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Modernizing Cox Communication's Access and Aggregation Network Infrastructure for Remote PHY Deployment

A Technical Paper prepared for SCTE by

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1. Introduction

Like other Multi System Operators (MSOs) and Internet Service Provider (ISPs), Cox Communications needed to transform its access and aggregation network infrastructure to meet increased bandwidth demands and support next generations of multi-services. The evolution of Internet of Things (IOTs), increased usage of social media and video sharing platforms have drastically increased traffic volume putting lot of stress in the existing legacy outside plants and related access network infrastructures. The legacy cable plant relies on RF technologies and analog optics that are difficult to scale, expensive to maintain and not suited to meet demands for new and emerging digital technologies. This required Cox to modernize its access network infrastructures by implementing Distributed Access Architecture (DAA) and going fiber deep to expand customer serviceability, increase bandwidth, and improve efficiency and performance of the access network. To enable the deployment of Distributed Access Architecture and related new technologies, Cox introduced a new packet switched access aggregation network called Converged Interconnect Networks (CIN) based on IPv6 routed technology to connect its headend with new access network.

Cox Communication has one of the largest deployments of Converged Interconnect Networks, Distributed Access Architecture and Remote PHY in North America that covers almost 40% of Cox's footprint. Cox's vision to design a standardized, elastically scalable, and future proof IPv6 routed network has enabled Cox to meet its immediate and future evolution of modern access network paving its path for Next Generation of DOCSIS technology.

2. Legacy Access Networks in Cox and its Limitation

Most Multiple Services Operators (MSOs) use linear point-to-point optical fiber on their access fiber network between headend and primary optical node. However, Cox communication access fiber network, as shown in figure 1, is unique in that it uses a single SMF fiber in a diverse ring topology to add a level of protection from the fiber cuts. The access network fiber topology uses a passive optical architecture to select the shortest path as a primary path between headend and primary optical node. The primary optical node can be located anywhere along the fiber route, resulting in a short path and long path that must be managed optically. The access fiber path can range in overall distance up to 60KM and meets at the primary optical node into an optical bypass switch. The optical bypass switch is responsible for selecting the primary and backup path and provide an optical failover associated with loss of light on the primary path during a fiber cut event. A typical primary optical node in Cox HFC network services 500 household passed (HHP).

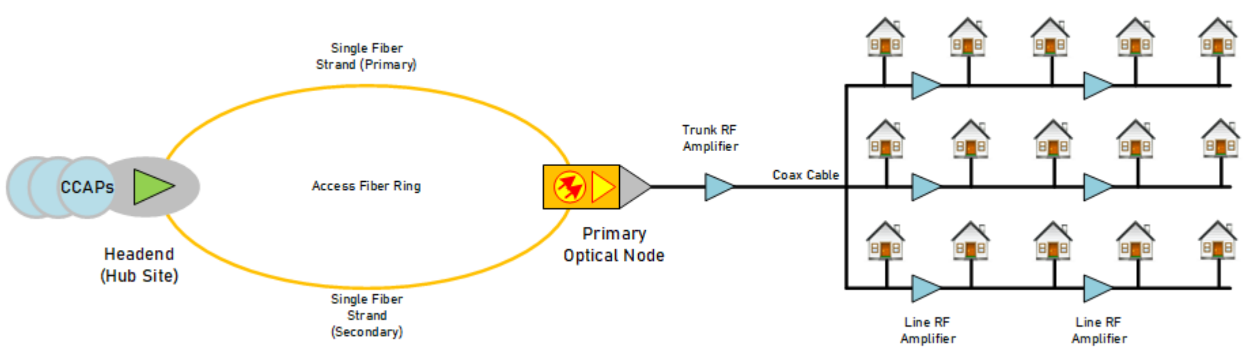

Figure 1 – Cox Communication Hybrid Fiber Coaxial (HFC) Network Architecture

Figure 2 shows the current access network infrastructure of Cox which includes several analog technologies embedded deep into the cable network. The Legacy cable networks have served customers well for a long time. However, with the increase bandwidth demand and new service requirements, these legacy networks are stretched to their capacity limits. Also, the analog nature of the infrastructure possesses several limitations to the expansion of the network and provisioning of new services. Today's legacy cable plants are prone to signal noise and signal quality degradation because of lots of RF amplifiers between customers and headend equipment. The analog technology also has distance limitation and capacity constraints. We are required to install new CMTS and related auxiliary equipment to provide services to communities that fall just beyond the boundary of the existing headend. Such analog infrastructure is also expensive to maintain and operate and are susceptible to environmental factors.

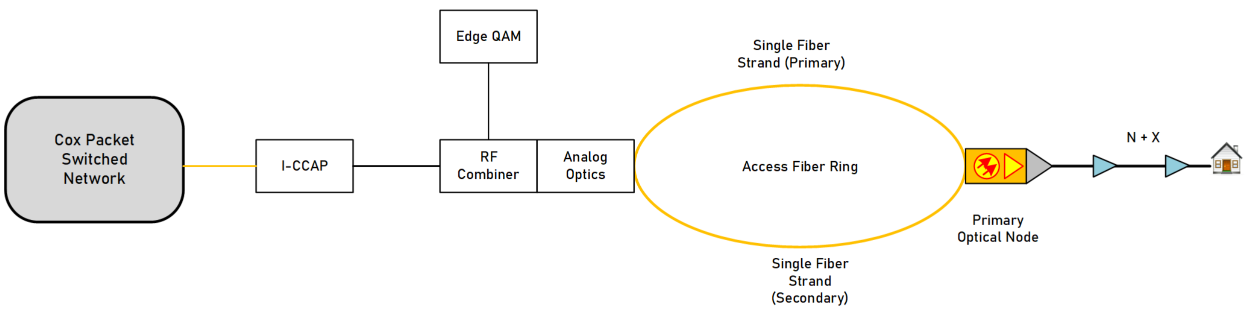

Figure 2 – Cox Communication Legacy Cable Network Infrastructure

As the demand for new and emerging digital technologies grew, the legacy analog architecture was not suited to meet the future requirement of digital communication services. To leverage and benefit from future access technologies like DOCSIS 4.0, R-OLT and beyond, it was imperative for Cox to modernize its analog access infrastructure that would meet customer demands and business requirements of current as well as future services. That is why Cox decided to implement the new access architecture to unlock new possibilities of future network capabilities. However, in doing so Cox needed to carefully integrate the current fiber and network assets to the new access network to maximize the utilization of existing infrastructure and reduce overall capital expenses.

3. Access and Aggregation Network Evolution in Cox

When we discuss the access network evolution in Cox network, it is relevant to know about the overall network architecture of Cox and various segments of Cox network. Like other ISP, Cox network is also a layered network as shown in Figure 3. Cox core backbone is a mesh of backbone routers that connect all its markets, data centers and peering centers. Each market constitutes a network called Regional Data Center (RDC) network that serves as an aggregation layer for that market's metro network. The metro network in each market is a collection of hubs/headends network that is based on hub and spoke architecture. Each headend network is also a hub and spoke network with a pair of hub aggregation routers that aggregates several access, business, and service routers.

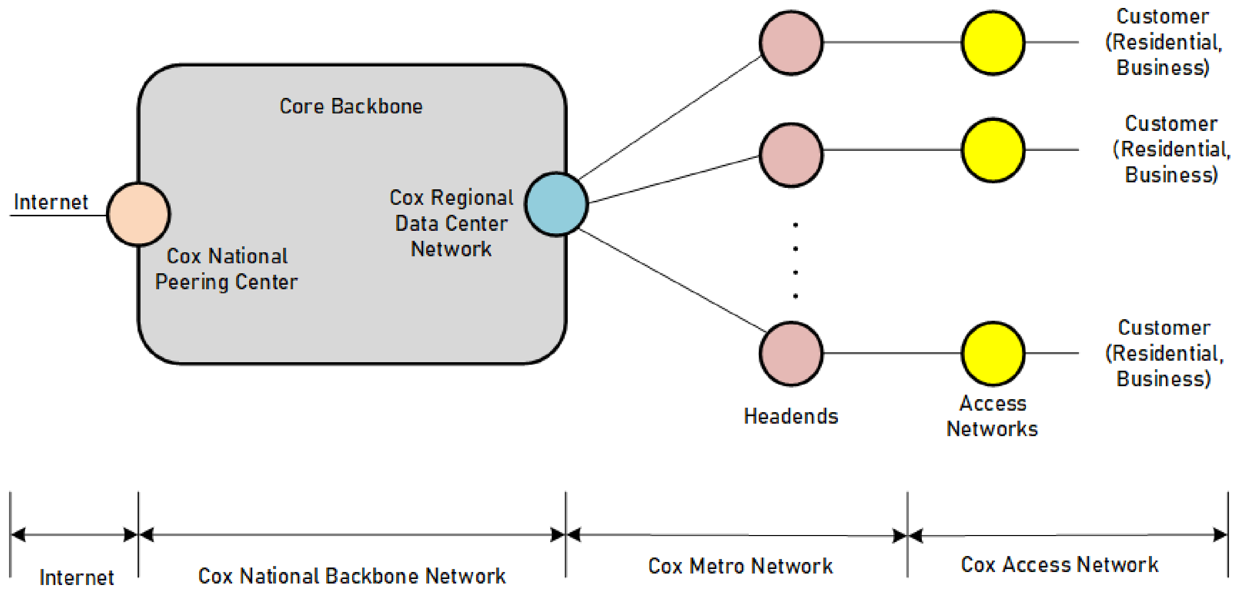

Figure 3 – Cox Communication High Level Network Architecture

As Cox faced continued pressure of increased bandwidth demand and scalability challenges in its legacy access network, it needed to evolve and transform its analog access network to modern digital access network. Distributed Access Architecture (DAA), a fiber deep technology developed by CableLabs was adopted to replace the current access network in Cox.

3.1. Distributed Access Architecture (DAA)

Cox has significant number of fibers and coax network infrastructure in its serving areas. It was important to utilize those existing fibers and network assets to save capital expenditure while continuing to provide higher capacity and reliable services to customers. CableLab's DAA technology was the right access architecture that would fully utilize Cox's existing access network infrastructure and transform it to modern digital access network.

DAA technology allows cable operators to disaggregate traditional I-CCAP into several key network components and functions and move them closer to the subscribers. It helps in reducing power and space requirement in already constrained headend and improve signal quality from customers to headend. The digital transformation also enables operators to automate and virtualize various aspects of new access network infrastructure.

DAA can be broadly classified into two technological variants:

a. **Remote PHY Architecture:** This architecture relocates PHY component of Integrated CCAP closer to the subscriber. A Remote PHY Devices (RPDs) replaces the existing fiber node or a primary optical node in Cox case. Given the maturity of RPHY specifications from CableLabs and availability of RPHY devices from various vendors, Cox has chosen RPHY technology as its DAA architecture. RPDs in Cox are deployed in N+0 as well as N+X model. Currently, Cox has successfully deployed 11,000+ RPDs covering 3.27 million HHP and 2.13 million subscribers.

b. **Remote MacPHY Architecture:** Another variant of DAA is Remote MAC PHY technology where the PHY as well as MAC domains are relocated close to the subscriber. The new access and aggregation network need to support seamless transition from RPD to RMD solution where the control plane and data plane are truly separated. These RMD devices eventually will replace the primary optical node and co-exists along with RPDs for sometime.

Deployment of large-scale Distributed Access Architecture in Cox had to overcome several challenges. Migrating from legacy access architecture to DAA required significant amount of planning, investment, and coordination among several departments in Cox. Deployment of DAA in Cox network was a paradigm shift from design, implementation, operation, and support perspective. The introduction of Layer 3 IP network in the form of Converged Interconnect Network between Digital CCAP and RPD has changed the operational and support modality of Cox metro and access network.

3.2. High – Level Cox Distributed Access Architecture (DAA) Topology

Figure 4 shows the high-level architecture of Cox DAA network deployment. As mentioned in section 1 of this paper, Cox access fiber network is unique in that it is a diverse ring topology from headend to primary optical node instead of linear point to point fiber. To preserve the ring topology of the access fiber, Cox designed and deployed Optical Communication Module Link (OCML) Extender as a DWDM component that would transport multi-wavelength optical signal over the existing ring fiber infrastructure. OCML amplifies and multiplexes 20 unique 10G DWDM wavelengths onto a single fiber. It also demultiplexes all DWDM wavelengths in the reverse direction.

Similarly, Mux/Demux Module (MDM) is a passive device that is located at the point where the legacy primary optical node exists today. MDM demultiplex all the unique DWDM wavelengths coming from OCML and separate them out to ports where RPDs are connected. MDM also multiplexes all the DWDM wavelengths coming from several RPDs onto a single fiber towards the OCML.

Cox utilizes ITU channel #18 through channel #37 for all downstream wavelength mapping whereas ITU channels from channel #42 to channel #61 are utilized for all upstream wavelength mapping. The concept of OCML and MDM has helped Cox to rapidly deploy DAA over existing access fiber infrastructure while preserving it unique ring topology. The use of standard ITU complaint wavelength in OCML/MDM also allows Cox to deploy 100G wavelength solutions in future.

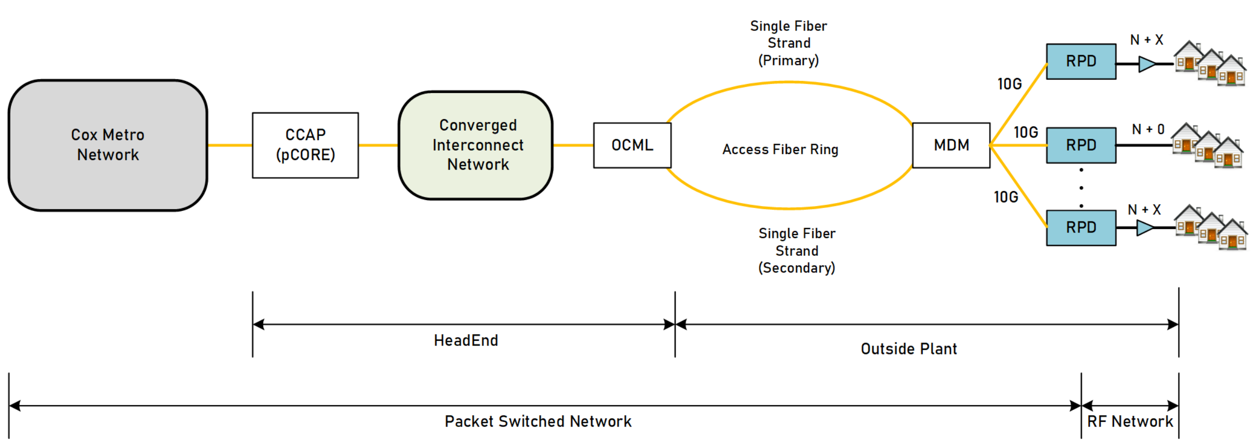

Figure 4 – Cox Communication High Level DAA Network Topology

3.3. Cox Converged Interconnect Network (CIN) Architecture

To enable the deployment of Distributed Access Architecture, Cox introduced a new packet switch network called Converged Interconnect Network (CIN) that connects Cox's headend with new digital access network. Cox's CIN infrastructure is Layer 3 based and is built on native IPv6 only that leverages loop-free communication using industry-standard routing protocols like IS-IS and BGP in control-plane and uses Zero Touch Provisioning (ZTP) to deploy massive number of aggregation switches needed to support the growing CIN deployment. Cox's CIN network is true IPv6 fabric that provides non-blocking, highly elastic, extensible network, and support any-to-any connectivity between RPDs and CCAP cores. This enables Cox to quickly move RPDs between CCAP cores without any physical work needed, and also enables Cox to deploy an "Extended CIN" technology for space-constrained head-ends. The CIN architecture solution deployed at Cox is also able meet the future requirement of regionalized controller based FMA architecture that is separate from the data plane for DOCSIS technology.

CIN Design Principles

As CIN was adopted to interconnect RPDs and various CCAP cores at headend, it blurred the line between several technologies and departments inside Cox. To maintain the CIN network, the collaboration between various teams and departments was integral. Although the CIN network primarily connects RPDs with digital CCAP's cores, it is capable of supporting future access network termination need like RMDs and R-OLTs. Following are few of several design principles Cox adhered to while designing the CIN architecture.

- Effectively and efficiently utilize existing network assets and architectures
- Standard deployment using one common architecture for different size hub sites/head ends
- Provide any – to – any reachability between RPDs and CCAP cores in the market
- Routed L3 only network based on industry standard and proven protocols like BGP, IS-IS and PIM
- IPv6 only network to conserve scarce IPv4 network and avoid complex architecture
- Efficiently utilize existing access fiber topology
- Automation friendly and ZTP capable

CIN Spine-and-Leaf Network Architecture

The implementation of Converged Interconnect Network required an extensive network architecture analysis, testing and meticulous planning. Several design architectures were considered for Converged Interconnect Network. Cox's desire to create Next Generation Access Aggregation Network that is elastic, resilient, fast, and easy to manage led to the implementation of already proven spine – and – leaf architecture in its CIN layer that is popular in Data Center Network today. By using the spine and leaf architecture in CIN, Cox was able to create a highly scalable and hierarchical network that can aggregate extremely large volume of physical connections at every headend.

Several possible combinations of spine – and – leaf architectures were considered for CIN in Cox metro network. Based on Cox's current metro design architecture and design requirement for new access aggregation network, Cox deployed independent RPD aggregation and DPIC aggregation at leaf layer and utilized existing hub aggregation routers as spine layer. Leaf routers that aggregate RPDs are called RPD Aggregation (RPA) routers and routers that aggregate Digital PIC interfaces of digital CCAP are called DPIC Aggregation (DPA) routers. Both RPAs and DPAs are connected to spine layer HUB routers. The overall CIN network as deployed in Cox metro network is show in figure 5.

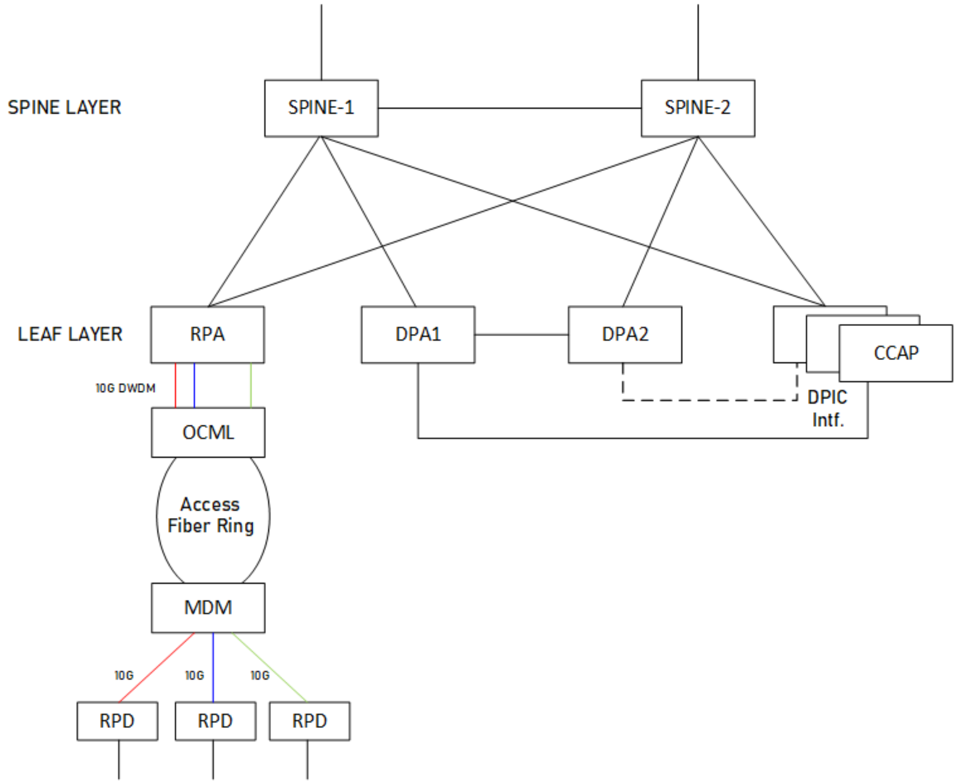

Figure 5 – Cox Communication CIN Topology

The new Converged Interconnect Network consists of following three segments:

- **Leaf Layer – DPIC Aggregation (DPA) Routers:** DPA routers aggregate DPIC interfaces from digital CCAP and are deployed in pair to provide High Availability feature.
- **Leaf Layer – RPA Aggregation (RPA) Routers:** RPA routers aggregate RPDs from outside plants and supports 10G DWDM Bidi optics
- **Spine Layer – Hub Aggregation (HUB) Routers:** A pair of P routers that aggregates RPAs, DPAs and CCAPs.

CIN Routing Design

The routing architecture of new access aggregation network needed to seamlessly integrate with existing metro routing architecture. To achieve all the design and business requirement of new access network, Cox deploys following routing protocols and services in CIN network.

- **Routed IPv6 only Layer 3 network:** To eliminate the dependency on IPv4 address and simplify the network architecture, Cox uses IPv6 only routed network in CIN. The IPv6 routed network allows for globally unique addresses thereby eliminating the need for complex network architecture.

- **IS – IS as an IGP:** Intermediate System – to – Intermediate System (IS – IS) Multi Topology in level – 1 is used as Interior Gateway Protocol in CIN to announce infrastructure prefixes like loopback and point – to – point interfaces of CIN devices.

- **MP – BGP:** Multi-Protocol BGP (MP – BGP) with unicast and multicast address families is used to advertise non-infrastructures prefixes. Spine routers are route reflectors to all leaf routers. BGP traffic engineering, like manipulation of local – preferences and route – aggregation, are used to enable deterministic routing and predictable traffic flows in CIN.

- **PIM:** As 99% of traffic in CIN is IPv6 multicast, PIM SSM is deployed as multicast routing protocol. MDLv2 is enabled on RPD Aggregation routers so that multicast listeners are automatically discovered on all MLD enabled interfaces.

- **Quality of Service:** To prioritize various types of traffic (control, user data, voice, video), class of service is configured with proper classification, mapping, and queuing.

- **802.1x:** To authenticate RPDs, RPD aggregation routers are configured with 802.1x authentication.

- **Other protocols and service**s: As a standard practice, all CIN layer routers are configured with other necessary protocols and services like LLDP, DHCPv6 relay, TACACS, NTP, SNMP etc.

3.4. Cox Extended CIN (E-CIN) Architecture

One of the main design features of CIN was to accommodate any – to – any connectivity between RPDs and CCAP cores in the market. The architecture, called Extended CIN, allows RPDs to connect to any CCAP cores that are not co-located at same headend. In E-CIN architecture, CCAP cores are located on a separate headend (called host site) than the RPD aggregation routers (called the E-CIN site). The high-level architecture for E – CIN is show in figure 6.

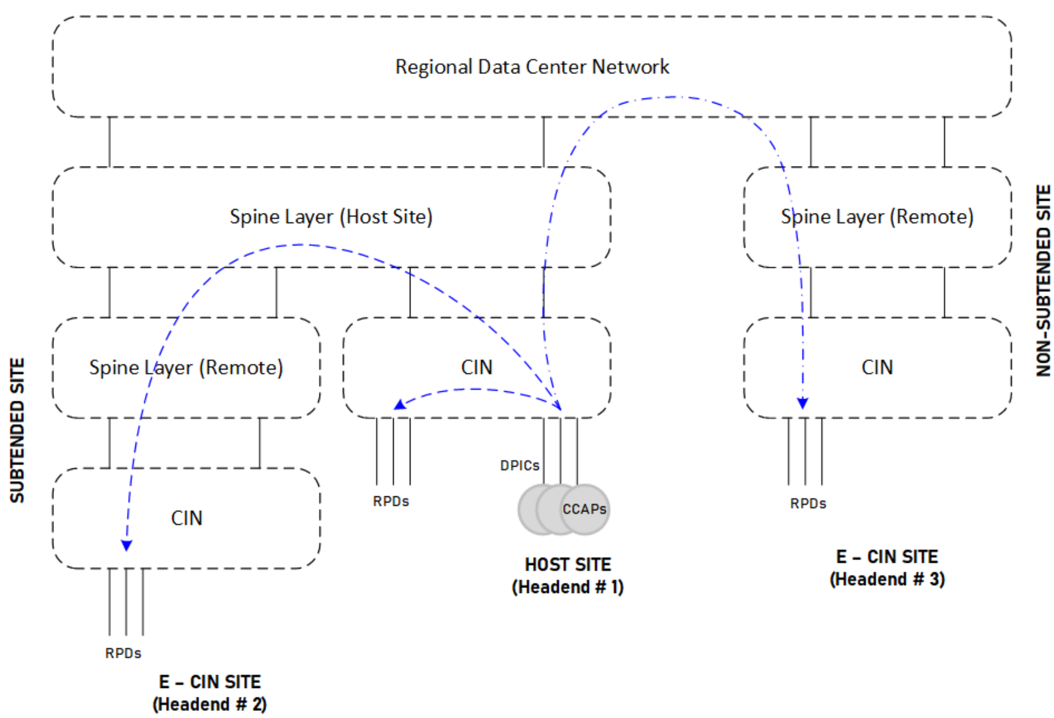

Figure 6 – Cox Communication High-level E – CIN Topology

In the E – CIN architecture of figure 6, host site's (Headend #1) CCAP cores serve headend # 2 (Subtended Headend to Headend #1) and headend # 3 (Non-subtended headend). Extended CIN, in some cases increases optical distance and introduces more hops in the routing path between host site and E – CIN sites which might add challenges to sensitive control plane and real time traffic. To address such issues, Cox has implemented some design features and specified the optical fiber distance for which E – CIN architecture can be implemented without sacrificing any traffic quality. Cox also implements IGP traffic engineering to keep E – CIN site traffic in optically shortest path. Also, proactive bandwidth capacity planning and augmentation ensures that there is enough capacity between host site and extended CIN sites all the time.

3.5. PTP Architecture

For proper DOCSIS operation, the timing synchronization between CCAP and RPDs is extremely important. To maintain such timing synchronization, Cox utilizes IEEE 1588/PTP protocols in hierarchical architecture. A pair of Grandmaster clock at the RDC level are master for all boundary clocks deployed at each headend. These boundary clocks provide timing for CCAP cores and RPD devices. Given the sensitive nature of timing synchronization between RPDs and CCAP, PTP traffic is symmetrically routed in CIN and metro network to eliminate packet delay variation. It is also treated as priority traffic in network to minimize queuing delay.

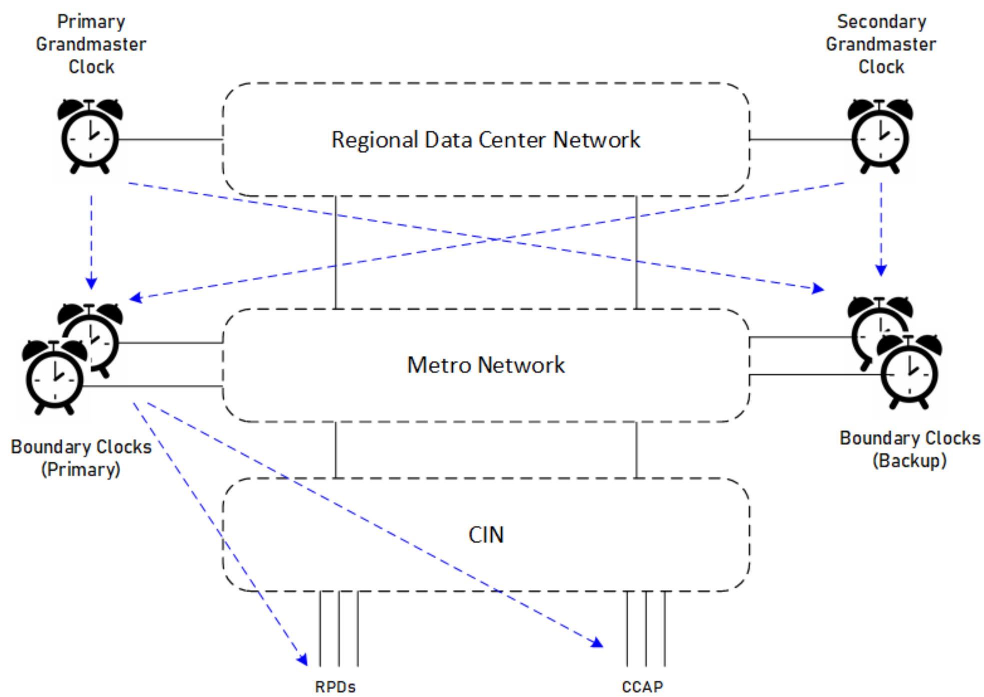

Figure 7 – Cox Communication High-level PTP Architecture

4. Access Aggregation Network Standardization and Automation

For the large-scale deployment like access aggregation network/CIN, it is extremely important to standardize the network deployment to minimize misconfigurations and enforce predictable network performance. A CIN playbook was created to document all protocols, services and configuration standards related to CIN deployment. To make the network automation easy, configurations on routers are done in such a way that they are user friendly and easily parse by any choice of programming languages. Configuration compliance are strictly enforced by compliance tools.

Network modeling and scale analysis showed that Cox will be deploying huge numbers of RPD and DPIC aggregation routers. As manual deployment of these devices is operationally expensive and consume lots of time and resources, Zero Touch Provisioning (ZTP) has been utilized to turn up these devices. ZTP engine is responsible to create configurations and apply them to all corresponding devices during new device turn up.

5. Conclusion

The tremendous growth in demand for bandwidth is pushing the legacy analog infrastructure to its capacity limits opening the opportunity to deploy modern network infrastructure in the access side of the network. Building upon this momentum of increased demand, Cox is deploying a new DAA and CIN architecture to push fiber deep into its serving areas. Cox started with Remote Phy (RPHY) as its preferred DAA technology. The foundation laid during the modernization of access and access aggregation network has far reaching impacts in Cox network. The access agnostic nature of new aggregation network allows Cox to deploy several IP and non-IP services over the same converged network. Pushing ubiquitous digital transmission technology as close to the subscriber as possible has helped Cox in delivering better services with improved quality to its valued customers. The real time performance monitoring of network assets deep into the network has also helped Cox to proactively address impending issues before it gets service impacting.

As Cox embarks on a path to the next generation of DOCSIS technologies like RMD/FMA, R-OLTs and business services, the new access and access aggregation network will offer the new and improved digital capabilities and versatilities as demanded by new and emerging technologies.

Abbreviations

DAA	Distributed Access Architecture
CIN	Converged Interconnect Network
CCAP	Converged Cable Access Platform
OCML	Optical Communication Module Link Extender
MDM	Mux/Demux Module
DWDM	Dense Wave Division Multiplexing
MP – BGP	Multi-Protocol Boarder Gateway Protocol
IS-IS MT	Intermediate System to Intermediate System Multi Topology
PIM	Protocol Independent Multicast
PTP	Precision Time Protocol
RPD	Remote PHY Device
RMD	Remote MAC PHY Device
FDX	Full Duplex
ESD	Extended Spectrum DOCSIS
DPIC	Digital Physical Interface Card

Bibliography & References

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