White Paper

Remote PHY Architectures: Operational Challenges and Opportunities

Unless you have been living under a rock for the past year or two, you understand that we are currently experiencing a time of unprecedented change in the HFC network including rapid industry adoption of Remote PHY. Insatiable customer demand for downstream bandwidth is the primary driver behind the changes that we are experiencing, and all signs point to the trend continuing if not accelerating. While customers are demanding speed increases that are at or above those predicted by the Nielsen curve, they are not willing to pay a higher price or sacrifice service quality or reliability to achieve them. Fiber-based competitors, both established and emerging, are ready to fill the void if cable cannot deliver, so failure is not an option. In this paper we will discuss what we have learned over the past few years working closely with network equipment manufacturers developing distributed access architectures to address these challenges and early-adopter cable operator customers planning how to best roll out these powerful but disruptive new HFC architectures.

Why Business as Usual for Growing Bandwidth Won't Work Anymore

The demand for increased bandwidth is not a new one for cable operators, but traditional methods of accomplishing this have reached their limitations:

- **More Carriers:** Many existing 750/860MHz and even some 1GHz plants have used all available spectrum, and even with analog reclamation freeing up some additional space there still is not enough available spectrum to add enough DOCSIS carriers to meet upcoming demands.
- **More Bits/Hz:** DOCSIS 1. and its TDMA carriers are generally limited to QAM due to inherent HFC performance limitations, so there are no real opportunities to squeeze more out existing carriers
- **Smaller Service Groups:** Node splits are still being used to shrink service group sizes but are facing both cost and hub rack space/power/cooling challenges

To accomplish these seemingly competing objectives of rapid bandwidth increases while holding the line on cost, cable operators have looked to the CableLabs technology portfolio that CableLabs including:

- **More Carriers:** DOCSIS 3.1 specifies optional upstream and downstream frequency extensions
- **More Bits/Hz:** DOCSIS 3.1 OFDM/OFDM-A & LDPC Error Correction make QAM look easy, and makes QAM well within reach for many plant sections
  - Full-duplex DOCSIS (FDX) is on the horizon. This is a game changer for enabling symmetrical Gb bandwidth but has architectural limitations and is beyond the scope of this paper.
- **Smaller Service Groups:** Distributed Access Architectures (DAA) enabling deeper fiber
  - Remote PHY, Remote MAC/PHY, Remote CCAP

Each of these innovations on their own bring significant value but also present new challenges and opportunities in how HFC plants are maintained, but when implemented in parallel the challenges are multiplied. In this paper we will focus primarily on DAA and the implications that it has on how plant maintenance and troubleshooting are performed.

Why Operators are Investigating Alternative Plant Architectures

As stated above, even with DOCSIS 3.1's abilities to stretch plant frequency ranges and wring more bits out of each Hz of spectrum, node splits are occurring at an unprecedented rate to enable service group sizes required to meet primarily downstream bandwidth requirements. There are examples of major operators globally expecting a 5-10x increase in fiber node counts over the next 5-10 years, and there are isolated examples of even more extreme growth. This exponential node count growth is creating the following challenges:

- **Cost:** The cost of each fiber node and backend gear to support them are not trending down fast enough to match the reduction in number of revenue-generating customers supported by each
- **Hub Rack Space:** CMTS/CCAPs are becoming increasingly more dense, but again not at a rate fast enough to offset the port count growth especially when the racks of required optical receivers and splitting/combining networks are considered.
- **Hub Power and Cooling:** Similar challenge – as more and more gear is crammed into existing hubs the power and cooling required to support them are simply not able to keep up It is worth noting that cable operators are pursuing fiber deep strategies including N+0 for reasons other than purely for service group size reduction. Pushing fiber deeper reduces the opportunities for ingress to enter the plant, and with homes/drops making up 80–90% of ingress sources reducing the number of homes per node also helps in this area. N+0 also removes actives from the system reducing power consumption and maintenance overhead for amp alignment. Looking forward it is expected that full-duplex DOCSIS (FDX) will require N+0, so running fiber deeper today is a sound strategy to prepare for when FDX is needed and available. Cable operators never seem to have regrets about deploying

It is worth noting that cable operators are pursuing fiber deep strategies including N+0 for reasons other than purely for service group size reduction. Pushing fiber deeper reduces the opportunities for ingress to enter the plant, and with homes/drops making up 80–90% of ingress sources reducing the number of homes per node also helps in this area. N+0 also removes actives from the system reducing power consumption and maintenance overhead for amp alignment. Looking forward it is expected that full-duplex DOCSIS (FDX) will require N+0, so running fiber deeper today is a sound strategy to prepare for when FDX is needed and available. Cable operators never seem to have regrets about deploying more fiber, and as 5G mobile services need massive numbers of cells each requiring backhaul, it is unlikely that this fiber will be underutilized.

The Solution: Distributed Access Architecture

The primary answer to the challenges listed above lies in distributed access architectures. By distributing portions of the HFC architecture which were previously centralized within hubs, DAA can overcome many of the cost/space/power/cooling challenges. There are many different variants of DAA currently under development, and industry consensus is that there will be no single winner. While there are many different variants under development the three dominant variants are Remote PHY, Remote MAC/PHY, and Remote CCAPSpecifications

The primary difference between each variant is which portions of the architecture are distributed:

- Physical Layer (PHY): Responsible for the transmission and reception of data between the access terminal and the access network; supports electrical or mechanical interfaces connecting to the physical medium (IEEE) (Bastian, 2017)
- MAC Layer (MAC): Responsible for controlling how devices in a network gain access to a medium and permission to transmit data (IEEE) (Bastian, 2017)

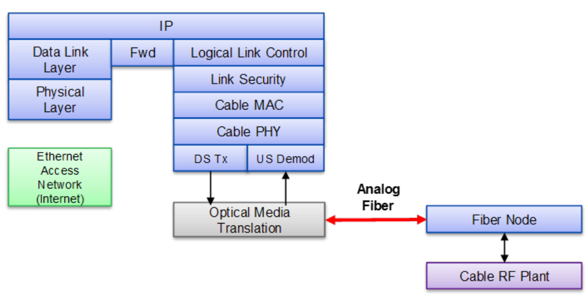

Figure 1 Current - Centralized Access Architecture

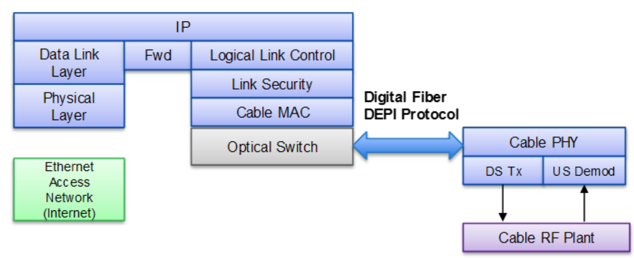

Figure 2 Remote PHY Architecture

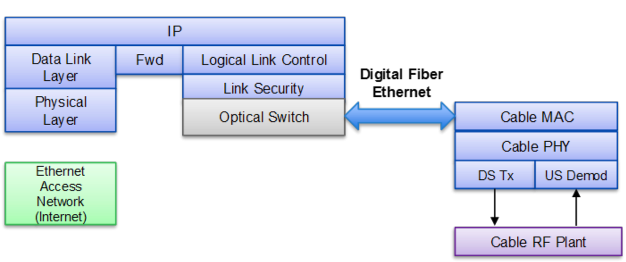

Figure 3 Remote MAC/PHY Architecture

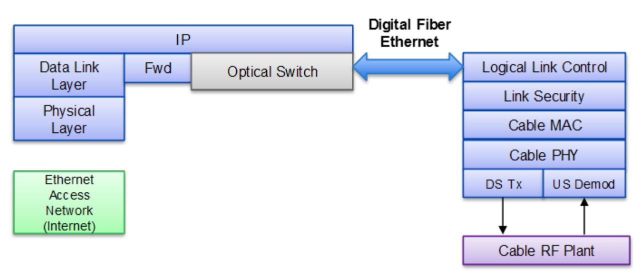

Figure 4 Remote CCAP Architecture

Benefits and Drawbacks of Each Approach:

- A couple of major benefits common to all DAA approaches are:
- Reduction in hub rack space/power/cooling required (savings vary per approach)
- Elimination of the analog optical link
  - ~8db SNR improvement possible with digital link vs. analog
  - Longer fiber runs possible vs. analog
  - Lower cost as digital link is a commodity, not unique to cable
  - Reduced maintenance costs as digital link simpler to set up and is more stable
  - Greater reliability of digital optical link

Details, Pros, and Cons of Each Approach

Remote PHY: In Remote PHY implementations the PHY layer of the CCAP is moved out to the node - essentially the upstream demodulation and downstream modulation functions. The MAC layer and layers above it remain in the hub. The hub-based CCAP core and PHY layer present out in the node communicate via pseudowires to manage timing and other critical functions. Headend space/power/cooling gains are modest in this implementation as the CMTS chassis is still generally present as with CAA but the racks of optical receivers and related physical RF cable routing can be eliminated. This approach is generally favored by traditional CMTS/CCAP vendors, although there are new entrants in this space.

Pros:

- Fully CableLabs specified
- Largest base of vendors developing
- Simplest gear deployed into the field

Cons:

- Timing concerns for long fiber runs
- Smaller reduction in hub space/power/cooling required

Remote MAC/PHY, Remote CCAP: In these implementations both the modulation/demodulation and the MAC layer are moved out to the node. Depending on the level of virtualization employed by each specific implementation the hub space/power requirements can be drastic. In the most extreme examples of Remote CCAP, it is said that these solutions will require only 10% of the rack space, consume 10% of the power, and cost half as much upfront vs a similar deployment using traditional centralized access architectures. This approach tends to be favored by new entrants who don't have existing headend components in their portfolio.

Pros:

- Uses commodity 10G Ethernet optical link and protocols
- Greatest reduction in hub space/power/cooling required
- True Ethernet present at the node

Cons:

- Pushing complexity into the field (upgrades, maintenance, theft)
- Fewer vendors pursuing
- Interoperability concerns, less comprehensive industry standardization

The benefits of DAA are clear, and it is no wonder than most operators surveyed in a recent SNL Kagan survey indicated that they will begin deployment by the end of 2018.

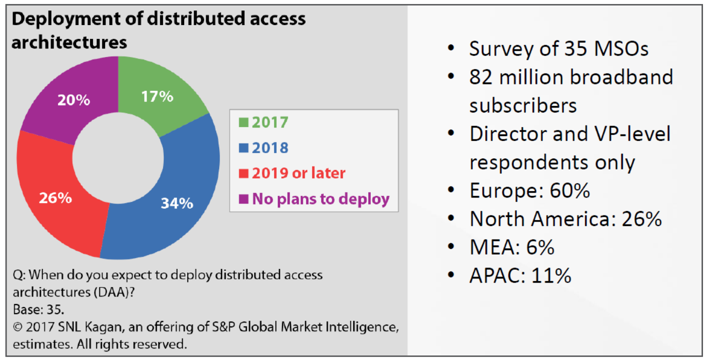

Figure 5 DAA Adoption Timing

The Challenges

Less well understood are the operational challenges that DAA implementation will create and how to leverage the opportunities that it will create. Operators have made significant investments into hub-based monitoring systems and field instruments that interact with them to provide optimal standardized plant maintenance and troubleshooting practices. At the core of all DAA variants is the removal of RF test points from the hubs as the downstream modulation and upstream demodulation functions move out into the field. This is a critical change as it disallows reuse of existing equipment and practices for many of the most common plant maintenance use cases including upstream ingress remediation and sweep.

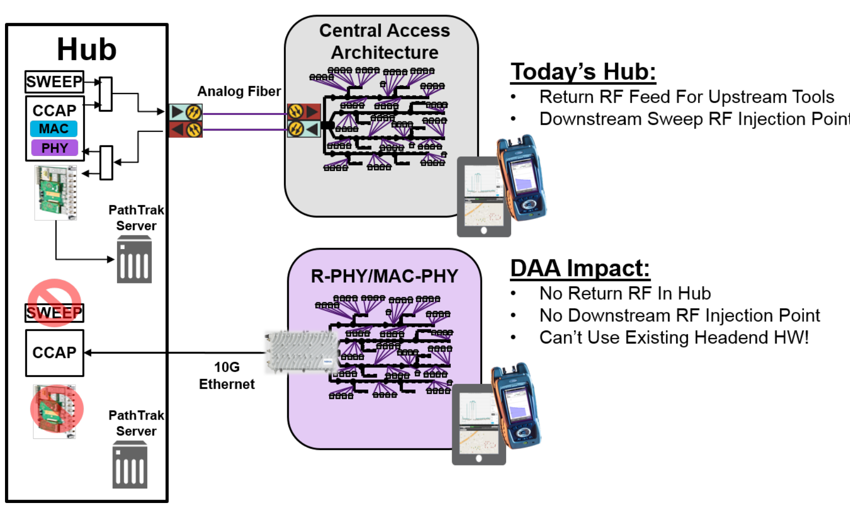

Figure 6 RF Test Points Removed from Hub with DAA

In discussions with operators globally it has become clear that DAA implementation will not be a milestone event, it will be an evolutionary process lasting a decade or more. Many operators will begin with Remote PHY implementations for all greenfield HFC nodes and for major N+0 expansions, later adding Remote CCAP implementations for specific situations. Just as operators tend to not single-source CMTSs today it is also expected that they will also multi-source Remote PHY gear over time. The result of this will be a plant that is a heterogeneous mix of architectures from a variety vendors: a nightmare for operators wishing to maintain standardized methods and procedures for the technicians who will maintain this wide mix of node architecture/vendor combinations on any given day. Add to these changes the transition to DOCSIS 3.1 and frequency extensions that many operators are in the midst of and you have a perfect storm creating headwinds against efficient and standardized plant maintenance processes against efficient and standardized plant maintenance processes.

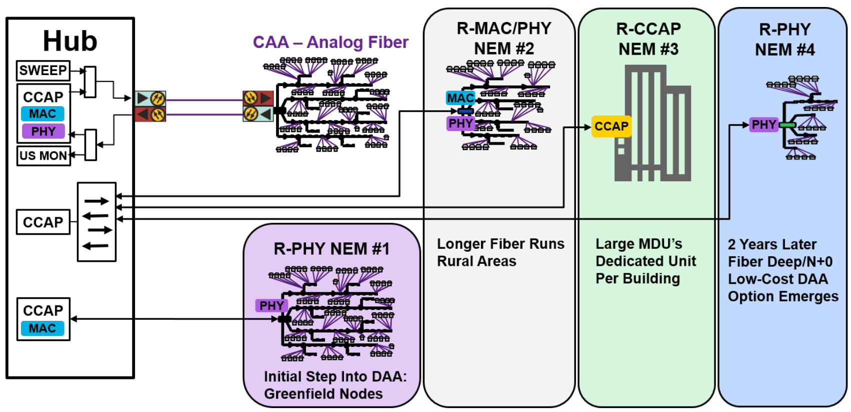

Figure 7 Proliferation of Architecture/Vendor Combinations

How the Industry is Dealing with These Challenges

As an industry we've learned our lessons from the past about making plant maintenance an afterthought for major transitions. The CableLabs PNM working group wrote many exciting new capabilities into the DOCSIS 3.1 spec, and most of these will pass through from centralized architectures to DAA. One problem is that the implementation of these new capabilities are lagging as the network equipment manufacturers (NEMs) focus on getting their gear to successfully pass packets first, and even when they begin implementing the PNM capabilities, gaps will remain. The good news is that forward-thinking operators and test vendors have thought ahead and driven solutions to ensure continuity of test during and after these transitions.

Use Case #1: Upstream Ingress Remediation

This is clearly the biggest issue to address as DAA implementation leaves operators without acceptable methods to address this critical use case. Highly capable remote upstream spectrum analysis is critical to the "85% use case" of ingress remediation. Purpose-built spectrum analysis gear like the PathTrak Return Path Monitoring System located in hubs have served this need well for decades, but without RF in the hubs these systems must adapt. CMTS and CCAP chassis have provided virtual spectral analysis for quite some time, but industry adoption of CMTS spectrum has been sparse to non-existent as current CMTS/CCAP hardware is unable to reliably detect short duration impulse noise spikes that are too common in HFC plants today and have the greatest impact on subscriber services. The good news is that early analysis of DAA hardware from some vendors shows markedly improved results in this area. The key conclusion is that when DAA is implemented resulting in the disallowance of hub-mounted spectrum analysis gear usage, some of the next generation of DAA hardware appears up to the task of replacing it.

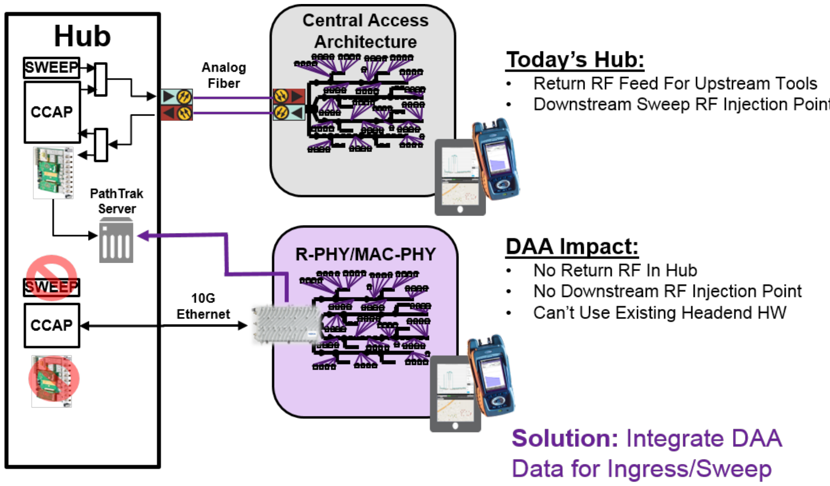

Figure 8 Integrate DAA Data Into OSS

Use Case #2: Sweep

While it is expected that long-term DAA implementations will migrate toward shallow cascade depths, there is still strong demand from operators for continuation of capabilities previously delivered by sweep systems. Appendix I of the CableLabs Remote PHY Specification (CM-SP-R-PHY-I06-170111) suggests (but does not specify) three possible approaches:

1. Use PNM Capabilities
2. Create Add-On HW Modules
3. Develop API With Field Meter Manufacturers

Option1 (PNM) addresses some use cases but has several drawbacks (discussed later in this section) that most operators interviewed believe prevents it from being a complete solution. It is expected to be utilized to help prioritize sweep activities and ensure that time is not wasted sweeping clean plant. Option 2 is highly undesirable due to cost, deployment/maintenance challenges, and creating another point of failure. Option 3 is the preferred direction of the majority of operators that we have spoken with to date.

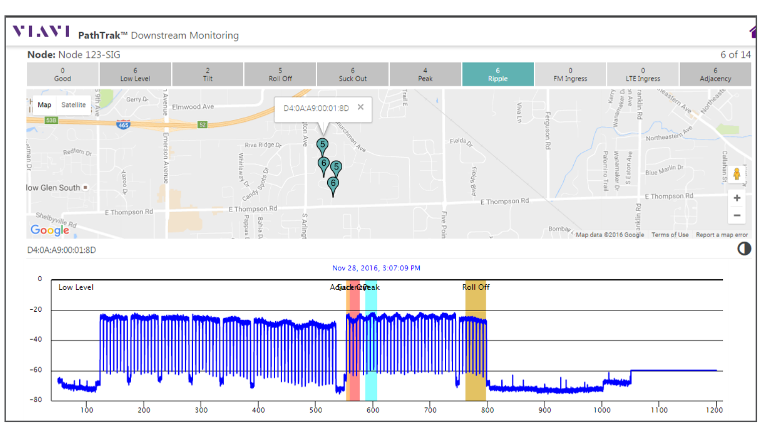

Figure 9 PNM Use To Prioritize Nodes For Sweep

Downstream sweep can generally be addressed by Sweepless Sweep for most use cases (see Figure 10 for details). But operators are still insistent upon demanding that DAA and test vendors deliver solutions for meter-based return sweep as prerequisites of purchase of either system, effectively creating arranged marriages to ensure interoperability.

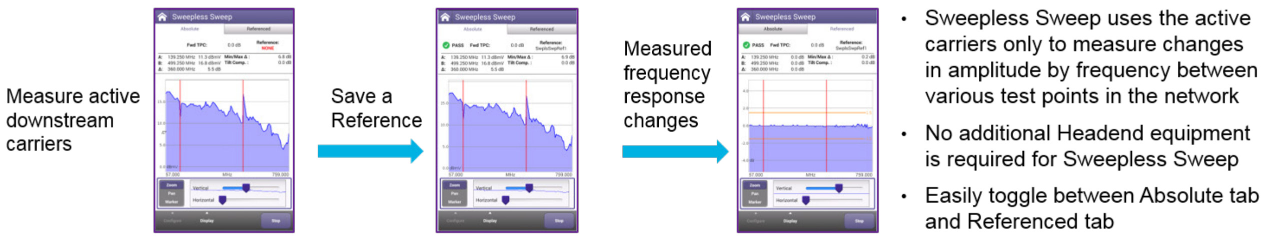

Figure 10 Sweepless Sweep For Downstream

Based on discussions with DAA early-adopter operators, the following criteria were commonly defined as required attributes for DAA-based sweep solutions:

1. Software-Based: Does not require any additional specialized hardware to be deployed
2. Multi-User: Allows simultaneous usage by multiple technicians with no interference
3. Standards-Based: Must use standardized telemetry communication mediums
4. Fast, and Full-Band Coverage: Must not require significant start-up time upon each usage and must cover full frequency band (not just occupied spectrum)
5. Reliable/Always Works: Must not require an active/functioning cable plant or cellular coverage to operate

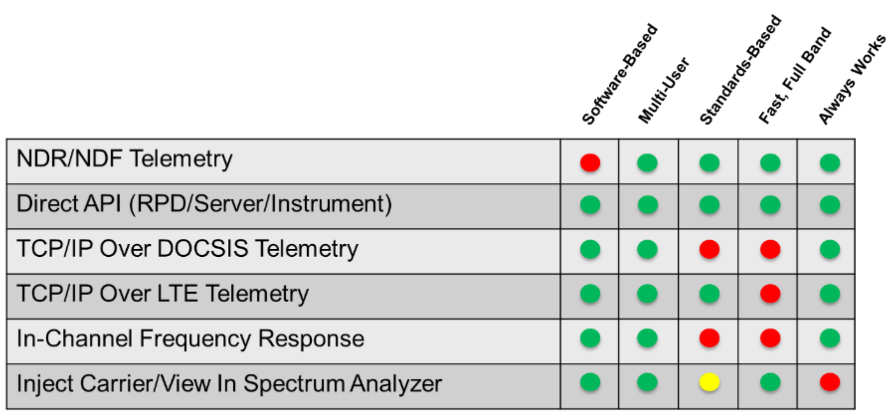

Figure 11 VIAVI Return Sweep Schematic

The following solutions were investigated against the above criteria with the direct digital API appearing as the only option covering all requirements. Figure 12 below illustrates an example implementation of this type of solution. In fully-virtualized form, the R-PHY/CCAP Interface function below is performed by one or more cores within existing virtual machines with more cores being added as needed to cover node count growth. The end result is a virtualized return sweep system that does not require any specialized HW in the hubs while providing an experience identical to that of traditional sweep for field technicians. They use their existing field meter, push the same buttons, and receive results identical to those for the traditional CAA nodes that they are also charged with maintaining.

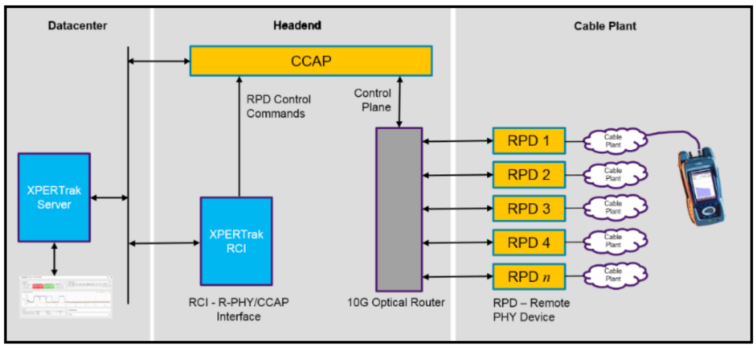

Figure 12 Return Sweep Options vs. Requirements

Use Case #3: Architecture/Vendor Proliferation

Operators have recognized the need to incorporate data from DAA units as virtual probes into their maintenance toolsets replacing dedicated hardware, and there are several options for doing so.

1. Add DAA MIBs into existing or planned internally-developed OSSs
1. Implement standalone OSS from each DAA vendor
1. Utilize existing HFC Maintenance OSS from test vendor

Build or expand internal HFC maintenance OSS: This option is not feasible for operators without internal application development resources, and even for those who do it becomes less desirable as the architecture/vendor proliferation occurs. Developing and maintaining interfaces to all the different DAA vendors is cumbersome, as while some capabilities are standardized invariably there are integration issues as new releases and SW/FW updates are created per-vendor. In general the hidden costs of internally developing and especially supporting and maintaining applications are often underestimated until it is too late. The other major drawback to internal development is the inability to support field meter interaction for ingress remediation and sweep use cases.

Implement standalone OSS from each DAA vendor: Some DAA vendors offer a troubleshooting solution with their service provisioning equipment, sometimes at no additional cost to the DAA hardware purchase. These are often point solutions which support that specific manufacturer's gear but often fall short with coverage of competitor's gear. Breadth and depth of capabilities vary widely between NEMs, but in general these systems are aimed at troubleshooting issues with that manufacturers gear and not designed to be comprehensive plant maintenance tools. These tools also do not support field meter interaction and lack sweep support. Another drawback with this option is that a new maintenance tool must be deployed, maintained, and users trained on its use for each DAA vendor selected. The resulting tool proliferation will also prevent apples to apples comparison of node performance across vendors in a multi-vendor system, confusion from techs on which tool to use for any given node, and overall higher effort and costs to maintain multiple solutions. In addition, being locked into a given providers solution can inhibit second-sourcing opportunities for service provision HW. Even if the DAA units are specified to be interoperable from a service provision standpoint, the differences in supporting toolsets between them can leave operators effectively locked into a single-source situation at times.

Pros:

- Potential lower up-front cost (sometimes free)
- Each point solution tailored to work well with that specific vendors gear

Cons:

- Spotty coverage for competitors gear
- No field meter interaction/sweep
- Tech confusion – different tool per node
- Higher overall TCO to deploy, train, and maintain multiple point solutions
- Add risk to second-sourcing network equipment, much bigger $ than T&M

Utilize existing HFC maintenance OSS from test vendor: Only test vendors like VIAVI offer solutions which support interaction with widely-deployed field instruments. These solutions are architecture and vendor neutral, support gear from multiple network equipment vendors equally, and provide consistency in measurement. These systems are already deployed at most operators and heavily used by multiple user groups minimizing training requirements. Operators can rely on a single system to seamlessly support their gradual transition from using dedicated monitoring hardware for centralized access architecture nodes to using data from DAA nodes as their networks evolve. Technicians don't need to know the underlying node architecture or vendor, they simply search for the node name in the tool and are presented with standard set of reports and live analyzers that look the same regardless of node type.

Pros:

- Use single system during HFC network transitions regardless of plant changes
- Leverage existing system, nothing new to maintain or train users on
- Not tied into any single NEM solution (de-risk NEM 2nd sourcing)
- Professionally supported and maintained solution, less likely to become shelfware

Cons:

- Higher perceived up front cost vs. internal development or tools included with DAA HW purchase

What will the Future Hold for DAA?

While we will not claim that our crystal ball is 100% accurate, we have seen commonalities in certain areas in working with DAA vendor development teams and early adopter service providers to make the following predictions.

1. Node counts in most developed regions will ***at least*** double in the next 5 years due to node splits, many operators/regions will experience much greater growth in node counts
   - a. Many systems have >300 subs/node today, targeting <100 in medium term
2. DAA will become the default for fiber deep/N+0 programs within 2–3 years as the technology matures
   - a. But a significant number of CAA nodes will remain 5 or even 10 years from now. DAA rollout will be gradual and evolutionary.
3. Homes connected via HFC will still greatly outnumber FTTx connections 5 years from today, likely still a majority 10 years from now
   - a. Full-duplex DOCSIS will enable symmetrical Gb services using existing drops at a fraction of the cost of running fiber to each home

How to Prepare for These Changes

Failing to plan for this confluence of changes is the equivalent of planning to fail. A lack of thoughtful preparation by service providers may only be discovered after starting field trials, uncovering that DAA implementation has left them with either no effective method of maintaining and troubleshooting their plants or at best a fragmented set of point solutions covering only part of their needs. The good news is that operators need not start from scratch as CableLabs, early adopter service providers, and forward-thinking test vendors have already laid the groundwork for you. There are solutions that are either available today or in active development to ensure continuity of test, but you must properly plan your implementation to include these solutions.

Key questions to ask when considering DAA equipment vendors:

1. Do they support CableLabs PNM capabilities (or have published roadmap to do so)?
2. Are their solutions accessible for 3rd party access or are they closed/proprietary?

Key questions to ask regarding alignment of tool strategy with DAA deployment:

1. Do you have path to sustain your core T&M capabilities?
2. Will your deployed base of instruments continue to interoperate with your OSS?
3. How will you handle future architecture/vendor proliferation?
   a. Can your tools support all combinations simultaneously?
   b. Is use of multiple parallel point solutions scalable from an IT, technician, and dashboarding standpoint?

We are in the midst of a period of unprecedented change in the HFC network. While at times it all may seem overwhelming, we will clearly emerge with a stronger competitive position to ensure that cable will remain the most cost-effective option to meet customers' broadband needs for at least another decade if not longer. Distributed access architectures are a prime example of this – they will provide the solution needed to enable exponential node count growth but will be highly disruptive to plant maintenance practices. By planning ahead and leveraging advancements available from CableLabs and leading test vendors, cable operators can retain critical plant maintenance and troubleshooting capabilities as well as introduce powerful new ones. Change is good for those who know how to take advantage of it.

VIAVI Solutions

Contact Us **+1 844 GO VIAVI**
(+1 844 468 4284)

To reach the VIAVI office nearest you,
visit viavisolutions.com/contact

remotephy-wp-cab-nse-ae
30186118 901 1018