ATLANTA, GA
OCTOBER 11-14

Practical Implementation of Profile Management Application (PMA) to Improve Data Throughput in the Presence of Impairments

A Technical Paper prepared for SCTE by

Brady Volpe
Founder and CEO
NimbleThis and The VolpeFirm
3000 Old Alabama Rd. Suite 119-434, Alpharetta, GA 30022
+1-404-954-1233
brady.volpe@volpefirm.com :: brady.volpe@nimble-this.com

Table of Contents

Title **Page Number**

List of Figures

Title **Page Number**

List of Tables

Title **Page Number**

1. Introduction

Speed. We never seem to get enough of it. This is certainly true when it comes to high-speed data. Over the past 20 years the data over cable system interface specification (DOCSIS) has undergone several iterations to accommodate more and more speed. DOCSIS 3.1 introduced new technologies specifically to support even more speed improvements. Specifically, orthogonal frequency division multiplexing (OFDM) in the downstream and orthogonal frequency division multiple access (OFDMA) in the upstream. OFDM and OFDMA are unique in their implementation of frequency allocation because they use very narrow slices of bandwidth in the RF spectrum to transmit data, called sub-carriers. A single OFDM channel is made of many sub-carriers. For example, a single 192 MHz OFDM block can contain 7600 subcarriers. These subcarriers are only 25 kHz or 50 kHz in bandwidth. Contrast this to our traditional single-carrier quadrature amplitude modulated (SC-QAM) channel which is typical 6 MHz (or 8 MHz for some non-North American systems).

Each subcarrier can have its own modulation from 16-QAM up to 4096-QAM (even high order modulations may be supported. Again, we can contrast modulation to legacy SC-QAM, which are limited to 64-QAM or 256-QAM. In the comparison of SC-QAM to OFDM we see a drastic difference between bandwidth (6 MHz vs 25 kHz) and modulation (256-QAM vs 4096-QAM).

As previously mentioned, in OFDM each subcarrier can have its own modulation. This means one subcarrier can be running at 4096-QAM while its adjacent subcarrier could be running at 16-QAM. This is a very power feature when impairments are present because each subcarrier can be optimized to ensure modems can receive data from each subcarrier no matter how bad the impairment. But how could one possibly know how to configure 8000 subcarriers? It's not possible. This falls into software called the profile management application or PMA coupled with proactive network maintenance (PNM).

This paper will explain how PNM and PMA work together to optimize the OFDM downstream and later the OFDMA upstream to maximize the data throughput in the presence of downstream and upstream impairments.

2. What is PNM?

Proactive network maintenance (PNM) has been steadily growing in acceptance and popularity over the past several years with adoption amongst cable operators from Tier 1 such as Comcast all the way to the smallest Tier 4 operators — both in the U.S. and internationally — as a tool for optimizing their work force and improving subscriber quality of experience (QoE). No longer is it seen as a shiny gimmick or a novelty to detect the poltergeist in the network before it goes bump in the night. It is a go-to network maintenance tool with the added benefits of workforce optimization.

PNM DOCSIS Overview

PNM in Data-Over-Cable Service Interface Specifications (DOCSIS) collects several key metrics including equalization data from cable modems, downstream spectrum capture from modems and upstream spectrum capture from the cable modem termination system (CMTS). Along with traditional SNMP metrics, this data is used to identify physical layer impairments often not identifiable with legacy monitoring systems and meters. Two key takeaways with a properly orchestrated PNM system are that it provides visibility into impairments most operators have lacked visibility into, and it provides clear, visible, and actionable insights, such as whether the impairment is in the subscriber's home or in the outside plant. This alone drives key decisions as to which resource to send (and where to send it!) to resolve a problem — intelligent problem solving = resource optimization.

Types of Problems Proactively Found

Proactive tools are rapidly seen as must-have tools as the need for nearly every industry to resolve issues before they occur is increasingly under demand. DOCSIS PNM specifically focuses on the physical RF plant. This means coax cable, connectors, and passive & active devices. Everything from the CMTS to the cable modem (CM).

Interestingly, the CMTS and CM are rarely the sources of problems. In fact, systems that use PNM see a rapid decrease in unnecessary modem replacements — the modem was never bad in the first place. The most frequently found problem is typically bad or improperly installed F connectors, such as the one in Figure 1.

Figure 1: F-connector not flush with the cable's dielectric

When connectors are not properly installed, this can create several problems:

- Micro-reflections
- Intermittent connections
- Signal ingress
- Signal egress

The problems are difficult to detect with a traditional signal level meter (SLM) but can cause intermittent issues with cable modems and set top boxes resulting in repeat calls to the subscriber's home. Further, improperly installed connectors allow egress out of the plant, causing possible regulatory issues with FCC Part 76 leakage regulations, as well as upstream and downstream ingress, potentially impacting many (or all!) subscribers on the same fiber node.

Figure 2: Trunk line outer shielding cut by technician when coring cable for connector, illustrates another common issue identified with PNM — outside plant impairments.

In **Figure 2** we see that the outer shield on a hardline coax has been cut the entire way around when a technician was overzealous during coring. When the shielding is compromised, the coaxial cable's impedance is no longer 75 ohms. This results in a major impedance mismatch, or micro-reflection. Further, ingress and egress will result from this exposed section of coax.

In the examples of **Figures 1 and 2**, these impairments may or may not be immediately obvious to the technician depending on the severity of the damage. However, one fact we know is that cable does not get better over time. Water ingress will create more corrosion and these impairments will result in eventual outages of either single modems or clusters of modems. The impact will be dissatisfied subscribers, and technicians in firefighting mode to find and fix the root cause.

What if there were a better method? A way that we could find these impairments before the customer was impacted. There is. It's **PNM**.

Impact to Home Techs

PNM starts with home installation technicians. They are the front line, installing new modems every day or visiting subscribers who are calling about issues with their modems. Having worked with PNM since 2012 I can tell you two facts: 1) the majority of return path ingress comes from individual subscribers' homes, 2) most hard-to-find impairments causing repeat truck rolls to come from subscribers' homes. And this is where the home techs spend most of their time.

Given the new visibility into micro-reflections and group delay, home techs can now see impairments previously hidden to them. Micro-reflections are typically the dominant issue in subscribers' homes due to bad wiring, such as the example shown in **Figure 3.**

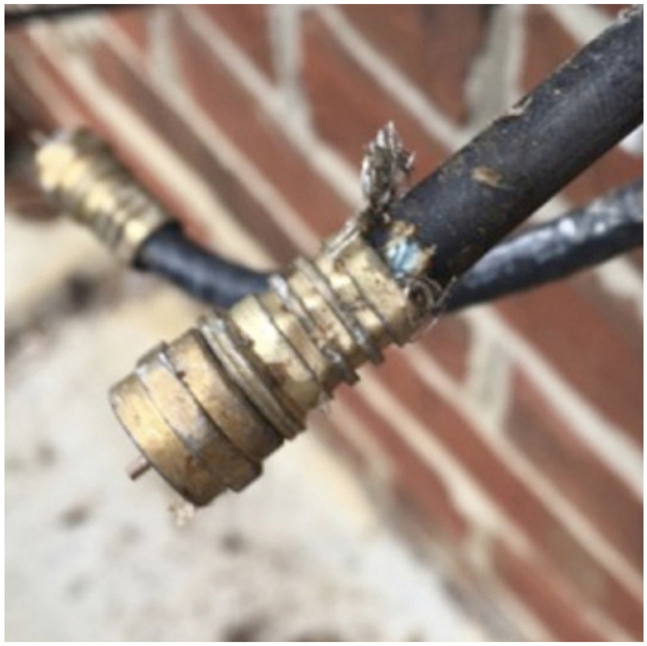

Figure 3: Crimp-on connector showing poor grounding and corrosion on shielding

The example shown in **Figure 3** is often difficult to find, especially when it exists under crawl spaces or trailers. However, the impacts can be maddening for technicians trying to resolve modem issues for frustrated or unhappy subscribers. Modems will report T3 timeouts, slow speeds, uncorrectable codeword errors and intermittently drop offline. Often the modem will be replaced by the tech in futility because traditional SLMs will not show micro-reflections. PNM will quickly show the micro-reflection and even estimate the distance to the micro-reflection, quickly showing the tech that there is a problem and where to look for the problem.

Every time a field tech installs a new modem or has an opportunity to gain access to a customer premise, this is an opportunity to be proactive. PNM gives the home tech the ability to test the subscribers' homes for several typical performance parameters, such as power levels and modulation error ratio (MER). And even more importantly they can test PNM metrics such as group delay, micro-reflections, and full band capture. These additional metrics go far to ensure every modem installed will perform well for the subscriber and will not allow ingress into the plant provided the tests pass. If the tests fail, the home tech should resolve the issues or escalate them to a more senior tech.

Impact to Maintenance Techs

Maintenance technicians face the same issues as field techs: impairments that are invisible with traditional tools. PNM provides visibility. Maintenance techs can now also see micro-reflections, damage to the outside plant, and group delay.

By identifying groups of modems affected by the same outside plant damage, we can form a Correlation Group. A Correlation Group is a cluster of modems seeing the same impairment. This cluster of modems can help triangulate and localize the outside plant impairment, thus identifying its location. Now maintenance techs know there is an outside plant impairment, they know how severe it is, where it is located and how many subscribers are impacted.

Frequently, outside plant impairments are made visible before subscribers notice the plant impairment. This is key to being proactive. The plant damage can be fixed on a schedule convenient to the operator or can be ignored until it degrades to the point that subscribers start to call CSRs. This becomes a company decision as to how they handle proactive activities.

PNM, DOCSIS 3.1 and RxMER

DOCSIS added many more PNM tests with the release of DOCSIS 3.1. One very power test added for OFDM and OFDMA is called RxMER. RxMER provides a modulation error ratio (MER) measurement for each subcarrier in the OFDM or OFMA channel. This means if an OFDM channel has 7600 subcarriers, one will receive 7600 MER results corresponding to each subcarrier. When plotted, it looks like a spectrum analyzer chart, but has different meanings. See Figure 4 for example OFDM RxMER.

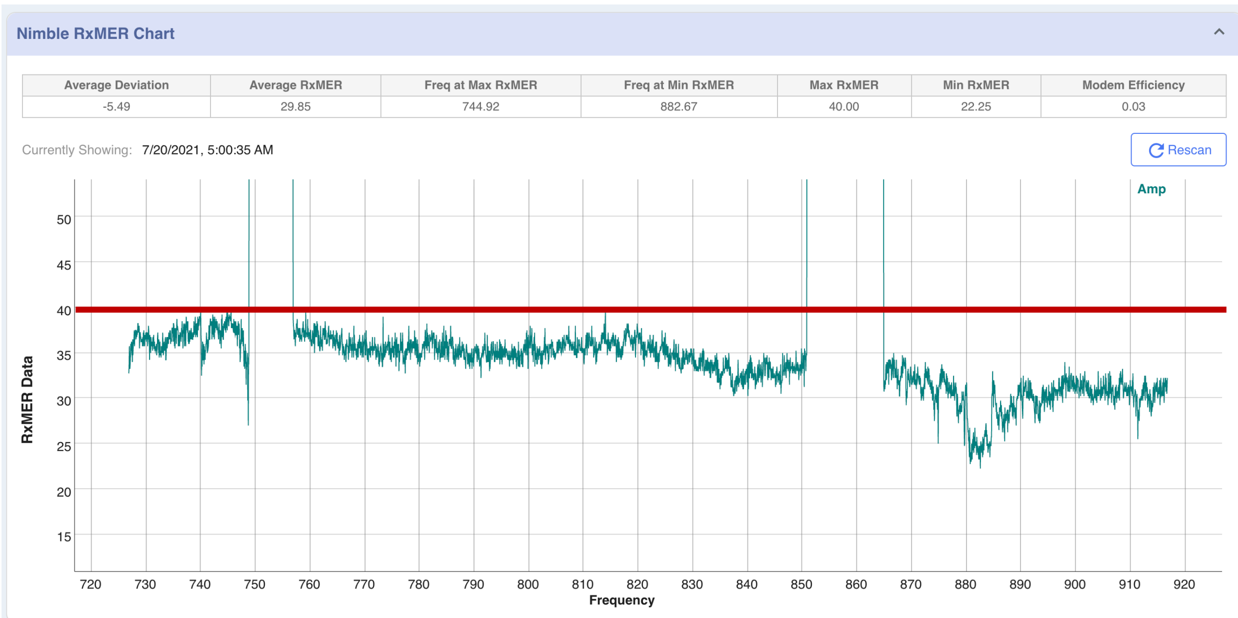

Figure 4: RxMER plot of OFDM channel from live plant

In **Figure 4** there are some unique observations one can make. First, the average RxMER is 29.85, as shown in the top of the chart. A red line is added at 39 dB MER, which is the threshold for which 4096-QAM is required. Ideally, all RxMER 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 1 for the mapping of RxMER to OFDMA modulation. Finally, there are two sections of the RxMER plot where the chart goes above 50 dB. One between 749-757 MHz and another between 851-865 MHz. These are called exclusion bands. Exclusion bands are configured in the CMTS to disable subcarriers where the cable operator knows high levels of RF ingress exists, such as LTE interference. Exclusion bands are helpful to disable subcarriers which we know will be severely impacted no matter how hard we work to clean up the HFC plant.

RxMER can be directly mapped to the modulation level 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 the [CM- OSSIv3.1] (*see Table 72 - CmDsOfdmRequiredQamMer Object*). Table 1 shows these mappings up to 16384-QAM, but field testing has indicated that these mappings are conservative. As indicated in Figure 4, 39 dB is often used as the limit for 4096-QAM rather than the CableLabs recommendation of 41 dB for 4096-QAM.

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*

Table 1: Mapping of Downstream RxMER to supported QAM Level [1]

3. What is PMA?

The profile management application (**PMA**) ingests RxMER data from a given node, analyses the RxMER data and outputs the optimal modulation for each subcarrier. The objective of this process is to increase network capacity.

Today's CMTSs support only a few profiles, which does vary from vendor to vendor. Let's look at an example vendor that supports four profiles, which can be called profiles 0, 1, 2, and 3.

A CMTS engineer may configure profile 0 to operative with every subcarrier at 256-QAM. Then profile 1 to operator at 1024-QAM, profile 2 to operate at 1024-QAM and profile 3 to operate at 4096-QAM. On the CMTS, these profiles would look something as follows:

- ofdm ds-profile 0 default-modulation 256qam
- ofdm ds-profile 1 default-modulation 1024qam
- ofdm ds-profile 2 default-modulation 2048qam
- ofdm ds-profile 3 default-modulation 4096qam
- ofdm frequency low-edge 834000000 high-edge 1026000000 plc-block 842000000

Every subcarrier in the above profiles is assigned the default-modulation. For example, for ds-profile 0, every subcarrier is configured for 256-QAM and for ds-profile 3, every subcarrier is assigned 4096-QAM. A subscriber's cable modem can dynamically choose which profile to use based on the impairments between the CMTS and cable modem. High modulations will allow higher data speeds and lower modulation will cause lower data speeds.

Finally, notice the very last line. This indicates the OFDM start frequency of 834 MHz and stop frequency of 1026 MHz. It also shows a physical layer link channel (PLC) frequency of 842 MHz. The PLC is a special narrow channel of 400 kHz wide that carries signaling and boot-strapping information (e.g., OFDM channel parameters and MAC management messages). This PLC can be easily recognized: it lies in the middle of a specially defined 6 MHz wide range containing 8 pilot subcarriers [2]. See Figure 5 for an example of the PLC in an OFDM channel.

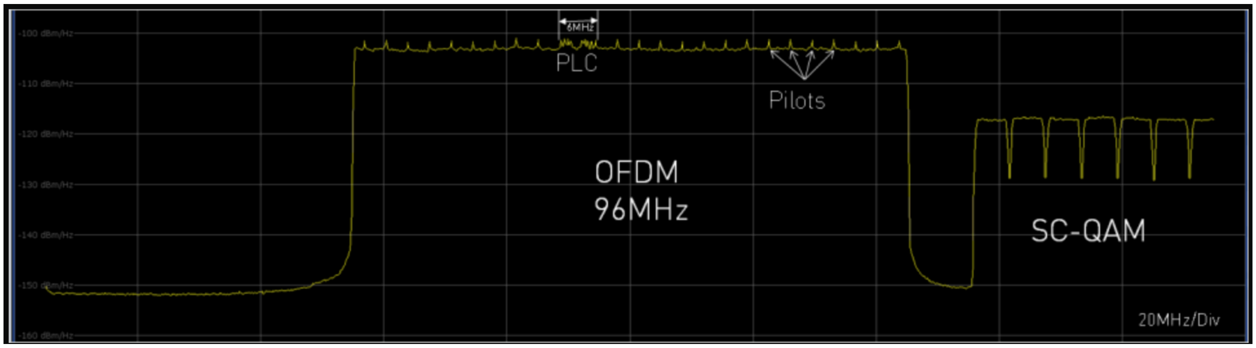

Figure 5: Example OFDM channel highlighting the PLC [2]

The PLC is of critical importance because it delivers signaling and MAC management messages to all cable modems. If the PLC is impaired, it will cause all cable modems to go offline. We will discuss more on this in the next section.

Today's CMTSs permit only four modulation profiles as shown in the example above. But what happens if RF impairments exist which are non-optimal for the configured modulations? As an example, what happens if there are significant impairments which permit modems from using 1024-QAM, but 512-QAM would be sufficient? Because 512-QAM is not an option in our select, modems must drop down to 256-QAM. This means we are leaving bandwidth on the table. Further, impairments vary over time. So even if we re-programmed the CMTS to support 512-QAM to regain our bandwidth, we may find a day later it needs a new update for different modulations. But again, how do we even know any of this information?

On top of this, how do we know the ideal location for the PLC on every node on every CMTS in the network? This can become a substantial amount of work when dealing with hundreds or thousands of nodes and a network that is constantly changing. We need a solution, and the solution exists – it's called PMA.

PMA is processing engine which analysis the RxMER data from every cable modem in each node. After analyzing the RxMER data, the PMA engine will provide the optimal modulation 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 requires. Further, PMA can be fully automated so that every node can be optimized multiple times per day to compensate for the ever-changing RF impairments.

Figure 6: shows a high-level concept of the PMA architecture as it is implemented in multiple MSO systems.

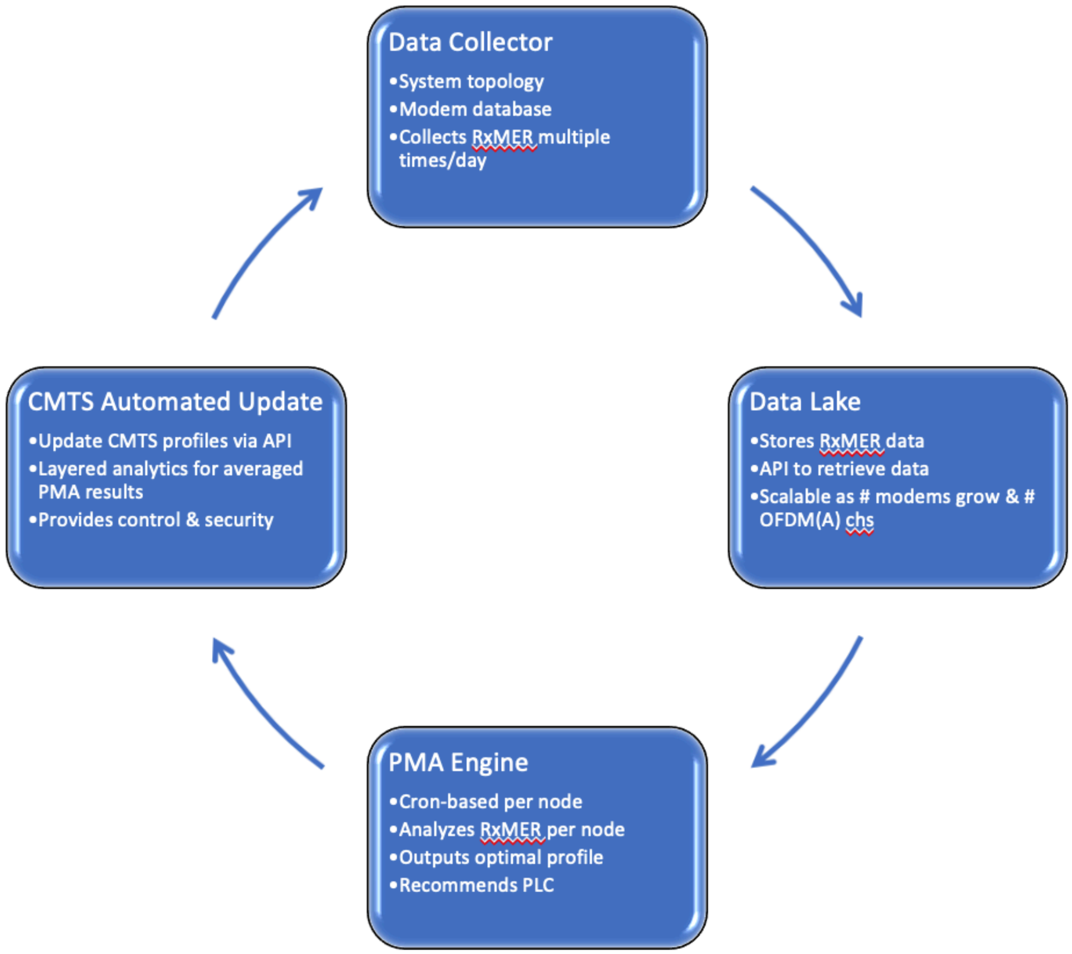

Figure 6: PMA System Architecture

Data Collector: The PMA process begins with the collection of RxMER data. To do this, the collector must first communicate with the CMTS to obtain a list of all cable modems and obtain topology awareness. Topology awareness simply means a mapping of each cable modem to its respective fiber node. The data collector then communicates with each cable modem to obtain the OFDM RxMER file. It also obtains additional telemetry information from the modem and CMTS to perform downstream and upstream PMA.

Data Lake: PMA can be performed on the fly; however, it is much more beneficial to make analysis on averaged data. Therefore, the data collector stores its data in a large database. Application programming interfaces (APIs) are implemented to easily retrieve data from the database.

PMA Engine: The PMA engine runs on a routine basis to pull the latest data from the Data Lake and process the data. It does so using an API to retrieve RxMER and other data for each fiber node in the network. Once complete processing, the PMA engine outputs a small file that contains the optimal profile and PLC placement for the given node.

CMTS Automated Update: The CMTS automated update is responsible for pulling the output files created by the PMA engine and applying the profiles to the CMTS. This ensures the cable operator has full control of when and how profiles are applied. Further, profiles can by modified by the cable operator via analytics so that they are further optimized according to the limitations of the cable operators CMTS equipment.

In the next section we will see the benefits than can be achieved through PMA.

4. What are the benefits of PMA?

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 sub-carrier level, though this is not yet supported by CMTS vendors, but we hope this is a feature that comes soon
- Through profile optimization per node, each node 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 modulations to ensure data throughput to their subscribers. PMA will allow operators to run at the highest modulation possible with confidence.
- PMA will 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 (think about a suckout or LTE ingress) exists, this will result in an outage. PMA will aid in preventing from such instances from occurring.
- Finally, the goodness PMA does in the downstream can be directly translated to the upstream:
    - We have always known that the upstream is a much harsher environment than the downstream.
    - As cable operators roll out OFDMA in the upstream, PMA can ensure OFDMA profiles (only two profiles are available in the upstream) are continuously optimized for subscriber data.

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

In 2019, Comcast developed a PMA system for generating and transacting D3.1 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 [3]:

- 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 released public press releases [4].

5. PMA in Action

To see the PMA engine in action, it is first important to understand the relationship between modulation efficiency, which is the bits per MHz, and required MER to support the given modulation. This relationship can be developed by adding the modulation efficiency to Table 1, which results in Table 2.

Modulation	CNR/MER (dB)	Modulation Efficiency
No Data	<12	0
QPSK	12	2
16 QAM	15.0	4
64 QAM	21.0	6
128 QAM	24.0	7
256 QAM	27.0	8
512 QAM	30.5	9
1024 QAM	34.0	10
2048 QAM	37.0	11
4096 QAM	41.0	12
8192 QAM	46.0	13
16384 QAM	52.0	14

Table 2: Modulation Efficiency vs Bit Loading vs MER

The PMA outputs both modulation and modulation efficiency (also called bit loading) when RxMER data is provided to it. Modulation efficiency is easier to plot and manipulate than modulation. So, this data can be used in plotting, however most users are familiar with MER. An easy lookup table can be generated to reference modulation efficiency to MER. This allows one to compare the RxMER data to the recommended MER profile for a given modulation.

Example RxMER data from all modems in a fiber node is shown in Figure 7. As is typical with RxMER data of many fiber nodes is that a portion of modems are showing very high level RxMER (>40 dB). These modems will be capable of supporting 4096-QAM across the entire spectrum. However, as can be seen in Figure 7, more than 75% of the modems fall below 41 dB MER with many modems falling below 30 dB MER. In fact, 25% of the modems on this fiber node fall below the 30 dB MER threshold across the entire spectrum. Modems falling below the 30 dB spectrum will only support 256-QAM or less! Keep in mind that legacy SC-QAM had a maximum modulation profile of 256-QAM.

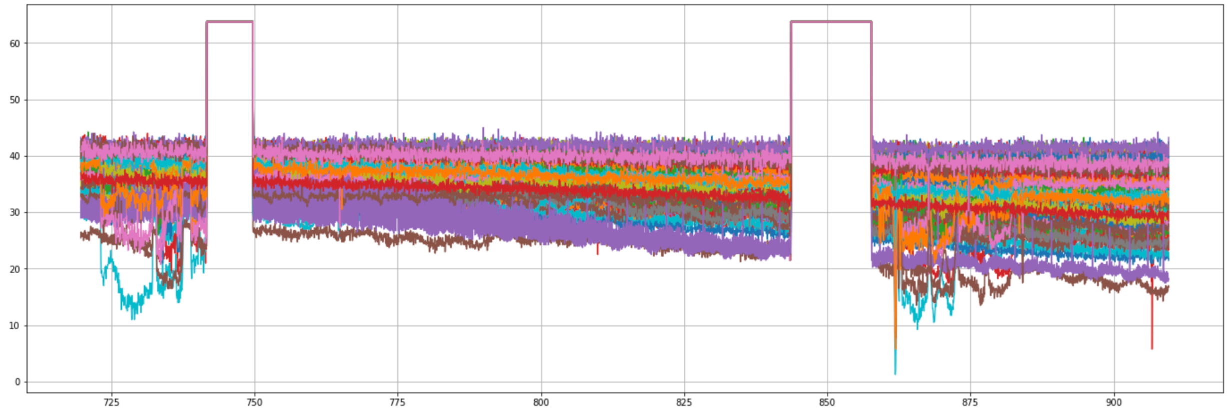

Figure 7: Sample set from a typical fiber node with varied impairments

This presents a challenge for cable operators to determine what modulation profiles should be assigned to this node. Without the PMA it is a guessing game. With the PMA, very inciteful information can be gathered which will allow the cable operator to configure the CMTS with the most optimal profiles to ensure all cable modems are supported with the limited number of profiles that are supported in the CMTS – remember the maximum today is only four profiles.

Figure 8 shows a typical recommendation from the PMA output given the RxMER input of Figure 7. The blue dotted line in Figure 8 indicates the absolute MER for each subcarrier, which translates to the respective modulation in Table 2. The red line indicates the maximum and minimum recommended modulation profiles from the PMA based on the RxMER input.

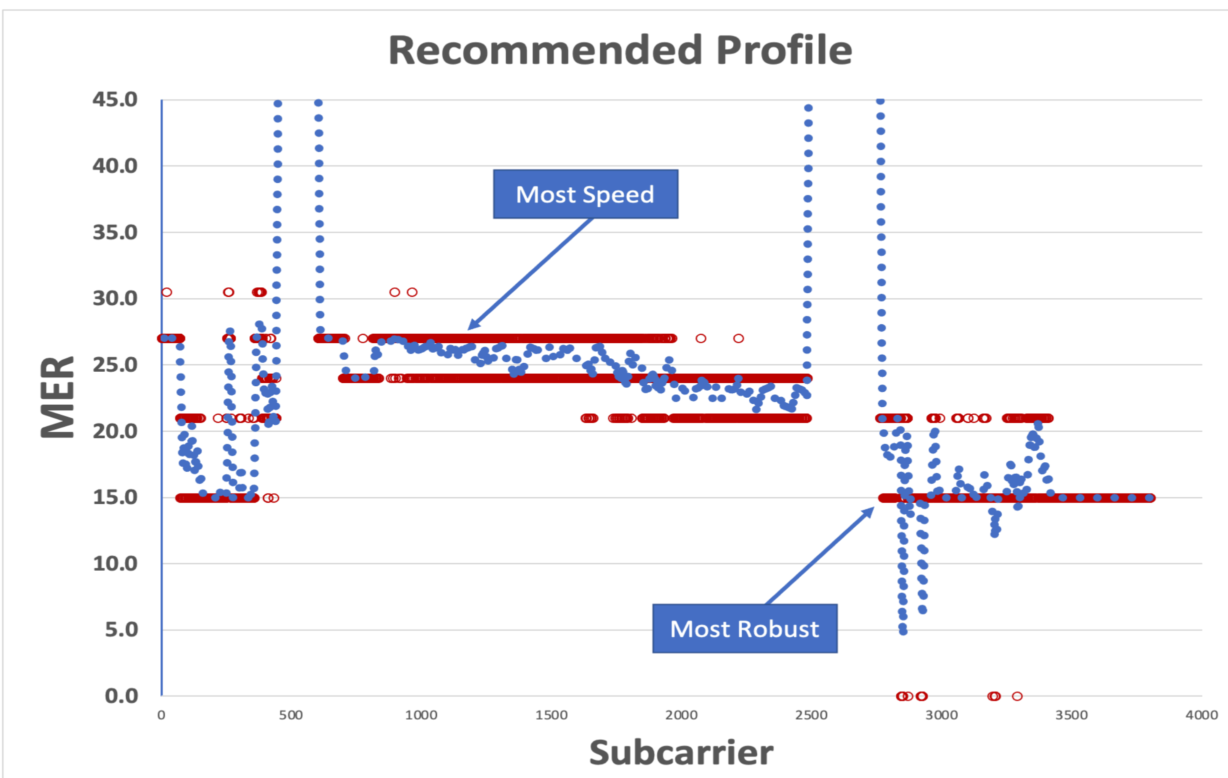

Figure 8: PMA profile recommendations for fiber node in Figure 7

In **Figure 8**, the upper limit red line is indicated as the "most speed" line. This means if the cable operator were to choose the upper end of the recommended profile, cable modems would likely achieve high data throughput, but would suffer more uncorrectable codeword errors. On the other hand, the "most robust" line indicates that choosing the lower modulation will ensure cable modems will have lower data speed but will likely have very errors because the modulation is set low and therefore resilient to errors in the presence of impairments.

Ultimately, the data that is being presented are minimum and maximum profiles which can be updated in the CMTS to support all impaired modems in the fiber node and still maintain maximum data throughput.

Let's consider the original configuration on the CMTS as follows:

- ofdm ds-profile 0 default-modulation 256qam
- ofdm ds-profile 1 default-modulation 1024qam
- ofdm ds-profile 2 default-modulation 2048qam
- ofdm ds-profile 3 default-modulation 4096qam

First, we know that keeping ds-profile 3 is a good idea, because there are modems that support >40 dB RxMER across the band. These modems will be able to use ds-profile 3 and obtain the maximum throughput of the OFDM channel.

Next, there should be a profile to support the "most speed" line at 27 dB MER, which correlates to 256-QAM. There should also be a profile to support the "most robust" line at 15 dB MER, which correlates to 16-QAM. Ideally, 16-QAM would be the lowest modulation configured, however today's CMTSs do not allow 16-QAM on the downstream, 64-QAM is the lowest order modulation for downstream communications, so this will be the most robust profile used. There are also several datapoints in Figure 8 at the 30.5 MER line, which correspond to 512-QAM. Our updated ds-profile on the CMTS for this impaired node would look as follows:

- ofdm ds-profile 0 default-modulation 64qam
- ofdm ds-profile 1 default-modulation 256qam
- ofdm ds-profile 2 default-modulation 512qam
- ofdm ds-profile 3 default-modulation 4096qam

The updated profile now ensures that modems at the high RxMER will be able to support very fast data speeds. At the same time, the modems experiencing RF impairments will be able to toggle between 512-QAM down to 64-QAM, depending on the number of impairments each modem is experiencing. This will result a good quality of experience for every subscriber on the fiber node. In essence, the CMTS has been modified for this fiber node to provide maximum data speed when possible and maximum robustness when required. Every subscriber should be able to continuously receive downstream data regardless of outside plant impairments or bad in-home wiring thanks to the PMA output results.

6. Future Considerations

Today's CMTSs are quite limited in that 1) they support only up to a maximum of four modulation profiles and 2) within a profile one can implement a constant modulation across the entire profile. This second point is much more limiting. Consider common use cases where OFDM is used at higher frequencies where roll-off is quite common (see the example roll-off in Figure 9). In this scenario, it would be common to have lower frequency subcarriers support high modulation while higher frequency subcarriers will support a lower modulation. Figure 9 shows this common scenario where lower frequencies have a higher RxMER of >35 dB (>1024-QAM) while higher frequencies drop below 35 dB RxMER (<1024-QAM). This is not possible with a constant modulation profile such as:

- ofdm ds-profile 3 default-modulation 1024qam

Poll Time	Mac Address	Average Deviation	Average RxMER	Freq at Max RxMER	Freq at Min RxMER
7/26/2021, 12:33:49 PM	[redacted]CD:EB	-3.74	36.26	739.25	909.25
7/26/2021, 12:33:49 PM	[redacted]9B:BD	-3.70	36.30	741.90	912.15
7/26/2021, 12:33:49 PM	[redacted]9F:31	-3.77	36.23	729.05	882.00
7/26/2021, 12:33:49 PM	[redacted]E8:23	-3.71	36.29	728.85, 732.90, 772.65	900.35, 901.45, 908.55, 912.1
7/26/2021, 12:33:49 PM	[redacted]9D:8B	-3.70	36.30	727.05, 738.70	882.00, 908.10, 912.75, 914.

Figure 9: RxMER data in roll-off region of HFC network

It is optimistic that CMTS vendors will enable new features to allow per-subcarrier or per-block of subcarriers modulation profiles. The PMA already outputs modulation recommendations for each subcarrier given a set of RxMER inputs. However, this data is not useful today. If CMTS vendors were to implement per-subcarrier or per-subcarrier block support, this would significantly enhance the granularity through which the PMA could optimize a given OFDM downstream. The net result would be increased capacity for every fiber node.

Further, obtaining RxMER data from modems is time consuming. It requires the use of simple network management protocol (SNMP) to configure the modems to send RxMER data back to a centralized collector. Once configured, the modems send a file using the trivial file transfer protocol (TFTP) to a TFTP server. This operation takes roughly 30-45 seconds per modem. Because plant impairments vary, it is important to gather RxMER data multiple times per day from each modem and update the CMTS accordingly. Averaging RxMER data can make the PMA engine even more accurate, but this takes tremendous effort to gather RxMER data rapidly. A future implementation on the cable modem side would enable the modems to stream RxMER data back to the collector and a configured basis. This would enable the collection of RxMER data more frequently without the addition of costly and energy hungry servers. A few code modifications in the cable modems would result in enormous cost and environmental savings in the datacenter.

7. Conclusion

In conclusion, the PMA is a useful add-on to PNM and DOCSIS 3.1 with OFDM. No cable plant is without RF impairments. Whether the impairments are in the outside plant or in subscriber homes, these impairments change over time. To provide reliable high-speed service over an OFDM channel it is important to configure the CMTS with the optimal profiles to maximize data throughput. The PMA provides operators the necessary visibility to ensure they are deploying the optimal profiles for each node.

A properly developed PMA engine will create profiles for each node every time RxMER data is polled from D3.1 modems in each node. Keeping in mind the architecture diagram of Figure 6, one can understand the lifecycle of the PMA and how this plays out. Data collection, data storage, PMA analysis and finally profile updates on the CMTS. Rinse and repeat. This process should be repeated at least four times per day for every node in the network, more frequently if possible. Why? Because RF impairments change during the day and maximizing data throughput and customer quality of experience (QoE) are critical in today's world where people work, learn, and play at home with a high dependency on data provided over DOCSIS networks.

While this paper primarily focused on the PMA in the downstream, the PMA works equally well, if not better in the upstream. The upstream is the Achilles heel of the HFC network, having even more RF impairments than the downstream. As cable operators roll-out more OFDMA channels in the upstream, it is anticipated that the PMA will become a critical component to maximizing upstream data throughput and subscriber QoE.

Abbreviations

AI	Artificial Intelligence
API	Application programming interface
bps	Bits per second
CM	Cable Modem
CMTS	Cable Modem Termination System
CNR	Carrier to noise ratio
DOCSIS	Data Over Cable Service Interface Specification
D3.0	DOCSIS 3.0
D3.1	DOCSIS 3.1
FBC	Full-Band Capture
FEC	forward error correction
HD	high definition
HFC	Hybrid fiber coax
Hz	hertz
ISBE	International Society of Broadband Experts
JSON	JavaScript Object Notation
MER	Modulation error ratio
OFDM	orthogonal frequency division multiplexing
OFDMA	orthogonal frequency division multiple access
PLC	Physical link channel
PMA	Profile management application
PNM	Proactive Network Maintenance
QAM	quadrature amplitude modulation
RF	Radio Frequency
SCTE	Society of Cable Telecommunications Engineers
SNR	Signal to noise ratio
bps	bits per second
FEC	forward error correction
HD	high definition
Hz	hertz
ISBE	International Society of Broadband Experts
QoE	Quality of experience
SCTE	Society of Cable Telecommunications Engineers

Bibliography & References

[1] Data-Over-Cable Service Interface Specifications DOCSIS 3.1 Physical Layer Specification (CM-SPPHYv3.1-I16-190121); Cable Television Laboratories

[2] https://www.excentis.com/blog/docsis-31-take

[3] 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

[4] https://www.nexttv.com/news/comcast-tech-chief-werner-says-network-is-handling-load-just-fine

Additional References:

"A Machine Learning Pipeline for D3.1 Profile Management", M. Harb, J. Ferreira, D. Rice, B. Santangelo, and R. Spanbauer, NCTA technical paper, 2019.

Convolutional Neural Networks for Proactive Network Management: Developing Machine Learning Models to Detect and Classify Impairments in D3.1 OFDM Channels, SCTE Cable-Tec Expo 2020, Ferreira, Harb, Subramanya

Code of Federal Regulations, Title 47, Part 76

