Critical Considerations For The Design Of A Robust And Scalable DAA Aggregation And Transport Network

A Technical Paper prepared for SCTE•ISBE by

Jon Baldry
Metro Marketing Director
Infinera
125 Finsbury Pavement, London, EC2A 1NQ
+44 7766 146 440
jon.baldry@infinera.com

Table of Contents

Title **Page Number**

List of Figures

Title **Page Number**

Introduction

The transition to distributed access architectures (DAA) and particularly Remote-PHY or Remote-MAC/PHY is undoubtedly one of the most significant architectural changes to hit the cable world. Whilst this has an enormous impact on the architecture of the last mile as it moves to an N+0 architecture there is a very significant knock-on effect to the DWDM optical network that supports this fiber-deep access network.

Cable MSOs across the globe are evaluating and planning for all aspects of DAA, including revamped DWDM-based optical infrastructure. As part of this evaluation MSOs need to consider some obvious and some less obvious impacts on the optical network, these include:

- **Scale** – DAA will drive massive bandwidth growth per home and therefore considerably high bandwidth within the aggregation and transport network. What advances in optical technology help drive down cost per bit in high-scale transport?
- **Fiber-Deep** – Pushing fiber and DWDM deeper into access networks brings additional challenges:
    - **Host independence** – Can DWDM optics deploy directly into 3rd party devices to avoid the need for additional DWDM termination hardware?
    - **Autotuneability** – Can DWDM optics help lower operational cost and rollout bottlenecks by learning their "color" from the network?
- **Limited space and power in secondary hubs** – Deploying real world networks quite often comes down to available space and power. How can the optical networking infrastructure help address this challenge?
- **Advanced CORD architectures** – The desire to move to CORD and Spine/Leaf architectures requires any Ethernet aggregation or switching to play a role in a wider Spine/Leaf architecture. How can this be achieved in modern packet-optical devices?

This paper will undertake an assessment of some of the recent trends in the optical networking and how they can be applied to address the considerations and challenges outlined above to help prepare cable MSOs for fiber-deep DAA.

Content

1. DAA – A Once in a Generation Upgrade to Cable Networks

An uninitiated person walking the corridors of the SCTE/ISBE Cable-Tec Expo in 2017 would be left in no doubt that the "distributed access architecture (DAA)", whatever that is, was the main topic of conversation within the cable industry at that time. If they have decided to return and attend again this year then they will see the same, or possibly even more, excitement around DAA on the show floor.

DAA gives the cable industry the opportunity to defend its historic competitive advantage in residential markets and to migrate the numerous parallel networks required to support additional non-residential services into a single converged interconnect network (CIN). The migration to remote-PHY (R-PHY) or remote MAC/PHY (R-MAC/PHY) and the removal of expensive to maintain hybrid fiber coax (HFC) enables cable MSOs gives operators the opportunity to modernize networks enabling support for enhanced high-quality services while also reducing ongoing maintenance costs. The excitement around

DAA within the industry is understandable and by now hopefully it is also clear to our previously uninitiated visitor.

However, DAA isn't without its challenges, especially when looking at the optical transport portion of the new network. The generic DAA architecture pushes the edge of the digital network much closer to the end user, typically via a remote PHY device (RPD) and extends the WDM-based transport network that previously terminated in the secondary hub significantly deeper into the access fiber plant, as shown in Figure 1. This is part of wider *Fiber Deep* trend across the telecoms industry where fiber and associated transmission equipment is pushed deeper into the access plant and closer to the end user, such as fiber to the tower in wireless networks and fiber to the home/building in non-cable residential and business networks. Many of the challenges we'll discuss here for DAA also apply to the wider fiber deep trend and often the solutions used to overcome these challenges create the opportunity to converge networks into a CIN architecture.

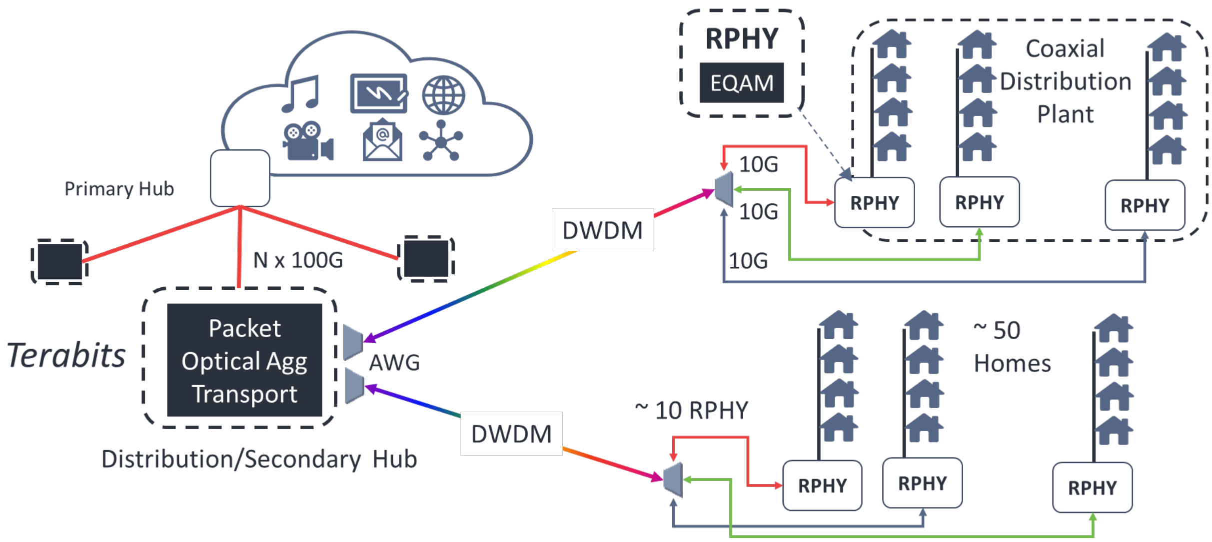

Figure 1 - Generic DAA Transport and Aggregation Network

2. DAA – A Once in a Generation Set of Challenges

The opportunity that DAA brings to cable networks globally is vast. The migration will bring a step-change to the quality and bandwidth of services that MSOs are able to offer while also modernizing the network to reduce ongoing maintenance costs. A change this big however brings new challenges that the previous network didn't need to consider or exacerbates existing challenges such as the inevitable limitations in available space and power.

2.1. Challenge 1 – Secondary Hub Scalability

DAA drive massive bandwidth into users' homes, which is the ultimate goal of DAA, and therefore will create a step change in bandwidth throughout the backhaul and transport network. DAA creates a new digital transport domain from the secondary hub to the RPD supporting 10G DWDM wavelengths per RPD. A typical secondary hub may well serve 300-400 RPDs and in some cases as many as 600-700 RPS, generating an unusually large number of 10G circuits that require efficient aggregation into 100G+ wavelengths for terabit-level transport to the primary hubs. Each 10G RPD circuit is anticipated to be carrying around 2-3 Gbit/s of traffic on day one, allowing the 10G circuits to provide plenty of headroom for future growth and allowing aggregation at the secondary hub to economically scale capacity to the primary hub as needed.

However, this enormous density of 10G circuits being terminated and aggregated in a single location creates another scalability challenge associated with managing the sheer volume of circuits and fibers in an economic and controlled manner.

2.2. Challenge 2 – Fiber Deep

Pushing DWDM from the secondary hub into the previously analogue optics domain closer to the end user is a key element of the DAA initiative. This enables the RPD to support the required high bandwidth 10G backhaul connection over distances of up to 60 or even 80 km. This longer reach enables the previous fiber plant to be redeployed for DAA with a chain of RPDs supporting a service area. Each RPD has a dedicated wavelength to/from the secondary hub and hardened DWDM filters can be used to support a wide variety of physical topologies.

The main challenge this brings is the operational challenge of handling the massive proliferation of DWDM end points. While each RPD is significantly simpler to install and maintain than a complete secondary hub, the previous end point of the digital DWDM network, we now must manage at least two orders of magnitude more end points. Each end point may only need a single DWDM wavelength but the largest DAA networks will ultimately have over a million RPDs. This creates a significant deployment management and logistics challenge and an additional ongoing sparing and maintenance challenge. In the ideal world we'd use automation and network intelligence to hide the complexing of DWDM from the RPD installation and maintenance with optics that behaved as if they were standard grey optics.

2.3. Challenge 3 – Limited Space and Power

As previously mentioned, to varying degrees the availability of space and power is always a concern in rolling out networks. There is always pressure in network design to optimize space and minimize power usage to keep ongoing operating costs down and to avoid expensive expansions and upgrades, if these are even possible. One advantage of DAA is that the approach includes the removal of older analogue equipment freeing up some space and power, but this can't be achieved until initial DAA equipment is deployed and ready to support a quick handover from the old network to the new on a spur by spur basis. If there is enough available rack space to support a clean initial DAA installation, then a dense solution with low power consumption is required to optimize available space and power. If there isn't enough space to support a separate clean installation on day 1, then compact and dense solutions become even more critical. Swapping equipment in and out of racks as networks evolve can lead to a fragmented and suboptimal use of the rack space and unfortunately there isn't a defrag button on the rack.

2.4. Challenge 4 – Increased Automation and Control

Operators globally are evaluating a range of approaches to the increased automation and control of the optical transport network required for DAA. Some operators are considering the central office rearchitected as a datacenter (CORD) approach that uses software defined networking (SDN) control and datacenter like operations to create an agile edge network. CORD encompasses the full DAA network from the RPD at the edge to content servers in the primary hub and any packet-optical transport network in between, requiring the transport solution to participate in the CORD network. This is a new paradigm for transport networks but one that is ultimately anticipated to become common place in many additional access network types such as 5G X-haul networks.

Other operators are looking at traditional network management and newer SDN control/orchestration systems for DAA management and control. Overall this range of requirements means that systems vendors providing DAA transport solutions need a lot of flexibility in management, control and orchestration options.

3. Transport Network Innovation for DAA

The optical networking industry is currently undergoing one of the highest, if not the highest, rates of innovation in its history. Innovation in advanced coherent optics is rapidly pushing the envelope of fiber capacity, packet-optical integration is bringing more sophisticated networking capabilities, SDN has brought a step change in multi-vendor network control to name just a few of the ongoing trends. Many of these can be applied to DAA networks to overcome the challenges outlined in this paper.

3.1. Addressing Scalability of Secondary Hubs

Recent advances in coherent optics have a clear role to play in the high capacity DAA networks to interconnect secondary hubs and primary hubs. Due to the large number of RPDs that will be aggregated in secondary hubs, networks collecting traffic from multiple secondary hubs will need to support terabits of traffic on day one and will need to scale significantly as bandwidth per user grows. Current networks support up to 10s of Terabits per second per fiber using quadrature phase shift keying (QPSK) and 16-quadrature amplitude modulation (16-QAM) modulation formats. Systems are in the process of migrating to 32-QAM and also increasing baud rates from 33 Gbaud and to 66 Gbaud. While WDM is a digital medium transmitting 1s and 0s, the engineering at the wavelength level is very much an analogue domain which involves adapting modulation format and baud rate to reach the optimum performance in terms of reach, total fiber capacity and cost per bit from both a capital and operational expenditure perspective.

Industry research is pushing these capabilities higher to 1024-QAM and 100 Gbaud [1][2], giving the potential to push fiber capacity closer and closer to the Shannon Limit in the future. Key to achieving these advances economically over useable distances is the use of techniques such as Nyquist subcarriers and advanced constellation shaping. These techniques are also used by some vendors to optimize performance in today's systems and can enable systems to outperform competitive solutions that have higher headline figures for modulation format and baud rate.

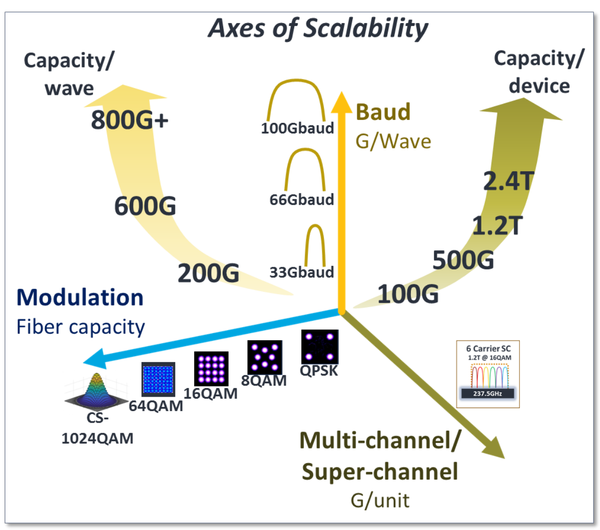

Figure 2 – Axes of Scalability in Next Generation Optical Networking

However, earlier in the paper we discussed the challenge of managing the scalability needed within the secondary hub itself. As DAA rollouts continue in the access network the secondary hubs will need to terminate hundreds of 10G circuits from RPDs and with the density of today's packet-optical aggregation systems this will be easily achievable within 1 rack. In fact, a single rack could support termination of over 1000 RPDs if needed to support a massive service area or in a consolidation scenario where multiple secondary hubs can be collapsed into a single location. Even putting this extreme example to one side, a secondary hub supporting 400 RPDs would need 800 fibers just to connect the individual 10G wavelengths from the DWDM filters terminating the RPD spurs and the 10G to 100G aggregation switch. These fibers dominate the fiber count within the configuration and could be a limiting factor in how easily a secondary hub can be upgraded to DAA and maintained.

One of the innovations that the optical industry has started to adopt to address this challenge is the use of multi-fiber push on (MPO) cables to drastically reduce the number of fibers needed in this part of the rack. MPO cables are already used for 100G connectivity so will be familiar to the installation crews. In this scenario each MPO cable will typically replace up to 20 individual fibers meaning the number of fibers needed for this 10G interconnect within the rack can be reduced by 95%. When all the other fibers within the rack are considered, the total number of fibers in the rack drops by 87% simplifying initial install and ongoing maintenance and allowing secondary hubs to scale smoothly as DAA is rolled out. Figure 3 shows a packet-optical system, with the side cover removed to expose individual SFP+ pluggable optics, that replaces 160 fibers with 8 MPO cables to support 80x 10G connections via the yellow cables. The unit also supports 8x 100G connections via the light blue MPO cables.

Figure 3 – Packet-Optical System With MPO-Based 10G Connectivity

3.2. Pushing DWDM "Fiber Deep"

The trend towards fiber deep networks is impacting a range of applications within metro networks, including DAA. Fiber deep impacts the network in several ways, such as requiring hardened DWDM filters and potentially hardened optical networking systems to be deployed in the access plant. The biggest impact on DAA networks is the rapid proliferation of DWDM endpoints in the network. In DAA the previous end point of the DWDM network was the secondary hub and each of these will now expand out to 300, 400, 600 or perhaps more RPDs. Obviously each RPD is significantly less complex than a secondary hub and only requires a single 10G DWDM link, but nonetheless each location now requires DWDM capabilities and installation/maintenance crews that have some DWDM knowledge.

DWDM systems usually require some form of DWDM hardware at each end of the optical link to convert wavelengths to grey (uncolored) optics for handover to the client system. For a single wavelength site such as an RPD site it would be very advantageous if this could be removed and the DWDM optics be housed directly in the RPD. Other systems can house DWDM optics directly, but in these cases the host systems must be aware of the DWDM optics and fully manage them. For this capability to be useful in DAA it would be good to also make the optics host agnostic so that the host equipment does not need to manage the DWDM characteristics of the optics and treats them the same as grey optics. This removes the cost of any additional DWDM hardware needed to house the DWDM optics without adding any additional complexity to the RPD site.

An additional challenge of the proliferation of DWDM optics out into the depths of the access network is the complexity of installing and maintaining 100,000s of DWDM optics. Tuneable optics will allow operators to avoid the inventory, sparing and project management issues of deploying 100,000s of fixed wavelength optics out to the field but these then require some tuning by installation or maintenance teams that deal with RPD sites and may not have the training or time to also manage DWDM optics. Autotuneable WDM PON optics now offer operators a solution to this challenge by allowing remote optics to learn their color from the network. This means field staff can treat these optics in the same way as grey optics and no DWDM specific training is required and sparing costs can be simplified compared to fixed optics.

Earlier WDM PON technology was limited in terms of capacity to 1Gbit/s and to reaches of approximately 20 kilometers, making it unviable for DAA. However, recent innovations have led to higher speed 10G optics supporting up to 80 km, making these optics an option for DAA. Additionally, these new autotuneable optics are host independent enabling them to be deployed in any RPD that accepts third party pluggable optics. Operationally, these optics give the potential to drastically reduce the complexity of DAA rollouts as deployment and maintenance teams can avoid the need to deal with any DWDM specific concerns as RPDs are deployed and maintained.

3.3. Available Space and Power – The Ultimate Limiting Factor For Network Rollout

Once all the big decisions are made on overall network architecture the real-world issues of fitting this into existing network facilities come into play. In a lot, perhaps even the majority, of network deployment scenarios the question of available space and power becomes the overriding factor for the feasibility of the network deployment. As detailed earlier, advances such as intra-rack connectivity using MPO connectors can have a significant on face-place density removing the need for multiple parallel fibers and associated “front-plate real-estate”.

Optical vendors are naturally focusing on high density solutions as a competitive advantage that has an obvious benefit to cable MSOs and other network operators. The denser the solution the easier it is to deploy, either in secondary hubs with space cleared for DAA or in the limited space that comes available as older pre-DAA systems are retired.

Power consumption often goes hand in hand with available space as a limiting factor in network rollouts. However, while the absolute power consumption is important from an ongoing cost perspective, power draw and fuse requirements can have a bigger impact. The downside of increased density is that more functionality/processing can be achieved in a smaller space and even though the power per Gbit continues to decrease the overall power consumption can rise leading to the need for ever higher fuse ratings on power feeds. The optical industry continues to focus on the combination of high density and low power consumption/fuse ratings and cable MSOs should pay special attention to this in DAA networks.

3.4. Advanced CORD Architectures – A New Networking Paradigm

New fiber deep network architectures such as DAA or 5G mobile transport networks have created the opportunity for network operators to virtualize and optimize many components of the network. As outlined earlier this has led to a range of approaches from operators that packet-optical equipment vendors and others need to address. This includes traditional own built network management systems, own built SDN controllers/orchestrators and open interfaces for third party controllers directly to devices, especially any involved in Ethernet switching or IP routing.

As shown in figure 4, in a traditional ring/arc-based metro network all primary aggregation nodes are built to support the line speed of the ring/arc and access nodes are often daisy-chained off these. The move to a CORD network built using packet-optical spine and leaf switches breaks this linkage by using dedicated WDM wavelengths to scale each leaf switch independently. At the wavelength layer a ring-based fiber plant can be logically broken into separate rings with each leaf dual homed to a pair of spine switches. The packet optical network can then be managed by a CORD controller along with the other components of the wider network to efficiently support networks such as DAA or 5G transport.

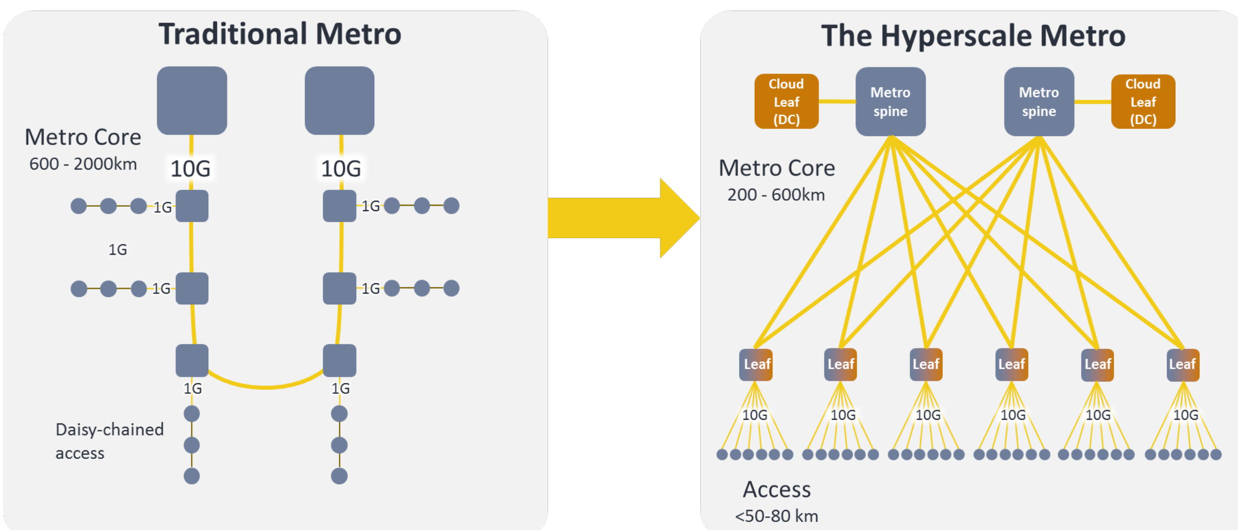

Figure 4 – CORD-based Hyperscale Metro Networks

In order to support CORD networks packet-optical transport systems will need to support a range of control options and will also need a degree of IP awareness to enable functionality such as segment routing. This should be achieved in packet-optical platforms without impacting the underlying transport performance characteristics such as low latency and SyncE and 1588v2 synchronization performance. This is especially the case in CIN networks where 5G mobile traffic will be carried in parallel to DAA traffic as the 5G traffic will need the sync and low latency performance to be optimal.

Conclusion

The industry's push to DAA is well underway and the challenges this creates for the optical network shouldn't be underestimated. At a high level the role of the transport network is simple, to transport bandwidth to/from an RPD in the most simple and economic way possible. However, DAA is perhaps unique in optical networking due to the sheer volume of RPD circuits that come together in the same place, the secondary hub.

The optical industry is innovating to help address these challenges and others found within other fiber deep applications with advances in fiber management, density, automation and control. By addressing wider fiber deep applications, such as 5G transport, this also creates the opportunity to support CIN architectures where the DAA capabilities need to expand to cover multi-service environments and differing performance requirements.

As operators embark on widescale deployments of DAA then operational and scalability issues will come to the center of attention so early visibility of these challenges and possible solutions to solve or mitigate against them is becoming increasingly important.

Abbreviations

CORD	Central Office Re-architected as a Datacenter
CIN	Converged Interconnect Network
DAA	Distributed Access Architecture
DWDM	Dense Wavelength Division Multiplexing
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
R-MAC/PHY	Remote MAC/PHY
RPD	Remote PHY Device
R-PHY	Remote PHY
SCTE	Society of Cable Telecommunications Engineers
SDN	Software Defined Networking
WDM	Wavelength Division Multiplexing

Bibliography & References

[1] *Constellation Shaped 66 GBd DP-1024QAM Transceiver with 400 km Transmission over Standard SMF,* Robert Maher, Kevin Croussore, Matthias Lauermann, Ryan Going, Xian Xu and Jeff Rahn [https://www.infinera.com/wp-content/uploads/Infinera-tp-Constellation-Shaped-66-GBd-DP-1024QAM-Transceiver.pdf]

[2] *Multi-channel InP-based Coherent PICs with Hybrid Integrated SiGe Electronics Operating up to 100GBd,32QAM,* R. Going, M. Lauermann, R. Maher, H.Tsai, M. Lu, N. Kim, S. Corzine, P. Studenkov, J. Summers, A.Hosseini, J. Zhang, B. Behnia, J. Tang, S. Buggaveeti, T. Vallaitis, J. Osenbach, M. Kuntz, X. Xu, K. Croussore, V. Lal, P. Evans, J. Rahn, T. Butrie, A. Karanicolas, K.-T. Wu, M. Mitchell, M. Ziari, D.Welch and F. Kish [https://www.infinera.com/wp-content/uploads/Infinera-tp-Multi-channel-InP-based-Coherent-PICs.pdf]

