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

A Technical Paper prepared for SCTE by

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# 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®) publications have undergone several iterations to accommodate more and more speed. DOCSIS 3.1 introduced new technologies specifically to support even more speed improvements. Specifically, DOCSIS 3.1 introduced 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 DOCSIS collects several key metrics including equalization data from cable modems, downstream spectrum captures 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 leads to 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 signal egress, 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, and 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.**

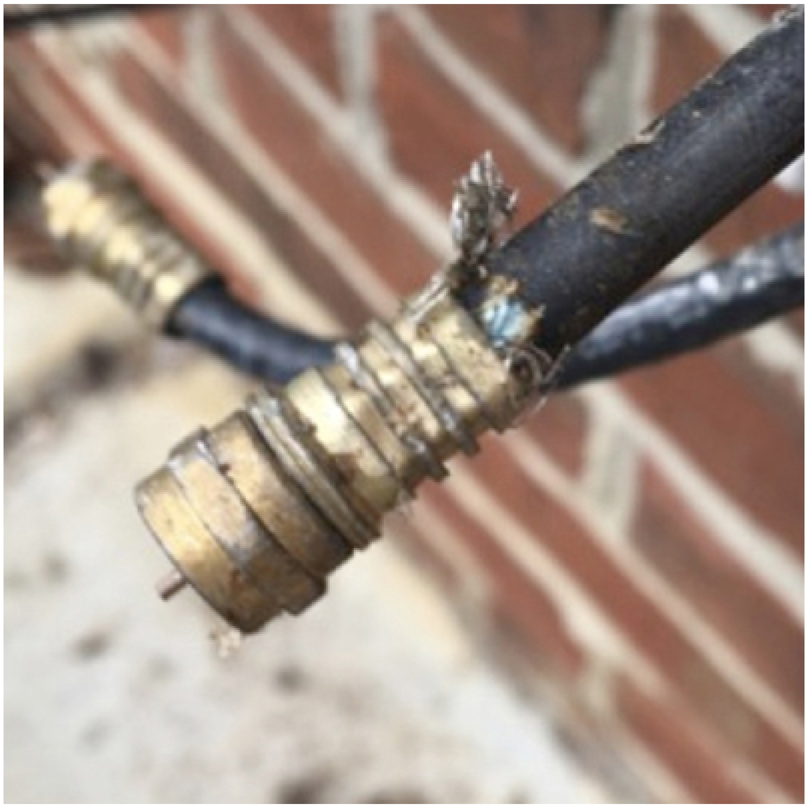

**Figure 3 - Crimp-on connector showing poor grounding and corrosion on shielding.**

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 technician should resolve the issues or escalate them to a more senior technician.

## Impact to Maintenance Technicians

Maintenance technicians face the same issues as field technicians: 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 technicians know there is an outside plant impairment, 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 per subcarrier 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, the tester will receive 7600 MER results, one corresponding to each subcarrier. When plotted, it looks like a spectrum analyzer chart, but has different meanings. See Figure 4 for an example plot of OFDM RxMER per subcarrier data.

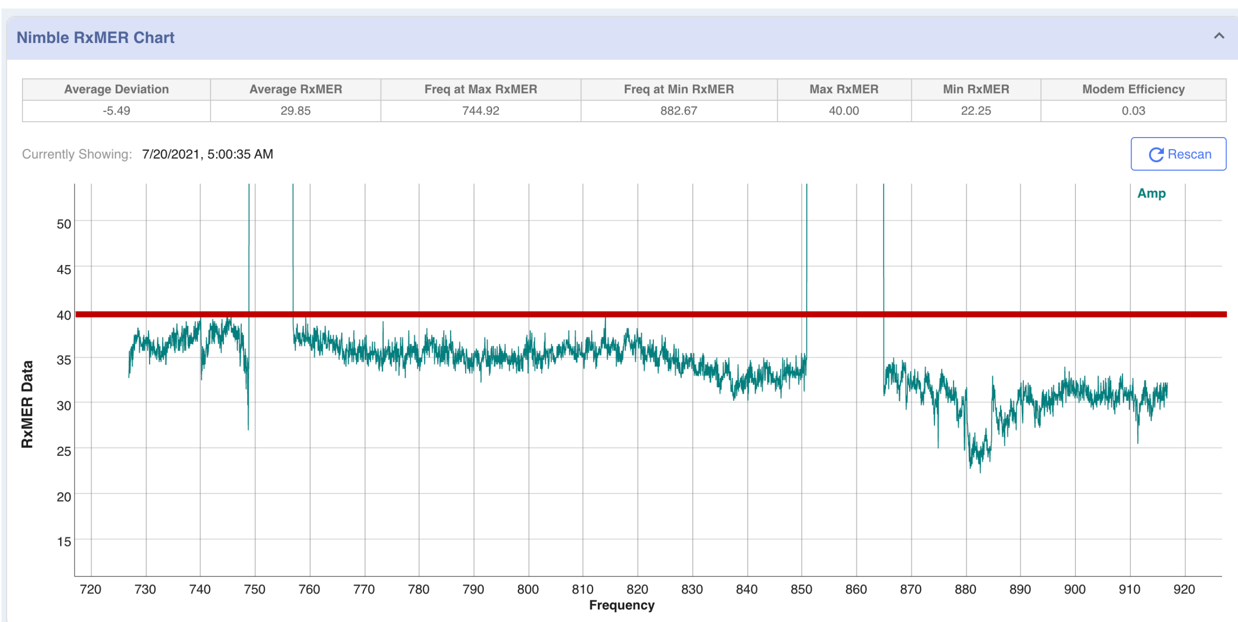


**Figure 4 - RxMER per subcarrier plot of OFDM channel from live plant.**

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 and 757 MHz, and another between 851 and 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.

**Table 1 - Mapping of Downstream RxMER to supported QAM Level [1].**

| 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* |

## 3. What is PMA?

The profile management application (PMA) ingests RxMER data from a given node, analyses the RxMER per subcarrier data, and outputs the following:

- A modulation profile which can be applied to the CMTS which is optimized for all modems in the presence of RF impairments. This single profile is used across the entire OFDM / OFDMA channel, but does not account for frequency specific impairments, such as band roll-off or LTE interference, as an example,
- A modulation profile per subcarrier, which can then be used to create segmented profiles on the CMTS. This is a more refined method that allows the cable operator to optimize their profiles based on frequency specific impairments and is particularly useful where impairments are not consistent

across the spectrum. There are many use cases for this, but some obvious ones are high frequency roll-off, LTE ingress, suckouts, and low frequency noise,

- A per-modem profile which can be applied to each modem by MAC address. This is an aggressive method of profile management, which is not supported by all CMTS vendors at the time of writing of this document. However, future support is expected. In this method, each cable modem can have a specific profile applied specific to the modems' RF impairments, thus optimizing the end users experience and ensuring every subscriber has maximum data throughput in the presence of changing RF impairments.

The objective of the above process is to not only increase network capacity, but to also prevent outages. If a subscriber's modems is offered a profile higher than what the modem can sustain in the presence of RF impairments, little or no data will flow over the OFDM channel to the modem. In most CMTS implementations, the OFDM channel is set to the "primary" or "preferred" channel. When the primary channel is down, the subscriber experiences no data or from their perspective, an outage. This results in customer service representative (CSR) calls and likely truck rolls. This is costly to the cable operator. The PMA can function in a similar way to pre-equalization in the upstream, by changing the CMTS profiles to prevent unnecessary CSR and truck rolls, thus saving the cable operator money. Further, the PMA saves the subscriber preventable outages and makes for happier subscribers.

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 operate with every subcarrier at 256-QAM. Then profile 1 to operator at 1024-QAM, profile 2 to operate at 2048-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 the cable modem. High modulations will allow higher data speeds and lower modulation will allow 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.

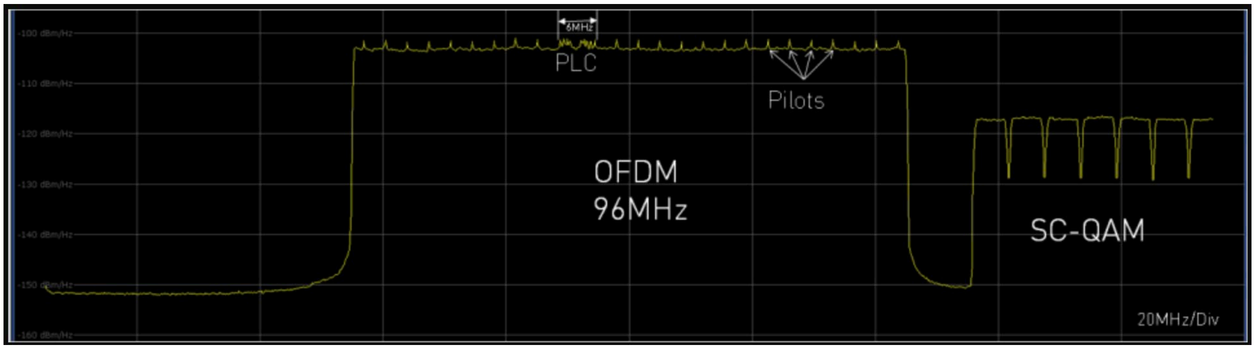


**Figure 5 - Example OFDM channel highlighting the PLC [2].**

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.

Some of today's CMTSs permit only four modulation profiles as shown in the example above, while others support more. 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 selected set of profiles, modems must drop down to 256-QAM. Thus, 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. What's more is that most operators program their CMTSs with a flat profile, such as 4096-QAM across the entire OFDM channel. Considering that OFDM channels can be 192 MHz wide, one can imagine that impairments such as roll-off at high frequencies would make 4096-QAM unusable at high frequencies. It is possible to program mixed modulations in segments. An example of this would be where lower frequencies that have high RxMER are configured for 4096-QAM. Similarly, higher frequencies in the roll-off band with low RxMER are configured with lower modulations such as 512-QAM or lower. But again, how do we even know any of this information such as what frequency bands should get which modulations?

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. It generally has four components as described next.

 

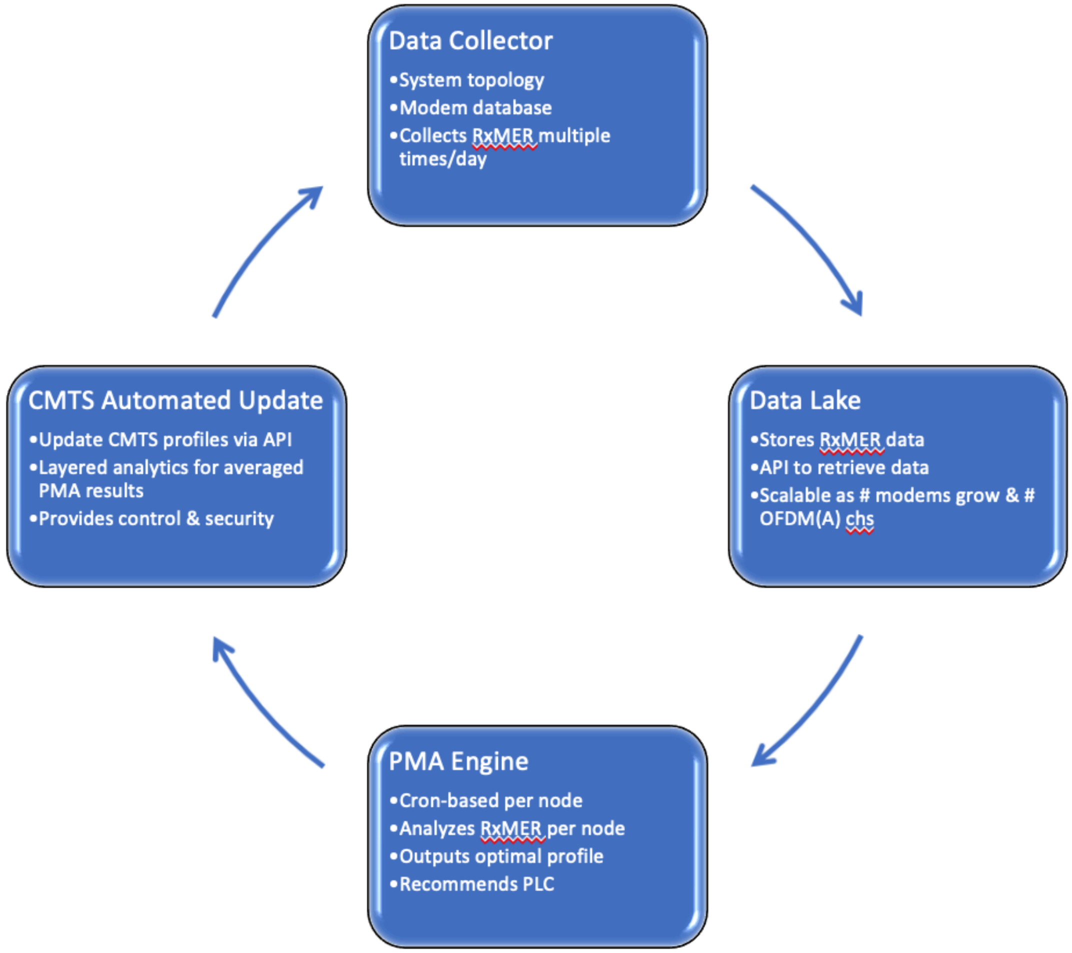


**Figure 6 - PMA System Architecture.**

**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 per subcarrier and other data for each fiber node in the network. Once done processing, the PMA engine outputs a file that contains the optimal profile set and PLC placement for the given node, along with the CM to profile assignments.

**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 and CMs. This procedure 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 operator's CMTS equipment.

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

## 4. What are the benefits of the PMA?

The PMA has several benefits, which are immediately realizable as follows.

- The PMA will provide the optimal profile for a fiber node:
  - The bandwidth gains in running a well-designed set of profiles can be anywhere from 15% to 40% capacity increase on a channel, compared with running the whole channel at 256-QAM. This can translate to a solid 200 to 400 Mbps extra capacity on each OFDM channel! [3]
- The PMA will reduce individual subscriber and likely entire node outages:
  - When running the PMA on each node on a regular basis, profiles are continuously being optimized for new impairments. Profiles are downgraded and upgraded, similar to how upstream dynamic modulation profiles are used for SC-QAM channels to accommodate dynamic changes in the upstream. But the PMA will do the same for the downstream and the upstream. This helps ensure subscriber traffic continues to flow over the OFDM and OFDMA channels during dynamic impairment changes.
- 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 such instances from occurring. Again, the PMA can help prevent critical fiber node outages resulting in significant cost savings from truck rolls and subscriber grief.

The PMA is not only beneficial in increasing extra capacity in the DOCSIS network, but also in reducing CAPEX expenditures through increased network reliability.

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 indicate its realized value [4]:

- 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 the PMA a huge success and subsequently released public press releases [5].

## 5. PMA in Action

To see a 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.

**Table 2 - Modulation Efficiency vs Bit Loading vs MER**

| Modulation | RxMER per Subcarrier | Modulation Efficiency |
|---|---|---|
| No Data | <12 | 0 |
| QPSK | 12.0 | 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 |

The PMA outputs both modulation and modulation efficiency (also called bit loading) when RxMER per subcarrier data are provided to it. Modulation efficiency is easier to plot and manipulate than modulation. An easy lookup table can be generated to reference modulation efficiency to RxMER per subcarrier. This allows one to compare the RxMER per subcarrier data to the recommended MER profile for a given modulation.

Example RxMER per subcarrier data from all modems in a fiber node is shown in Figure 7. As is typical with RxMER data of many fiber nodes, 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.

 

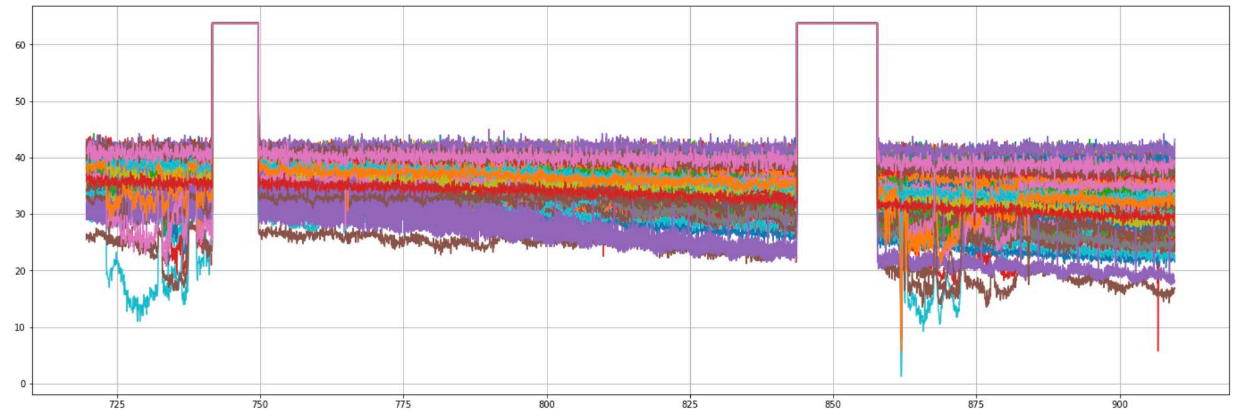


**Figure 7 - Sample set from a typical fiber node with varied impairments.**

This presents a challenge for cable operators to determine what modulation profiles should be assigned to this node. Without a PMA it is a guessing game. With a 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 well supported with a finite number of profiles that are supported in the CMTS.

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 a PMA based on the RxMER per subcarrier input. The red lines are broken into segments which can be applied to a CMTS that support mixed modulations in a segmented method. Additionally, the suggested profiles in this section are examples only and should not be considered as recommendations for any production system without prior testing.

 

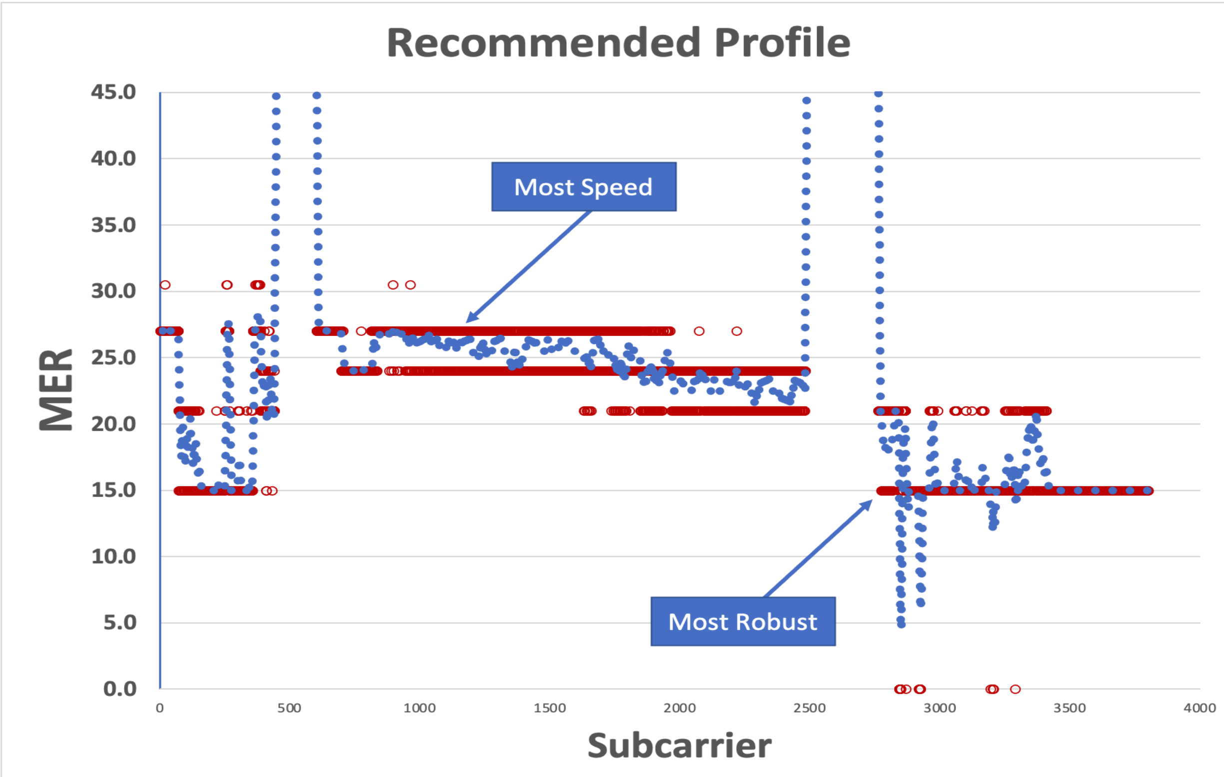


**Figure 8 - PMA profile recommendations for fiber node in Figure 7.**

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 few if any uncorrectable 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 are some very impaired modems. To these modems always can transmit data profile 0 will be downgraded to 64-QAM, which is a very robust profile. Profile 1 will also be downgraded to 256-QAM for slightly less impaired modems. Profile 2 will be modified to a segmented profile to align the PMA profile output shown in Figure 8. There are three segments aligning with the three primary tiers in Figure 8 of 64-QAM, followed by 512-QAM and then back to 64-QAM. The segmented modulation in profile 2 represent the optimal profile from the PMA output that will give the maximum data throughput for modems. Finally, profile 3 of 4096-QAM is enabled for modems not experiencing impairments. Modems not experiencing impairments will be able to use profile 3 and will see the maximum data throughput the OFDM channel can support.

- ofdm frequency low-edge 807000000 high-edge 903000000 plc-block 850000000
- ofdm ds-profile 0 default-modulation 64qam
- ofdm ds-profile 1 default-modulation 256qam
- ofdm ds-profile 2 low-freq-edge 807000000 high-freq-edge 817000000 64qam
- ofdm ds-profile 2 low-freq-edge 817000000 high-freq-edge 877000000 512qam
- ofdm ds-profile 2 low-freq-edge 877000000 high-freq-edge 903000000 64qam
- ofdm ds-profile 3 default-modulation 4096qam

This updated profile provides an example of how one can update a CMTS profile based on PMA output to ensure 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 the segmented profile 2 or drop to even lower modulations supported in profile 1 or 0. 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.

The profiles above can be updated in an automated method each time the PMA is run on a given node to update profiles based on changing plant conditions.

## 6. Future Considerations

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. Because plant impairments vary, it is important to gather RxMER data multiple times per day from each modem and update the CMTS accordingly. Taking multiple RxMER samples per cable modem and averaging these samples together for a single modem can make the PMA engine even more accurate. This is because a single RxMER sample from a modem could be impacted from an impairment, but multiple samples will provide a more concise data sample. However, doing so 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 or to perform the averaging on the modem itself. As a side note, full band capture averaging is performed by most cable modem vendors today, so RxMER averaging should be doable capability. This would enable the collection of RxMER data more frequently without the addition of costly and energy hungry servers. Today, cable operators rely on servers in their data centers to collect RxMER data, which as previously mentioned, this is a CPU intensive process and not green for the environment. As the industry focuses on optimizing data throughput, it must also focus on green initiatives. These initiatives start with pushing computations at edge devices such as cable modems rather than server farms collecting data from modems.

As shown in this paper, today it is possible to create segments in profiles. This is very effective for addressing frequency specific impairments to optimize throughput and help ensure subscribers do not experience outages. There is a limitation with this, however. Segmented profiles will often not address specific in-home wiring issues where an individual subscriber's modem is severely impacted. For this, CMTS vendors must support modem-based profiles. The PMA will output a profile for each modem. At least one CMTS vendor currently supports this functionality. As an industry it is important that achieving per modem-profile support in the CMTS is adopted. This will further improve capacity gains and the reduction of CSR calls and truck rolls for subscribers with bad in-home wiring. Like upstream pre-equalization, the PMA will output a profile to temporarily address subscribers with in-home wiring issues and ensure that their modems remain online until such a time that their wiring issues can be addressed. From this standpoint, the PMA can be considered a proactive application as it can flag individual subscriber issues having low, but still working modulation profiles.

# 7. Conclusion

In conclusion, a 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. A PMA provides operators the necessary visibility to ensure they are deploying appropriate profiles for each node. Further, it is evident that the PMA can be quite effective at reducing CSR calls and truck rolls via its inherent ability at improving the robustness of OFDM and OFDMA channels. This results in a cost savings for cable operators as well as keeping subscribers happy and online.

A properly developed PMA engine will create profiles for each node every time RxMER per subcarrier data are polled from DOCSIS 3.1 modems in each node. Keeping in mind the architecture diagram of Figure 6, one can understand the closed loop process of a 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, and 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, a PMA can work 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 a 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 |

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