Cable Access Network Evolution

Network connectivity service is the key foundation of the global digital transformation. Over the years, service providers have undergone a remarkable transition, evolving from the pioneers of 90s Internet building, to becoming intricate connectivity portals that tackle a multitude of complex challenges. Their role has expanded far beyond providing basic connectivity, as they now navigate a vastly transformed digital landscape. As such, the wholesale transition to remote work and the rapid proliferation of complex applications such as virtual reality, online gaming, and IoT has resulted in a significant shift in customers' expectations from network operators. Customers who were previously content with simple, fast and inexpensive connectivity now demand secure, fast, and reliable digital services connectivity. This shift is transforming cable network operators from traditional connectivity providers to digital transformation platforms.

To support this transformation, cable operators are undergoing an architectural and infrastructure evolution. They have consolidated network functions by multiplexing data and video services onto a single Converged Cable Access Platform (CCAP) device. This convergence of services has increased efficiency and reduced Total Cost of Ownership (TCO). Moreover, operators are adopting a versatile new architecture dubbed Distributed Access Architecture (DAA). DAA decentralizes network functions and places RF components closer to users, thus mitigating port congestion, improving scale, and lowering headend equipment needs.

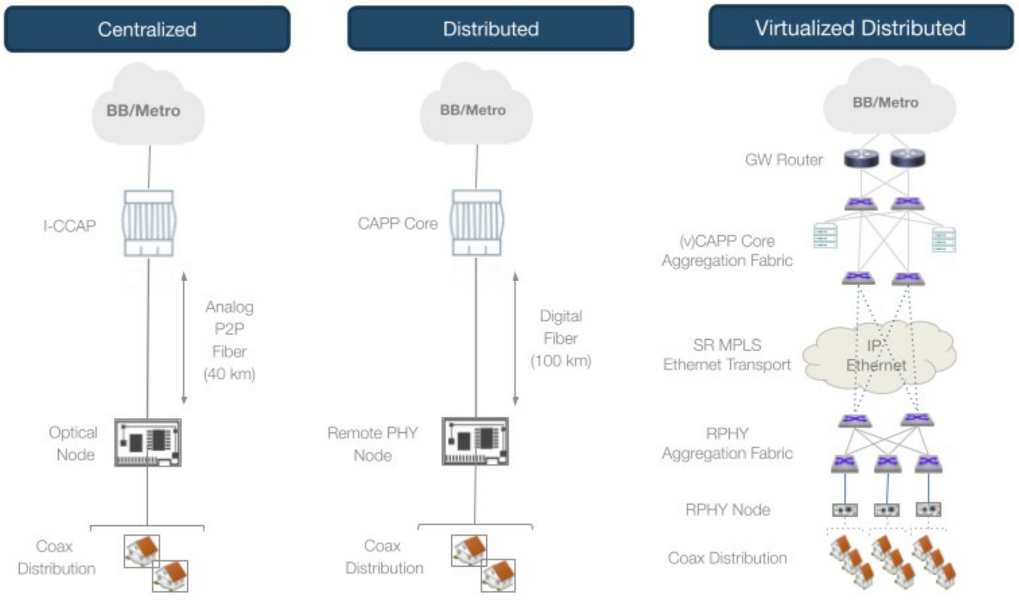

Figure 1: Cable Access Network Evolution

However, to fully realize the benefit of a distributed architecture, cable network operators need to transition from the current, semi-proprietary, point-to-point network to a flexible, converged, IP over Ethernet architecture, commonly known in the industry as the Converged Interconnect Network (CIN). The implementation of CIN presents a great opportunity for cable operators to fully unlock the value of a key asset- valuable dark fiber infrastructure, to achieve a new level of scale, efficiency and service innovation.

Delivering Next Gen Cable Services

There are two main approaches to implementing the DAA architecture: Remote PHY and Remote MAC PHY. Both Remote PHY and Remote MAC PHY involve moving certain processing functions from the headend to remote locations. The remote PHY approach moves the physical layer (PHY) of the network out of the headend to the node. Similarly, Remote MAC PHY, involves moving both the PHY and media access control (MAC) layer processing functions from the headend to remote devices. While the choice of which approach to adopt depends on the unique needs and goals of the cable operator, the lion's share of current deployment is based on remote PHY. As such, the remainder of the document will focus on remote PHY based implementations.

Enabling the separation of head end functions and the deployment of fiber-deep remote IP managed digital nodes (RPDs) requires the implementation of a flexible and scalable Converged Interconnect Network (CIN). This network serves as the interconnection between the IP-enabled RPDs and the core services. The CIN offers advantages beyond merely linking Distributed Access Architecture (DAA) core and edge services efficiently. CIN unlocks unprecedented opportunities by utilizing cable operators' extensive fiber infrastructure to effectively deliver multiple high value services. This includes legacy video, DOCSIS, PON, and emerging lucrative services such as 5G backhaul and mobile edge computing (MEC).

CIN The Arista Way

Service Providers in general, and cable operators in particular, are faced with a dual challenge: managing an aging and progressively intricate infrastructure while grappling with declining revenue from traditional connectivity services. Hence, network modernization is the key to unlocking new revenue streams while lowering cost and complexity.

While there isn't a single CIN design template that can meet all operators' needs, satisfying certain essential requirements can ensure that cable operators can cost-effectively adapt to changing demands while also providing reliability and performance. A successful distributed architecture deployment solution must include:

- **Non-blocking any-to-any connectivity** between the Remote PHY Devices (RPDs) and the centralized Converged Cable Access Platform (CCAP) core services.
- **Cost-effective redundancy** for fiber, link, and node connections between all distributed components, ensuring seamless remote node failover between CCAP core elements.
- To ensure accurate data transmission and processing requires support for advanced **timing functions** and **robust QoS**.
- Transitioning to DAA and IP-based CIN adds more network elements, and can disrupt existing management and maintenance models. **Automation** is a key requirement to effectively manage infrastructure at scale, maintain service velocity, and reduce costly manual errors.

Arista offers a comprehensive solution framework for cable network modernization (CIN build-outs) that meet the above requirements. This framework is based on cloud principles and is based on four key approaches:

- *Open IP fabric architectures*
- *Technology transitions leveraging Merchant Silicon*
- *Operational efficiency via Automation*
- *Enhanced Service Assurance*

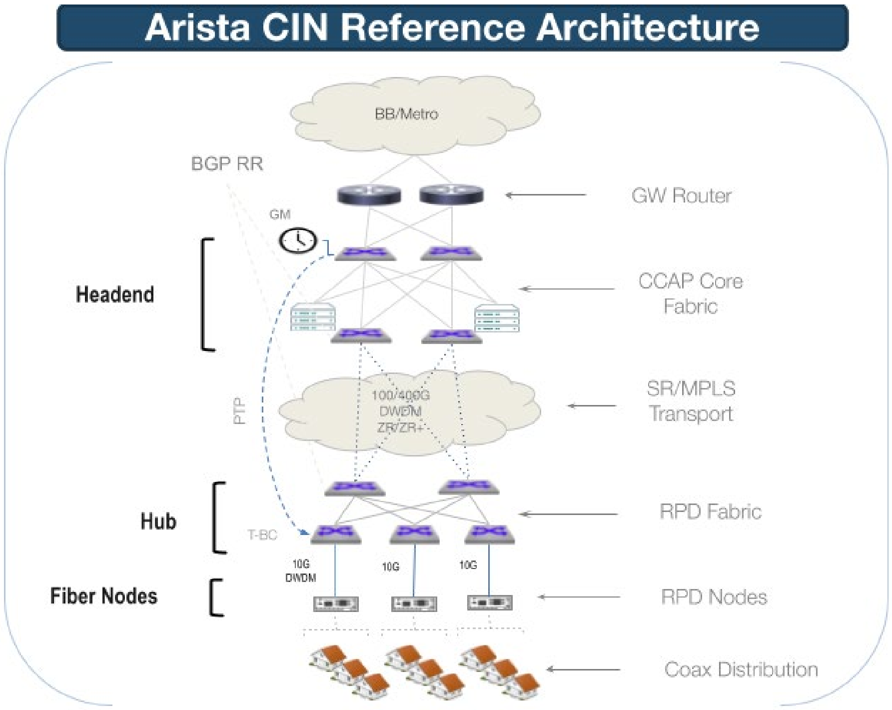

Figure 2: Arista CIN Reference Architecture

The Arista CIN reference architecture can be broadly categorized into two components:

- The Aggregation Fabrics consist of two crucial components: the Edge Fabric and the CCAP Core Fabric. The Edge Fabric aggregates RPD elements at the network's edge, while the CCAP Core Fabric handles aggregation for the core services infrastructure at the headends. This fabric architecture provides a high-performance, highly available, and secure environment with a non-blocking architecture that enables seamless elastic scalability.
- Inter-Fabric Transport which enables a scalable, high-performance, highly available any-to-any transport network for connecting the edge and core fabric

Aggregation Fabrics

The Arista architecture of the aggregation fabric is open, scalable, resilient, and secure. As illustrated in Figure 3, the fabric serves as both an access layer for edge nodes (RPDs) and an aggregation layer for CCAP core elements. The fabrics based on Arista products offer advanced support for CIN architecture through a range of key features. These include CIN-optimized platforms with the highest density of 25/100/400G per RU, low power and cooling per RU, and advanced multicast and QoS capabilities.

By leveraging the EVPN control plane, the architecture enables seamless and simplified end-to-end service provisioning between the edge and core service fabrics. This design facilitates effortless scale-out over a CLOS topology, providing flexible layer-2 and layer-3 services, multicast capabilities, advanced convergence, and resilience through multihoming, load balancing, and broadcast suppression.

EOS-based fabrics support a set of rich features that allows for remote self-provisioning and recovery, flexible transport tunnel options, and seamless WAN integration. Flexible BSS/OSS integration is through protocols like NETCONF/YANG, gRPC/gNMI, REST, and SDK, enabling seamless CI/CD. Additionally, the system offers advanced service assurance capabilities that includes hi-fidelity telemetry with model-based streaming, hardware-assisted Sflow, IPFIX, and inline network monitoring (INT).

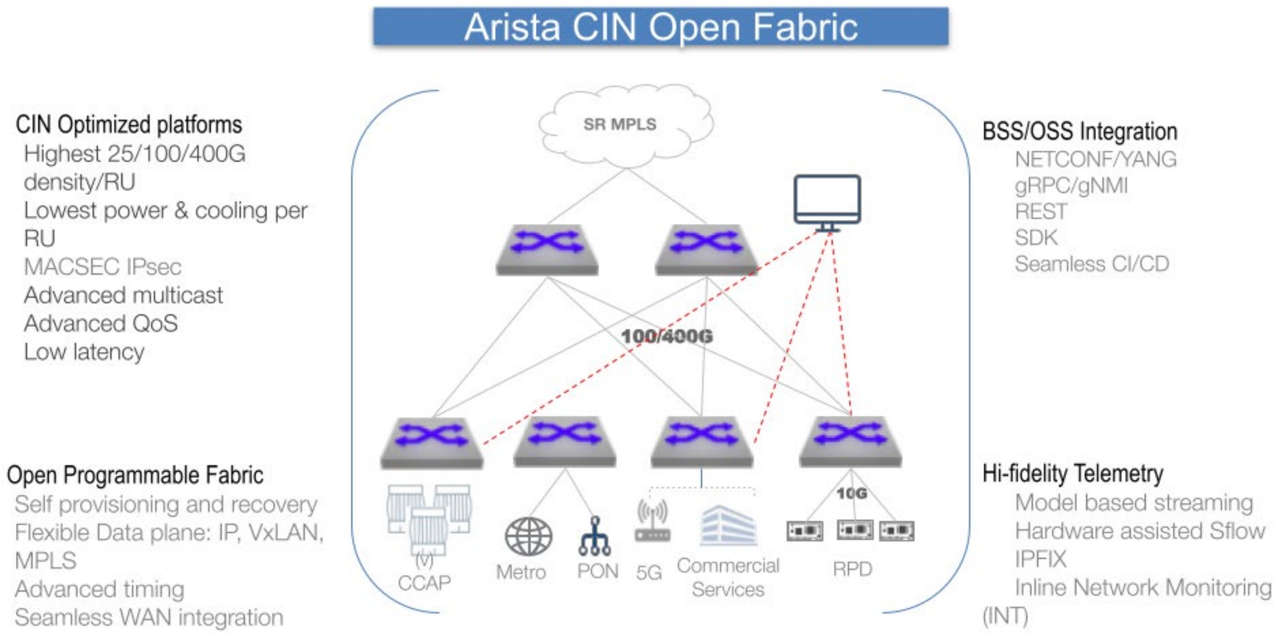

Figure 3: Arista CIN IP Fabric

Table 1: provides a comprehensive list of must-have features, fully supported by Arista's open IP fabrics, enabling a successful CIN deployment.

Feature	Description
Non-Blocking Performance	High performance, low latency, fully non-blocking fabric with support for 10/25/100/400G connectivity and a road map to 800G and 1.6Tbs.
Secure Transport	Advanced security features including 802.1X and line rate MACSEC encryption for up to 400G to ensure end-to-end data integrity and secure connectivity between the RPD and CIN infrastructure through authentication and encryption.
Advanced Multicast	Support for scalable dynamic multicast protocols: PIMv4, PIMv6, IGMPv3, MLDv2 and EVPN multicast through a simple underlay or multicast VPN.
QoS	Advanced VoQ and robust traffic prioritization options such as DSCP, 802.1Q, EXP bits, and advanced congestion avoidance (shaping) and congestion management features (policing).
Maximized Node Uptime	With the RPD aggregation nodes being single-threaded without redundancy, upgrading them can impact hundreds of downstream customers, making ASU an important feature.Accelerated Software Upgrade (ASU) , a unique high availability feature supported by EOS virtually eliminates long upgrade times by compressing costly node upgrade downtime from tens of minutes to sub-seconds.
Network Timing	Support for ITU-T G.8275.2 and Synchronous Ethernet for timing synchronization between the RPDs and the CCAP core. To ensure accurate timing throughout the network, tall elements in the CIN fabrics need to be PTP-aware and the RPD aggregation leaf must be enabled as support boundary clock (T-BC).

Inter-fabric Transport

Remote PHY specifications leverage a tunnel-based architecture (L2TPv3) to connect the Remote PHY Devices (RPDs) to the MAC function. It is crucial to support strict timing specifications and ensure symmetric and predictable traffic flow between the RPDs and the CCAP Core services. This requires avoiding packet drops, asymmetrical latency, and out-of-order packets.

Hence, the remote PHY fabric and CCAP core services require a reliable and flexible inter-fabric IP transport (Figure 2). To meet all the outlined requirements, the inter-fabric transport must leverage advanced traffic engineering, robust high availability capabilities, high performance multicast services and a flexible QoS framework.

Arista's inter-fabric transport architecture leverages EOS' next-generation Segment Routing (SR) transport stack and BGP EVPN control plane. By utilizing SR-TE, the network optimizes bandwidth utilization, guarantees symmetric paths, and maintains ordered packet delivery. Additionally, fast reroute features like TI-LFA prevent extended disruptions and preserve high quality-of-experience.

Furthermore, EOS supports a rich BGP EVPN implementation that enables flexible services over the transport architecture, supporting Layer-2 and Layer-3 VPN for segmented services. For example, EVPN-VPWS allows operators to create pseudowire connections, emulating point-to-point circuits between RPDs and core services. Similarly, Layer-3 multicast VPN effectively isolates and delivers video multicast services over Segment Routing MPLS (SR-MPLS) transport.

In CIN-based DAA topologies, where several hundred 10G-enabled RPDs are aggregated, traditional optical networks using line systems and ROADM technology become complex and expensive. Arista offers cable operators with extensive support for industry-standard coherent optics, utilizing tunable ZR/ZR+ optics.ZR/ZR+ based routers will provide cable operators a cost-effective and efficient alternative for transporting signals in metro networks. ZR/ZR+ based solutions will provide::

- Enhanced reach and bandwidth efficiency for transporting aggregated signals in metro networks.
- Cost efficiency through the elimination of costly transponders and line systems, simplifying network infrastructure, and reducing overall costs for cable metro networks.

Technology Transition Leveraging Merchant Silicon

While network modernization will bring about immense benefits, it also requires substantial capital outlay. Meanwhile, operators are facing the twin challenges of budget constraints and environmental limits of space, power, and cooling at the headends and hubs. Hence, operators have to select infrastructure that can lower their capital expenditure, provide the highest cost to performance, and meet the operational prerequisite of lower power, space and cooling.

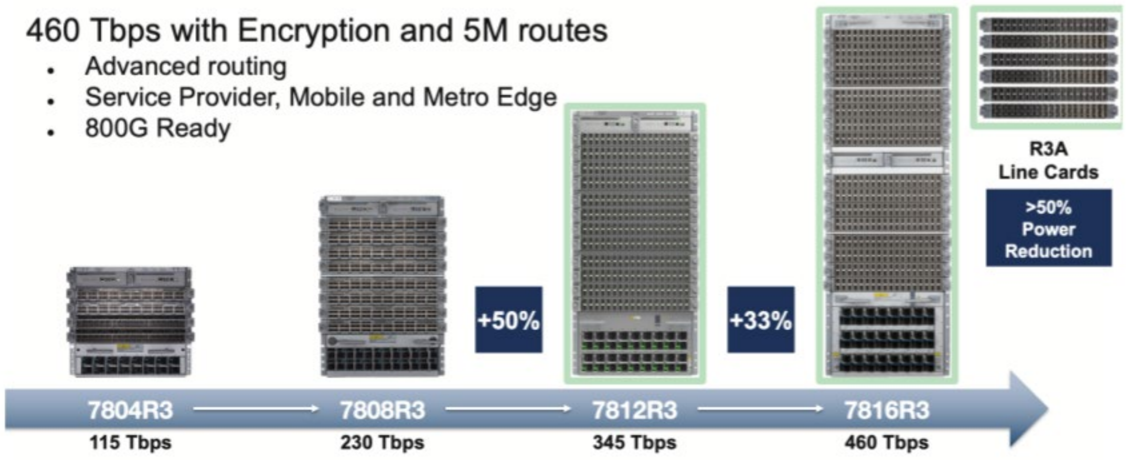

Figure 4: Arista 7800R3 - Systems and Line Cards

Arista's merchant silicon-based hardware designs are purpose built to provide cable operators a cost-effective modernization path. Arista's merchant silicon-based leaf-spine architectures leverage Moore's Law to provide an effective TCO compression strategy. Unlike traditional 'scale-up' proprietary bespoke hardware architectures, Arista's platforms leverage the merchant silicon curve, doubling the network bandwidth and reducing the cost-per-bit every 24 months, providing unparalleled cost-effective scale-out architecture (Figure 4). Using environmentally efficient platforms based on merchant silicon will enable cable operators to seamlessly increase capacity and introduce new services while lowering space and power consumption.

Moreover, leveraging Arista unique EOS's single binary architecture ensures seamless transitioning between different generations of packet processors, keeping pace with Moore's Law. A single-binary software image across all hardware simplifies network administration and ensures a consistent user experience and system stability and performance through technological evolutions.

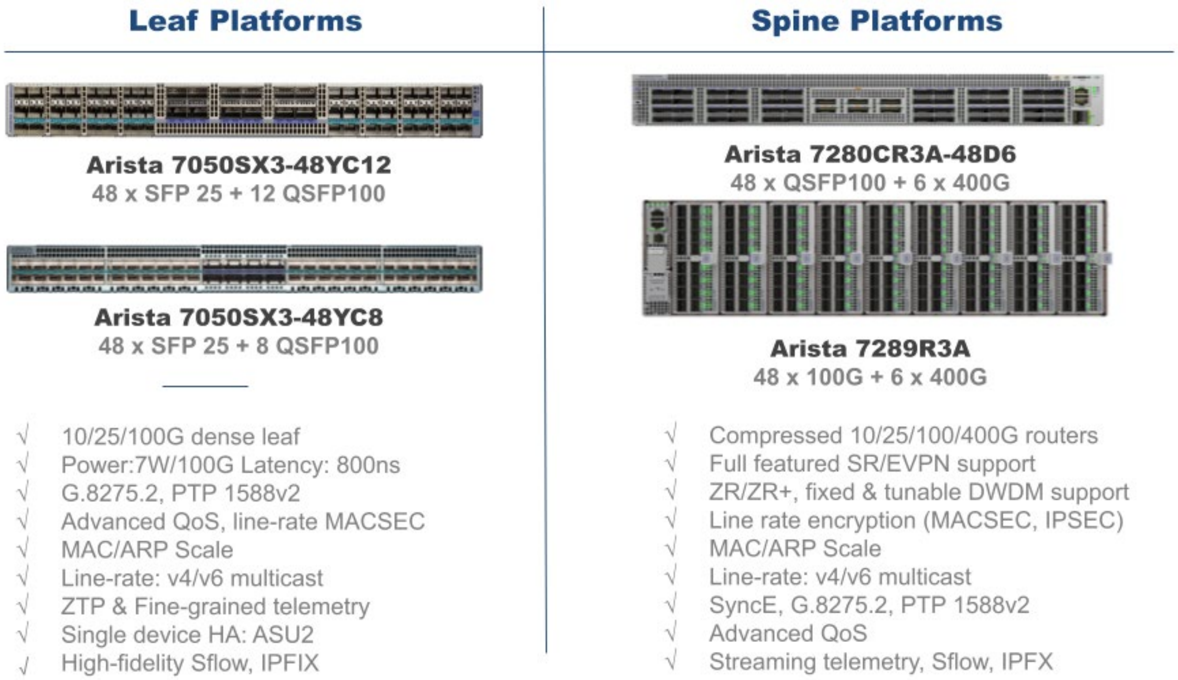

Figure 5: Arista X-series and R-series portfolio for CIN IP Fabric

Figure 5 shows a sample CIN-ready Arista platform leveraging the most advanced merchant silicon architectures.

- The Arista 7050X3 family provides flexible 10G, 25G and 100G configuration options. Combining high density and industry leading power efficiency, low latency (800ns) with typical power consumption under 7W per 100GbE making them ideal building blocks for remote PHY device aggregation.
- Within the 7280R3A family, the 7280CR3A is a deep buffer 25G, 100G and 400G router designed for the highest performance routing requirements in a 2RU form factor, while the Arista 7289R3A is 14.4 Tbps compact modular router providing flexible interface choices ranging from 10G to 400G.

Automation

The transition to IP-based CIN architecture in cable networks can introduce disruptive changes to existing management and maintenance models including time consuming upskilling of personnel. The manual management approach of the analog network has become obsolete, inefficient, and too costly to maintain. Automation simplifies and optimizes large-scale infrastructure management while reducing the risk of costly human errors. Leveraging Arista modern network operating models like repeatable design patterns, automated operations via software control, and an open, flexible architecture, cable operators can harness cloud networking principles, to garner operational efficiency and cost savings.

Arista's EOS offers a comprehensive set of open APIs and protocols, providing the industry's most advanced programmability and extensible software stack. Leveraging EOS extensibility and programmability features, operators can seamlessly support device rapid deployments, change management, troubleshooting, and software upgrades at scale. Moreover, EOS allows for easy integration into an existing operator's OSS/BSS ecosystem via a rich set of structured APIs that include:

- eAPI: EOS supports a JSON-based Remote Procedure Call (RPC) mechanism, offering a REST-like interface for seamless programmability.
- OpenConfig, NETCONF, and Restconf: EOS supports industry-standard transport protocols, enabling integration with external systems through structured APIs.
- Native Linux APIs and scripting: EOS provides access to native Linux APIs, allowing operators to leverage existing Linux-based tools and scripts for automation.

- Native scripting with Go and Python: Operators can write scripts in Go or Python directly on the EOS platform, enabling custom automation and integration with other systems.
- EOS Zero Touch Provisioning (ZTP) automates the configuration of new or replacement platforms without the prerequisite "truck rolls" or manual user intervention. An extension to ZTP, Zero Touch Replacement (ZTR), enables switches to be physically replaced, with the replacement switch picking up the same image and configuration as the existing switch it has replaced.

The integration of CIN into the cable network ecosystem paves the way to a new and efficient approach to managing the network lifecycle. However, testing and deploying a distributed system like CIN can indeed be challenging due to the inherent complexities involved. To that end, cable operators can enable Arista's **Continuous Integration/Continues Development (CI/CD)** methodologies that seamlessly deploy and operate their networks at a lower cost. The Arista CI/CD pipeline will assist designing, integrating, testing, and delivering network infrastructure changes.

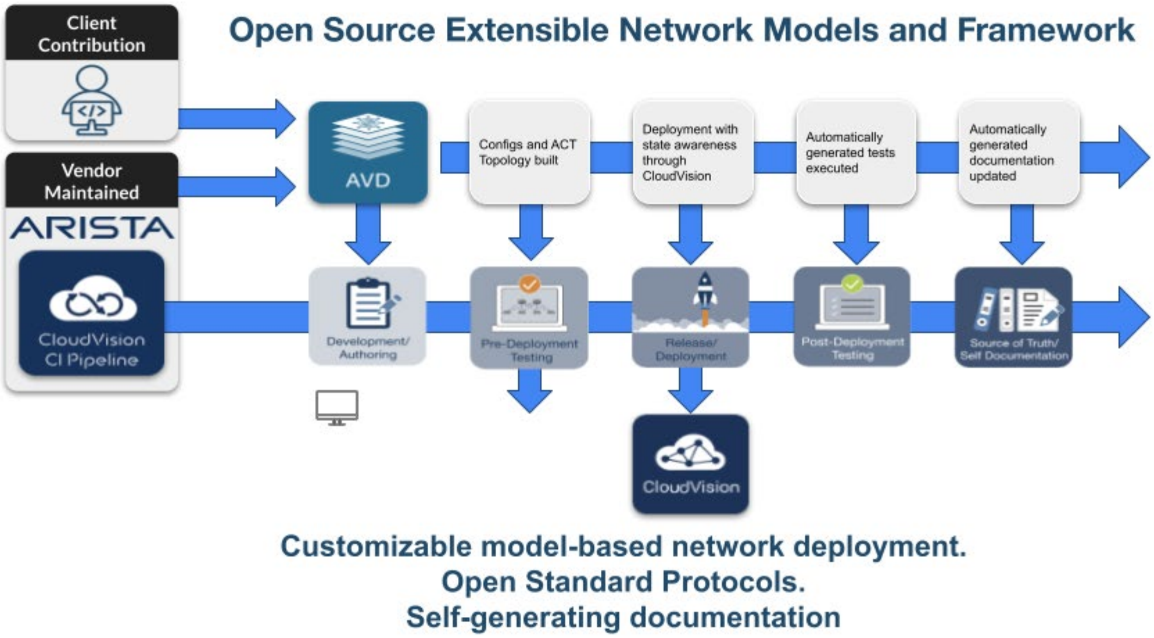

Figure 6: Infrastructure As A Code

As an example, operators can utilize Arista's Validated Designs (AVD) to automate full network configurations based on input of only a small number of variables. The AVD concept allows the network to be both driven by and consumable as code. As a part of the Arista CI Pipeline, AVDs provide flexible open data models and comprehensive workflows tailored to the remote PHY edge and core fabrics and integrated into the existing operators multi-domain multi-vendor management ecosystem. Leveraging a consistent software image across all edge and core platforms, Arista's CI/CD will simplify and automate configuration to deliver consistent, and error free deployment and maintenance of the remote PHY and CAPP core multi-domain fabrics.

Advanced Observability

In today's modern service provider networks, operating at scale demands a shift from reactive network monitoring to a more comprehensive observability paradigm. This new approach enables proactive measurement and monitoring of infrastructure, focusing on the entire connectivity and service experience of end-users, rather than individual devices. Recognizing this need, Arista has developed NetDL (Figure 7), a powerful tool that serves as a multi-modal and multi-tenant network-centric data lake that enables the application of AI/ML technologies and facilitates collaboration with third-party ecosystems. NetDL empowers operators to achieve holistic observability, providing deep insights into network behavior, performance, and user experience.

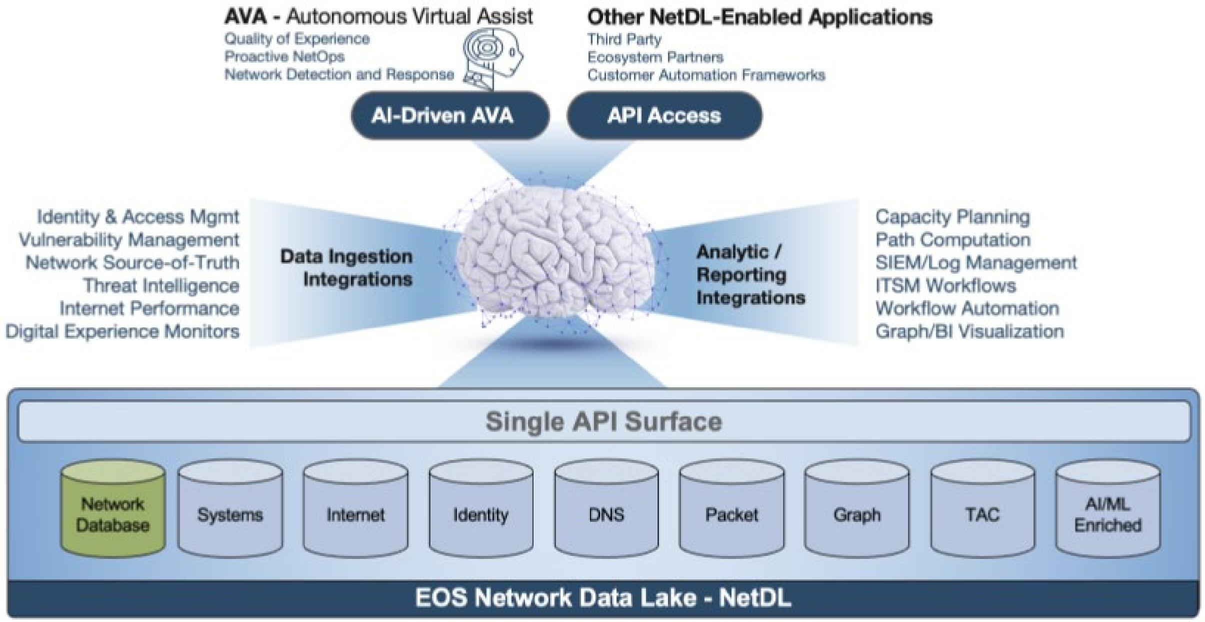

Figure 7: EOS NetDL - The Foundation for Data Driven Networking

NetDL telemetry solution offers comprehensive insights into both control plane and service plane metrics. As an example, by enabling in-band (INT) telemetry and utilizing real-time streaming telemetry features, operators gain the ability to identify and trace critical control messages like PTP packets as they traverse the network. This provides a powerful tool to pinpoint congestion delays caused by specific CIN hops, or identify the devices responsible for jitter and packet drops during transit.

On the control plane, operators can monitor protocol states, routing information base (RIB) status, utilization of the forwarding information base (FIB) hardware table, and the health of optical transceivers. Real-time monitoring of metrics such as buffer utilization and device health is made possible through NetDL.

CIN operators can leverage IPFIX flow reports, available through NetDL, to extract detailed flow information, enabling the identification of flow behavior between remote PHY nodes and the CCAP core services. Furthermore, IPFIX flow reports offer a straightforward solution for detecting and diagnosing out-of-order packet arrival in L2TPv3 tunnel packets caused by load balancing operations on transit CIN links.

By leveraging NetDL and the advanced capabilities of Arista EOS, operators have the tools to proactively manage their networks, ensuring optimal performance and delivering exceptional service experiences. This comprehensive understanding of both the control plane and data plane empowers operators to effectively monitor and optimize the grade of service for devices, resulting in superior network performance. With NetDL as a foundation, operators can embrace AI-driven network operations, unlocking the full potential of their networks and driving continuous improvement.

Summary

A successful transition to next-generation distributed access architecture and converged IP network requires adoption of a cloud-centric approach to design, build and operate the cable network. Arista's solution based on merchant silicon platforms and state-of-the-art network operating system (EOS) enables cable operators to cost-effectively scale their services while reclaiming valuable environmental footprint through significant savings in space, power, and cooling at the headend and hubs.

Leveraging EOS, cable operators can streamline their workflow and optimize resources by leveraging remote infrastructure self-provisioning, self-monitoring, on-demand programmatic capacity allocation, and bandwidth management. Arista's design framework and innovative platforms deliver on technological superiority, architectural flexibility and unparalleled TCO to modernize cable networks for the cloud era.

By deploying future-proof cable network infrastructure solutions, operators will be well positioned to provide an outstanding customer experience while ensuring sustained success in the long run. Arista's continued innovation in best-in-class software, high performance hardware and advanced network management will deliver the scale and performance required by operators to support next-generation disruptive cable services.

Abbreviations Glossary

BGP	Border Gateway Protocol
CCAP	Converged Cable Access Platform
CMTS	Cable Modem Termination System
DAA	Distributed Architectures
DEPI	Downstream External PHY Interface
DOCSIS	Data over Cable System Interface Specification
EAPI	Arista Extensible API
ECMP	Equal-Cost Multi-Path
HFC	Hybrid Fiber Coax
I-CCAP	Integrated CCAP
IS-IS	Intermediate System to Intermediate System
IPFIX	Internet Protocol Flow Information Export
INT	in-band telemetry
GNMI	gRPC Network Management Interface
L2TPv3	Layer 2 Transport Protocol version 3
LSP	Label Switching Path
MPLS	Multi-Protocol Label Switching
NETCONF	Network Configuration Protocol
PSP	Packet Streaming Protocol
REST	Representational State Transfer
RPD	Remote PHY Device
RR	Route Reflector
R-PHY	Remote PHY
SR	Segment Routing
SFLOW	Sampled Flow
TE	Traffic Engineering
UEPI	Upstream External PHY Interface
VOD	Video on Demand
YANG	Yet Another Next Generation

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