers include features like interference management, detecting the presence of other RF signals, and enhancing the signal quality by optimizing amplification parameters and managing that interference, maintaining higher signal quality, minimizing distortion, and contributing to better overall system performance.

Utilizing UTSC with smart amplifiers involves using event-based triggers that monitor incoming RF signal characteristics and triggering the capture of spectrum data when specific conditions are met. Some of these conditions include signal strength, signal-to-noise ratio, interference levels, or any other relevant QoS metric.

Using the spectrum capture data, adaptive adjustments can be made to the amplification parameters in real time to optimize performance. The smart amplifier can modify gain, frequency selection, and other parameters available to ensure the best signal quality possible.

By allowing the amplifier to make informed decisions using spectrum analysis, it can mitigate potential customer impacts, either negating the need to send a technician, or allowing them the time to arrive onsite and investigate further without additional load on call centers or technical support representatives.

The UTSC technique is particularly useful in environments with rapidly changing RF conditions or where interference sources can impact signal quality. By capturing and analyzing the RF spectrum on demand, the smart amplifier can respond in real-time, ensuring consistent performance, and enhancing the overall quality of communication or signal processing.

This approach may require integration of specialized hardware such as spectrum analyzers or software defined radios (SDRs), and software within the smart amplifier system to operate effectively.

5.3. OFDMA RxMER per Subcarrier

RxMER per subcarrier data for OFDMA channels is important for fault identification, localization, troubleshooting, node health scoring, KPI reporting, and a host of other metrics critical to plant operations. Use of this data is consistent with the use of RxMER per subcarrier data for OFDM channels.

5.3.1. PMA

OFDMA RxMER per subcarrier data can be used by a PMA to optimize modulation profiles for upstream OFDMA channels. Upstream impairments vary frequently in many aspects including intensity and impact, and cable operators may need to reconfigure their OFDMA profiles as much as once per hour which requires obtaining that data at the same frequency. Running RxMER data collection and other PNM tests and queries concurrently is required to meet this business objective; but as discussed previously, this data collection frequency has some challenges.

Figure 10 shows a representation of RxMER per subcarrier data for an upstream OFDMA channel starting at 10 MHz and ending at 22 MHz. One can observe there is a significant amount of RF noise across the spectrum, preventing the modems from operating at 1024-QAM as observed by the light yellow and reddish lines. The more frequent the subcarrier dB reading, the darker the color. These lines represent 123 cable modems which have been clustered together, having a similar reported upstream RxMER per subcarrier.

The PMA engine analyzes this data and creates a near-ideal profile given the impairments observed. This profile is indicated by a purple line, which has stepped profiles. Each step in the profile can be used to generate a command which will be run on the CMTS either manually or automatically to compensate for the impairments. In Figure 10, one can observe that the optimal profile modulations are between QPSK and 32-QAM[5] given the level of severe upstream noise. While this is not the ideal 1024-QAM, it will allow cable modems to remain locked to the OFDMA channel and enable those modems to take advantage of the capacity of the OFDMA channel, thus alleviating load from the SC-QAM channels.

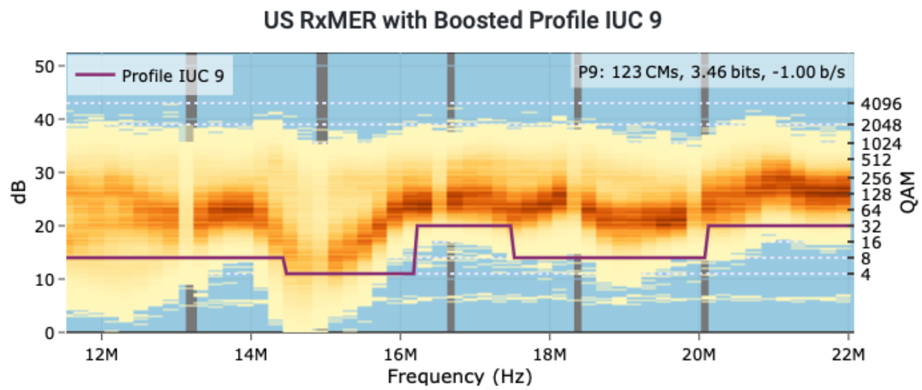

Figure 10: Upstream RxMER per subcarrier of OFDM channel with suggested PMA profile (purple line) (courtesy: OpenVault)[6]

CMTS vendors are currently exploring alternative mechanisms to deliver RxMER per subcarrier data in bulk, including streaming telemetry mechanisms such as a Kafka bus to periodically publish data, making it available to a subscribed PNM collection application. Such streaming mechanisms would benefit applications like PMA and help to meet the requirements of the cable operator.

6. Bulk Data Collection Challenges and Recommendations

There are several challenges with obtaining large amounts of rapidly sampled upstream data. Some examples include:

- Obtaining RxMER per subcarrier data while running any other PNM tests or queries, such as UTSC, or while another PNM application is running, can prevent data delivery. For example, on some platforms one can obtain RxMER but not UTSC data at the same time, and vice versa. This can limit troubleshooting in that more than one problem cannot be analyzed simultaneously, and only a single technician can work on the platform at a given time. Fault management can be urgent, and technician time is valuable.
- Further, on some vendor platforms, it is only possible to obtain data for one modem at a time (single threaded or per modem basis). This results in a significant amount of time necessary to query all needed data on a single CMTS.
- On some CMTSs, obtaining some forms of data can introduce an out-of-service event to end users, which is clearly unacceptable.

[5] This customer was looking for robustness/resiliency/stability on the DS and capacity on the US, resulting in very robust (e.g., low order) modulation profiles

[6] These charts are heat maps of the RxMER subcarriers for a 24-hour period with multiple poll cycles. The darker the color (red) the more frequent the reading. If there were no variations over time, this would result a straight dark red line.

6.1. Operational Considerations

The use of TFTP by the DOCSIS 3.1 PNM bulk-file transfer mechanism may require some network configuration changes if there are any firewalls between the CM or CMTS and the destination TFTP server. TFTP is a UDP-based protocol that uses ephemeral ports to transfer data.

Figure 11 shows the upload sequence in which Ports X and Y are ephemeral port numbers.

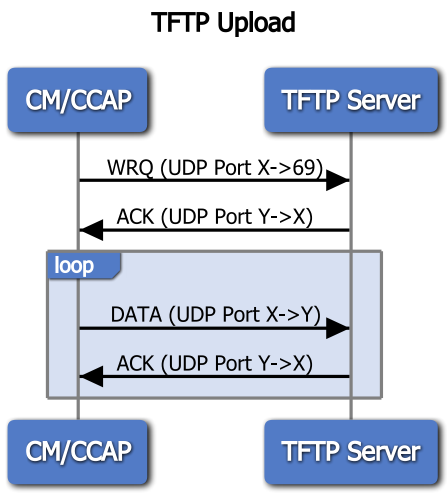

Figure 11: TFTP upload process (from [3])

For the TFTP upload process to complete, any network firewalls between the CM or CMTS and the TFTP server must be configured to allow UDP traffic from the ephemeral port range between the CM or CMTS and TFTP server. Though it may be possible to use source and destination addresses to configure an explicit rule for CMTS devices, it is not practical for CM subnets. As such, rules allowing UDP Port 69 and all UDP traffic in the ephemeral port range destined for the TFTP server are required to support the PNM bulk-file transfer mechanism.

6.2. Security and Reliability Considerations

TFTP and SNMP are currently not required to be encrypted; however, one can add application layer security if desired. For example, an HTTPS proxy can be added in front of data collectors like CCF, which allows encrypted posts and gets.

UDP, which is low priority, is the assumed transport mechanism. As such, a capacity limit is reached if there is too much traffic, and the UDP packets can be dropped, causing a loss of PNM information. Further, there is a general assumption that if a test fails or if information is corrupted in the transfer process, then a retry of the test is warranted. The application layer (in this case the PNM application) is assumed to manage the information reliability.

In addition, CMs can be limited in their processing of PNM information. If a PNM request takes five minutes to complete and is only initiated when requested, then the CM will not likely respond to other requests until the first is completed. Consider this limitation when requesting data from CMs.

6.3. Deployment Considerations

The network needs to have a TFTP server to receive and hold the TFTP files that are responses to the data requests.

Also, firewall rules on the network must allow the TFTP packets to travel from the CM to the server and to any applications that need the data.

Similarly, SNMP requires firewall rules to be configured to allow the traffic in both directions.

Virtual machines (VMs) are commonly used to deploy PNM data collectors such as CCF. The VM should have the compute power and configuration required to adequately support its deployment. It is common to have one PNM data collector instance for each CMTS, but different models are possible and should be considered based on expected use.

In at least one implementation, data and files generated by CMTS can remain in the local memory and would need to be removed via script or command on a regular basis to prevent it from becoming overutilized and unavailable.

6.4. New Data Transfer Methods

Defined in 2021, there is a new bulk data transfer mechanism described in section 7.5 of CCAP-OSSIv31 [2] This mechanism is defined to better facilitate obtaining the increased amounts of disparate data from the CMTS resulting from PNM tests; it is also useful for other large data acquisition requirements.

Based on the experience of previous methods, a small group formed from the CableLabs PNM-WG to define improved methods that would allow more effective data transfer and thus more useful PNM testing involving the CMTS.

In the configuration of a bulk data transfer, the destination for the resulting file is set, along with the transfer protocol of choice: TFTP, HTTP, or HTTPS. When using TFTP, the CMTS must have a TFTP client to complete the file transfer, initiated at the request of the PNM server. gNMI is also an option specified,[7] but it is not supported by DOCSIS 3.1 devices for PNM. However, there is nothing preventing a CMTS vendor from offering it.

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[7] gNMI (gRPC Network Management Interface) is a protocol used for network management and configuration. It's a protocol developed by Google and is part of the larger gRPC framework, which is a high-performance, open-source remote procedure call (RPC) framework that uses HTTP/2 for transport and Protocol Buffers for serialization. It is specifically designed for network devices and systems to provide a standardized way of managing and configuring them. This method is often used in conjunction with other technologies like YANG models (Yet Another Next Generation) which define the structure and semantics of network data. YANG models provide a common language to describe configuration and operational data for network elements.

gNMI provides many improvements over TFTP and L2TP, including higher efficiency and scalability, secure communication, and asynchronous notifications, allowing devices to send updates to the management system in real-time when changes occur.

Though the working group is also moving toward streaming telemetry using YANG, which significantly improves methods for data acquisition, the updated method discussed here can be implemented in DOCSIS 3.1 through a software update.

For R-PHY networks, UTSC data is delivered to a PNM server over an L2TP pseudowire. While efficient, and a necessary difference due to the nature of R-PHY, vendors have not yet aligned on how to configure data collection on RPDs.

7. Conclusion

As defined throughout this paper, there are many options for collecting PNM related data. While they all have their own requirements and present their own challenges, none are out of reach, and only need the necessary constructs to be deployed.

Downstream data collection provides valuable insight into what is going on and which customers are impacted, especially when utilizing the spectrum capture functionality of D3.0 and above modems and applying OFDM RxMER calculations within a PMA application to create appropriate profiles for each customer to get the most of their service tier.

Upstream data collection challenges seem daunting, being limited by CMTS implementation and a singular device supporting thousands of customers, but new data transfer mechanisms are being developed to allow the required data to be transferred are rates required for real time measurement and network adaptation.

UTSC, a novel feature that allows operators and vendors alike to capture and analyze upstream data and use it to their advantage without having eyes on glass during impairments, changes the landscape significantly. It allows for the possibility of remote configuration changes within node housings that support digital RF boards and smart amplifiers, enabling frequency optimization and adaption to impairments, potentially mitigating customer impacts and allows technicians the time to troubleshoot.

While collection frameworks and data transfer mechanisms have their unique considerations, as we evolve so will they. Also, as new use cases are defined, and new best practices are published, our collective efforts will benefit both ourselves and our customers experience.

Abbreviations

4G	fourth generation [mobile telecommunications technology]
5G	fifth generation [mobile telecommunications technology]
ADC	analog-to-digital converter
AGC	automatic gain control
CCAP	converged cable access platform
CMTS	cable modem termination system
CPE	customer premises equipment
CSV	comma separated values
CW	continuous wave
DAA	distributed access architecture
dB	decibel
dBmV	decibel millivolt
DC	direct current
DFT	discrete Fourier transform
DOCSIS	Data-Over-Cable Service Interface Specifications
DSP	digital signal processing
FFT	fast Fourier transform
FM	frequency modulation
HFC	hybrid fiber/coax
I	in-phase (real)
Hz	hertz
kB	kilobyte
kHz	kilohertz
log	logarithm
LTE	long term evolution
MHz	megahertz
MIB	management information base
OFDM	orthogonal frequency division multiplexing
OFDMA	orthogonal frequency division multiplexing access
OSSI	operation(s) support system interface
PLC	1) physical layer link channel; 2) PHY link channel
PNM	proactive network maintenance
Q	quadrature (imaginary)
QAM	quadrature amplitude modulation
RBW	resolution bandwidth
RF	radio frequency
RPD	remote PHY device
SC-QAM	single carrier quadrature amplitude modulation
SCTE	Society of Cable Telecommunications Engineers
SNMP	Simple Network Management Protocol
TDR	time domain reflectometer
TFTP	Trivial File Transfer Protocol
TV	television
UHF	ultra-high frequency
UTSC	upstream triggered spectrum capture

Bibliography & References

[1] Data-Over-Cable Service Interface Specifications DOCSIS® 3.1 Cable Modem Operations Support System Interface Specification CM-SP-CM-OSSIv3.1 (Cable Television Laboratories)
[2] Data-Over-Cable Service Interface Specifications DOCSIS® 3.1 CCAP™ Operations Support System Interface Specification CM-SP-CCAP-OSSIv3.1 (Cable Television Laboratories)
[3] PNM Current Methods and Practices in HFC Networks (DOCSIS® 3.1) CM-GL-PNM-3.1 (Cable Television Laboratories)
[4] DOCSIS® Best Practices and Guidelines PNM Best Practices: HFC Networks (DOCSIS® 3.0) CM-GL-PNMP (Cable Television Laboratories)
[5] Full Scale Deployment of PMA, Lessons Learned from Deploying the Profile Management Application System at Scale and Considerations for Expanding the System Beyond OFDM, A Technical Paper prepared for SCTE•ISBE by Maher Harb, Bryan Santangelo, Dan Rice, Jude Ferreira, Comcast
[6] Comcast Tech Chief Werner: Peak Traffic Up 60% in Some Cities, But Network Is Handling It (*Multichannel News*)
[7] Combined Common Collection Framework Architecture Technical Report (Cable Television Laboratories)
[8] SCTE 280 2022, Understanding and Troubleshooting RF Spectrum
[9] DOCSIS 3.1 Physical Layer Specification CM-SP-PHYv3.1

