THE MoCA® PNM PARADIGM SHIFT

A Technical Paper Prepared for SCTE/ISBE by

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1. Abstract

Cable operators have benefited greatly from Proactive Network Maintenance (PNM). Some of those benefits have included remote localization of impairments and aggregation of performance data via customer deployed devices, rather than dedicated test instrumentation. Another advantage has been the real-time feedback to technicians while working to mitigate impairments disrupting revenue-generating services. Up until now, making DOCSIS-based services work better has been one of the driving forces behind the development of a solid PNM infrastructure and knowledge-base.

For years, PNM experts have been pondering the potential of incorporating PNM strategies and concepts into other technologies, like the home networking technologies developed by the Multimedia over Coax Alliance (MoCA). Fortunately, DOCSIS has served cable operators very well, solving many problems facing cable television (CATV) networks today. However, cable operators are learning that issues facing MoCA deployments aren't easily diagnosed via the DOCSIS PNM. For example, current generation MoCA PNM can identify whether there's an incompatible splitter or drop amplifier within the customer's home network, which is introducing too much loss in the MoCA band of operation. And because MoCA is a mesh technology, it may be more effective in honing in on precise locations of home network defects impacting performance, like damaged cables or loose connectors.

This paper will define the use-cases that would be exclusive to MoCA PNM and present these proof-of-concept diagnostics, along with test results illustrating their effectiveness. There is much to learn with blending PNM concepts with mesh based network topologies and MoCA is just one such technology to be mastered, and in doing so, the stage will be set to launch a similar effort enabling diagnostics for Wi-Fi® standards as well.

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2. Introduction

Today's diagnostic systems are challenged to effectively identify and isolate home network defects specifically impacting the home network performance. These defects include incompatible drop amplifiers and splitters, and missing Point-of-Entry (POE) filters.

For the most part, access networks and home networks have operated on mutually exclusive frequency bands. Access network service space has traversed both the access and home network to deliver voice, video, and high speed data from a centralized hub to devices deep within the home via transport technologies, such as DOCSIS. Home network services on the other hand, ideally operate within the home between multiple CPE in support of services including, any room DVR, or Wi-Fi extension.

Today's DOCSIS-based, PNM solutions have helped us detect many problems. Since DOCSIS is a point-to-multipoint (PTMP) network topology, it is capable of detecting problems located within the communication path between the cable modem termination system (CMTS) and its associated cable modems (CM). In particular, current PNM solutions have been very strong for detecting defective components associated with micro-reflections or echoes in the access and home networks. However, DOCSIS-based PNM has been challenged to detect splitters and drop amplifiers that impair MoCA as well as missing POE filters. The basis for this will become apparent within the next few paragraphs.

One of the main reasons DOCSIS-based PNM is incapable of diagnosing incompatible splitters, and drop amplifiers, along with missing POE filters is because the traditional access and home network operating bands are mutually exclusive frequency spaces. Readers may be happy to know that the spectral boundaries previously separating these technologies will begin to blur in the newer generations of DOCSIS 3.1 (D3.1) and MoCA.

Some overlap in these bands may already exist as cable operators continue to upgrade their networks to support D3.1 deployments, with its required operating bands extending above 1,002 MHz and up to 1,218 MHz. It is anticipated that the newer generation of MoCA will operate well below 1,002 MHz in order to support higher capacity. Currently, the spectrum overlap between 1,125 and 1,218 MHz will represent approximately 17% of the MoCA Extended D (ExD) band, where the remaining 83% of the band will unfortunately not be visible to newer D3.1 devices, even with meeting mandatory requirements.

In addition to limited frequency overlap, DOCSIS PTMP based diagnostics can only characterize a subset of the communication paths that exist in the home, because there are home network devices that are MoCA only, i.e. Wi-Fi/MoCA extenders. This uniquely positions MoCA, which is a multipoint-to-multipoint (MPTMP) mesh technology to more comprehensively characterize the home network because it has the visibility of the coaxial home network operating bands and MPTMP CPE. This capability of coordinating with one another will provide bidirectional diagnostic information associated with MoCA based CPE.

This paper will investigate prospects of diagnostic solutions for detecting excessive path loss, a trait associated with incompatible splitters and drop amplifiers, as well as a system for detecting missing POE filters. With these diagnostics processes in place, cable operators can benefit from reduced operating cost and time to repair, as well as improving the customer experience, and how these new processes complement and enhance the already strong suite of capabilities already provided by DOCSIS-based PNM.

3. MoCA Telemetry Options

MoCA diagnostic solutions are at a state where DOCSIS diagnostics was almost a decade ago. Much of the diagnostic feedback related to MoCA is in the form of physical layer throughput, and unfortunately is too coarse to provide root cause identification of network components contributing to a service disruption. For example, today's MoCA 1.1 home network diagnostics primarily leverage full mesh rate (FMR) table, which represents throughput capabilities between all mesh devices, see Table 1.

Node	1	2	3
1	-	201	208
2	149	-	270
3	213	205	-

Table 1 Full Mesh Rate (FMR) Mbps PHY Rate

This information is available via the MoCA 1.1 simple network management protocol (SNMP) management information base (MIB).

By inspecting the FMR table, rates that fail to meet some pre-defined threshold, for example 200 Mbps PHY Rate for MoCA 1.1, are flagged for further investigation by field installers, who are responsible for determining cause of the failure. Failure to meet a threshold may be caused by a variety of defects including incompatible drop amplifiers, splitters, or missing POE filters. Unfortunately, FMR values alone do not diagnose and isolate defects. Today it is the field technician that must visually inspect or connect test equipment to the home network in order to identify and isolate potential root causes of the service degradation.

As was referenced previously, but worth repeating here as we dig into the details of a new PNM paradigm, mesh networks are uniquely positioned to provide comprehensive MPTMP home network characterization, which encompasses substantially more detail, specific to the home network, than any DOCSIS-based PTMP PNM solution can provide. Having MoCA PNM like automation in the home network, field installers can be diverted to more pressing issues and do not require the visual inspection or connected test equipment to the home network in order to identify and isolate potential root causes of the service degradation.

4. Remote Diagnostics Leveraging Cable Operator Product Deployment Statistics

Before describing the processes by which we diagnose MoCA only issues within the home network, we'll need a framework for deciding when and how to act with respect to new data coming from MoCA diagnostic channels. The good news is that the processes we are about to talk about are not new to our industry, or even to the engineering sciences in general. If anything, the approach we will describe here merely formalizes a decision-making approach the cable operator community has likely had in place for a long time.

This approach is analogous to processes that have long been in place for manufacturing industries to monitor, manage, and minimize defects across production lines. However, the key difference is that instead of capturing variation and statistics specifically associated with a particular manufacturing process, we intend to extend the statistics and variation to also capture deployment variation specific data associated with making these products generally available to cable operator consumers. So what value would deployment data add to observed manufacturing statistics? The eternal optimist in us says the differences would be negligible.

Cable operators document their specifications well, accounting for all the consumer environmental conditions and capturing all the key performance indicators (KPIs) that matter. Manufacturers design and build products that meet those specifications and demonstrate compliance across all the cable operator defined environmental conditions. When everyone does their job well, the differences between manufactured and deployed product KPIs will indeed be negligible, even when the numbers extend to cable operator footprints of millions of consumers. The realist in us says "that no matter how good plans are defined and executed, Murphy's Law is ever present and there will always be surprises". Essentially, there will always be moments when the designer says, "hmmm…, I didn't see that coming, back to the drawing board."

That's what this approach is all about. Defining normal behavior based on statistics and variation, and thus creating the opportunity for us to easily recognize when we do well and when we do not do so well with respect to those established norms. We will examine KPI norms across large deployed populations, similar to how manufactures assess KPIs associated with new production runs.

We will use the complimentary cumulative density functions (CCDF), which are nothing more than a particular format or view of our large population KPI data. This statistical data format will assist us in intuitively understanding the statistical nature of new KPI data with respect to established norms, acknowledging that some amount of variation will always be present. When we do our jobs correctly, variation, however much is present, will ideally have a negligible impact on the end user experience.

The process of obtaining a CCDF curves are well understood and documented. In fact, most of us may already be familiar with histograms or bell curves used to describe statistical behavior over a population. Ever benefit from having a statistical curve applied to your final score in high school or college? The CCDF is essentially derived from the bell curve, illustrated in Figure 1. Bell curves plot the frequency of KPI occurrence against the KPI values themselves. For large datasets tending toward the classic Gaussian distribution, commonly occurring KPIs cluster around the average KPI value, while the less commonly occurring KPI values end up in the tails of the bell curve, above, below, and further away from the average.

Aggregating or summing the frequency of occurrence of the KPIs from 0 to 1 is what leads to the cumulative density function (CDF). Taking the compliment of the CDF or subtracting the probability of any given KPI value from 1, 1-P(KPI), is what leads to the CCDF. The value of using CCDF versus a histogram, or a CDF really boils down to personal preference of assessing large datasets. The CCDF format is appealing because the majority of the population data is centered about the origin making dataset comparisons more palatable.

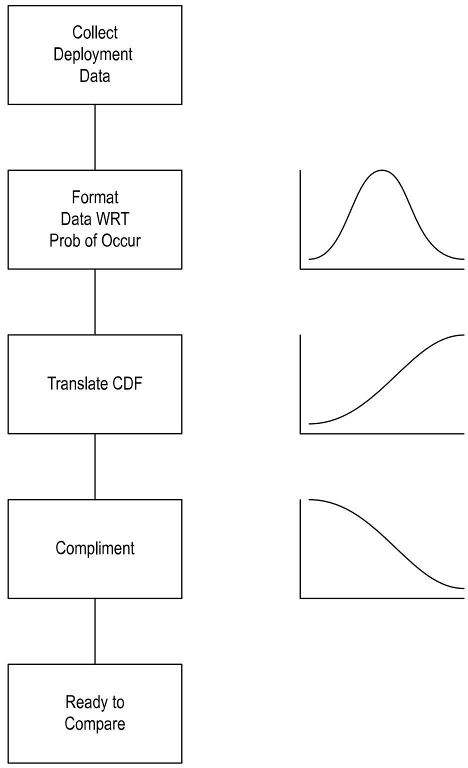

Figure 1: Creating CCDF From Statistical Data

So with some CCDF background under our belts, let's now examine a generalized KPI CCDF example illustrated in Figure 2. The y-axis is reserved for probabilistic measure, with an origin at 0 probability, and its maximum at a probability value of 1 or 100%. KPIs very near the origin have a low likelihood of occurrence, while one can be assured of occurrence with KPIs near 100%. The horizontal, or x-axis is a little more flexible in that it can be any KPI of interest or measure of *goodness*. In our example, *goodness* improves for values further away from the origin, while values close to the origin are not so good. The directionality of *goodness* is chosen such the greatest areas of the CCDF curve are always near the origin, making it easier to make comparisons, as we will soon see.

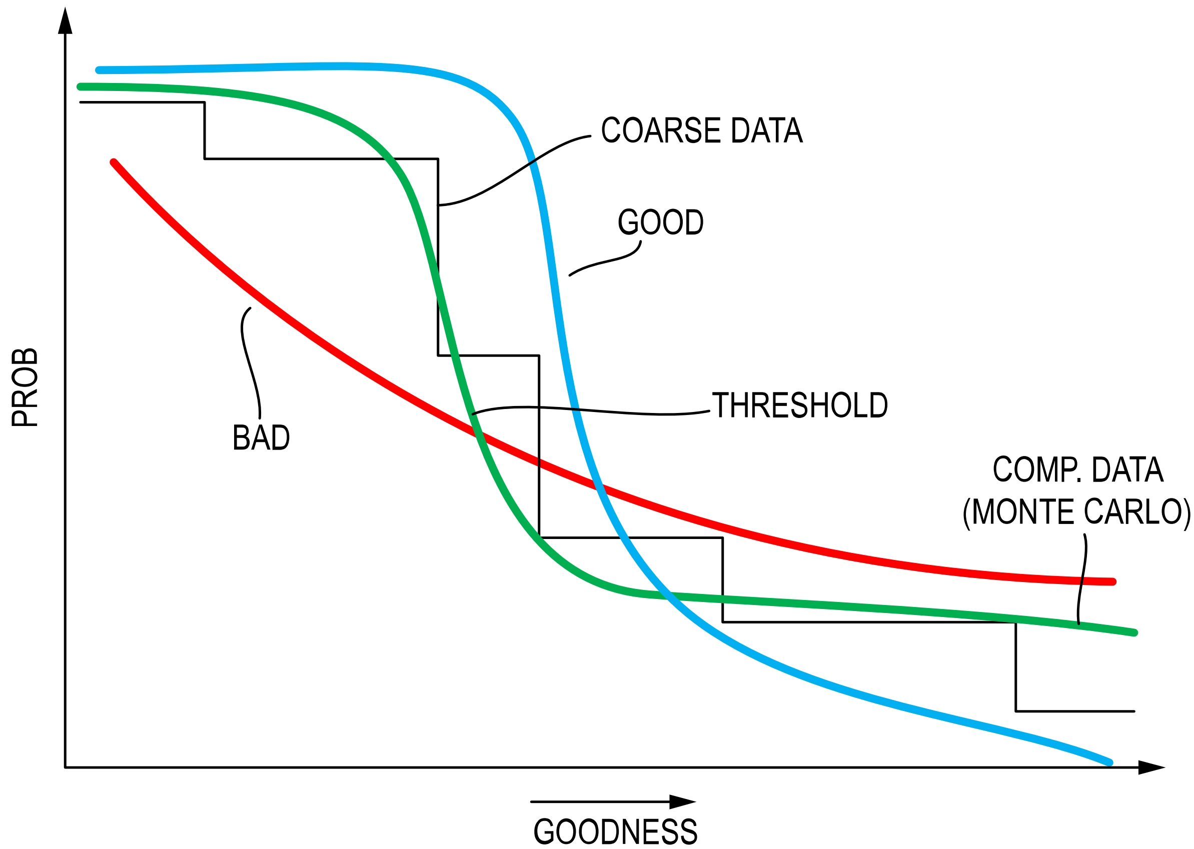

Figure 2: KPI CCDF Example

The green curve, labeled "Threshold" in Figure 2, represents an example of a population norm. For example, this could be the aggregation of cable operator deployment data encompassing a specific KPI associated with an entire population of deployed products, like downstream receive SNR. Maybe the cable operator feels that this data is representative of the population in general, and therefore the curve can be established as a cable operator norm, setting expectations for average KPI performance and reliability, or variation. Low variation thresholds will result in mostly vertical CCDF curves, where the vertical line coincides with the population KPI and the variation will be minimal leading to small tails above and below the vertical KPI line. As an example, a sample cable modem (CM) signal to noise (SNR) population norm could be approximately 36 dB, with very small percentages (roughly 5%) being 2 dB above and below 36 dB. Additionally, 95% of the population SNR will be at least 36 dB.

If a cable operator wanted to introduce a newer generation cable modem, which would be represented by the "*Blue*" curve in Figure 2, leveraging the same SNR KPI. Comparing the newer generation cable modem SNR data is obviously better than the green because its average measure of goodness is higher and its variation of performance is equal or less. A right-shifted CCDF can be appropriately labeled as a "*Good*" CCDF, while a left-shifted CCDF can be considered bad, since their performance is worse for the majority of KPIs. The red curve, labeled "*Bad*", also the same KPI, but maybe in this case represents an older generation cable modem technology deployment, whose average measure of goodness is lower and its variation of performance is higher when compared to threshold, essentially lower KPI and flatter curve overall.

As was noted previously, representing large datasets in this manner is not new, in fact many similar comparisons have been made previously by manufacturers comparing performance of new production runs to previously established factory production thresholds, or when standards organizations compare performance of different standard generations. Key things to remember when using the CCDF is unique cable operator information can be exploited, specifically aggregating statistical performance, associated with various technology deployments, which may be difficult to reproduce in a laboratory environment. Armed with a fundamental understanding of the CCDF curve, we're now in a position to use these curves to make remote diagnostic decisions with respect to MoCA channel statistics and home network craftsmanship. The first use-case to examine will be in identifying excessive path loss that may be associated with drop amplifiers and splitters that are incompatible to MoCA.

5. Detecting Devices That Are Incompatiable To MoCA Signaling

MoCA has been engineered to be an extremely robust home networking technology. For example, engineers knew that MoCA signals needed to be strong enough to jump across splitter ports, a path not originally conceived of when CATV networks were first designed. In fact, splitter jumping still is considered an undesirable network trait in access networks. So much so that the loss, called output-port-to-output-port (OP2OP) isolation is generally specified to be very high, for example 25 dB on many devices including taps, and passives. What's even more impressive is that MoCA can splitter jump at extremely high frequencies, remembering in the introduction where it was pointed out that the MoCA operating band was 1,125 to 1,675 MHz. At these frequencies, attenuation is generally much higher than what is experienced within the DOCSIS bands, not just for coaxial cable, but for splitters and drop amplifiers too.

Figure 3 illustrates the amount of attenuation a MoCA channel can experience. In Figure 3, the spectrum analyzer was set on max-hold from 1GHz to 1.7GHz. We instructed the MoCA endpoints to link up on D-Channels D1 – D10. The response you see is the summation of MoCA beacon which is used to establish a MoCA Network Link.

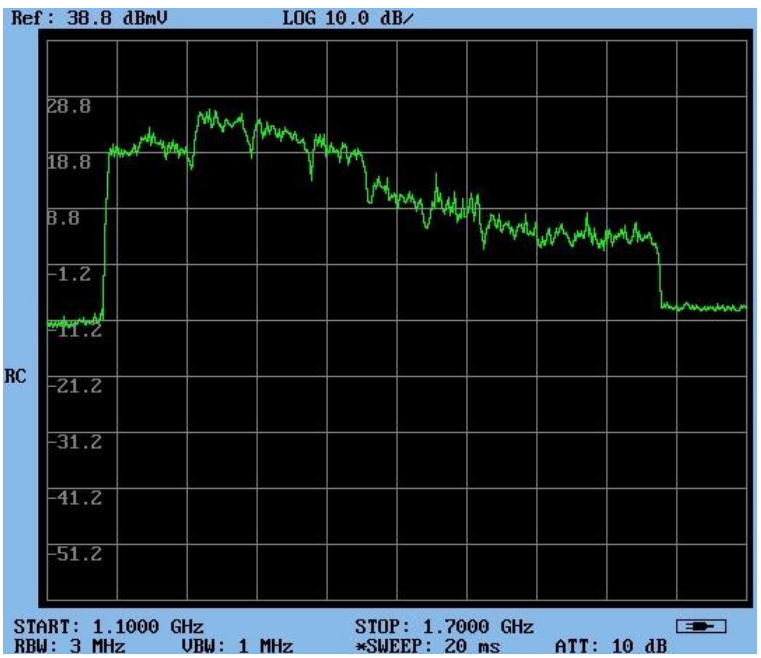

Figure 3: OP2OP Isolation Of MoCA Exd OFDM Beacon Signals From D1 Thru D10

Another complication is that many legacy splitters and drop amplifiers that have been installed in consumers' homes that don't support frequencies above 1 GHz. Therefore, these bands can have what are called "suckouts" or small bands of frequencies which have extremely high loss. To make matters worse, suckouts can occur at random frequency locations and for random port combinations. Again, MoCA engineers are aware of this, so they engineered MoCA to be capable of working around suckouts. Since its inception (MoCA 1.1 was created in April 5th, 2011), MoCA protocol has been intelligent enough to detect suckouts and form networks around them. Figure 4, from [1], illustrates MoCA's splitter jumping capability.

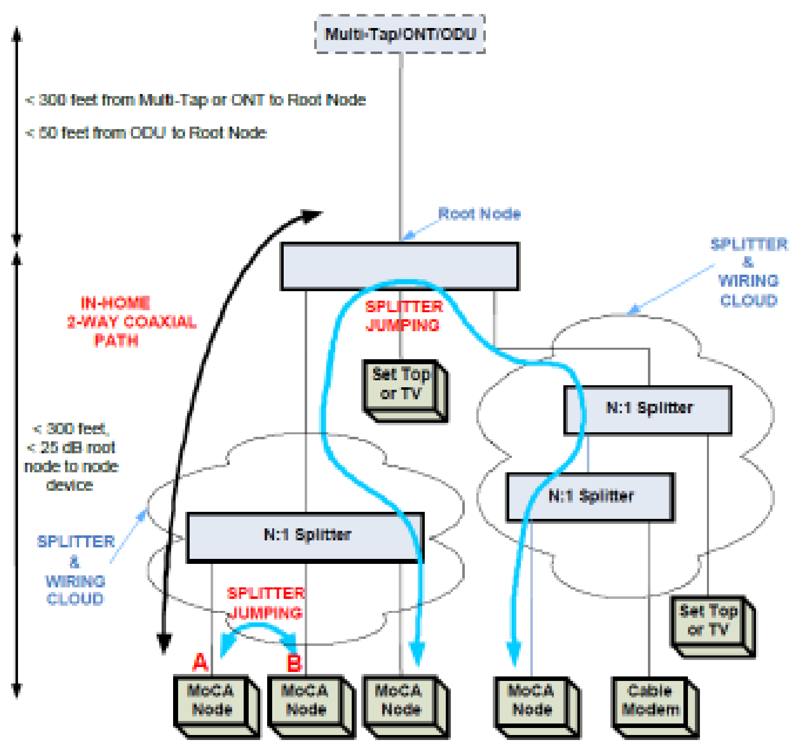

Figure 4: MoCA Network Diagram Illustrating Splitter Jumping

Deployment of MoCA has led cable operators-to converge upon a much simpler network model. As was discussed previously, cable operators deploy MoCA with a target capacity of at least 200 Mbps to support services like any room DVR. Cable operators have been able to achieve this at scale, but with a much simpler home networking approach. First, MoCA's operating center frequency may be constrained, or limited to the lowest operating center frequency, 1,150 MHz for MoCA 1.1. Second, loop through, or cascaded splitter networks illustrated in Figure 4 and the right side of Figure 5 have been traded for home-run networks illustrated on the left side of Figure 5. Home networking topology Figure 4 and Figure 5 were recently introduced in an SCTE operational best practices, see [1] for details.

These simplifications, which optimize home networking path loss, have enabled cable operator to meet throughput performance targets more easily. Unfortunately, networks are not static, and as service targets advance toward achieving higher capacity using more bandwidth, cable operators will need help in identifying when path loss challenges arise for those new bandwidth requirements. Fortunately, there is an approach for remotely diagnosing of when path loss may become objectionable and its basis is in exploiting what MoCA has been capable of since it was originally conceived.

In April of 2017, MoCA created the MoCA 2.0 SNMP MIB for its membership, and with it making available the home network probing technology it uses to learn about channel suckouts or more generally, channel path loss. This information is now available to cable operators to remotely poll MoCA 2.0 capable devices and learn whether excessive path loss, i.e. suckouts, exist within any given MoCA deployment. In fact, anything that would objectionably impact MoCA path loss and ultimately throughput performance is now accessible to cable operators to see.

Armed with this knowledge, cable operator can make decisions about how best to deploy higher capacity home networking services, like 1 Gbps High-Speed Data service. The approach we describe differentiates between compatible versus incompatible devices within the home network space. A large percentage of home networks use splitters to distribute both access network and home networks signals throughout the home. A smaller percentage of home networks will use drop amplifiers, active components to incrementally reduce path loss within the home network. The process we will describe will be agnostic to both types of components and will simply detect when and where objectionable amounts of path loss exists.

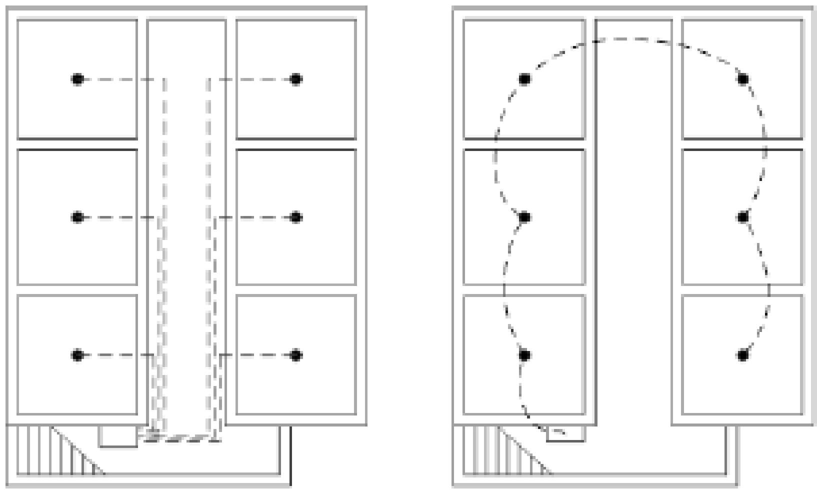

Figure 5: Preference For Home-Run (Left) Over Loop-Through (Right) Home Network Topology

Remembering the CCDF from earlier, we'd now like to discuss a statistical threshold for compatible splitters and drop amplifiers. Cable operators could collaborate with their vendor partners to create a statistical description or CCDF of OP2OP isolation performance for all compatible splitters and drop amplifiers illustrated in Figure 6. The average or mean of the compatible splitter or drop amplifier OP2OP isolation, labeled μ_{COMP}, could be a value of 25 dB, whereas 99.9% (Figure 6 non-shaded area) of the devices measured could have an OP2OP isolation better than 30 dB. It's also important to note that there will be a certain degree of variation or reliability required, which is described as standard deviation, labeled σ_{COMP}.

Maybe an acceptable value for standard deviation would be ±1 dB, or 24-26 dB about the mean. Lastly, a very small percentage of the population 0.1% (Figure 6 shaded area) could have OP2OP isolation values greater than 30 dB. Armed with our statistical description, we could use this data as a starting point to help us decide between compatible versus incompatible splitters and drop amplifiers. We could also poll a population of deployed MoCA devices that are performing well and obtain an ideally similar, but perhaps slightly different set of statistics. The point is that whatever our threshold is, it is based on solid data associated with a favorable end user home networking experience.

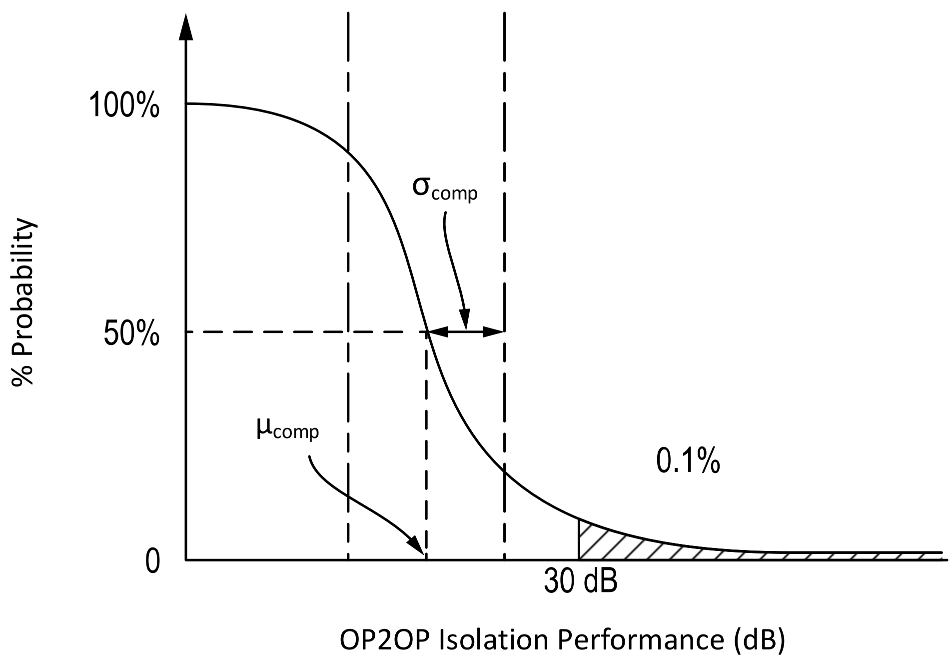

Figure 6: Compatible Drop Amplifier And Splitter CCDF

When trying to differentiate incompatible drop amplifiers and splitters that appreciably degrade the end-use experience, comparisons of any new data will be made against established thresholds. The new data can come from a home network where the end user has logged a ticket, citing unfavorable home networking experience. All of the MoCA 2.0 capable devices could be polled for estimates of path loss to all of the other MoCA 2.0 capable devices participating in that particular home network.

The data can be aggregated into a CCDF curve for comparison to the established threshold. Cases where both the newly measured mean and standard deviation of the OP2OP isolation performance are appreciably worse than the established threshold can implicate objectionable path loss and possibly OP2OP isolation as a potential root cause, thus flagging that home network for remediation. Figure 7 illustrates such a case where it can easily be seen, via the red curve, that both the mean and standard deviation are appreciably worse than the desired threshold, which is illustrated via the black CCDF curve.

Also notice how the red, incompatible CCDF, curve flattens out and shifts right, indicating higher standard deviation (reduced reliability) and higher loss values. An excessive path loss alarm can be shared with the installer, prior to arriving at the home, guiding the installer to investigate whether incompatible splitter or drop amplifier exists within the home network. Upon replacement of the incompatible device with a compatible one, immediate feedback can be provided to the installer on whether path loss falls below threshold or if the path loss problem persists.

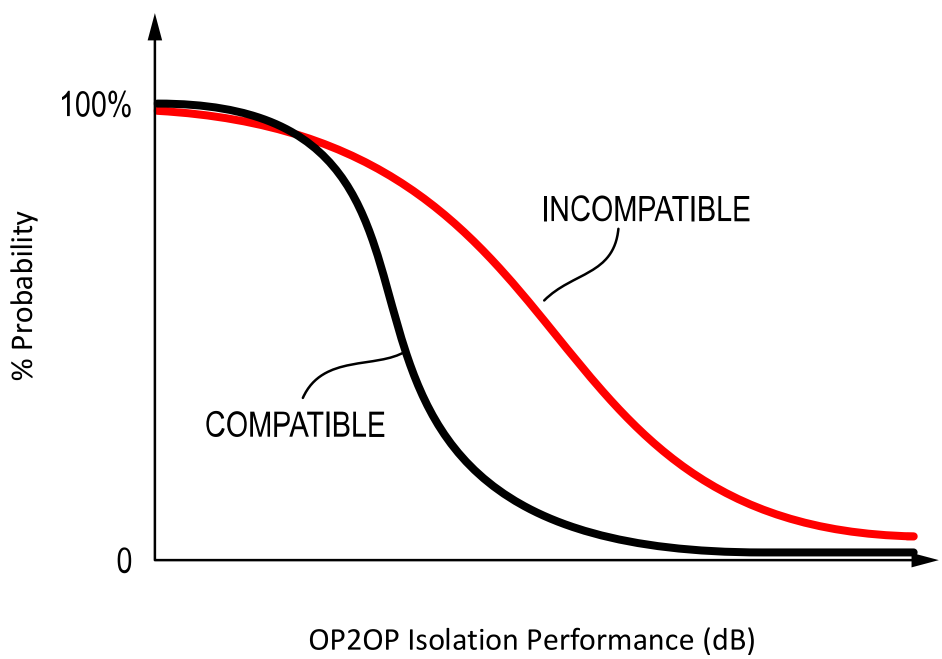

Figure 7: Incompatible Drop Amplifier And Splitter CCDF

What has been demonstrated is a process for establishing thresholds for acceptable home networking path loss and a general statistical-based method of indicating when path loss thresholds are not being met. One of the leading causes of objectionable path loss today is suckouts from incompatible home splitters and drop amplifiers. Perhaps a process similar to what has been described here may be exploited by cable operators wishing to leverage higher bandwidth service that require MoCA technology, and remotely isolate and identify some of the legacy home network components that may no longer be compatible in reaching that goal.

6. Sample Data Via Alternative Channel Assessment (ACA)

Previous references reviewed how MoCA is a designed to be a robust protocol. Unlike in D3.1, where its signals are required to have as close to a flat OFDM spectral response as possible, MoCA can have areas of the occupied OFDM spectrum that are highly attenuated. Unfortunately, this robustness comes with a cost of lower subcarrier modulations, which in turn can potentially lower the PHY/MAC rate link.

Cable operators are migrating to MoCA-friendly splitters (MFS) and MoCA-friendly drop amplifiers (MFDA), but at an additional cost per unit. This upgrade to the MFS is reserved for customers that “MAY” have physical (PHY) layer issues. With the new MoCA 2.0 ACA feature, we have a better view of the characteristics of the OP2OP isolation. This provides another option in the PNM tool kit to assist the customer account executive (CAE) or field technician in determining why the customer is experiencing a PHY layer or an IP/Network connectivity issue.

The following section details the retrieval and processing of the ACA data. Due to the process of how the ACA is determined in the MoCA specification, the user needs to add a correction factor so that the ACA response is analogous to a spectrum analyzer.

The following example is a 4-way non-MoCA-friendly splitter (NMFS), where the ExD MoCA channel frequency response is not a flat spectral response.

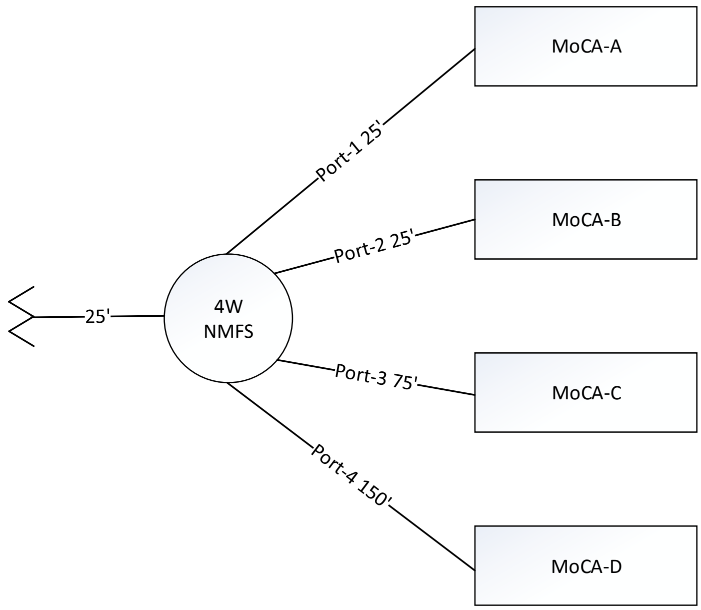

Figure 8: 4-Way NMFS Home Network Configuration

6.1. General ACA Retrieval Process

This section briefly describes the process of retrieving the ACA error vector magnitude (EVM) probe data. It is assumed that in a mesh environment, the user will need to perform the ACA EVM probe to each of the MoCA enabled devices. Optionally to save time, users may ignore the reverse EVM probe path, but it is recommended that the reverse ACA EVM probe be performed for detecting path loss asymmetry, which is a condition associated with older generation, non-MoCA-friendly drop amplifiers, specifically when using VoIP/passive port connections. Reverse ACA EVM probes, in general, are a good idea to avoid any surprises and to have a more precise average of the path loss since there may likely be differences among the bidirectional paths.

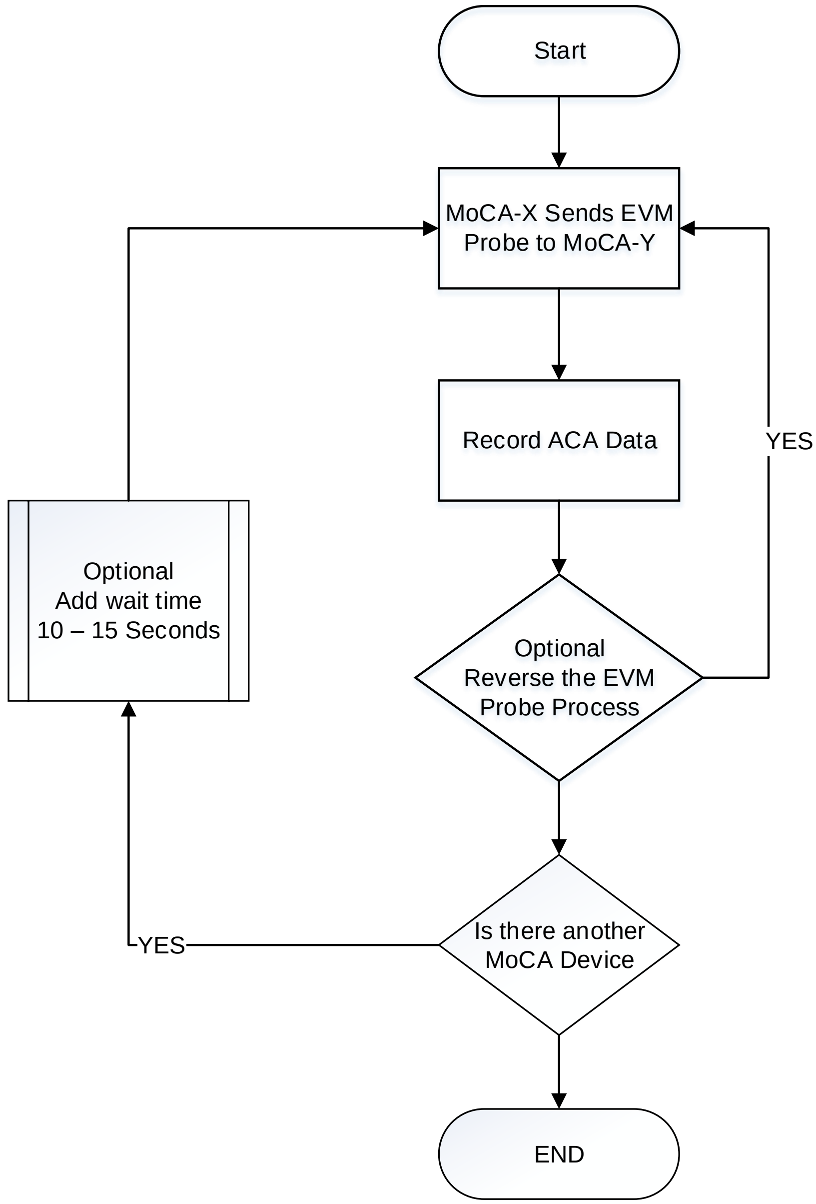

Figure 9: General ACA Retrieval Process

6.2. Processing The ACA EVM Probe Data

The ACA EVM probe operation discussed in this section, is the process of applying a correction factor to achieve a spectrum analyzer analogue.

When initiating an EVM Probe between two MoCA endpoints, this requires that the MoCA network is quiet, with the exception of the two MoCA devices that are being evaluated. Typically you assign a MoCA endpoint to send an EVM Probe to a destination. In this example, we are performing an EVM Probe from Channel D1 through D10, but skipping the odd D-Channels: D3, D5, D7 and D9 so that we do not have over lapping spectrum. This is done for convenience only. The user can implement overlapping spectrum, but keep in mind when graphing, averaging is needed for the two overlapping dBm points on the same subcarrier.

6.3. Normalizing The EVM Probe Data

To get a better representation of the actual OP2OP isolation we will need to perform a correction of the EVM probe data. In this example the system on a chip (SoC) implementation performs an AGC of the receive EVM probe. When graphing the power levels over frequency Figure 10, it would appear to be a more flat response, with possible oscillation, or ripples across the OFDMs. This interpretation would be incorrect, as this is not what is actually happening on the wire. To understand the actual response, the user will need to perform a correction of the EVM probe data.

Normalization requires two pieces of information:

1. ***mocaIfAcaTotalRxPower***
   a. This is the actual measured 100 MHz receive power in dBm, including OFDM guard bands at the F-Connector
2. ***mocaIfAcaPowerProfile***
   a. This is the per-subcarrier processed receive EVM in dBm.

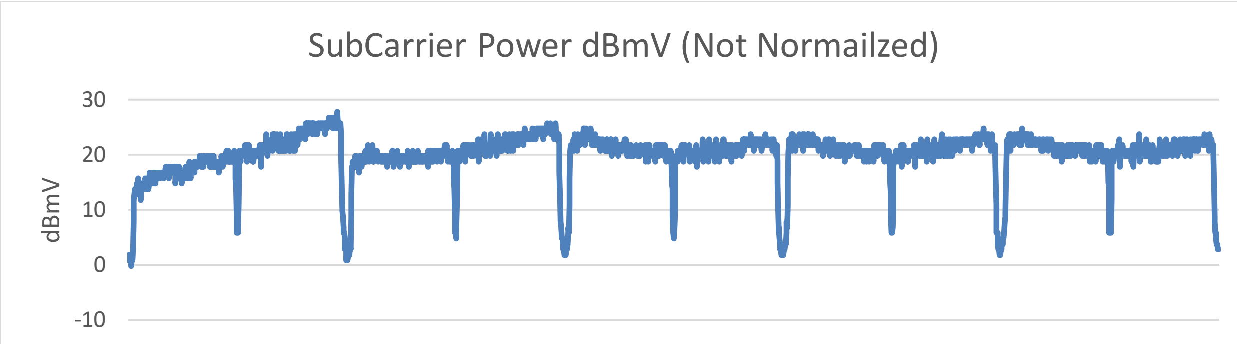

Figure 10: ACA EVM Probe (Not-Normalized)

Figure 10 represents the non-normalized EVM probe response. The normalization of the EVM probe is an easy process. The following provide the mathematical equations to perform the normalization operation, involving three steps.

6.3.1. Step 1 – Integration Of The EVM Probe Per-Subcarrier Power

Integrate the ACA power profile OFDM subcarrier dBm EVM measurement to calculate its total channel power, using Equation 1and defined variables for $EVMBin$ and EVM_{CPCALC}

$\boldsymbol{EVMBin} \;\; = The\ stored\ array\ of\ EVM\ Probe\ dBm\ levels\ from\ \text{index}\ SubCarrer_0 to\ \text{index}\ SubCarrier_{\mathrm{N-1}}$

$\boldsymbol{EVM_{CPCalc}\ in\ dBm} = The\ Total\ Channel\ Power\ calculated\ from\ the\ EVM\ Probe\ Data$

Equation 1: Total Channel Power Equation

$$EVM_{CPCalc}dBm \; = 10 * \log_{10}\left(\sum_{n=0}^{EVMBin.size-1}\left[10^{\frac{EVMBin(n)}{10}}\right]\right)$$

6.3.2. Step 2 – Calculating MoCA Channel Correction Offset

Calculate the correction offset

$$if\ EVM_{CPCalc}dBm < \ ACATotalRxPower$$

$$EVM_{Offset} = \ |EVM_{CPCalc}dBm + ACATotalRxPower\ dBm|$$

$$else\ if\ \ EVM_{CPCalc}dBm > \ ACATotalRxPower$$

$$EVM_{Offset}dBm = \ |EVM_{CPCalc}dBm - ACATotalRxPower\ dBm|$$

6.3.3. Step 3 – Normalizing MoCA Channel

Apply the correction offset to normalize the EVM Probe Data

$$Iterate\ all\ subcarriers, \boldsymbol{i} = 0..N$$

$$EVMBin_{Correction}(i) = EVMBin(i) + \ EVM_{Offset}\ dBm$$

Since all results are in dBm, it will need to be converted to provide dBmV value:

Equation 2: $dBm\ to\ dBmV\ Conversion$

$$dBmV = 10 * Log_{10}\left(\frac{75\Omega}{1 * 10^{-3}}\right) + dBm$$

Figure 11 represents the revised EVM probe with a normalized response. Comparing Figure 10 with Figure 11 clearly illustrates the need for normalization when attempting to learn about the effects of the MoCA RF communication channel. This particular MoCA communication channel appears to be dominated by OP2OP isolation, since there appears to be significant reverse tilt across the MoCA band. Reverse tilt illustrated in Figure 11 isn't enough to diagnose incompatible splitters, since vendors are capable of applying processing needed to compensate for the tilting effects typically observed in OP2OP isolation profiles.

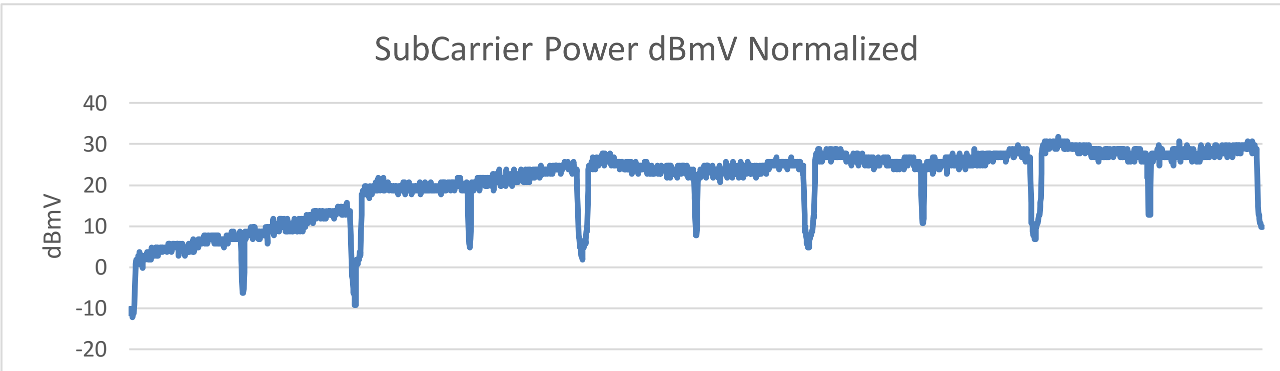

Figure 11: ACA EVM Probe (Normalized)

The next four figures represent the PTP EVM probe normalized responses. As you can see, although this would be considered an incompatible splitter for MoCA because it does not include support for the band of operation, it does provide some flatness after starting with D1 across all port combinations.

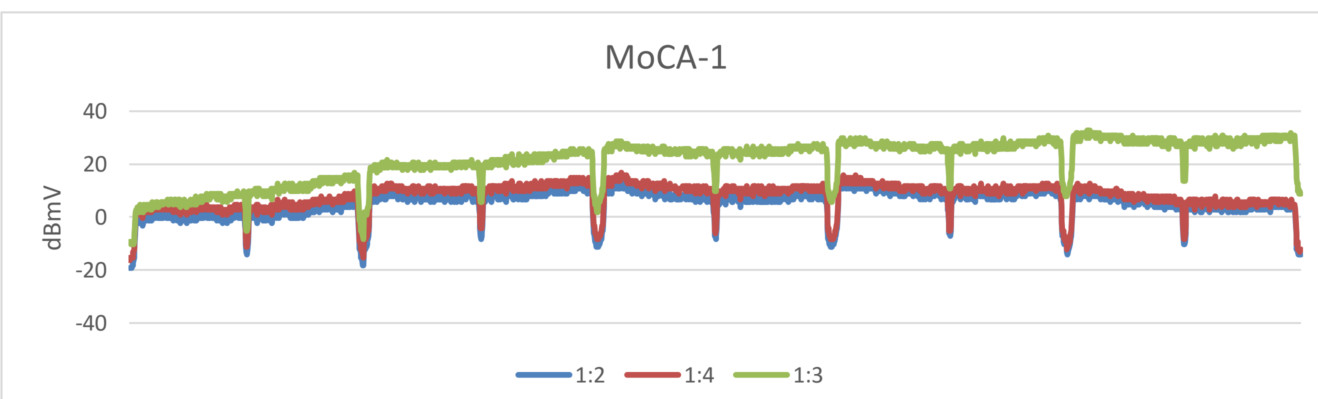

Figure 12: MoCA-1 PTP EVM Probe Overlay To MoCA-2, 3 And 4

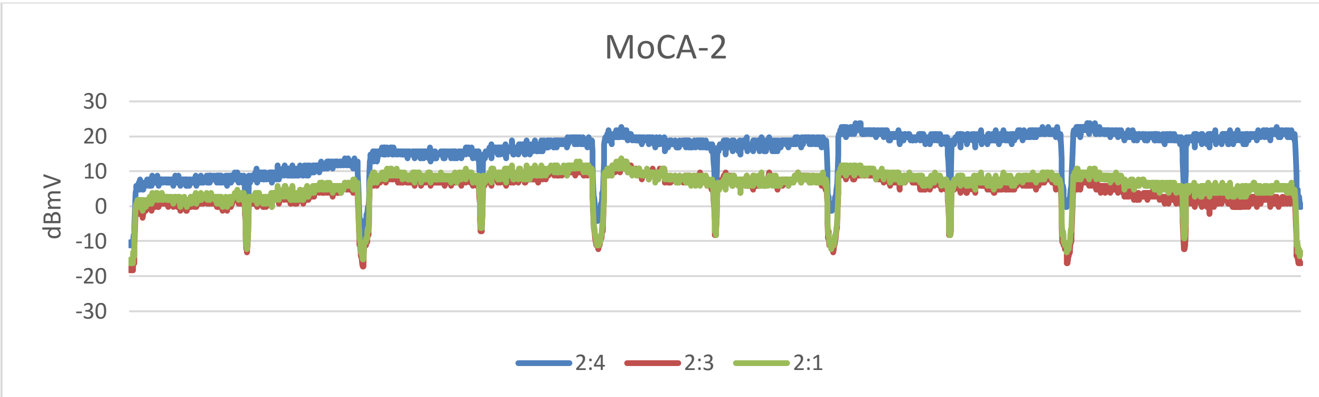

Figure 13: MoCA-2 PTP EVM Probe Overlay To MoCA-1, 3 And 4

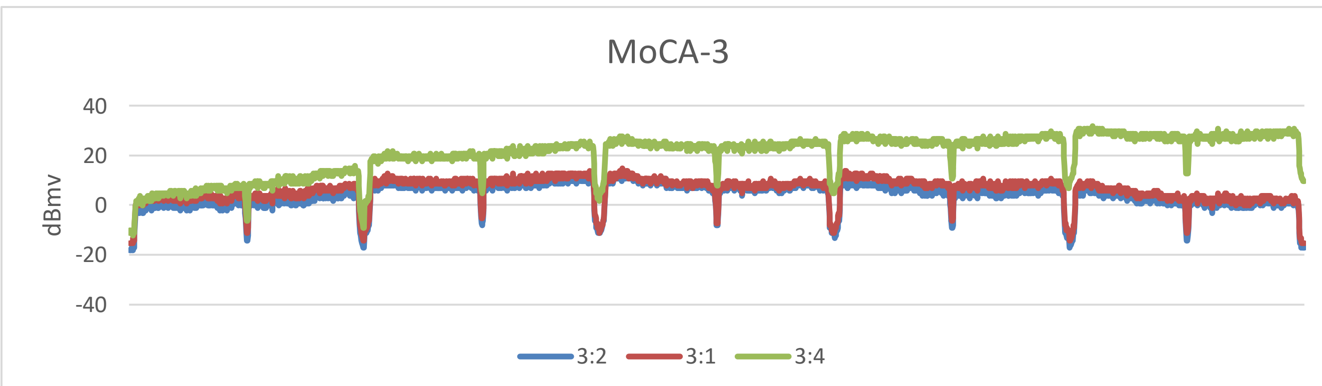

Figure 14: MoCA-3 PTP EVM Probe Overlay To MoCA-1, 2 And 4

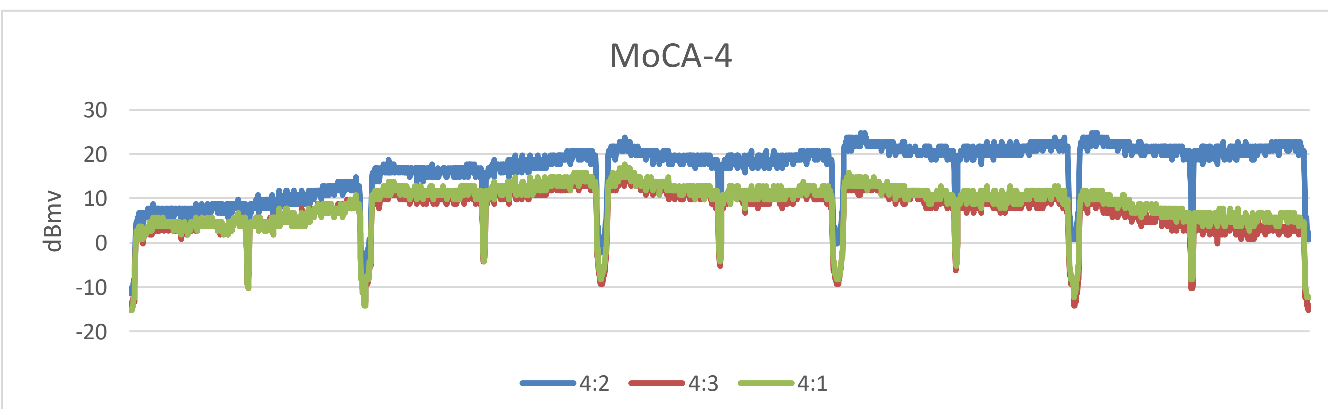

Figure 15: MoCA-4 PTP EVM Probe Overlay To MoCA-1, 2 And 3

Figure 16 demonstrates the potential to detect suckouts. In this example, we see a highly attenuated signal below D1. This response is actually the lower edge of the high-pass filter (HPF). The HPF is allowing only D1 – D10 channel and rejecting all frequencies below 1,125 MHz internal of the MoCA embedded device.

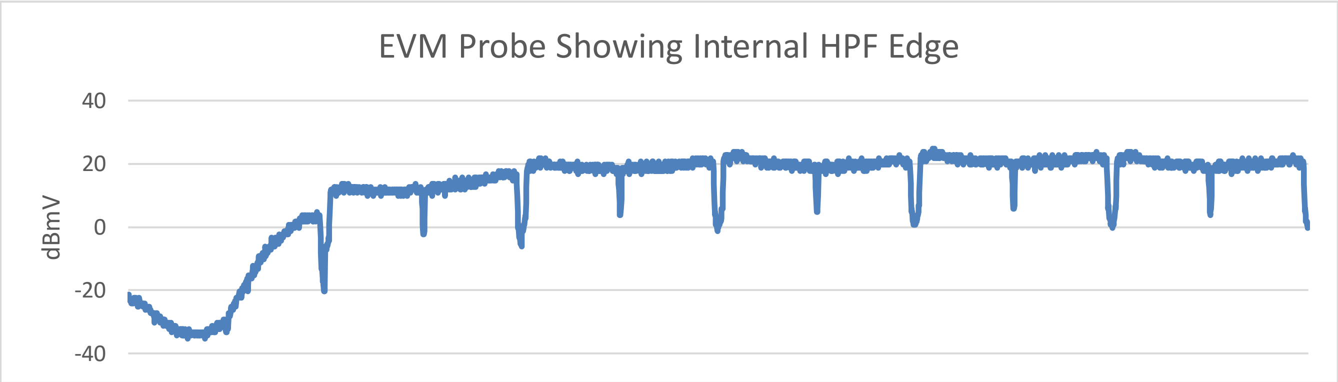

Figure 16: PTP EVM Probe Showing HPF Edge

7. Detecting Missing Point-Of-Entry (POE) Filters

Point-of-Entry (POE) filters are installed in a subscriber's drop to provide optimum MoCA security and performance. Some acceptable locations for POE filters in the subscriber drop include at the tap spigot, ground-block, or as the closest possible point on the WAN side of the root splitter or drop amplifier input, see Figure 17 for an illustration.

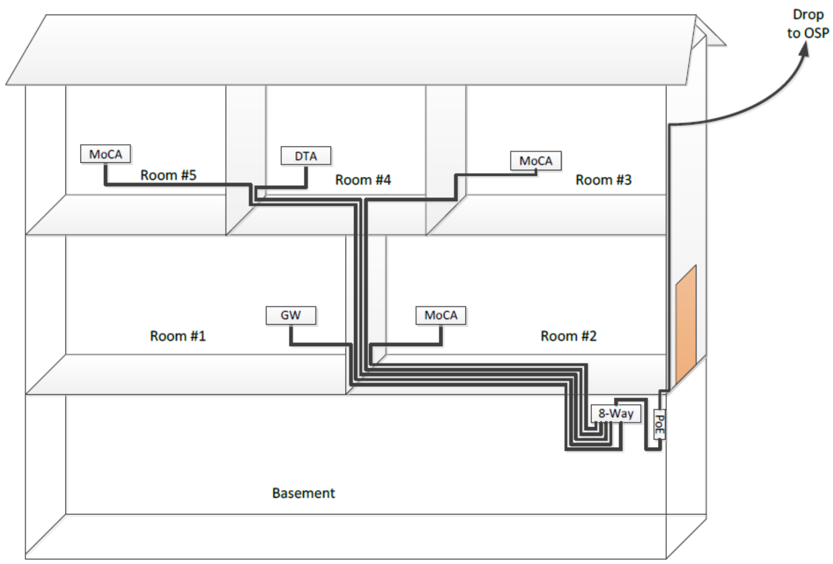

Figure 17: POE Filter Installation Example

POE filters are low pass filters and correctly including them in a MoCA install serves two key purposes. The first purpose is to isolate the home network from neighboring home networks by attenuating the MoCA signals at the home network's point of entry. Deployment of well-designed POE filters can prevent neighboring MoCA from seeing each other and protect a MoCA network from any eavesdropping.

The second purpose POE filters serve is that they improve the MoCA connectivity with their 0 dB return loss in the MoCA frequency band. MoCA signals that are incident on the POE filter will reflect, with no loss contribution from the POE filter, back into the home network, and can result in a stronger MoCA signal if the reflected path has lower loss than the original path. A great explanation of POE filter response can be found in [1]

Cable operators may have discovered that installing POE filters in every MoCA deployment has proven to be challenging. Ideally, POE filters are installed at the tap spigot or the ground block for every MoCA deployment, however POE filters aren't included in all installations or are inadvertently removed by the customers. When POE filters are missing, MoCA becomes susceptible to security and performance issues previously described.

Remote detection of missing POE filters is ideally done prior to or during MoCA activation, providing real time feedback to the onsite installer or customer and ensuring optimal security and performance. Methods that detect missing POE filters via bridged MoCA networks are unacceptable because detection is happening too late, when both security and performance may have already been compromised.

There are multiple methods of analyzing MoCA channel characteristics to detect influence the POE filter presence has on a MoCA. Remembering that a properly installed POE filter fundamentally impacts the home network MoCA channel RF characteristics, and exploiting that knowledge enables the cable operator to look at a variety of home network characteristics in order to assess whether or not a POE filter is present. For this paper, we will consider echoes, tilt, and attenuation (of continuous waves) as potential methods for detecting POE filters in MoCA deployments.

Echo Detection

Approximately 0 dB return loss of the POE filter will introduce additional MoCA signal propagation paths, where the net effect on the channel response will be ripple. Traditionally, passband ripple has been considered to be bad in the legacy PNM mindset, because echoes in access networks usually means pairs of damaged or defective HFC components contributing to the generation of echo.

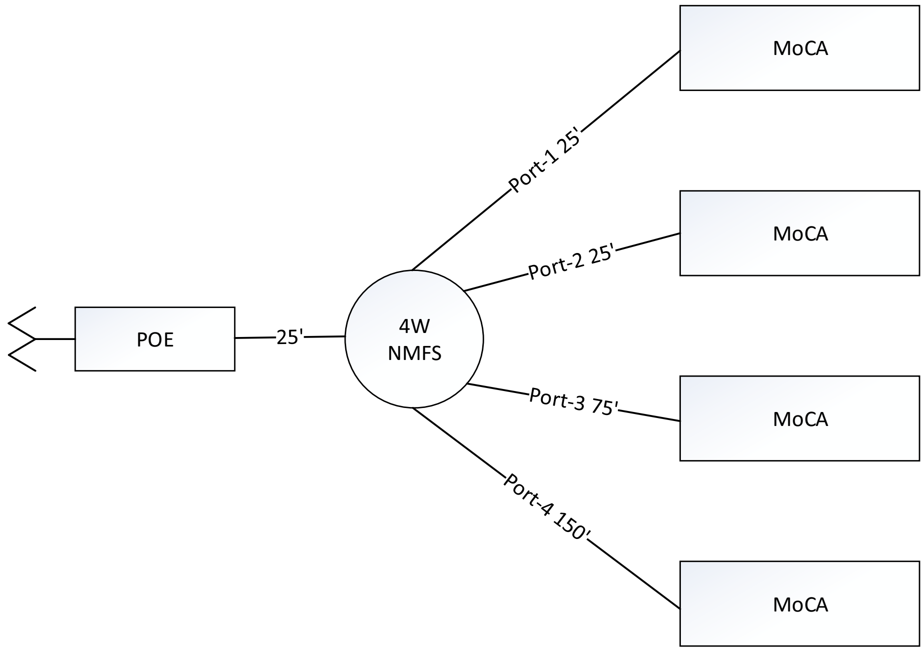

Figure 18: 4-Way Non-MoCA Friendly Splitter With 25' POE 75Ω Terminated

Echoes in the MoCA network are actually good and in fact intentional, because of the introduction of the POE filter, thus detecting them within the MoCA network tells the cable operator that the POE filter has been successfully included in the MoCA activation. Figure 19 is example of a MoCA RF channel response with and without a correctly installed POE filter, it can be seen that the POE filter MoCA channel response has appreciable ripple, while not including the POE filter results in a much flatter channel response.

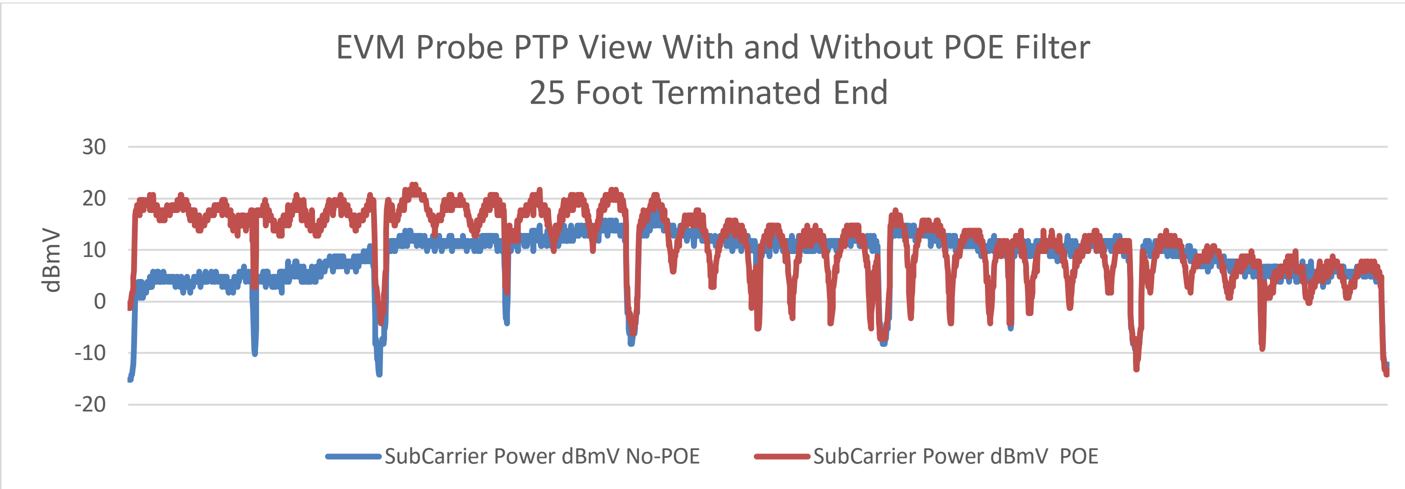

Figure 19: EVM Probe PTP Viewpoint With/Without POE

8. Tilt Detection

Channel responses that include a POE reflection path, the blue path of Figure 20 may be the dominant, or least loss path, and strongest when the POE filter is installed at the input of the root device. A root device may be either a MFDA or MFS, resulting in increased tilt from insertion loss instead of the OP2OP isolation. Differentiating between MFDAs and MFSs versus non-MoCA friendly equivalents is important because the suckouts present in non-MoCA friendly devices could corrupt the POE filter detection process. Therefore, detection of compatible home network devices, with more predictable RF performance throughout the MoCA band will needed before attempting to detect the presence of POE filters.

MoCA based CPE installed in homes without POE filters will depend largely on OP2OP isolation of the root device, the red path in Figure 20, which ideally is a flat loss or possibly reverse tilted over frequency for MoCA-friendly amplifiers and passives, resulting in less forward tilt than the path with the POE filter.

Thus another approach for detecting installed POE filters could be in analyzing the forward tilt observed across the MoCA devices. The approach would be similar to previous CCDF approaches, but in this case the analysis would aggregate tilt measurements into a CCDF, and compare those measured CCDFs to an established tilt threshold CCDF that is associated with installed POE filters. Threshold comparisons, like what has been illustrated in Figure 21, could be used to decide whether or not POE has been installed by essentially detecting the additional tilt, from the root device and cable, associated with the MoCA signals traversing the blue path of Figure 21. Threshold CCDF could be based on population measurements of POE filtered MoCA deployments and may converge to a minimum tilt value, where tilt is defined as the approximate linear variation over frequency across the MoCA operating band.

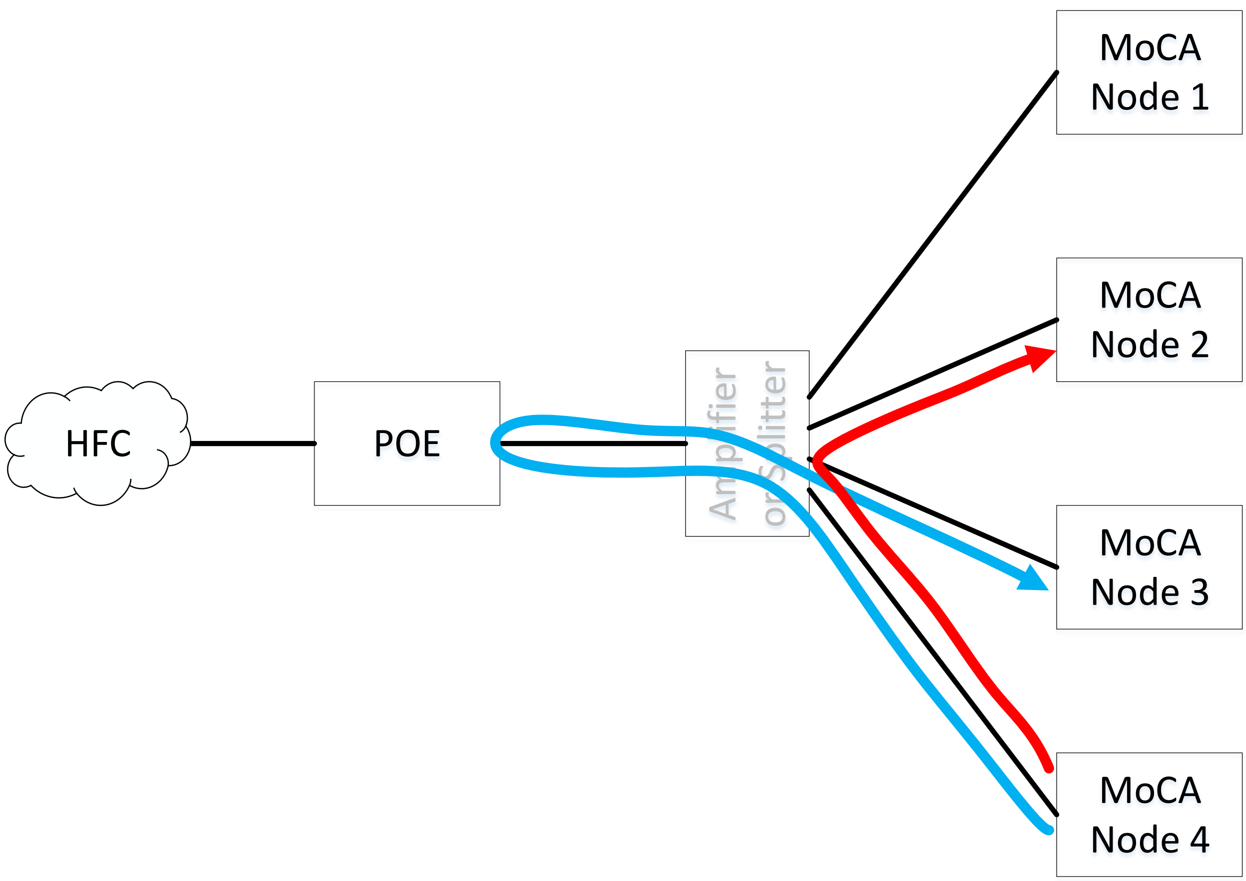

Figure 20: MoCA Communication Paths With A POE Filter Present

Generally, attenuation increases with frequency in both the insertion loss of coaxial cable, drop amplifiers, and splitters. Whereas, vendors design drop amplifiers and splitters to meet a constant OP2OP isolation value across frequency. These subtle differences of attenuation over frequency may provide enough clues to enable cable operators to distinguish when any given network is dominated by OP2OP isolation or Insertion Loss, like in the case of Figure 21, where a CCDF observation with less forward tilt reveals its average tilt to be lower than the population threshold.

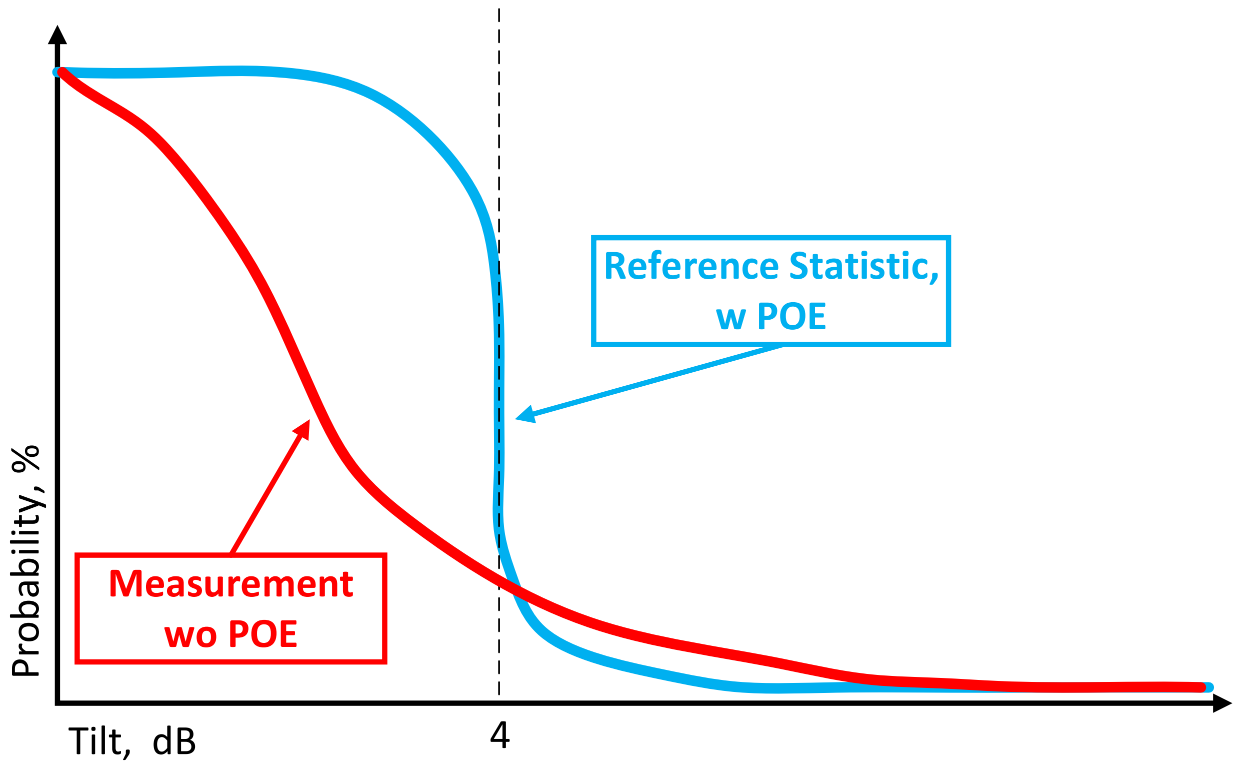

Figure 21: MoCA Tilt Assessment Against Correctly Installed POE Filter Population Threshold

9. CW Detection

Perhaps an overly simplistic and limited approach to detecting the presence of POE filters could be through the use of continuous wave (CW) signals. Traditionally, cable operators have used CW signals to perform access network RF alignment. A typical scenario would be for a cable operator to localize CWs at low, medium, and high center frequency locations. The CW RF signal level would be measured via access network test points, typically available in active elements such as Optical Nodes.

This is a proposal to continue the use of CWs not just for access network RF alignment, but detect whether or not a POE filter is within the home and significantly attenuating the CW, as would be observed by a MoCA capable CPE and illustrated in Figure 22. In order to accomplish this, the CW would ideally be centered at the lowest receive frequency of the MoCA capable CPE, or 1,125 MHz. In order for the center frequency adjustment to successfully broadcast from the headend to all subscribers, the access network would have to have been upgraded to allow passage of downstream signals up to at least the DOCSIS 3.1 requirement of 1,218 MHz.

The access network is designed to ideally deliver 0 dBmV over frequency, of all downstream signals, to all CPE, though some variation is expected, in fact some cable operators may maintain a range like an RF receive level between +10 to -8 dBmV per 6 MHz signal. CWs used for RF alignment purposes may be maintained to be slightly higher than their service delivering signal counterparts. The unique path loss (PL) associated with each customer deployment is primarily what determines the downstream RF receive level to customer CPE, which varies with drop length and equipment used, including passives, amplifiers, and POE filters, within the home networks. DOCSIS 3.1 networks will likely exhibit the lowest PL since they are designed to support up to 1,218 MHz pass band, with design budget allowances for up to 200' of RG11 drop cable and four outlets, path loss should be at its lowest below the start of the MoCA operating band, or 1,125 MHz. Above 1,125 MHz the POE lowpass filter response will significantly attenuate signals coming into or out of the home in order to isolate MoCA networks from one another. Therefore, the broadcast CW receive level should be appreciably attenuated, below the expected receive level range previously discussed by at least 40 dB or more depending on the POE filter design. Figure 22 illustrates a case of a missing POE filter. The downstream passband between 1,002 and 1,218 MHz will only be used by D3.1, which is why it has been labeled as such. When no MoCA POE filter is installed, the CW will pass through both the access and home network with attenuation expected for all downstream access network signals, and hence be detectable by home CPE capable of operating at 1,125 MHz, i.e. MoCA nodes.

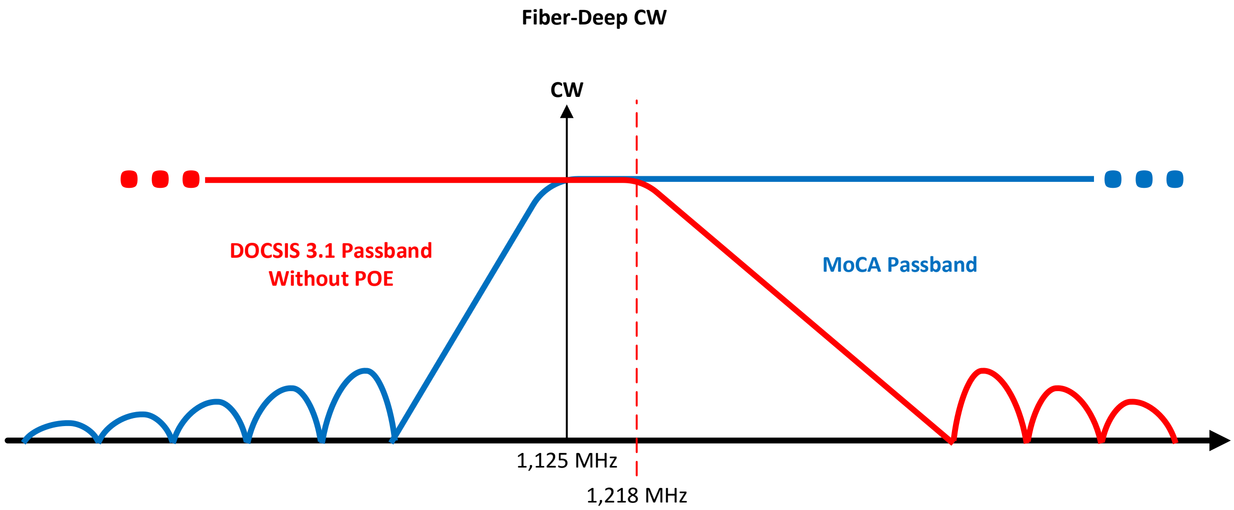

Figure 22: Expected Passband Responses, No POE Filter Present

Correctly installed POE filters will exhibit the most attenuation above the POE filter cutoff range, 1,002 MHz for example. POE filters provide a stopband attenuation of at least 40 dB starting at 1,125 MHz. Acceptable methods for missing POE filter detection would involve defining CW downstream receive power as the KPI for the deployment population to establish known thresholds for this value, when POE filters are correctly installed. Remote detection of the POE filter could be performed by first collecting an estimate from all MoCA nodes within a subscriber home network in question, and determining whether the CW receive power is lower than a population threshold, for example -40 dBmV.

MoCA 2.0 SNMP MIB can be used to support each of discussed approaches for detecting missing POE filters. Through either analyzing channel characteristics including ripple or tilt responses or by detecting broadcasted CWs in the access network, MoCA 2.0 nodes are capable of providing valuable information regarding the contribution of a correctly installed POE filter. Cable operators can now leverage this information to provide timely feedback to installers or customers when missing POE filters are detected, and circumvent any loss of performance and/or security of MoCA

. Up to this point, this paper has only discussed the value MoCA PNM can bring to existing cable operator services, we would now like to discuss how MoCA PNM can assist with enabling a new service, a higher upstream capacity or midsplit based service delivery.

10. New service assessment, Midsplit Self Install Kits (SIK)

Self-Install Kits (SIK) represent significant percentage of cable operator's new technology rollouts, allowing for optimized deployment and operations and would ideally continue with the rollout of network capacity enhancements, including D3.1 midsplit technology. Newer generation cable operator product's, including the D3.1 capable products may be capable of remotely changing their return path diplex filter configuration from a traditional standard split diplex to a midsplit diplex filter. The traditional standard split diplex filter supports return path of 5-42 MHz, or approximately a 30 Mbps upstream speed service tier, while the midsplit diplex filter can support an expanded return path, or 5-85 MHz, which would enable service providers to provide approximately 100 Mbps (or higher) upstream speed service tier to customers.

Midsplit SIK success depends upon a cable operator's ability to remotely qualify customer home networks for enhanced capacity services, without compromising existing revenue generating services, such as video. Cable operator's, via their installation practices, craftsmanship, and home network product performance typically maintains a path loss, of at least 25 dB, between a D3.1 midsplit-capable product and any video device. However, use of many commercially available home network products, from common retail channels, may result in a much lower path loss than cable operators' 25 dB

We have observed through limited laboratory testing, that D3.1 midsplit-capable transmissions within the 54-85 MHz band can disrupt existing video services when the transmission power of the D3.1 midsplit-capable device is approximately 20 dB higher than the video signal receive power, at the set top box receiver. The higher D3.1 midsplit-capable transmission power can cause many set top boxes to become nonlinear via a phenomenon known as adjacent channel interference (ACI) or more commonly known as ACI susceptibility.

In order to remotely assess whether a customer could participate in midsplit self-install, knowledge of the path loss between the current cable modem and set top boxes would need to be known. If these devices also supported MoCA, then the tools previously presented could be leveraged here to get a path loss estimate for cable operators. Using MoCA 2.0 SNMP MIB data associated with the ACA OIDs, path loss estimates would be collected for the MoCA operating band.

Using MoCA band path loss estimates combined with known product specifications for drop amplifiers, splitters, and drop cable, cable operators could estimate path loss for the midsplit operating band, provided that no incompatible devices were detected in the MoCA home network. As an example, if a cable operator were to measure 20 dBmV receive level from a ACA EVM probe, then subtracting that value from the known transmit level of 55.75 dBmV would result in a MoCA path loss of approximately 35.75 dB. If a POE filter was detected and 4-way MoCA-friendly splitter was used, then the path loss would be dominated by the splitter's IL and not OP2OP isolation.

The MoCA-friendly IL for the MoCA operating band is 11.5 dB, and 4 dB less, or 7 dB, for midsplit operating band. Deducting 11.5 dB twice from the path loss, remembering that the MoCA signal passes through the splitter twice when a POE filter is installed, than the remaining 12.75 dB can be assumed to be from cable attenuation. RG6 drop cable has approximately 8 dB loss per 100 ft, in the MoCA band, resulting in an equivalent RG6 cable length of approximately 155 ft,

Estimating the midsplit band loss, based on 2 dB loss per 100 ft, for the same length of cable results in approximately 3 dB of cable attenuation. The 3 dB of cable attenuation is an estimated value and may not be a true representation of cable loss for a variety of reasons, for example, the POE filter and the root splitter may not be collocated.

Additionally, the equivalent midsplit attenuation for this example needs to be based on the OP2OP isolation of the splitter, or 25 dB, because the midsplit signals won't reflect off the POE filter. Therefore, the midsplit path loss estimate is 25 dB + 3 dB = 28 dB.

Armed with the midsplit path loss, cable operators can estimate whether there will be an ACI susceptibility issue when activating a midsplit service. The estimation requires either querying the CM for its maximum transmit power or obtaining its maximum transmit power from the manufacturer specifications. 57 dBmV per 6.4 MHz could be an example of a maximum upstream transmit power. The minimum set top box receive power will also need to be queried as well, for example 0 dBmV per 6 MHz. The desired to undesired signal ratio (D/U) can be estimated with the downstream set top signal being the desired signal, and the CM upstream transmit signal being the undesired signal via Equation 3

Equation 3: Set Top Box Desired To Undesired Ratio Estimate (D/U)

$$\frac{D}{U} = [U(Upstream\ Transmit\ Power) - D(Downstream\ Receive\ Power)] - Midsplit\ PL$$

To finish our earlier example, a $D/U = 57\ dBmV - 0\ dBmV - 28\ dB = 29\ dB$. Since the D/U is 29 dB, or 9 dB higher than our previously referenced threshold of 20 dB, this home network will likely require remediation in order to support midsplit based services and therefore would not qualify for a SIK. Remediation would involve improving the isolation between the CM and set top boxes. There are different ways of accomplishing this, either with enhanced isolation splitters providing OP2OP isolation of ≥ 35 dB or via notch filters, whose stop band attenuation would add ≥ 48 dB isolation. Both of the remediation approaches discussed would likely require field installer support.

11. Conclusions

Multiple use cases have been examined where MoCA can uniquely assist cable operators in solving a variety of challenges associated with secure and optimal MoCA deployment. Excessive loss conditions between individual MoCA links can be identified, possibly from incompatible device suckouts. Missing POE filters, negatively impacting security and performance can be identified much earlier in the MoCA deployment process. Lastly, ACI susceptibility issues preventing midsplit service rollouts may be identified using MoCA PL estimates in conjunction with existing DOCSIS telemetry metrics for CMs and STBs.

The additional data flows from MoCA diagnostics can be managed and acted upon based on thresholds aggregating large deployment populations of MoCA-capable devices. The referenced KPIs, including path loss, tilt, and receive power, were illustrated how KPIs can be any meaningful variable needed by cable operators wishing to make diagnostic decisions and the CCDF curve can be a way to facilitate meaningful comparison between established and new performance datasets.

12. Acknowledgements

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13. Abbreviations And Definitions

ACA	Alternative Channel Assessment
ACI	Adjacent Channel Interference
CAE	Customer Account Executive
CATV	Cable Television
CDF	Cumulative Density Functions
CCDF	Complimentary Cumulative Density Functions
CM	Cable Modem
CMTS	Cable Modem Termination System
CPE	Customer Premise Equipment
CW	Continuous Wave
DOCSIS	Data over Cable System Interface Specifications
EVM	Error Vector Magnitude
ExD	MoCA Extended D
FMR	Full Mesh Rate
Hz	Hertz

KPI	Key Performance Indicators
NMFS	non-MoCA-friendly splitter
MFS	MoCA-friendly Splitters
MIB	Management Information Base
MoCA	Multimedia over Coax Alliance
MPTMP	Multipoint-to-Multipoint
OP2OP	Output-Port-to-Output-Port
POR	Point-of-Entry
PNM	Proactive Network Maintenance
PTMP	Point-to-Multipoint
PTP	Point-to-Point
ISBE	International Society of Broadband Experts
SCTE	Society of Cable Telecommunications Engineers
SIK	Self-Install Kit
SNMP	Simple Network Management Protocol
SNR	Signal-to-Noise
SoC	System on a Chip

14. Appendix

All data collected for this paper can be accessed at:

https://github.com/mgarcia01752/SCTE-NOS-2017-JOURNAL-MOCA-PNM-PARADIGM-SHIFT

15. Bibliography And References

[1] SCTE, “Operational Practice for the Coexistence of DOCSIS 3.1 Signals and MoCA Signals in the Home Environment” [Online]. Available: http://www.scte.org/SCTEDocs/Standards/SCTE%20235%202017.pdf

[2] M. Garcia, "SCTE-NOS-2017-JOURNAL-MOCA-PNM-PARADIGM-SHIFT," 2 9 2017. [Online]. Available: https://github.com/mgarcia01752/SCTE-NOS-2017-JOURNAL-MOCA-PNM-PARADIGM-SHIFT.

