VIAVI Solutions

White Paper

How DAA and DOCSIS 3.1 are Enabling 5G to Become the Next Killer App for Cable

Introduction

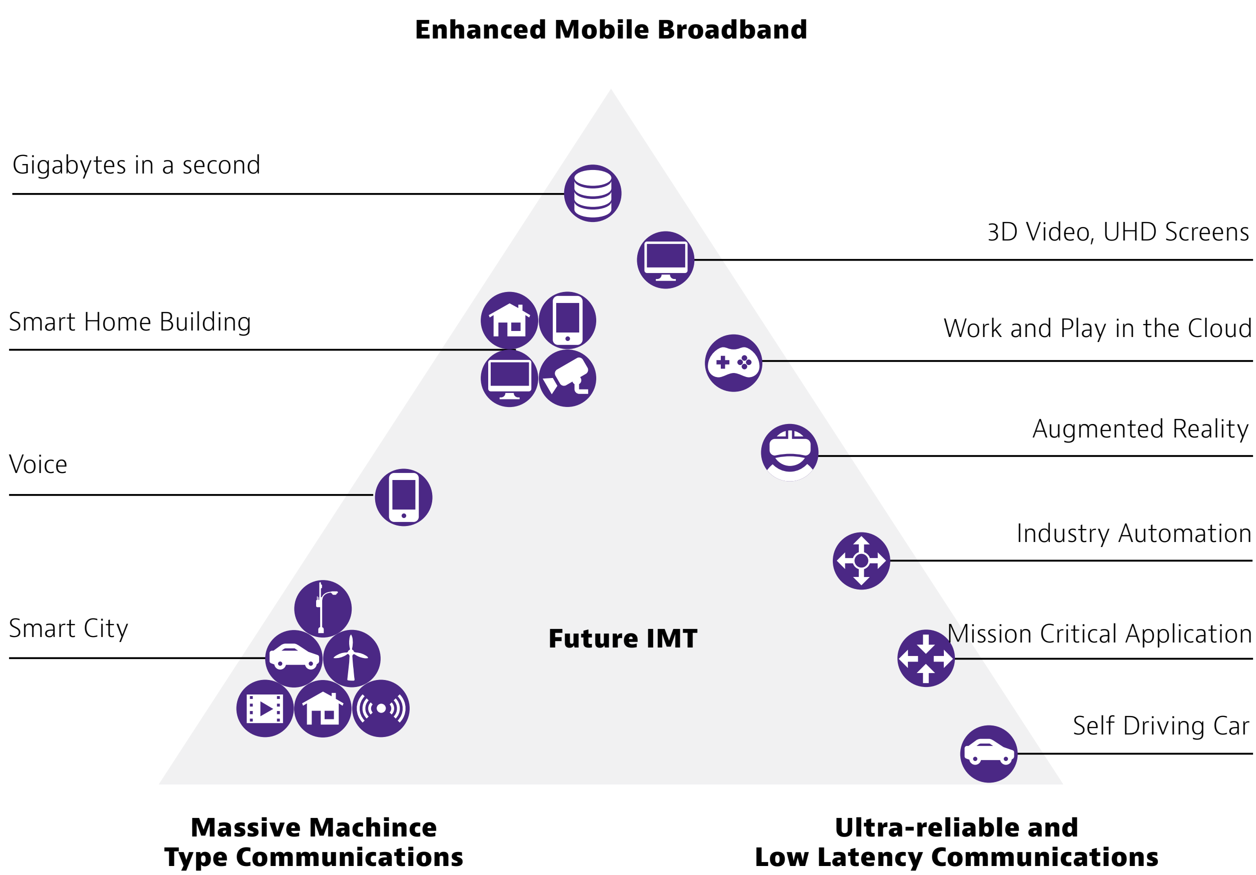
5G. Two simple characters which have created so much attention in telecom circles and in the media in general recently. This attention is not without merit however, 5G promises to revolutionize many aspects of our everyday lives and will likely enable new applications that we haven't imagined yet. Mobile connectivity has expanded at a rapidly increasing rate after the transition from 3G to 4G/LTE, and the 5G transition is expected to create an even more significant step change through the speed, latency, and reliability improvements that it will deliver. But none of this can happen without significant transformation of the wired networks which will ultimately provide connectivity to the 5G wireless radios.

5G can be both a friend and foe to cable operators, winners and losers will be decided based on who has the right network in the right places. 5G fixed wireless access (FWA) threatens the cable stronghold on residential broadband services in many regions as it eliminates deployment of physical last mile infrastructure to connect each home as a barrier to entry, but questions remain about the short-term economics behind this use model and its sustainability as a long-term substitute as data consumption rates continue to accelerate. FWA and 5G in general also create a vast opportunity for cable operators to provide various services for the 20-50x number of wireless access points 5G will require to support some use cases.

Anticipated 5G Use Cases

The promise of 5G goes well beyond the ability to download HD movies faster or enable more reliable streaming of Netflix while on the move. The numerous envisioned use cases for 5G can be boiled down to three primary categories:

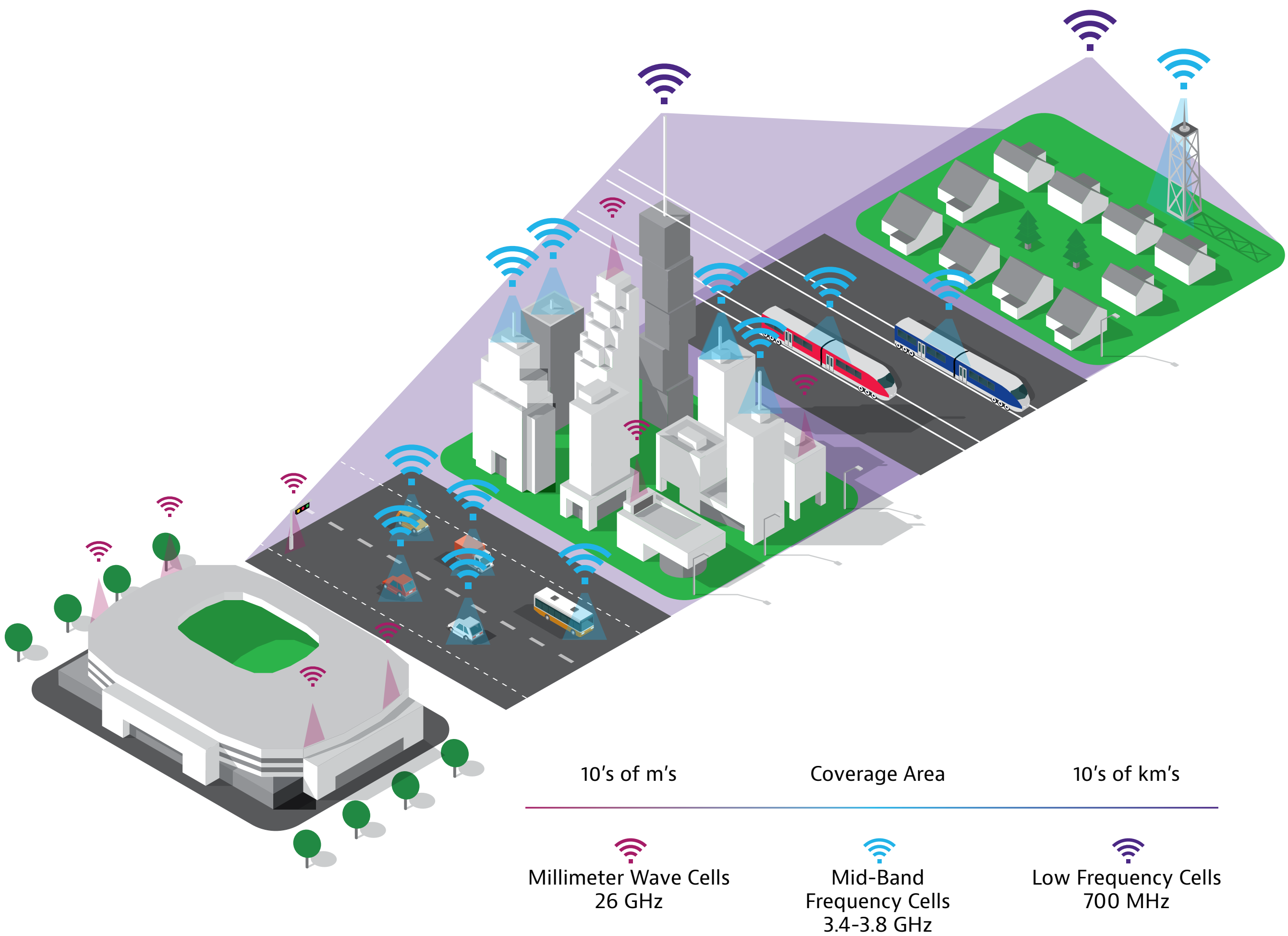
- **Enhanced mobile broadband (eMBB)** delivers high bandwidth data services with peak rates of 10Gbps or more. Augmented/Virtual Reality (AR/VR) and 8K/UltraHD video are examples of applications that would drive this use case.
- **Ultra-Reliable Low Latency Communication (uRLLC)** delivers millisecond or lower latencies needed for real-time applications along with high reliability and 99.9999% availability. Vehicle to Vehicle or Vehicle to Infrastructure (V2X) communications and remote surgery are examples of applications enabled by uRLLC.
- **Massive Machine Type Communication (mMTC)** use model is focused on Internet of Things (IoT) and smart city applications which require connectivity for hundreds of thousands of devices per square km while maximizing power efficiency.



Network Impact

Numerous network changes will be required to deliver on the seemingly competing objectives of the use cases above.

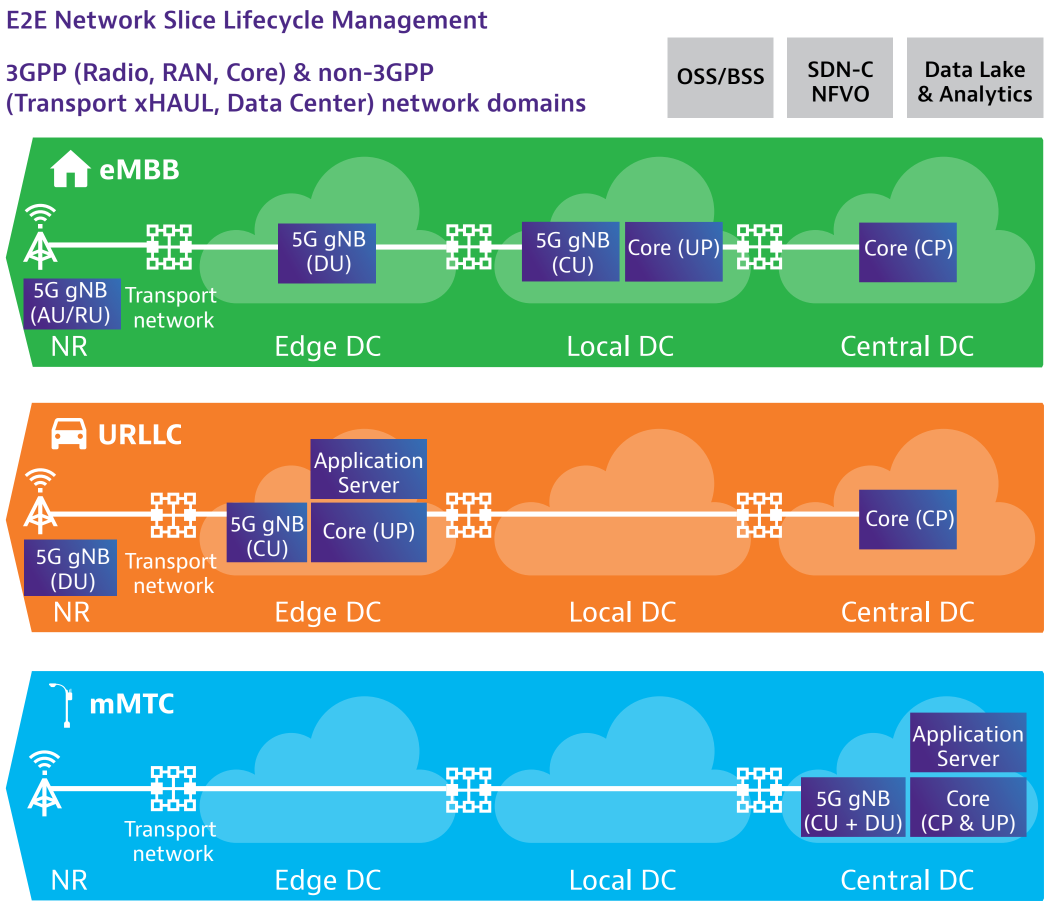
Changes in spectrum bands to be used will drive significant densification of 5G access points and the network that will be used to interconnect them. Access point coverage areas in general are inversely proportional to their frequency band – the higher the frequency the lower their coverage area. The graphic below illustrates general frequency bands, their uses, and how their deployments will often overlap.



The mm-wave band has immense bandwidth capabilities but very limited range due to their propagation properties. Where a 600MHz macro cell can cover an area of hundreds of square kilometers, a mm-wave small cell may only cover 100m radius or less depending on terrain, etc. The result of this is a 20-50x increase in the number of access points that will be required to cover select use cases from 4G to 5G.

Macrocells covering large areas are still expected to be used in 5G, but most will likely be operating at lower frequencies (600MHz) for covering larger areas albeit at much lower data rates. The use of small cells to allow precision targeting of services where needed is expected to drastically increase. Herein lies one of the larger opportunities for Cable operators as each of these small cells will require installation, real estate, powering, backhaul, and ongoing maintenance. Cable is well positioned to provide some or all of these small cell requirements, and deployment of distributed access architectures (DAA) will only increase these revenue opportunities for MSOs.

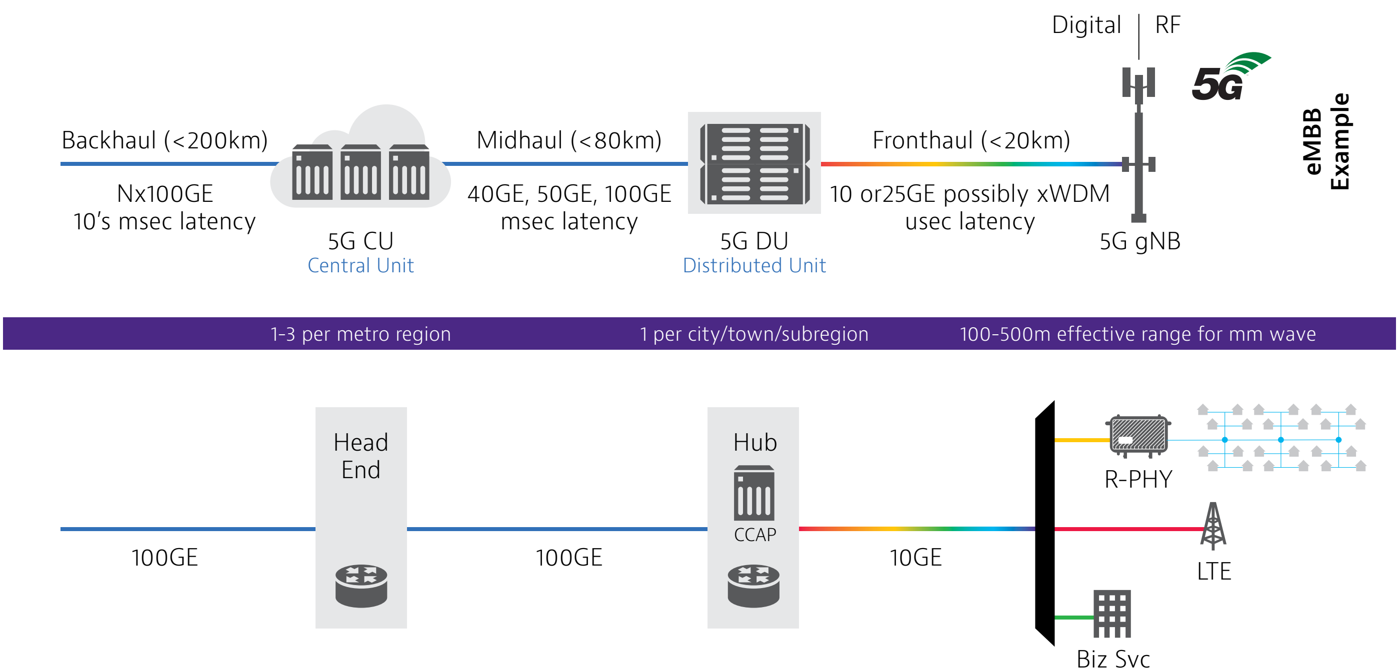
In much the same way that cable operators are redistributing various network functions per specific system needs through the different DAA variations, mobile operators are tailoring their network architectures to match the needs of specific situations. The image below shows the ideal breakout of the different network functions to service each of the primary use cases.



Building separate networks to service each use case in a region is cost-prohibitive, but through virtualization of these functions and network slicing a single infrastructure set can be selectively and dynamically "sliced" to optimally service each of the use cases simultaneously. It is beyond the scope of this paper to deep dive network slicing but there is a lot of great reference material available for those who desire to learn more.

Similarities Between 5G and Cable Distributed Access Architectures

As stated above, there are several parallels between the evolution of mobile networks to support 5G and Cable network evolution. Some of these similarities are evident when an eMBB-focused 5G architecture is overlaid on a Cable Remote PHY network:



Similarities:

- 5G Central Unit (CU) and cable Headend
    - There are typically 1–3 serving a major metro area or region
    - Both connect to the core network
- 5G Distributed Unit (DU) & cable Hub
    - Both are deployed in similar proportions relative to their parent elements (Central Unit/Headend)
    - Both are typically fed by 100G Ethernet
- 5G gNB & DAA Node
    - Both are demarc points where digital signals are converted into RF domain
    - Both cover relatively similar geographical areas depending on terrain, population density, etc
    - Both are typically fed by 10GB optical Ethernet
    - Both use IEEE 1588v2 PTP timing for synchronization

As one studies the similarities between 5G and HFC networks many of the revenue opportunities for Cable operators become evident:

xHaul (Fronthaul, Midhaul, Backhaul)

- Backhaul from CU out to the core network can also leverage 100GE links present in cable networks
- Midhaul between 5G DU and CU can leverage 100GE links commonly used to interconnect hubs to centralized headends
- Fronthaul between the 5G DU and gNB's can often be serviced by 10GE links, exactly what cable operators are going to be peppering widely across their footprints as part of DAA deployments.

Cable operators have several options to monetize their deployed fiber assets to provide 5G xHaul

- Lease dark fibers already deployed, characterized, proven ready to support 5G needs
- Lease spare wavelengths on existing DWDM links
- Offer Ethernet bandwidth as a service using deployed fiber
- Offer DOCSIS 3.1 xHaul – Potentially
    - DOCSIS 3.1 is being studied as a potential 5G xHaul option, especially once Full Duplex DOCSIS (FDX) is launched to provide symmetrical 10GB services. Traditional DOCSIS latency in the 10's of milliseconds was fine for 4G backhaul but does not meet the needs of many 5G use cases. To address this challenge research is underway into innovative methods to embed DOCSIS latencies within established 5G latencies enabling incremental latencies in the 1–2msec range. Details of Bandwidth Report (BWR) and Pipelining techniques are beyond the scope of this paper but there are excellent resources available covering full details.

In addition to connectivity, all 5G access points will need a physical location to be mounted and powered, and cable is well-positioned to support both needs. Cable networks have infrastructure in place to provide typically 60V or 90V anywhere in the plant from the node to the last amplifier in each cascade. This covers many locations that are far from the nearest electrical utility, making 5G access point powering via HFC an attractive option. Cable operators also have pole attach rights in key locations to support both the HFC network as well as Wifi hotspots. Consumer use cases for 5G mobile data and Wifi are often similar, so the specific locations that cable operators have chosen for hotspot deployment based on high density of mobile data users are often ideal for 5G access points as well. There are operators strand-mounting 4G access points today although the differences in antenna requirements for some 5G use cases may make this more challenging going forward.

The opportunities for cable operators to leverage their assets for 5G support and generate incremental revenue are many, and the one major underlying trend than enables most of them is deployment of Distributed Access Architectures. DAA is a key enabler to shrinking DOCSIS service group sizes through node splits and pushing 10GE fiber deep into MSO networks, but its implementation also creates many new challenges for those who must monitor and maintain the network.

Framework for Efficiently Operationalizing DAA

The diagram below provides a general framework to guide thoughts around planning for, deploying, and maintaining DAA nodes in your network. It should be looked at more as a menu than a recipe – not all items will apply in all cases but regardless it is a good starting point for planning your specific rollout. This framework was created and refined through close interaction with early-adopter MSO's of all sizes from around the globe and leading DAA network equipment vendors. While there is inevitably some variation from provider to provider, many of the general themes were quite similar across the board.

Headend/Hub Construction	Fiber Construction	RPHY Installation and Cutover	Maintenance
Network Equipment Installation Connector end face inspection DWDM Ethernet and Transport test MPO and AOC test GPS antenna test **Shelf RPD Verification** Characterize RF DOCSIS service test Video test Voice test	**Deploy new fiber link/ Upgrade existing plant** Connector end face inspection Fiber Characterization (IL/ORL/OTDR/CD/PMD) **Install DWDM passive components** Connector end face inspection End-to-end channel loss and continuity (DWDM OTDR)	**RPD Install** Connector end face inspection SFP+ Optics test Ethernet test PTP test **RPD Configuration** Characterize RF DOCSIS service test Sweep	Leakage Ingress suppression PTP wander tests Video test DWDM Optical Power levels Fiber fault location · Break, bend Service Assurance Tests · Fiber, HFC, Ethernet **All construction and installation tests potentially applicable**

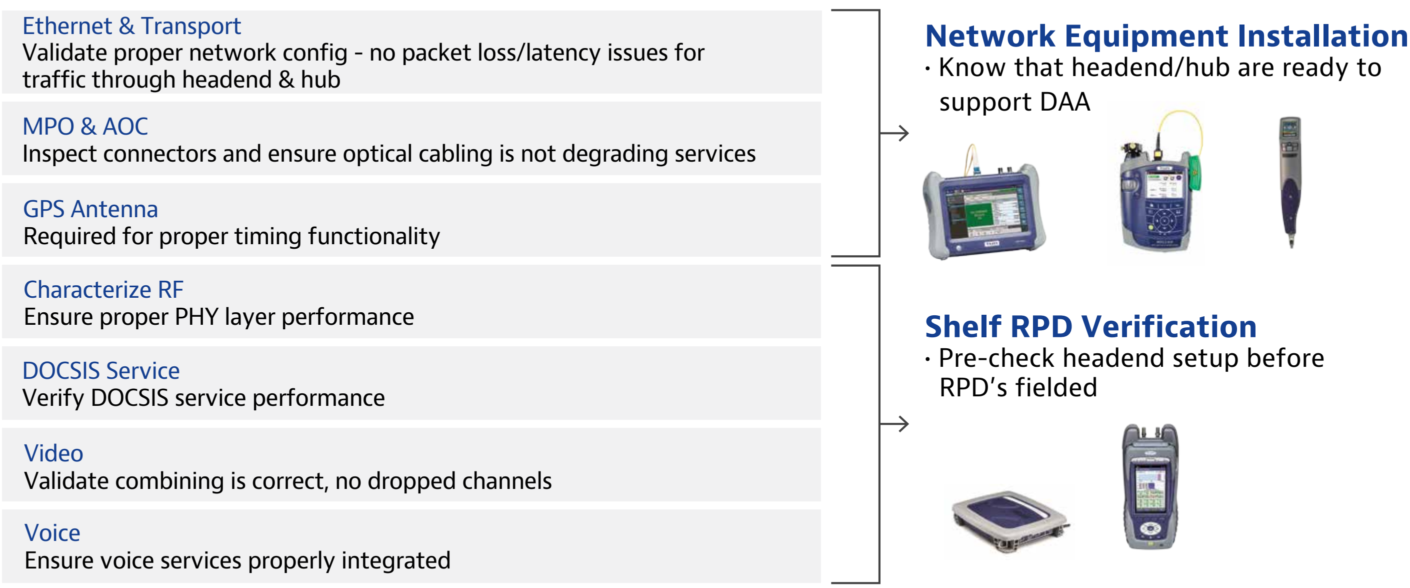
Test Considerations Across DAA Deployment Lifecycle

Note that the DAA deployment lifecycle above is broken into four distinct phases:

- **Headend/Hub Construction –** In this initial phase the service provision equipment and portions of the transport network are prepared to support primarily the inside plant segment of the DAA network.
- **Fiber Construction –** This phase generally occurs either after or in parallel with Headend/Hub construction. The focus here is characterizing existing fiber and deploying/testing/characterizing new fiber, muxes, and other optical components as needed to support the new network architecture.
- **DAA Node Installation and Cutover –** This phase is where the actual DAA node is physically installed, configured, tested, and services cut-over.
- **Maintenance –** This includes activities that are needed to monitor, maintain, and troubleshoot DAA nodes after cutover. Note that this list may also include most of the tests included in previous sections as different types of problems emerge in normal network operation.

Headend and Hub Construction

This phase is all about ensuring that service provision equipment and supporting network infrastructure are prepared to support DAA nodes once deployed.



Headend and Hub Construction Considerations

This phase can be divided into two primary sections:

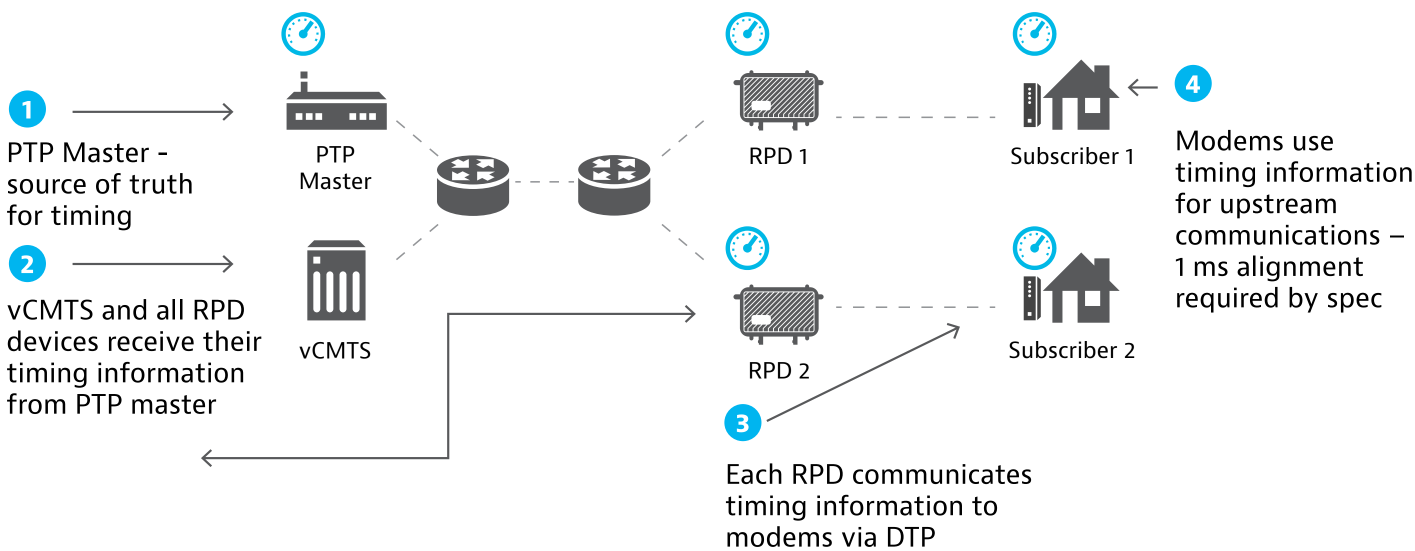
- Network Equipment Installation
- Shelf RPD Verification

Network Equipment Installation can include physical installation and configuration of new CMTS/CCAP chassis. Some operators will take this opportunity to consolidate CCAP's and migrate them upstream into headends, with the ultimate longer-term goal of virtualizing them within data centers. This is also the point where leaf/spine architectures are sometimes introduced enhancing network efficiency and resiliency but also introducing new complexities. Besides testing the CCAP's themselves for proper functionality, the network interconnecting them must be tested to ensure no packet loss or latency issues.

As these changes occur and network functions virtualize and migrate upstream, headends start looking more like datacenters. This trend drove the adaptation of the telco CORD acronym (Central Office Rearchitected as a Datacenter) into HERD (Headend Rearchitected as a Datacenter) for cable. Two common datacenter technologies that have begun migrating into Cable are MPO (Multiple Push-On) connectors and AOC (Active Optical Cables).

Both allow operators to increase density primarily in headends but also improve efficiency. On the flip side both new-to-cable technologies also introduce testing challenges. MPO connectors are cumbersome to inspect without the right tools, and a single contaminant can take out multiple fibers due to their close proximity within the connectors. With AOC's cables now become active components and must be tested for performance/bit errors in addition to basic connectivity.

Network timing is critical, especially for Remote PHY nodes which split the MAC and PHY layers sometimes at distance of 10's of km. PTP (Precision Timing Protocol) is the most common method used to maintain network sync for R-PHY nodes, but it can also be used for video/audio sync in R-MACPHY nodes. PTP timing requires connectivity with the GPS satellite constellation, testing of the GPS antenna is critical to enable reliable PTP timing functionality.

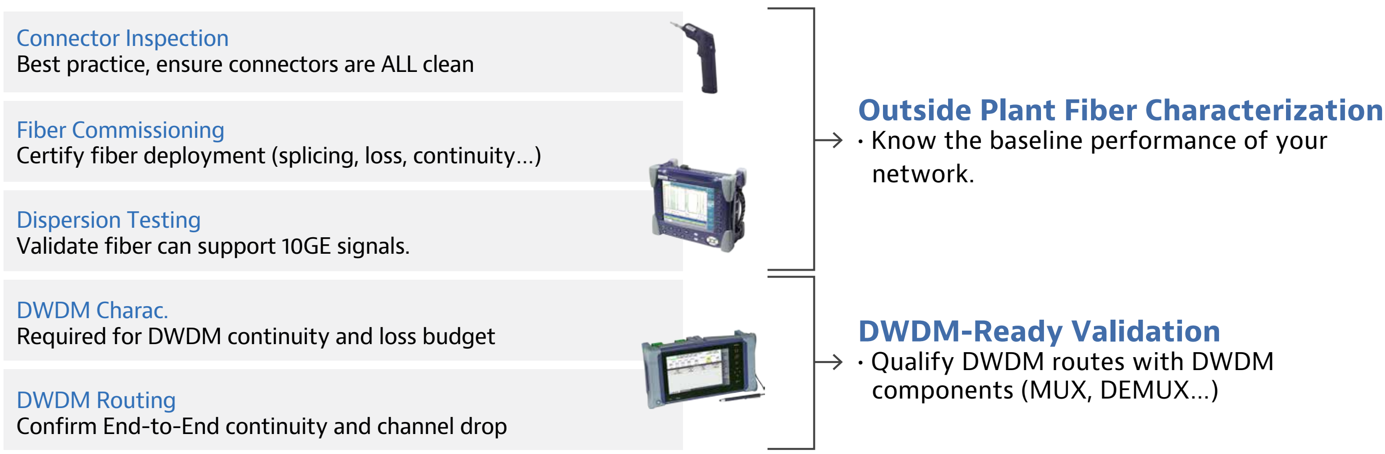


PTP Use in R-PHY

Shelf RPD Testing is sometimes used as a pre-check to verify that everything is ready from hub/headend/network standpoint to support future DAA node cutover. By turning up a sample DAA node within the headend, headend-based functionalities can be tested long before the first DAA node is sent out to the field for deployment. Video is a great example of a functionality that can't be thoroughly tested before turning up the first DAA node. When headend/hub changes are made in traditional networks a common verification practice is to connect a set top box at the output of the combining network and flip through the channels to verify that all are present and working. This is not possible with DAA because there is no RF present in the headend/hub to connect a set top box. Even if RF were available there would be nothing present to test—the video signal itself is created for the first time at the DAA node. Turning up a sample shelf DAA node allows verification of headend support for DOCSIS, video, and voice capabilities before calling the headend/hub construction phase complete.

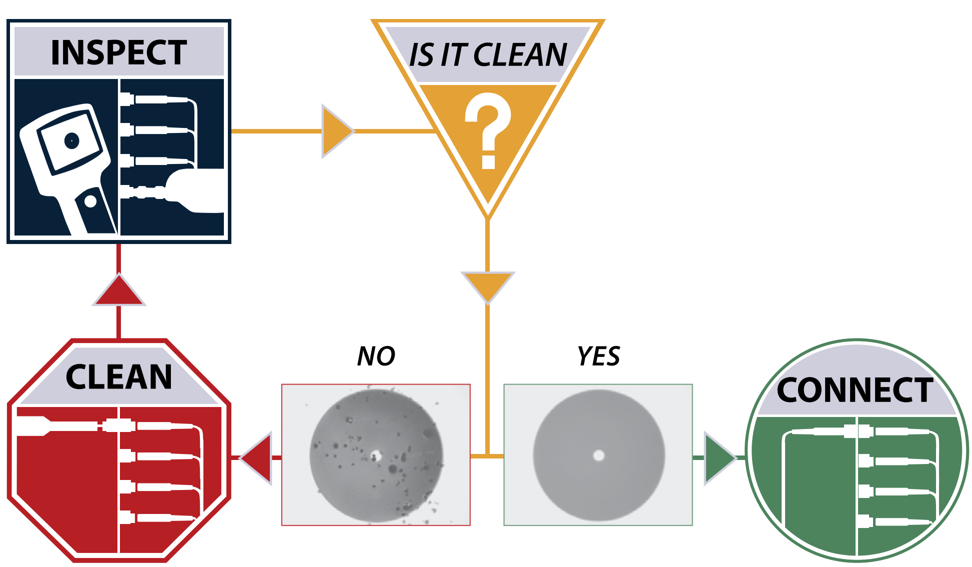
Fiber Construction Workflow

This phase focuses on ensuring that the fiber portion of the network is ready for DAA node installation and turnup. This phase naturally separates into the outside plant fiber characterization and DWDM-ready validation sections.



Fiber Contruction Considerations

Anytime that fiber connectors are being connected cleanliness is of the utmost importance. Multiple studies have shown that contaminated or damaged fiber end faces cause 80% or more of fiber-related networking issues, always remember to inspect before you connect.



Outside Plant Fiber Characterization includes baselining optical characteristics for both new fiber being deployed and existing fiber. Just because fiber deployed 20 years ago has performed well with legacy low-speed analog signaling does not mean that it is capable of supporting services needed to support 5G and other higher-speed use models.

Full fiber characterization cannot be performed without taking a network out of service, and DAA deployment provides the perfect opportunity while the network is already being taken down to ensure that deployed fiber assets can deliver advanced services when needed in the future.

Typical Fiber Characterization tests may include:

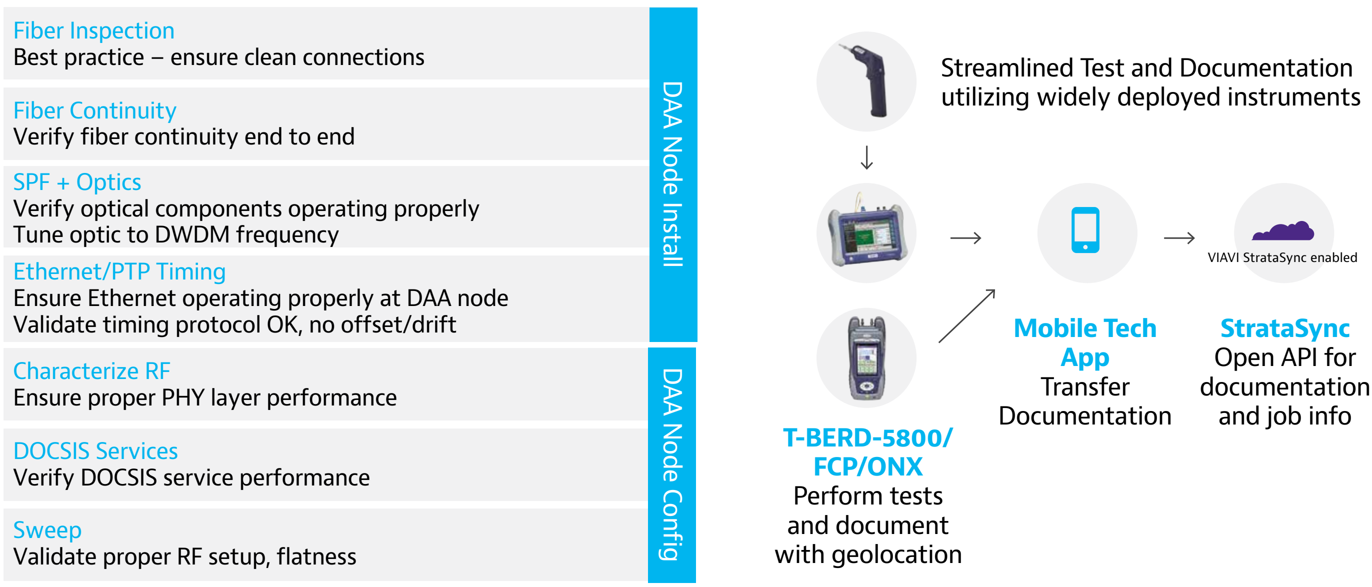
Test Parameters	Measurement
Connector Inspection	Inspection Scope
Bi-directional Insertion Loss	Loss Test Set
Bi-directional Optical Return Loss (ORL)	Loss Test Set
Bi-directional connectors/splice measurements	OTDR
Distance Measurement	OTDR
Reflectance Measurements	OTDR
Polarization Mode Dispersion (PMD)	PMD Analyzer
Chromatic Dispersion (CD) measurement	CD Analyzer
Attenuation Profile (AP) measurements	Spectral Analyzer

Some of the testing may seem obvious (Insertion loss, optical return loss, reflectance), but the tighter Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD) specifications to support 10GE signaling reintroduces the need for dispersion testing. While counterintuitive, dispersion is generally not a problem for faster 100GE links as they often use coherent optics which are more robust to this problem.

The second portion of the Fiber Construction Workflow focuses on DWDM functionality. DWDM is frequently used in DAA deployments to better leverage existing deployed fiber as well enabling future revenue opportunities. Once individual fiber links have been characterized, end-to-end DWDM route validation is needed to ensure complete routes are within specification. DWDM OTDR's are required to test for end to end continuity, loss, etc through the MUX's/DEMUX's present across individual routes as well as full-channel testing across each MUX/DEMUX pair.

DAA Installation and Cutover Workflow

As its name implies, this section is split between testing required during the actual DAA node installation and testing required during the configuration and cutover.



DAA Installation and Cutover Considerations

DAA Node Installation testing begins with fiber inspection and cleaning (if necessary) and end to end continuity check – nothing else matters if signal is not present on the fiber. Next steps include verifying that the optical components including the SFP are working properly. If tunable SFP's are being used they must be tuned to correct wavelength at this point. Tunable SFP's are gaining in popularity despite their higher cost/unit vs fixed wavelength units. The ability to stock just one SKU in each truck capable of covering all wavelengths vs 16 or more different SKU's makes them an attractive option for an increasing number of operators. Once the optics are up and running it is important to run Ethernet validation tests including PTP timing tests. Ethernet connectivity to CCAP and end to end throughput testing ensures the performance and stability of the Ethernet link feeding the node.

For DAA Node Config and Cutover, the focus is on ensuring that the services provided by the node are operating properly. Standard DOCSIS service testing at the node output validates that specified services levels can be met, and RF testing including sweep ensure that the RF setup is solid and won't be the cause of intermittent problems later.

DAA Maintenance and Troubleshooting Workflow

Once the entire DAA value stream is operational and nodes are cut over, they will still need to be monitored and maintained. While many operators will drive fiber deeper into their plant via DAA deployment, most of the drivers of plant maintenance remain as very few operators are pushing to N+0 with cascade depths typically remaining at N+3 or higher. In a DAA plant squirrels will still feast on cables, cars will still run into poles, and most importantly homes/drops will continue to drive ingress remediation truck rolls. The need for plant maintenance does not change, but how it is performed must change as DAA transforms networks.

Leakage
Efficiently find/fix plant integrity issues

Ingress Suppression
Continue to address the "85% problem"

PTP Wander
Ensure timing issues don't cause BER

PTP Wander
Verify correct channels present and in-spec

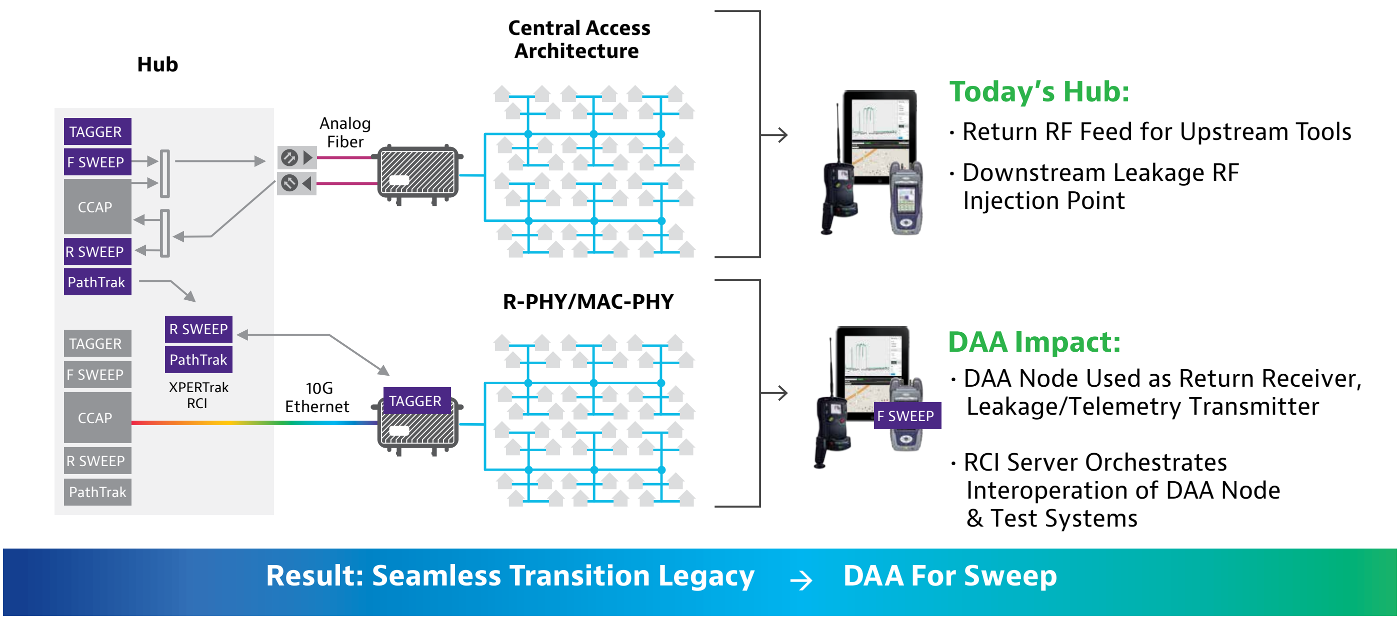
Fiber Assurance
Find breaks faster proactively address bends

HFC Assurance
Detect and localize QoE-impacting plant issues

Ethernet Assurance
Validate end to end performance to detect issues before customers complain

DAA Maintenance & Troubleshooting Considerations

It is well understood by now that all DAA variants eliminate RF test points from hubs, disallowing the use of traditional rack-mounted return path monitoring, forward/return sweep, and leakage taggers. With ingress remediation commanding 85+% of maintenance tech time, it is critical that operators retain essential capabilities like return path monitoring and leakage to address it. Return sweep is also still considered mandatory by operators globally for amp alignment, critical troubleshooting use, and as a companion to PNM tools. Fortunately, a solution has been developed in cooperation between the leading test vendor and all major DAA infrastructure vendors that enables reuse of existing field meters and technician workflows for return sweep, and upstream ingress monitoring and remediation. Based on CableLabs standards, this solution is applicable to networks deploying DAA systems from any vendor with CableLabs compliant NDF/NDR implementations. Use of DAA nodes to transmit leakage tags was an early request from operators to DAA vendors and is also now generally available.



Virtualization Enables Test Capability Continuity

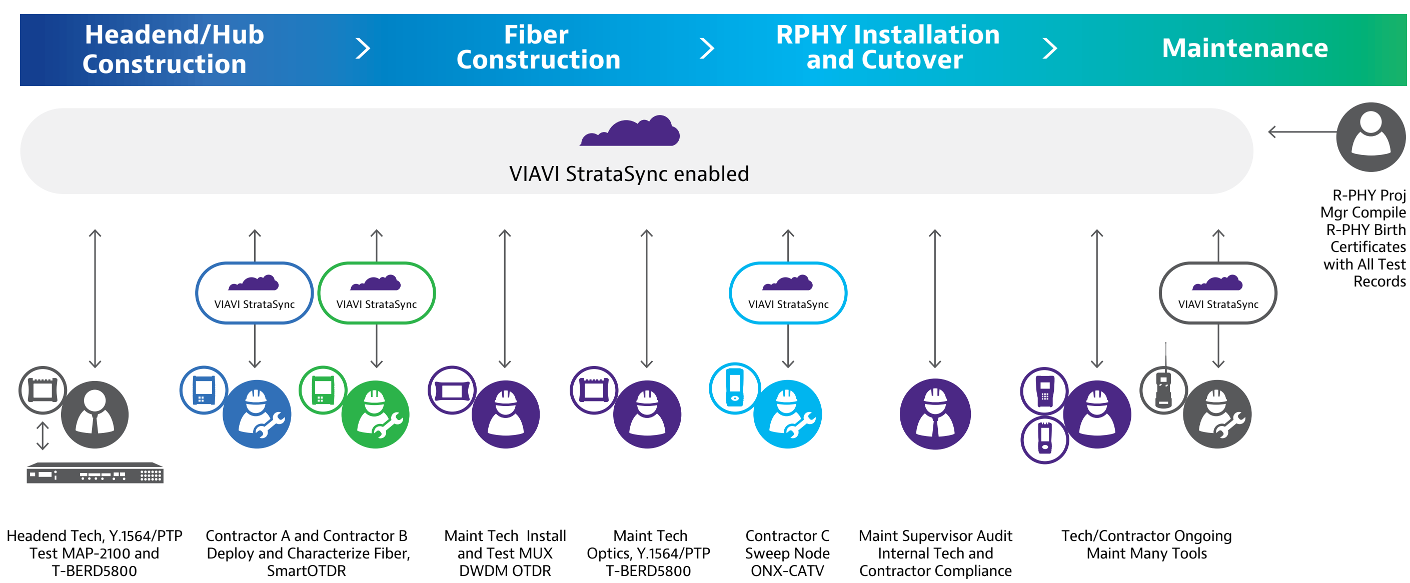
Beyond the field activities listed above, assurance systems are still critical to ensure that operators can:

- Quickly be alerted to issues impacting subscriber QoE
- Trend network performance to spot emerging issues before they become customer impacting
- Maximize maintenance ROI by focusing work on issues that matter most

As discussed earlier, PTP timing accuracy is critical to maintaining network synchronization. Complete loss of PTP services are catastrophic especially for Remote PHY nodes as they will cease to operate but as a result are relatively easy to detect with the correct test gear. Less obvious are subtle shifts in PTP timing, networks may still function but will begin to experience BER. Without proper training and test capabilities these situations are impossible to diagnose for maintenance technicians and will likely result on excessive time chasing false symptoms and customer frustration.

DAA Deployment Project and Data Management

By now you should have a good understanding of the types of tests that need to be considered at each stage of a DAA deployment lifecycle, why they are needed, and some of the challenges presented at each stage. The bigger challenge comes in when the overall lifecycle is viewed in its entirety from a program management standpoint including the interdependencies between stages. There are many different workgroups involved including both direct and contractors, a wide variety of test equipment, and a ton of test data to be collected, analyzed, and stored. Knowing when all prerequisite tests have been completed and passed before proceeding with the next step in the process is tedious, time-consuming, and error-prone unless the process is centralized and automated. Creation of a birth certificate upon DAA node cutover including all test data relevant to its performance can be invaluable when trending performance over time and troubleshooting issues but is not feasible using manual methods. For these reasons and others it is recommended that a cloud-based workflow management system be used to ensure correct tests are being deployed to test gear per task, data is being centrally collected and analyzed including from contractors, and is made available on-demand via dashboards or for export via API. Below is an example deployment of a cloud-based workflow system and how it is used across the DAA lifecycle.



DAA Deployment Project and Data Management WorkFlow

Conclusion

There is no doubt that 5G is coming and coming fast, whether it will be more of a friend or foe to cable operators will likely depend on how well they are prepared to monetize deployed assets to support its rollout. Cable is ideally positioned with prime access point locations, vast coverage with powering infrastructure, and most importantly a dense fiber network compatible with 5G access point needs. With proper planning, DAA deployments can leave MSOs even more well prepared to fight the 5G FWA threat by

- Enabling a powerful DOCSIS network upon which to offer a competitive broadband service offering yet is cost effective to maintain with existing staff
- Creating a portfolio of fiber assets which are pre-certified as capable of carrying services needed for 5G support

Deploying DAA and maintaining networks containing DAA nodes will not come easy without proper planning and execution, but for those who do it right the benefits will be lucrative.

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