Evolution and Revolution:
The Many Paths to DOCSIS® 4.0

Learn about the many evolutionary and revolutionary options for transforming your HFC network.

Increased bandwidth consumption—particularly in the upstream—and consumer demand for new, bandwidth-hungry services has pushed the capacities of many current HFC networks to their limits. Traditional methods of increasing bandwidth capacity, such as node splits, have reached the point of diminishing returns in this evolving environment. Cable operators must consider new strategies for expanding bandwidth capacity and network speeds to keep pace with new technologies and consumer demands—strategies that encompass headend operation, video delivery, and network optimization and evolution.

COMMSCOPE®

The Challenge

How quickly, and to what extent, should these changes occur? That's the question everyone in the cable industry is asking, and the answers are complex. During the past three years, for example, consumer bandwidth usage growth during peak periods has slowed down. Yet growth in upstream bandwidth consumption by consumers has increased during this same period.[1] To further complicate matters, historical jumps in bandwidth consumption typically coincide with consumer adoption of new technologies. The popularity of video streaming, for example, resulted in a huge surge in bandwidth consumption between 2010 and 2018.[2] It's possible that we may see an analogous surge in bandwidth consumption as 4K streaming and gaming, smart devices, and Virtual or Augmented reality are adopted by consumers in the next decade and beyond.

These trends suggest that a graduated approach to network expansion—one that addresses immediate capacity needs while laying the groundwork for future improvements—is prudent. Stage one, roughly encompassing the next three to five years, should address current trends in network bandwidth consumption (approximately 20% compounded annual growth in the upstream and 18% compounded annual growth in the downstream) while providing enough capacity for the introduction of new consumer services. The second stage, roughly encompassing the next five to 10 years, will require bandwidth capacities and speeds that support multi-gigabit service tiers while also maintaining efficient service group sizes in rural, suburban, and urban environments.

With this graduated approach in mind, cable operators can adopt a dual strategy for improving their networks to increase capacities and speeds. First, traditional HFC networks can be upgraded to support full DOCSIS 3.1 capacity, with supporting improvements in the headend, CMTS layer, and home devices. Since a DOCSIS 3.1 network looks very much like a traditional HFC one—the changes are largely confined to increasing the operating capacity of existing actives and passives in the network—a DOCSIS 3.1 network may be seen as an *evolutionary* stage of development that lays the foundation for the expanded bandwidths and speeds available with DOCSIS 4.0.

Eventually, cable operators may decide to remake their networks using advanced technologies like Distributed Access Architecture (DAA) or Passive Optical Networks (PON). This *revolutionary* approach utilizes non-traditional, virtualized network components, pushes headend quality signals to the edge of the network, and introduces modes of delivering and managing content that greatly increase available bandwidths and network speeds—thereby unlocking the full capacities of the DOCSIS 4.0 network.

Evolving the Network, Part 1: DOCSIS 3.1

DOCSIS 3.1 supports a maximum downstream spectrum of 258–1218 MHz and a maximum upstream spectrum of 5–204 MHz. It allocates up to 192 MHz bandwidth per OFDM downstream channel with 4092-QAM modulation. In the upstream, it allocates up to 96 MHz bandwidth per OFDMA channel with 1024-QAM modulation. DOCSIS 3.1 supports up to three OFDM downstream channels and two OFDMA upstream channels.

There are two, high-capacity bandsplits that support DOCSIS 3.1 operation. A mid-split operates with a 108-1218 MHz downstream spectrum and a 5-85 MHz upstream spectrum—the minimum downstream and upstream spectrums required for DOCSIS 3.1 operation. A high-split operates with a 258–1218 MHz downstream spectrum and a 5–204 MHz upstream spectrum. High-splits optimize the full downstream and upstream capacity available in a DOCSIS 3.1 network.

1 John Ulm, Zoran Maricevic, Ph.D., and Ram Ranganathan. Broadband Capacity Growth Models: Will the end of Exponential Growth eliminate the need for DOCSIS 4.0?, pg. 11. https://tinyurl.com/3ms7bxf4
2 Ulm, et. al. Broadband Capacity Growth Models, pg. 22.

Optimizing an existing network for DOCSIS 3.1 operation allows cable operators to achieve significant gains in both upstream and downstream capacity. A mid-split upgrade, for example, typically increases downstream capacity by approximately 60% and upstream capacity by 65% over sub-split capacities.[3] High-split upgrades result in even more dramatic increases in upstream capacity— approximately 310%, or five times the capacity supported by sub-split operation (see Table 1).[4]

Split	New Upstream Spectrum (MHz)	D3.0 Upstream Capacity (Mbps) @ 6.4 MHz per Channel	D3.1 Upstream Capacity (Mbps) @ 6.4 MHz per Channel
Sub-Split	5–42	Up to 150	Up to 250[5]
Mid-Split	5–85	Up to 330	Up to 330 Up to 540
High-Split	5–204	Up to 330	Up to 1350

Table 1. Sub-split, mid-split, and high-split upstream capacity in a DOCSIS 3.1 network

Utilizing the DOCSIS 3.1*Enhanced* (D3.1*E*) solution in a mid- or high-split DOCSIS 3.1 operation enables cable operators to increase the number of OFDM blocks in the downstream— which, in turn, leverages existing CMTS infrastructures to realize significant capacity gains. While current generation DOCSIS 3.1 cable modems only support two OFDM downstream channels, the expanded downstream and upstream bandwidths available with next-generation DOCSIS 3.1 cable modems supports an expanded bank of four OFDM channels. This is done by bonding OFDM channels from existing CMTS and/or Remote MAC-PHY equipment, resulting in a 4x2 solution that is fully supported by DOCSIS 4.0 cable modems. Alternatively, cable operators can operate D3.1*E* using DOCSIS 4.0 cable modems ahead of full DOCSIS 4.0 operation in a DOCSIS 3.1 high-split network to support an expanded bank of five OFDM channels, resulting in 5x2 solution. Both D3.1*E* options are discussed in more detail later in this Solution Brief.

Optimizing the Outside Plant for DOCSIS 3.1

To fully optimize the outside plant for DOCSIS 3.1 operation, cable operators should implement 204/258 MHz high-split operation either directly from a sub-split band or after an intermediate mid-split network migration. 204/258 MHz high splits can support asymmetrical 5G/1G service tiers, which maximize the potential bandwidth capacity available in the DOCSIS 3.1 spectrum.

COMMSCOPE MID- AND HIGH-SPLIT PRODUCTS

- 1.2 GHZ TAPS AND PASSIVES

- FACTORY CONFIGURED 1.2 GHZ AMPLIFIERS

- FACTORY-CONFIGURED 1.2 GHZ NODES

- 204 MHZ DIGITAL RETURN TRANSMITTER FOR NC4 AND OM4 SERIES NODES

- FACTORY-CONFIGURED RxD NODES AND UPGRADE KITS

- HIGH-SPLIT UPGRADE KITS

- FACTORY CONFIGURED MID- AND HIGH-SPLIT NODE AND AMPLIFIER RF MODULES

- MID- AND HIGH-SPLIT BANDWIDTH UPGRADE KITS FOR NODES AND AMPLIFIERS

Cable operators, however, must consider several potential issues related to the expanded, high-split upstream spectrum. These include relocating downstream channels that exist at sub-85 MHz frequencies, addressing potential ingress or leakage issues at frequencies above 85 MHz, and moving legacy Out-of-Band (OOB) set-top channels to higher frequencies.

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[3] Jim McGuire. Preparing for DOCSIS 3.1, pg. 4. https://ja.commscope.com/globalassets/digizuite/1878-wp-113924-en-preparing-for-docsis-3-1.pdf
[4] McGuire, pg. 4.
[5] This capacity figure is theoretical; the 5-42 MHz portion of the spectrum is not used in DOCSIS 3.1 mid- or high-split operation. OFDMA channels in both mid- and high-split operation begin at 43 MHz, as shown in the table.

In sub-split networks, the OOB channel resides at a sub-102 MHz frequency. A cable operator's base of legacy set-top boxes will probably include a mix that:

- Cannot receive OOB signals of 102 MHz or higher

- Can receive OOB signals of 102 MHz or higher

- Cannot receive signals at the upper edge of a high-split 258 MHz downstream bandwidth

A cable operator should therefore consider the effort and cost involved in evaluating and, if necessary, replacing legacy set-top boxes that cannot receive OOB signals of either 102 MHz or 258 MHz. Typically, most current set-top boxes can operate at the 102 MHz return frequency, but if the cable operator opts for a high-split upgrade, then a targeted deployment of DOCSIS Set-top Gateway (DSG) set-top boxes—which can fully support 258 MHz frequencies—will need to be part of any upgrade plan.

Traditional leakage detection signal choices also become an issue in high-split networks. In sub- or mid-split networks, the leakage detection frequency is typically located between 135 and 138 MHz in the downstream band. But high-split downstream bands begin at 258 MHz, which requires the leakage detection frequency to be moved into the upstream band, where it can reside at the same frequency. While high-split leakage detection is extremely complex, CommScope has worked with leading vendors to successfully implement leakage detection in I-CCAP, R-PHY, and R-MACPHY CMTS architectures.

How does a cable operator cost-effectively optimize a current HFC network for DOCSIS 3.1? Primarily by updating current active network components—such as amplifiers and nodes—and any associated taps and passives for mid-split or high-split operation at 1.2 GHz.

A typical HFC network is shown in Figure 1. Common HFC network architectures include N+3, N+4, N+5, and N+6 designs, in which N indicates a node (with either analog or digital return) and the number following indicates the number of amplifiers after the node.
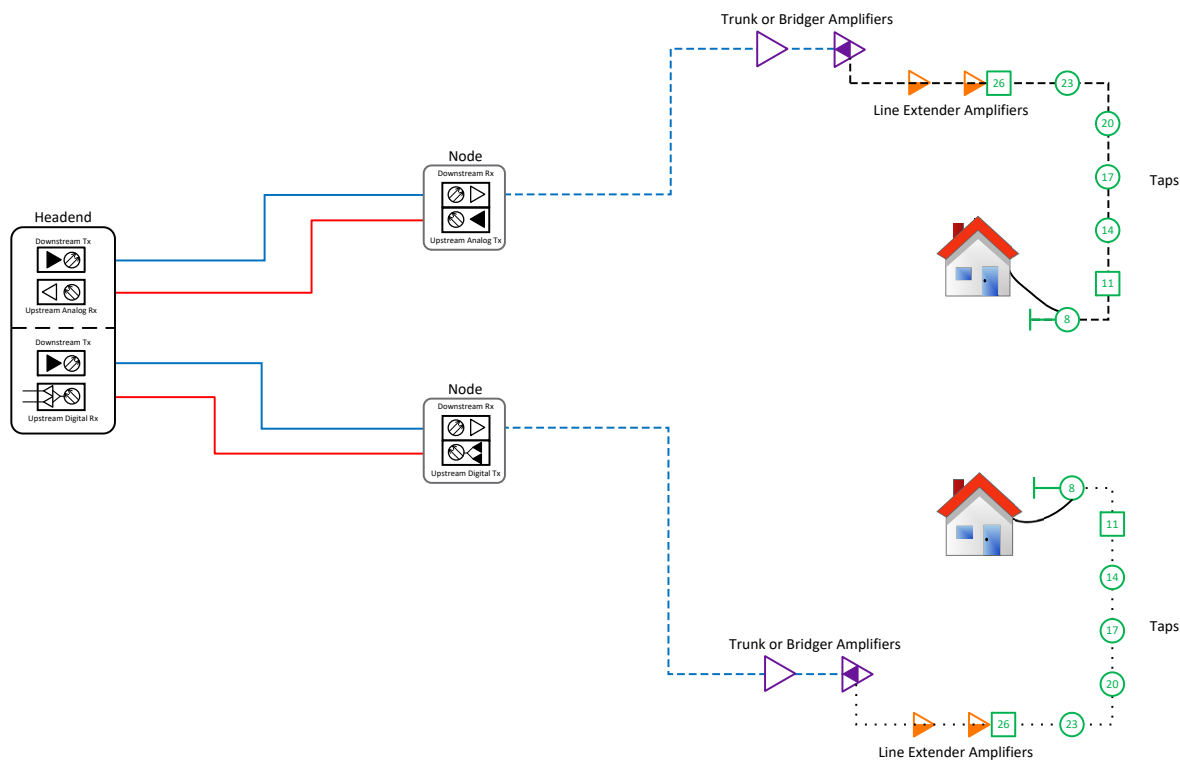

Figure 1. Typical HFC Network

To modify an existing active device, the cable operator can upgrade or replace the RF module in an amplifier and/or node to support the new operating bandwidth. CommScope offers bandwidth upgrade kits for both nodes and amplifiers that include diplex filters—which separate the upstream and downstream bandwidth frequencies—and associated plug-in components that are installed in an RF module. Alternatively, field technicians may remove an existing RF module in an amplifier or node and replace it with an RF module

that has been configured in the factory to support either an 85/102 MHz or a 204/258 MHz split. Additional modifications to the active may be required to support 1.2 GHz operation; for example, field technicians may also need to install 1.2 GHz port seizure assemblies in amplifier housings designed to operate at frequencies up to 1 GHz. Similarly, the optical modules installed in a node operating at frequencies up to 1 GHz may need to be replaced with equivalent modules that support 1.2 GHz operation. For high-split return operation from an HFC node, CommScope has the DT4600 digital return transceiver—compatible with NC4 Series and OM4 Deep Lid nodes—and CWDM and DWDM analog transmitters, which are compatible with OM4 standard lid and OM6 series nodes.

Taps and passives can be upgraded for 1.2 GHz operation by replacing the lower frequency faceplates with new faceplate assemblies that support higher frequency operation. This is primarily done to minimize insertion losses to maintain existing RF levels for Customer Premises Equipment (CPE) devices to ensure optimal DOCSIS 3.1 operation in the home.

Optimizing DOCSIS 3.1 Network Performance: D3.1*Enhanced* (D3.1E)

D3.1*E* operation can expand the OFDM capacity of a current DOCSIS 3.1 network by deploying next-generation DOCSIS 3.1 Customer CPE devices in homes that subscribe to high-speed services, which typically require greater network capacity. Due to the limitations of legacy DOCSIS 3.1 CPE chipsets, DOCSIS 3.1 plants operating at up to 1.2 GHz in the downstream and 204 MHz in the upstream could only support limited speed tiers to homes, becuase these legacy CPE chipsets could only bond up to two OFDM channels and 32 single carrier QAMs (SC-QAMs). Thanks to advances in these chipsets, however, next-generation D3.1E CPE devices can support bonding of up to four OFDM channels and 32 SC-QAMs in these same networks; the devices also support speeds of up to 1.7 Gbps in the upstream in both mid- and high-split networks. By surgically targeting customers that subscribe to high-tier services, cable operators can optimize the capacity and speed of high-tier services without any additional network upgrades or the incremental costs and service disruptions that may occur in a transition to DOCSIS 4.0 operation.

Note that mid-split networks provide an additional 150 MHz of downstream bandwidth when compared to high-split networks; mid-split upstream bandwidth is, however, more limited than high-split upstream bandwidth, which provides an extra 119 MHz of bandwidth.

A second D3.1*E* option, which is suited for cable operators who plan to migrate from high-split DOCSIS 3.1 network operation to DOCSIS 4.0, is discussed in "D3.1*E* as an Intermediary Step to DOCSIS 4.0" on page vi.

Table 2 shows the potential gains with D3.1*E* deployments in mid- and high-split DOCSIS 3.1 networks.

D31 Mid-Split Spectrum	DOCSIS 3.1 CMTS Channels		Max. DOCSIS 3.0 SG Configuration Examples		Max. D3.1/ D3.1E SG Configuration Examples			
	SC-QAM (6 MHZ)	OFDM	Max. D3.0 Subs	Max. D3.0 DS Tier	Max. 3.0 + 3.1 Subs	Max. D3.1 DS Tier	Est. D3.1E DS Tier	Raw D3.1E DS Tier
108 – 684 MHz	32	2 x192	100	500 Mbps	274	3 Gbps	3 Gbps	3.7 Gbps
	0	3 x 192	0	—	226	3 Gbps	4 Gbps	4.7 Gbps
108 – 876 MHz	32	3 x 192	100	500 Mbps	255	4 Gbps	5 Gbps	5.7 Gbps
	0	4 x 192	0	—	206	3 Gbps	6 Gbps	6.7 Gbps
108 – 1068 MHz	32	4 x 192	100	500 Mbps	235	4 Gbps	7 Gbps	7.7 Gbps
	0	4 x 192	0	—	187	3 Gbps	8 Gbps	8.7 Gbps
D3.1 High-Split Spectrum	DOCSIS 3.1 CMTS Channels		Max. DOCSIS 3.0 SG Configuration Examples		Max. D3.1/D3.1E SG Configuration Examples			
	SC-QAM (6 MHz)	OFDM	Max. D3.0 Subs	Max. D3.0 DS Tier	Max. 3.0 + 3.1 Subs	Max. D3.1 DS Tier	Est. D3.1E DS Tier	Raw D3.1E DS Tier
258 – 834 MHz	32	2 x 192	100	500 Mbps	274	3 Gbps	3 Gbps	3.7 Gbps
	0	3 x 192	0	—	226	3 Gbps	4 Gbps	4.7 Gbps
258 – 1026 MHz	32	3 x 192	100	500 Mbps	255	4 Gbps	5 Gbps	5.7 Gbps
	0	4 x 192	0	—	206	3 Gbps	6 Gbps	6.7 Gbps
258 – 1218 MHz	32	4 x 192	100	500 Mbps	235	4 Gbps	7 Gbps	7.7 Gbps
	0	4 x 192	0	—	187	3 Gbps	8 Gbps	8.7 Gbps

Table 2.Potential Capacity and Throughput Improvements with D3.1*E* Mid- or High-split Network Deployments

Evolving the Network, Part 2: DOCSIS 4.0

Optimizing a sub-split network for DOCSIS 3.1 operation is a necessary first step to DOCSIS 4.0. While a mid- or high-split upgrade significantly improves the network speeds and capacities that were achievable in sub-split operation, DOCSIS 4.0 builds upon those improvements to achieve even greater network speeds and capacities.

When comparing the two modes of operation, the most significant gains are realized in the upstream spectrum: DOCSIS 3.1 supports a maximum upstream capacity of up to 1.7 Gbps, while DOCSIS 4.0, supports upstream capacities of up to 8.7 Gbps. Though DOCSIS 3.1 upstream capacities are adequate for current services—typically, a current broadband subscriber's upstream data consumption is only around 10% of their downstream data consumption[5]—in the future, as interactive applications and devices become more common, upstream data consumption may increase considerably.

DOCSIS 4.0 supports a maximum downstream spectrum of 108-1794 MHz and a maximum upstream spectrum of 10-684 MHz. It allocates up to 192 MHz of bandwidth per OFDM downstream channel with support for 4092-QAM modulation. In the upstream, it allocates up to 96 MHz bandwidth per OFDMA.

D3.1*E* as an Intermediary Step to DOCSIS 4.0

D3.1*E* is a solution for optimizing DOCSIS 3.1 mid- and high-split network capacity and throughput (discussed in "Optimizing DOCSIS 3.1 Network Performance: D3.1*Enhanced* (D3.1*E*)" on page v). But D3.1*E* can also be deployed as an intermediate step between high-split DOCSIS 3.1 and full DOCSIS 4.0 operation. Cable operators who plan to make the transition to DOCSIS 4.0, but who wish to optimize high-speed service tiers in the interim, can deploy DOCSIS 4.0 CPE devices to future-proof the network for full DOCSIS 4.0 deployments.

This mode of D3.1*E* operation can bond five or more OFDM channel blocks, subject to the appropriate hardware-based CMTS/I-CCAP (such as E6000® CER) CCAP Core with a Remote PHY Device (RPD), Remote MACPHY Device (RMD), or virtual CCAP Core (such as vCore) with RPD support, and support speeds of up to 1.7 Gbps in the upstream. As an intermediary step to full DOCSIS 4.0 operation, D3.1*E* deployments with DOCSIS 4.0 CPE devices can immediately support even higher service tiers than an Enhanced DOCSIS deployment in a DOCSIS 3.1 mid- or high-split network. After migrating to full DOCSIS 4.0 operation, however, cable operators will see a significant upgrade in upstream channel capacity and speeds with the DOCSIS 4.0 CPE, from a maximum of two OFDMA channel blocks in a high-split DOCSIS 3.1 network to a maximum of seven OFDMA channel blocks.

Table 3 shows the potential gains with D3.1*E* deployments that utilize DOCSIS 4.0 CPE devices.

D3.1 High-Split Spectrum	DOCSIS 3.1 CMTS Channels		Max. DOCSIS 3.0 SG Configuration Examples		Max. D3.1/D3.1*E* SG Configuration Examples			
	SC-QAM (6 MHz)	OFDM	Max. D3.0 Subs	Max. D3.0 DS Tier	Max. 3.0 + 3.1 Subs	Max. D3.1 DS Tier	Est. En. D3.1*E* DS Tier	Raw En. D3.1*E* DS Tier
258 – 834 MHz	32	2 x 192	100	500 Mbps	274	3 Gbps	3.7 Gbps	4.5 Gbps
	0	3 x 192	0	—	226	3 Gbps	4.7 Gbps	5.5 Gbps
258 – 1026 MHz	32	3 x 192	100	500 Mbps	255	4 Gbps	5.7 Gbps	6.5 Gbps
	0	4 x 192	0	—	206	3 Gbps	6.7 Gbps	7.5 Gbps
258 – 1218 MHz	32	4 x 192	100	500 Mbps	235	4 Gbps	7.7 Gbps	8.5 Gbps
	0	5 x 192	0	—	187	3 Gbps	8.7 Gbps	9.5 Gbps

Table 3. Potential Capacity and Throughput Improvements with D3.1*E* Deployments using DOCSIS 4.0 CPE Devices

For more information about this D3.1E option, refer to https://www.commscope.com/blog/2023/easing-into-docsis-4.0-on-legacy-docsis-3.1-infrastructure/.

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5 "DOCSIS 4.0 Technology." https://www.cablelabs.com/technologies/docsis-4-0-technology. Accessed on 3-30-23.

Two Paths to DOCSIS 4.0

Cable operators have two options for achieving full DOCSIS 4.0 operation. Extended Spectrum DOCSIS (ESD) operates at a downstream bandwidth of 1794 MHz and an upstream bandwidth of up to 684 MHz. Full Duplex DOCSIS (FDX) uses a traditional upstream mid-split bandwidth but shares an upstream and downstream spectrum that begins at 108 MHz and extends to 684 MHz. The maximum downstream FDX bandwidth, however, is limited to 1218 MHz, which eliminates the need to upgrade other network components to support an expanded upper frequency limit.

CommScope has a full portfolio of ESD and FDX options for either network architecture. Which path to DOCSIS 4.0 a cable operator chooses will depend on several factors specific to their budget, network infrastructure, and service portfolio. Yet cable operators aren't limited to an "either/or" approach. A cable operator, for example, could improve one segment of the network for ESD operation and another for FDX. Either way, both approaches can leverage a significant portion of an existing network infrastructure to support these improvements.

Evolution: The Extended Spectrum DOCSIS (ESD) Network

To operate at ESD bandwidths, the existing HFC network must be updated to support the extended DOCSIS 4.0 downstream and upstream spectrums. Typically, this involves upgrading the currently deployed base of taps, passives, nodes, and amplifiers to support ultra high-split, 1.8 GHz operation. Cable operators may also need to replace RF coaxial cable in targeted areas of the network to reduce the losses incurred by operating at higher bandwidths and to replace older cables that can no longer meet these extended performance requirements. In addition, new fiber cable may need to be installed to support new ESD node deployments.

ESD uses a traditional, bifurcated spectrum: the downstream and upstream bands occupy discreet portions of the entire spectrum. Like legacy bandwidths, the bands are separated in amplifiers and nodes by diplex filters, which prevent noise or ingress from crossing into one band from the other. Dividing the spectrum like this allows cable operators to choose how symmetric—or asymmetric—to make the network.

> ## COMMSCOPE ESD, DAA, AND NODE PON PRODUCTS
>
> - FACTORY-CONFIGURED 1.8 GHz AMPLIFIERS
>
> - FACTORY CONFIGURED 1.8 GHz NODES
>
> - FACTORY-CONFIGURED RxD AND R-OLT NODES
>
> - RxD AND R-OLT NODE UPGRADE KITS
>
> - BANDWIDTH UPGRADE KITS FOR NODES AND AMPLIFIERS

Typically, converting a sub-split network for ultra high-split operation begins with an intermediary upgrade from sub-split to high split operation. In this intermediary stage, a cable operator may deploy additional line extender and bridger amplifiers, with the latter replacing external splitters and feeding two-way taps in the extended network spectrum. The number of new active deployments depends on the size of the service group that the upgraded network will be servicing and its capacity requirements.

CommScope ESD amplifiers and nodes support electronic attenuation and equalization instead of the plug-in attenuator pads and equalizers used in traditional HFC actives. This feature operates through an app interface, accessible when a technician is at the amplifier or node in the field, that provides a snapshot of the amplifier or node output for "on the fly" attenuation and equalization as needed.

CommScope ESD Nodes operate with either RxD modules (in DAA architectures) or R-OLT modules (in PON architectures). Traditional receivers and transmitters used in HFC nodes are not compatible with ESD operation at bandwidths higher than 1218 MHz in the downstream or 204 MHz in the upstream. Cable operators will have to replace either their existing HFC nodes with factory-configured RxD or R-OLT nodes or else use upgrade kits to modify their existing HFC nodes for DAA or PON operation.

Evolution: The Full Duplex DOCSIS (FDX) Network

An ESD network retains the traditional separation between upstream and downstream bands, which is achieved via diplex filters in amplifiers and nodes. Full Duplex DOCSIS, on the other hand, enables dynamic use of the spectral band by "directing" portions of the spectrum toward the upstream or downstream band based on demand. FDX can operate in one of two network architectures: an N+0, FTTX architecture using only an FDX node; or a standard HFC network that deploys both FDX amplifiers and nodes.

The simultaneous transmission of signals in an FDX network is achieved through signal Echo Cancellation (EC). EC eliminates interference between upstream and downstream transmission by removing any reflections in the downstream from the upstream. These reflections would otherwise interfere with upstream performance. FDX does mimic traditional splits, however, by allocating a larger portion of the spectrum to the downstream. But by transmitting signals concurrently, FDX more efficiently uses the available spectrum.

By using the spectrum more efficiently, an FDX network can support increased downstream capacity at lower frequencies. In some networks, for example, it may not be cost-effective or logistically feasible to upgrade existing 1 GHz taps for the maximum 1.2 GHz downstream band supported by the FDX spectrum. In this scenario, a cable operator can deploy a 108-1002 MHz downstream band and still achieve 6G speeds (along with 5G speeds in the upstream). If the network supports operation at the maximum 108-1218 MHz downstream band, then the downstream capacity can increase to approximately 7.5G.[6]

> **COMMSCOPE FDX PRODUCTS**
>
> - FACTORY-CONFIGURED FDX AMPLIFIERS
> - FACTORY CONFIGURED FDX NODES
> - FDX NODE UPGRADE KITS
> - BANDWIDTH UPGRADE KITS FOR NODES AND AMPLIFIERS

Revolutionizing the Network: DAA and PON

Distributed Access Architecture (DAA) and Passive Optical Network (PON) technologies leverage existing HFC network architecture to remake and redeploy the edge of the network. As a result, neither architecture requires traditional headend optics—which provides significant savings in equipment maintenance and upgrades, reduced headend space, and power requirements.

DAA and PON networks use a modular, node-based approach that is easily scalable. Either technology can speed the transition from a traditional, coaxial-based HFC network architecture to a virtualized, potentially all-fiber infrastructure.

The Revolutionary Network: DAA

DAA decentralizes and virtualizes headend and network delivery. DAA operation places the digital to RF interface at the optical-coax boundary in the node. Analog fiber technology in HFC networks is replaced with IP-based transport over digital fiber links to create a software-defined network. The analog links from the headend are also replaced, converting the service group's analog fiber link to a digital fiber Ethernet link. The digital Ethernet link increases the available bandwidth by improving performance and increasing the number of available wavelengths for use in the network.

By driving digital to analog conversion closer to the home, DAA provides better spectral efficiencies and increases the number of wavelengths supported on each fiber. Other key advantages of DAA networks include:

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6 Ulm, et. al. Broadband Capacity Growth Models, pg. 48.

- Enhanced performance via digital Ethernet links

- Migration to centralized data centers

- Flexible advertising, channel lineups, and bandwidth management

At the edge of the network, DAA uses one of two approaches. Remote PHY (R-PHY) moves DOCSIS signal generation out of the headend and into a module in the access node. Remote MACPHY (R-MACPHY) does the same for DOCSIS signal

generation and processing. There are pros and cons to either approach—primarily centered around cost of deployment and the extent to which they support virtualization—but these are mitigated by their operational flexibility. There is no "one size fits all" approach to DAA; rather, cable operators can choose the approach that best supports their specific network architectures, requirements, and goals.

Figure 2 shows a typical DAA network architecture with an R-PHY node.
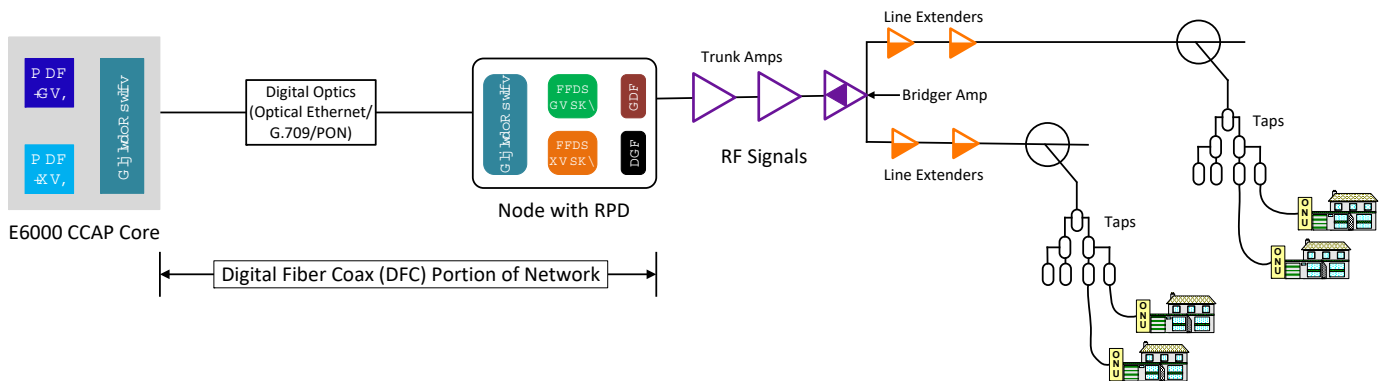
Figure 2. DAA Network Architecture with an R-PHY Node

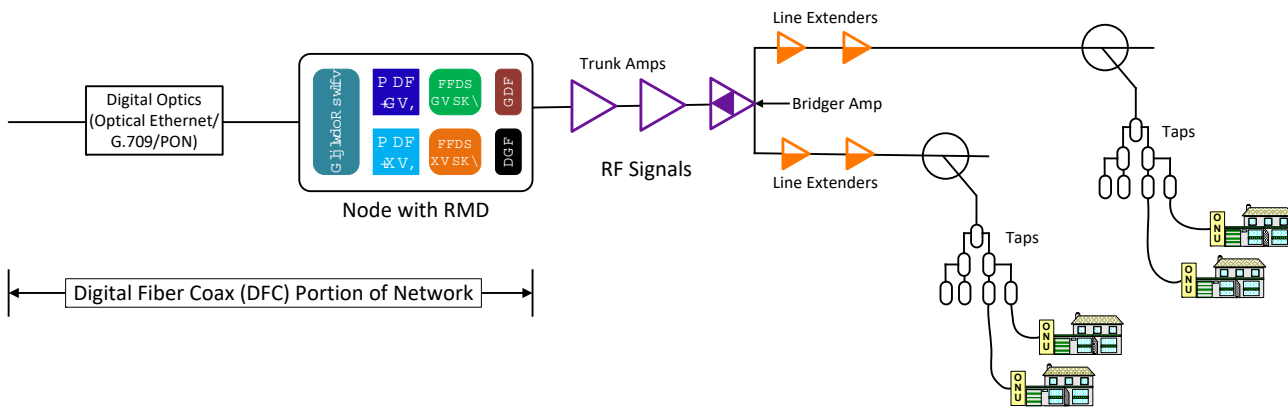Figure 3 shows a typical DAA network architecture with an R-MACPHY node.

Figure 3. DAA Network Architecture with an R-MACPHY Node

Cable operators can choose to operate DAA with either a physical or virtual CCAP core. Many of the bandwidth-increasing activities that interest cable operators can be achieved even with an existing E6000 I-CCAP. Cable operators can use these platforms (such as the I-CCAP Core) for RxD operation to realize a quick and cost-effective transition to DAA.

The Revolutionary Network: Node PON

Next-generation Node PON deployments utilize a R-OLT module, which moves PON optical line terminals (OLTs) from the headend into a node. Node PON can be deployed to migrate or supplement an existing DOCSIS HFC network. This node-based approach maintains DOCSIS provisioning compatibility with 10G EPON. It can also utilize XGS-PON—with SDN-based Domain Management—for network provisioning and telemetry gathering. Both approaches provide a seamless, efficient path for driving fiber deeper into the network—in both urban and rural Brownfield and Greenfield applications—while reducing the energy, maintenance, and operational requirements of traditional headend operation.

Next-generation Node PON technology can also be a game changer for select business customers, high-bandwidth residential subscribers, MDUs, rural deployments, and other market opportunities. Next-generation Node PON deployments use a cloud-to-edge approach that gives a cable operator the opportunity to smoothly choose between an EPON network—the fastest route to PON, which requires minimal changes to headend and CPE architecture—or a GPON network, which maximizes network performance and restructures back office technology.

The CommScope R-OLT device has the key strategic advantage of supporting both leading PON technologies: IEEE EPON/10G EPON and ITU GPON/XGS-PON. IEEE EPON/10G EPON requires minimal changes to current CPE and headend architectures and is fully compliant with CableLabs DPoE v2.0 standards. By integrating with standard DOCSIS interfaces, 10G EPON lowers the cost of deployment for cable operators. 10G EPON ITU GPON/XGS-PON operates from a cloud-based PON Domain Manager that supports platform interoperability for provisioning and ONU management as well as zero-touch on-boarding and provisioning speeds deployment. Cable operators can choose either PON technology to evolve existing Brownfield networks or expand a network via Greenfield builds.

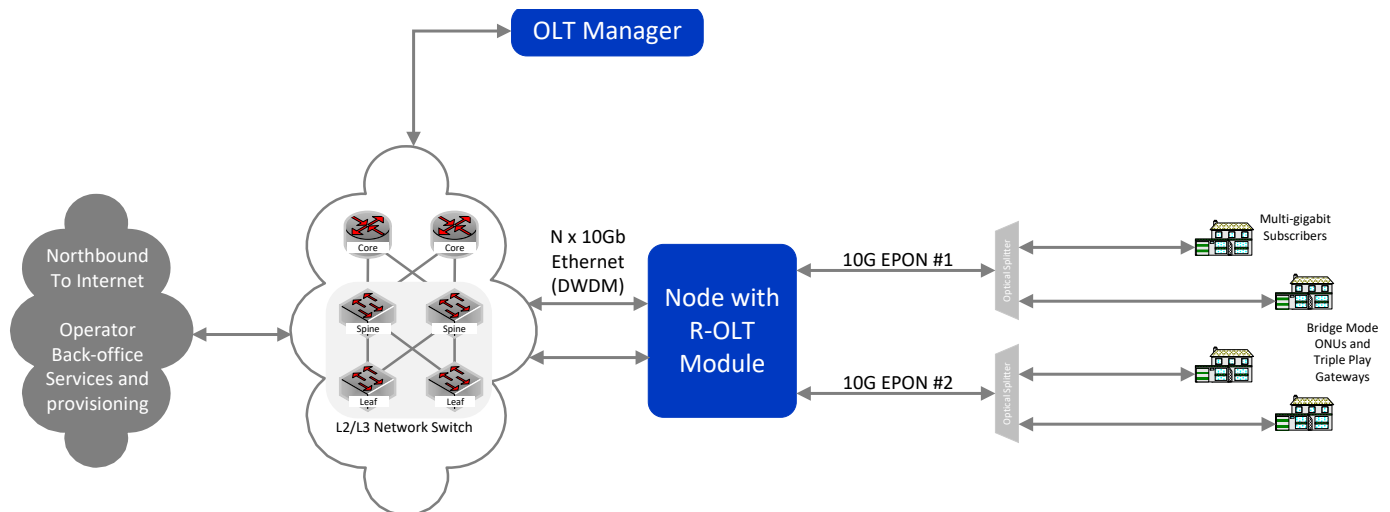Figure 4 shows a typical Node PON network architecture.

Figure 4. Typical Node PON Network Architecture

Conclusion: The Path Forward

There are many options for optimizing traditional HFC networks for DOCSIS 3.1 and 4.0 operation and/or transitioning to DAA and Node PON network architectures. CommScope is uniquely positioned to help cable operators choose the path forward that best suits their business objectives. CommScope's full, end-to-end portfolio of reliable, proven products and solutions, coupled with our decades of experience in partnering with cable operators to optimize and evolve their networks, provides the support and performance cable operators need to remain competitive now and in the future. CommScope is the partner cable operators can rely on to guide them through the next era of network evolution and beyond.

For more information about the technologies, products, and solutions discussed in the Solutions Brief, contact your CommScope Sales Representative.

CommScope pushes the boundaries of communications technology with game-changing ideas and ground-breaking discoveries that spark profound human achievement. We collaborate with our customers and partners to design, create and build the world's most advanced networks. It is our passion and commitment to identify the next opportunity and realize a better tomorrow. Discover more at commscope.com

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