Optimizing an HFC Cable Access Network for D3.1*Enhanced* Technology

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Contents

Overview

Next-generation network technologies, such as DOCSIS® 4.0, Distributed Access Architecture (DAA), and Node PON, have generated a lot of interest in the cable industry. While these solutions can dramatically increase the bandwidth capacities and speeds currently available with HFC cable access networks, they also require significant capital expenditures. These costs are significant enough that even Tier 1 cable providers are adopting a surgical approach to DOCSIS 4.0 upgrades.

While DOCSIS 4.0 DAA operation is the next step in the evolution of HFC networks, many cable providers haven't yet fully exploited the full capacities of DOCSIS 3.1 network upgrades. There are still a substantial number of HFC networks currently operating at sub-split bandwidths; moreover, many of these networks use DOCSIS 3.1 in the downstream path only. Full DOCSIS 3.1 operation requires an upgrade from 42/54 MHz sub-split operation to an 85/102 MHz mid-split or 204/258 MHz high-split frequency to boost upstream bandwidth capacity and speed. Yet CommScope® estimates approximately 80% of Converged Cable Access Platforms (CCAPs) currently in operation support full DOCSIS 3.1 operation, but only 30% of them currently operate with mid-split or high-split networks.[1]

The introduction of D3.1*Enhanced* (D3.1*E*) functionality enables cable providers to further enhance and extend the downstream capacities of a mid-split or high-split DOCSIS 3.1 network by using next-generation DOCSIS 3.1+ or DOCSIS 4.0 CPE devices, which support a greater number of OFDM channels than legacy DOCSIS 3.1 networks. While standard DOCSIS 3.1 operation supports a maximum of only two OFDM channel blocks in the downstream, a network with D3.1*E* functionality supports up to five OFDM channel blocks. D3.1*E* functionality, in fact, can expand the maximum downstream speed tiers available in a standard DOCSIS 3.1 network by anywhere from ~260% (from ~3 Gbps to ~8 Gbps downstream in a mid-split DOCSIS 3.1 HFC network) to ~320% (from ~2.5 Gbps to ~8 Gbps downstream in a high-split, D3.1 HFC network).

D3.1*E* technology demonstrates that HFC-based broadband network technology is still viable and will remain so for the foreseeable future. For many cable providers, it makes little economic sense to leap from sub-split operation to a completely rebuilt, next-generation network without first transitioning to full DOCSIS 3.1 operation using their current network assets. In fact, market research suggests that the adoption of multi-gigabit access speeds by subscribers—the primary operating benefit of full DOCSIS 4.0 and PON deployments—is still a niche market.[2] D3.1*E* technology enables cable providers to surgically target those portions of their networks that demand multi-gigabit services by enhancing their current networks with strategically deployed mid-split/high-split network upgrades and DOCSIS 3.1+ or DOCSIS 4.0 CPE devices.

1 Based on internal CommScope research.
2 Wilson, Stephen. Analyzing the Future of Cable Networks: DOCSIS 4.0 and FTTP Upgrades. Pg. 21.

Advantages of D3.1*E* Technology

D3.1*E* technology supports surgically targeted upgrades in select areas of the network to increase downstream capacity, meet service requirements, and enhance service offerings without incurring the costs of a full plant upgrade. D3.1*E* technology also has several other advantages that support a more conservative approach to enhancing and optimizing the performance of an HFC access network.

Overall Cost Savings

Plant upgrades incur a variety of immediate and on-going costs. Besides the obvious costs of upgrading and/or replacing equipment in the field, there are also costs associated with:

- Outside plant construction, including replacing cable and splicing in new actives to support increased spans (typically required due to higher attenuation in networks operating at higher DOCSIS 4.0 frequencies)
- Inside plant construction, including adding and/or expanding chassis, increased powering requirements, and software, firmware, and licensing upgrades
- On-going plant maintenance, the costs of which typically increase by ~5% for each plant upgrade. For example, upgrading a 1 GHz plant for 1.2 GHz operation may increase maintenance costs by ~5% over current maintenance costs; upgrading the same plant from 1.2 GHz to 1.8 GHz operation may increase maintenance costs by ~10% over current maintenance costs[3]

D3.1*E* technology can maximize the performance of current network assets without incurring some of the more burdensome costs described above. D3.1*E* technology, in fact, is significantly more economical than other network upgrade options, including DOCSIS 4.0. While the costs of DOCSIS 4.0 upgrades will vary based on a variety of factors, CommScope has done cost analyses for common DOCSIS 4.0 network upgrade scenarios. As shown in Table 1, these costs are quite substantial for the data rate improvements supported by DOCSIS 4.0 and reiterate the value that cable providers can derive from D3.1*E* technology, which can maximize the return on investment for mid-split and high-split plant upgrades.

Upgrade Scenario	Current Draw Change	Changes in Cost per Mile	Changes in Costs per Homes Passed	Changes in Equipment Upgrade/ Constructions Costs[4]	Customer Data Rate Improvements
Rural Deployments					
1.2 GHz High Split to 1.8 GHz DOCSIS 4.0 ESD	~80%	~255%	~255%	~255%	DS: ~7.5–12 Gbps US: ~1.25–4.5 Gbps
Suburban Deployments					
1.2 GHz High-Split to 1.8 GHz ESD DOCSIS 4.0	~80%	~210%	~270%	~200%	DS: ~7.5–12 Gbps US: ~1.25–4.5 Gbps
Urban Deployments					
1.2 GHz High-Split to 1.8 GHz ESD DOCSIS 4.0	~80%	~250%	~200%	~250%	DS: ~7.5–12 Gbps US: ~1.25–4.5 Gbps

Table 1: Approximate Increase in Costs of a 1.8 GHz DOCSIS 4.0 Upgrade from High-Split DOCSIS 3.1 Network Operation

3 Based on internal CommScope cost modeling comparing sub-split to high-split and high-split to ESD plant upgrades. These percentages may vary according to specific factors that fall outside the scope of this White Paper.
4 Includes (but is not limited to) inside and outside plant equipment upgrades (for example, new or upgraded actives and passives; CMTS/vCore software licensing; new or updated headend optics; DAA software licensing); pedestal and/or cable arial installations; and other miscellaneous construction costs

Targeted Deployments

D3.1*E* technology also supports targeted, surgical deployments in those areas of the network that require enhanced bandwidth capacity and throughput speeds. This ability supports the rollout of premium tier, multi-gigabit services to subscribers and while deferring expensive DOCSIS 4.0 constructions or FTTH network overbuilds until a later date. By leveraging network-wide plant upgrades, D3.1*E* technology also simplifies the introduction of premium services, allowing cable providers to keep pace with their competition by satisfying consumer demand for new and improved experiences.

Extending the Life of Current Network Assets

Mid-split and high-split plant upgrades that support D3.1*E* technology can also extend both the life and effectiveness of those current network assets for at least ten years and, perhaps, longer.

Take node splits, for example. Cable providers typically performed node splits to expand maximum tier speeds, increase bandwidth capacities, and reduce traffic congestion to subscribers' homes by dividing an existing service group into segments. Each successive node split required additional downstream receivers and upstream transmitters to be installed in a node. After a node reached its maximum 2x2 or 4x4 segmentation (depending on the model node used in the field), cable providers had no choice but to introduce a new node into the network—a process which entailed new construction in the field and the reconfiguring of the headend to support the new node—to support each new service group.

For example, a node servicing a service group of 300 subscribers that is segmented for 4X operation would now service four service groups of 75 subscribers each, which translates into approximately four times the bit speed per group and increased speeds to the homes serviced by each group. By deploying D3.1*E* technology in conjunction with a mid-split or high-split plant upgrade, however, a cable operator can further extend tier speeds—the typical goal of a frequency split upgrade—while extending the bits per home available to existing service groups beyond what was available with a node split before it was augmented with D3.1*E* technology. The advantages are twofold: there's a greater return on investment on the equipment bought and deployed to segment the node, and the life of that equipment is now extended because—with the increased speeds available to each segment—cable providers can introduce premium service tiers that may not have been supported by the initial node split. This also mitigates the need to deploy new nodes to maintain the top speed tiers available to service groups serviced by a single node segment.

When all is said and done, node splits in a sub-split network are not a long-term solution for enhancing network performance. A typical node split in a sub-split network has a life-span of two to three years before it reaches full capacity; a mid-split plant upgrade, on the other hand, typically has a life-span of ten or more years. The pandemic, and the resulting spike in network traffic that resulted from shelter in place directives, made it clear that sub-split HFC networks—particularly 5–42 MHz plants operating in North America—did not adequately support high-traffic operating scenarios; clearly, a mid-split or high-split plant upgrade is a more economical alternative to node splits. D3.1*E* technology only reiterates the wisdom of this approach.

D3.1*E* Technology and Aging Plant Considerations

A mid-split plant upgrade from an aging sub-split plant has two advantages: first, by modernizing the plant to support D3.1*E* technology; second, by replacing end-of-life actives, passives, and other obsolete network equipment, cable providers can extend the life of an HFC cable access network by ten years or more. A deployment of D3.1*E* technology is therefore the perfect time to address aging plant concerns and replace end-of-life or obsolete equipment.

Frequency Split Upgrades or Full Cutouts?

When considering whether to upgrade an aging plant with frequency split upgrades or a full 1.2 GHz cutout, two factors are in play: costs and the age of fielded equipment. Generally, frequency split upgrades are less costly than a full upgrade to 1.2 GHz plant operation; the latter, after considering several cost factors—such as labor, construction, and CMTS upgrades—can cost as much as 200% more than frequency split upgrades.[5] However, in some instances fielded devices may have reached an age at which a simple frequency split upgrade is not a viable, long-term solution for increasing operating bandwidths.

Outside plant active devices such as amplifiers and nodes may have a maximum field life of more than 20 years. The longer a device remains in service, however, the greater the chance that it will fail. For example, CommScope internal research has shown that a population of amplifiers will usually experience approximately 4% failure in their tenth year of service, but by the twentieth year of service the failure rate more than triples to 13%. As these devices reach end-of-life, continuing to upgrade them to support higher plant frequencies clearly becomes an inefficient use of capital resources and opens the door to major service disruptions. A good rule of thumb is:

- For plants between 10 and 15 years old, replace failed devices with new ones
- For plants 15 years old and older, consider proactively replacing actives and passives (even if they haven't yet failed) to support new plant splits

In either of these scenarios, any potential cost savings from frequency split upgrades need to be weighed against the threat of equipment failures and outages. Capital resources that were previously expended on repairing and upgrading aging equipment can instead be invested in entirely new, 1.2 GHz (or even 1.8 GHz) actives that are factory-configured to support mid-split or high-split operation out of the box. Additionally, CommScope 1.2 GHz amplifiers and nodes can, at a future date, be upgraded to support 1.8 GHz operation if an operator plans on transitioning to DOCSIS 4.0 operation. Otherwise, cable providers can easily upgrade these new actives for high-split operation in the future by using a frequency split upgrade kit and upgrading the transceivers deployed in nodes with either a high-split, DT4600 digital return transceiver or upgrading the node for DAA operation at either 85/102 MHz or 204/258 MHz.

CommScope's 1.8 GHz Extended Spectrum DOCSIS (ESD) amplifiers and nodes can also support 1.2 GHz operation. While the standard operating mode of an ESD amplifier works well for most 1.2 GHz spans, there may be scenarios where the combination of gain and gain tilt required exceeds the capabilities of the amplifier. In these scenarios, cable providers can install a fixed equalizer plug-in with minimum insertion loss at 1.2 GHz. When this plug-in is used in higher tilt 1.2 GHz spans, it enables the amplifier to reduce the amount of 1.8 GHz electronic equalization utilized, which increases the amount of available gain in the amplifier to support operation in legacy 1.2 GHz networks. The plug-in can therefore postpone the need to install Booster amplifiers while cable providers are preparing to upgrade their plants for full DOCSIS 4.0 1.8 GHz bandwidths.

Similarly, CommScope 1.8 GHz NC and OM series nodes can also operate in 1.2 GHz networks in two common operating scenarios. First, the nodes can be shipped with a factory installed RxD (Remote PHY or Remote MACPHY) module that fully supports 85/102 MHz or 204/258 MHz splits in DAA networks. Alternatively, cable providers can choose to simply upgrade the RF modules in existing nodes to modules with 1.8 GHz capability while utilizing current 1.2 GHz receivers and transmitters for operation in existing HFC cable access networks. In either scenario, the DAA module or existing analog/digital optical modules will support current system levels to maintain current network operation, while setting the stage for the installation of next-generation DOCSIS 4.0 DAA modules to support full 1.8 GHz DOCSIS 4.0 operation. For ESD nodes operating in a DOCSIS 3.1 DAA network, the only change needed would be reconfiguring the attenuation and equalization, again in support of 1.8 GHz RF levels. In all these deployment scenarios, the node will fully support current network RF levels at 1.2 GHz.

Any of these approaches to modernizing an aging plant—whether cable providers plan to operate at DOCSIS 3.1 for the foreseeable future, or if cable providers consider a DOCSIS 3.1 upgrade as an intermediate step to DOCSIS 4.0 operation—will help future-proof a network for the foreseeable future while optimizing network performance with D3.1*E* technology. This may allow cable providers to reduce operating costs associated with end-of-life equipment while increasing network capacity and performance.

5 Based on cost modeling done internally by the CommScope sales team.

Advantages of Deferred Network Rebuilds

Fiber to the Home (FTTH) and the two primary DOCSIS 4.0 network architectures—Extended Spectrum DOCSIS (ESD) and Full Duplex DOCSIS (FDX) —are the technologies that provide the most significant increases in network capacities and speeds. The primary question, though, is this: after accounting for consumer demand and market competition, do the gains in network performance that can be achieved with these technologies justify the significant costs associated with rebuilding a network to deploy and support them?

FTTH, for example, has limited utility in today's broadband environment. While approximately 51% of homes in the United States have fiber access, it took cable providers close to 20 years to reach this number of fiber deployments. Industry analysis indicates that it will take at least a decade to deploy fiber to the remaining 50% of homes, especially since the most "upgradable" homes were done first.[6] Thus, the operational advantages of FTTH are diminished by the fact that FTTH cannot be deployed currently in large areas of an existing network. The costs per homes passed associated with an FTTH overbuild are also significantly higher than a mid-split or high-split plant upgrade to D3.1*E* operation, as shown in Table 2.

Upgrade Option	Downstream Band (MHz)	Upstream Band (MHz)	ISP/OSP Costs per HP ($)	CPE Costs per HP ($)	Total Costs per HP ($)[7]
D3.1*E* 1 GHz mid-split	102–1,003	5–85	~95	~15	~110
D3.1*E* 1.2 GHz high-split	258–1,218	5–204	~160	~80	~240
FTTH	N/A	N/A	~520	~170	~690

Table 2: Approximate Costs of per Homes Passed: Deployment of D3.1*E* Technology vs. FTTH

Despite these higher costs, an FTTH overbuild only provides similar gains in potential maximum downstream speed tiers to the deployment of much more economical high-split D3.1*E* technology, as shown in Table 3. While FTTH deployments do significantly increase upstream speed and capacity, for most homes with current devices and services downstream performance is arguably more important. Viewed from this perspective, the ROI of an FTTH overbuild is still negligible when compared to the ROI of an optimized D3.1*E* network upgrade.

Operating System	Maximum Downsteram Speed Tier	Maximum Upstream Speed Tier
D3.1*E* 1.2 GHz high-split	~8 Gbps	~1.25 Gbps
FTTH	~8 Gbps	~7 Gbps

Table 3: Gains in Upstream and Downstream Speed Tiers: Deployment of D3.1*E* Technology vs. FTTH

DOCSIS 4.0 network rebuilds also involve significant costs. While both D3.1*E* and DOCSIS 4.0 technology support multi-gigabit service tiers, cable providers can deploy D3.1*E* technology without incurring significant capital expenditures, increased powering budgets, wide-scale construction projects, and untimely service disruptions that may occur with a full DOCSIS 4.0 network rebuild. CommScope has done internal price modeling that compares the typical costs involved with ESD, FDX, and D3.1*E* network rebuilds, as shown in Table 4.

Operating System	Estimated Costs Per Homes Passed[5]	Maximum Downstream Speed Tier
D3.1*E* 1.2 GHz high-split	~$240	~8 Gbps
1.2 GHz FDX	~$360	~7.5–12 Gbps
1.8 GHz ESD	~$380	~7.5–12 Gbps

Table 4: Estimated Costs for D3.1*E*, FDX, and ESD Network Rebuilds

6 Abrovna, Masha. "More than 50% of U.S. homes now have access to fiber, FBA says." https://www.fierce-network.com/broadband/more-50-us-homes-now-have-access-fiber-fba-says#:~:text=A%20new%20report%20from%20the%20Fiber%20Broadband%20Association%20(FBA)%20found. Accessed 9/13/24.

7 Estimates based on CommScope modeling for a 400 home service group in a suburban environment; these estimates may change based on the number of homes passed, geographic location, and other variables. These numbers are representative and may not reflect the costs incurred for these upgrades in an actual deployment.

As these comparisons show, an optimized deployment of D3.1*E* technology is a viable middle ground between standard DOCSIS 3.1 and full FDX or ESD network operation, enabling cable providers to remain competitive without significantly altering their current network footprint. Moreover, since cable providers can upgrade sub-split networks for D3.1*E* functionality with a mid-split upgrade, they are also one step closer to fully optimized D3.1*E* functionality in a high-split network. While high-split operation typically requires a plant upgrade to 1.2 GHz operation—requiring both inside and outside plant upgrades, such as passives, nodes, and amplifiers—cable providers can also defer high-split upgrades while still realizing the benefits of D3.1*E* functionality in their current mid-split networks; depending on variables such as geographic location and the number of homes passed, the mid-split portion of the network can remain at 1 GHz operation for the foreseeable future and still operate with D3.1*E*'s increased downstream capacities and speed tiers.

Preparing for D3.1*E* Functionality: Reclaiming Downstream Bandwidth

Like most HFC cable access network solutions, the maximum gains in network performance that can be achieved with D3.1*E* technology are dependent upon several factors. Both inside and outside plants, for example, should have the infrastructure in place to achieve the full capacities and speeds supported by D3.1*E* technology. To lay the groundwork for fully optimized D3.1*E* operation, cable providers should consider strategies for reclaiming and/or augmenting downstream bandwidth.

As noted earlier in this paper, cable providers will begin to see the biggest improvements in network capacities and speeds with deployments of D3.1*E* technology in a mid-split plant. Since D3.1*E* functionality is primarily a way to increase downstream capacity by expanding the number of bonded OFDM channel blocks that can be supported in a mid-split or high-split network, reclaiming bandwidth and increasing the available spectrum from sub-split to mid-split or high-split operation is crucial to fully optimizing D3.1*E* performance; the reclaimed bandwidth provides the spectrum needed to deploy additional bonded OFDM channel blocks.

Strategies for Reclaiming Bandwidth

Cable providers can reclaim downstream bandwidth in several ways, which are discussed in the following sections.

Transition to IP Video

One strategy for reclaiming bandwidth is eliminating MPEG QAM video channels and transitioning to IP video operation. Using this strategy, cable providers can reclaim either 6 or 8 MHz per channel in the downstream band (depending on a plants's geographical location and current channel configurations). The cable provider can then reassign that bandwidth to an additional OFDM carrier (which typically occupies 192 MHz of downstream bandwidth) for D3.1*E* operation. (Note that this modification wouldn't provide any substantial performance enhancements in a network operating with standard DOCSIS 3.1 CPE devices; in these networks, the CPE devices would already be operating at maximum downstream capacity—that is, two OFDM carriers and 32 SC-QAM channels.)

Utilize MPEG-4 Compression

A prerequisite for IP video transmission, cable providers can use MPEG-4 compression to reduce the size of a video file. The compressed file can then be transmitted at lower bit rates than an uncompressed file without any noticeable degradation in audio or video quality. This capability requires less bandwidth to transmit the file than would otherwise be the case if the cable provider was transmitting uncompressed files; MPEG-4 compression, in fact, supports the transmission of high-definition content over the same downstream bandwidth previously used for standard-definition content. By effectively using MPEG-4 compression in the network in conjunction with an IP video deployment, cable providers can:

- Reclaim portions of the spectrum for bonded OFDM/A channels
- Potentially unlock the maximum bit rate speeds that can be achieved with D3.1*E* functionality

Deploy Switched Digital Video (SDV)

Switched Digital Video (SDV) operation limits how channels are broadcast throughout a network. Instead of broadcasting all channels at once across the network, SDV operation only broadcasts the most popular. Less popular channels are broadcast only when a specific set-top box tunes to them. In this way, SDV enables the network to use bandwidth selectively, any unused bandwidth can be reclaimed and repurposed for other services and/or channels. In turn, this allows CPE devices to download content more quickly, since larger portions of the downstream bandwidth remain unused. These unused portions of the downstream bandwidth can then be repurposed for bonded OFDM channel blocks.

Examples of Bandwidth Reclamation

Some real-world scenarios will demonstrate how some of these strategies for reclaiming bandwidth can prepare a network for D3.1*E* operation. For example, consider a sub-split 1 GHz network that supports a mix of 60 broadcast channels, Video on Demand (VOD) channels, and SC-QAM channels. By increasing this hypothetical network's available spectrum with a mid-split upgrade, the downstream can now support two bonded OFDM channel blocks and 32 SC-QAM channels in addition to the broadcast and VOD channels.

Figure 1: Mid-split Network with Two Bonded OFDM Channel Blocks and 32 SC QAMs

If the cable provider in this scenario replaced broadcast and VOD channels with an IP video deployment in this same network, it would free up enough downstream bandwidth to support three bonded OFDM channel blocks and 32 SC-QAM channels.

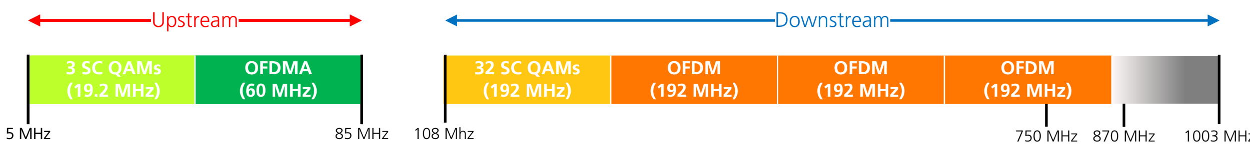

Figure 2: Mid-split Network with IP Video, Three Bonded OFDM Channel Blocks, and 32 SC QAMs

Upgrading from mid-split to high-split and extending the downstream spectrum to 1.2 GHz in this example with an IP video deployment enables support for up to four bonded OFDM channels and 32 SC-QAM channels (with next-generation DOCSIS 3.1+ CPE devices) or up to five bonded OFDM channels and 32 SC-QAM channels (with DOCSIS 4.0 CPE devices).

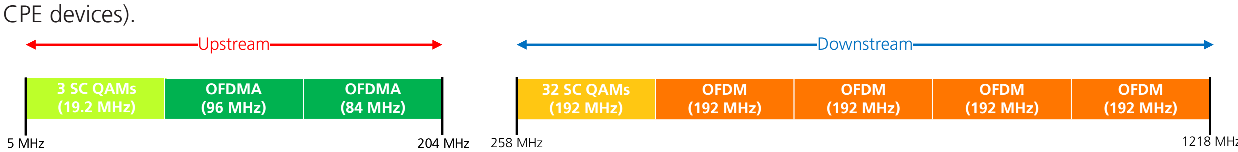

Figure 3: High-split Network with IP Video, Four Bonded OFDM Channel Blocks, and 32 SC QAMs

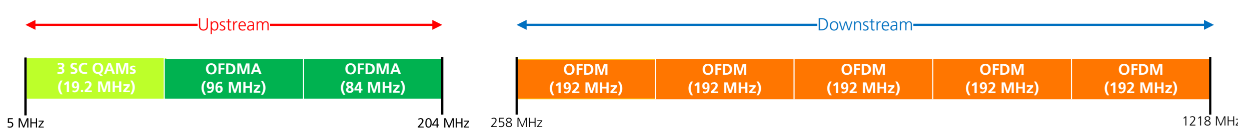

Figure 4: High-split Network with IP Video and Five Bonded OFDM Channel Blocks

In the scenarios described above, moving from sub-split operation, upgrading the plant's frequency split, and reclaiming bandwidth to support OFDM/A operation can result in a significant increase in maximum downstream speed tiers, as follows:

- Sub-split plant with legacy DOCSIS 3.1 CPE devices: approximately 2.5 Gbps
- Mid-split plant with next-generation DOCSIS 3.1+ or DOCSIS 4.0 CPE devices: approximately 8 Gbps

Table 5 compares maximum downstream capacities available with standard DOCSIS 3.1 and D3.1*E* splits.

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

Table 5: Comparison of Maximum Downstream Capacity in DOCSIS 3.1 and D3.1*E* Mid-split and High-split Networks

When considering which CPE device to deploy, cable providers should take their future upgrade plans into consideration. If a cable provider considers D3.1*E* technology an intermediary step to an eventual DOCSIS 4.0 network upgrade, then deploying DOCSIS 4.0 CPE devices has the advantage of "future-proofing" D3.1*E* network technology against any future capital expenditures. Cable providers that plan to operate a DOCSIS 3.1 mid-split or high-split network for the foreseeable future, on the other hand, can deploy next-generation DOCSIS 3.1+ CPE devices. At the time of this writing, these devices do not require a Joint Development Agreement (JDA), but DOCSIS 4.0 CPE devices do; for those cable providers who do not have any immediate plans to upgrade their networks for DOCSIS 4.0 operation, the JDA required for DOCSIS 4.0 CPE devices obviously would be an unnecessary expense.

The majority of bandwidth reclaimed for D3.1*E* functionality will occur in the downstream path, since this portion of the spectrum benefits the most from expanded capacities. Cable providers can, however, add enough bandwidth in the upstream path in a mid-split or high-split 1.2 GHz network to support two bonded OFDMA channels and up to an additional 3 SC-QAM channels. With these expanded upstream spectrums, cable providers can potentially achieve 1.25 Gbps upstream throughput speeds, or approximately 12X the upstream capacity available in a standard sub-split network.

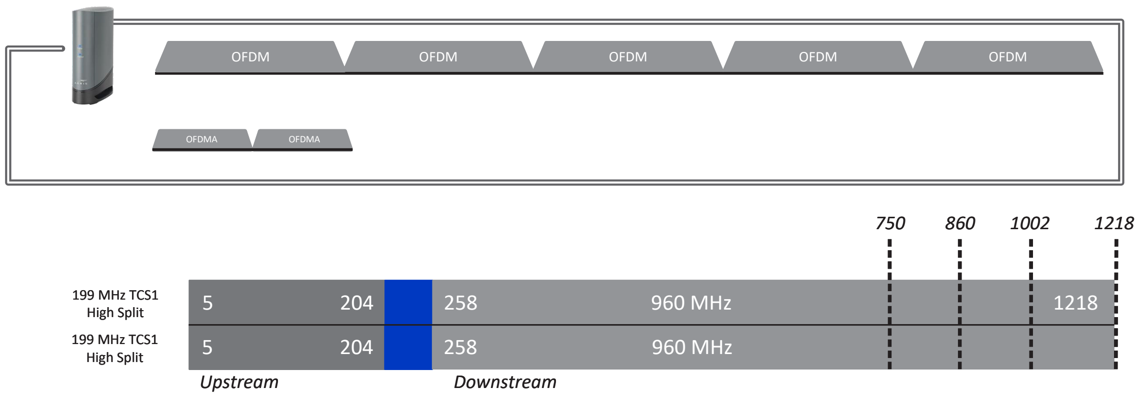

Figure 5: Maximum OFDM/A Capacity in a High-split D3.1*E* Network Deployment

D3.1*E* Technology and the Inside Plant

CommScope has tested D3.1*E* technology successfully in I-CCAP, Remote PHY, and Remote MACPHY headend architectures; the technology is therefore flexible enough to operate on a "big iron" I-CCAP deployment and remain in place if—or when—a cable provider upgrades for DAA operation.

Mid-Split and High-Split Operational Considerations

Cable providers must address several potential issues related to mid-split and/or high-split operation that are not applicable to sub-split operation. These include relocating downstream channels that exist at sub-102 MHz frequencies, addressing potential ingress or leakage issues at frequencies above 102 MHz, and moving legacy Out-of-Band (OOB) set-top channels to higher frequencies.

In sub-split networks, the OOB channel resides at a sub-102 MHz frequency. A cable provider'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 lower edge of a high-split 258 MHz downstream bandwidth

A cable provider should therefore consider the effort and cost involved in evaluating and, if necessary, replacing legacy set-top boxes that cannot receive OOB signals above either 102 MHz or 258 MHz. Typically, most current set-top boxes can operate at higher than 102 MHz downstream frequencies, but if a cable provider 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.[8] 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.

8 Leakage is detected at the headend by technicians using leakage detection meters. For leakage detection in high-split networks, cable providers will need to purchase new full spectrum leakage detection meters that support the expanded, high-split 204/258 MHz spectrum.

D3.1*E* Functionality and I-CCAP Configuration: E6000® Converged Edge Router (CER)

Beginning with Software Release 13, CommScope's Gen 2 E6000 CER will support D3.1*E* functionality; cable providers optimizing their headend for D3.1*E* functionality should upgrade to Software Release 13 ahead of a D3.1*E* deployment. This support will allow MSOs with an installed base of Gen 2 E6000s to leverage and monetize their existing headend equipment as they roll out new service offerings supported by D3.1*E* technology. As cable providers move to DAA operation, the new D3.1*E* operating features implemented with Release 13 and later will be incorporated into CommScope's vCCAP Evo™ virtual CMTS solution. This will allow cable providers to keep services supported by D3.1*E* technology in place as they transition to virtualized DAA operation.

Cable providers operating an E6000 I-CCAP will need to load a D3.1*E* license, which supports up to three OFDM channels per port. Once the license is loaded, cable providers will then need to reset cable modems being serviced by the I-CCAP. Finally, cable providers should enable the E6000's enhanced limits mode, which supports downstream bonding of the additional three OFDM channels supported by the D3.1*E* license.

To support expanded OFDM channel bonding with Release 13, the number of DCAM connectors in the CMTS core needs to be reduced from 16 to 15, with the remaining 15 connectors supporting three bonded OFDM channel blocks and 32 QAM channels. (Note that this is typically not applicable for Remote PHY networks, subject to hardware limitations.) Cable providers can also combine additional connectors to support up to five OFDM channel blocks. While this configuration will decrease the density of the HFC network, the improvement in downstream performance enabled by D3.1*E* technology will provide an acceptable trade-off in most operating scenarios.

D3.1*E* Functionality and I-CCAP Configuration: C40G and C100G

Beginning with Software Release 8.12, legacy Casa Systems® C40G and C100G I-CCAPs will support D3.1*E* functionality; cable providers optimizing their headend for D3.1*E* functionality should upgrade to Software Release 8.12 ahead of a D3.1*E* deployment. This support will allow cable providers with an installed base of C40Gs and/or C100Gs to leverage and monetize their existing headend equipment as they roll out new service offerings supported by D3.1*E* technology.

The number of OFDM channel blocks supported by Software Release 8.12 will depend on the I-CCAP's configuration. C40G and C100G I-CCAPs operating with downstream DOCSIS QAM module DS8x192 will support a maximum of three bonded OFDM channel blocks for D3.1*E* functionality; I-CCAPs operating with the BDM2m bidirectional module—which increases channel density by supporting six downstream and 12 upstream channel ports—will support up to four bonded OFDM channel blocks for D3.1*E* functionality in high-split networks.[9]

D3.1*E* Functionality and The Outside Plant

D3.1*E* functionality can also significantly improve and optimize Outside Plant operation. Some of these improvements are inherent in DOCSIS 3.1 networks, while other Outside Plant optimization scenarios require targeted upgrades to support D3.1*E* functionality.

Optimizing Downstream Performance

As we've already noted earlier in this paper, D3.1*E* technology increases a mid-split or high-split DOCSIS 3.1 network's downstream speed tiers and capacities by expanding the number of OFDM channel blocks supported in the downstream path. Besides optimized speed tiers and capacities, D3.1*E* OFDM operation also optimizes network performance by:

- Improving bit error performance through customized frequency profiles
- Introducing sophisticated bit error/noise correction features into the network
- Making better use of Modulation Error Ratio (MER) in delivering signals to CPE devices.

9 CommScope's vCCAP Evo virtual CCAP platform supports a maximum of five bonded OFDM channel blocks when operating in support of Remote PHY operation.

Customized Frequency Profiles

OFDM operation supports customized frequency profiles, which optimize throughput by muting any subcarriers in the profile that are subjected to interference. Each profile contains dynamic configuration values, which include the modulation level for each subcarrier (typically spaced at either 25 kHz or 50 kHz per OFDM block); each profile is managed by the CMTS.

Cable providers can create up to five customized frequency profiles. The advantage of this multi-profile approach is the handling of under-performing CPE devices; in multi-profile operation, such devices are automatically reassigned to a different frequency profile without impacting the performance of other CPE devices in that same frequency profile. This capability minimizes errors and maintains throughput quality to CPE devices serviced by the frequency profile.

Enhanced Bit Error/Noise Correction

OFDM operation also supports Low Density Parity Check (LDPC), which dynamically corrects bit errors in OFDM blocks that occur due to excessive noise. This function enables a network operating with D3.1*E* technology and OFDM channels to support greater density of bits per second per hertz, which in turn supports higher QAM modulation levels. LDPC enables cable providers to set an average Signal Noise Ratio (SNR) for modulation levels within each frequency profile. OFDM operation is therefore a more efficient way of correcting for noise than Single Carrier QAM.

Better MER Performance

Due to improved bit error performance and noise correction, and the use of tightly spaced orthogonal sub-carriers, OFDM blocks can support modulation up to 4096-QAM. This is a significant operating advantage, since maximum modulation is dependent on MER; as MER drops, so do maximum modulation levels. The drop in MER compensates for the increased levels of modulation errors. Mid-split and high-split DOCSIS 3.1 networks operating with DAA typically require ~43 dB of CNR to support 4096-QAM operation; mid-split or high-split DOCSIS 3.1 networks operating with traditional HFC optical modules typically require ~35 to ~40 dB of CNR to support 1024-QAM.[10] Cable providers should note that degradation will occur in a chassis-based QAM modulator transport link; the amount of degradation from the operating headend to the customer CPE device will depend on several unique factors, including span lengths and the number of actives in the transport link.[11]

MER is measured by how tightly or how loosely symbol points are grouped in a signal constellation; the looser (or "fuzzier") the signal grouping, the worse the MER performance. Tighter signal groupings indicate optimal MER performance. In a linear video network, MER is calculated in a QAM receiver after a digital signal is demodulated. While the RF output from the CMTS to the QAM receiver results in minor signal degradation, the greatest amount of signal degradation in this mode of delivery occurs from the headend to the node. Further degradation occurs from the node to CPEs in a service group.

As signals are transmitted to a modem in a QAM network, MER is calculated by using the performance of the modems in the service group that is farthest from the transmitting node—that is, the modems receiving the lowest bit rates due to the distance of the transmitted signal. In this transmission scenario, the "noise" generated by these modems would force other modems in the transmission path to connect to lower modulations of the 6 MHz QAM channel, degrading the throughput speeds available to the modem and thus essentially forcing the devices to operate at DOCSIS 3.0 levels.

OFDM operation, however, can improve MER because OFDM channels occupy a much smaller "slice" of the downstream spectrum than the 6 MHz required for QAM transmission. This greatly reduces the "fuzziness" inherent in QAM constellations. Additionally, OFDM operation supports multiple modulation profiles, which allows for more efficient bandwidth distribution to all service groups in the downstream path.

10 Cable Labs. Data-Over-Cable Service Interface Specifications. DOCSIS® 3.1 Physical Layer Specification. CM-SP-PHYv3.1-I20-230419. https://www.cablelabs.com/specifications/CM-SP-PHYv3.1.

11 Node-based DAA operation eliminates link degradation entirely by using digital optical transport and eliminating the physical QAM modulator entirely; QAM modulation is instead performed in the RxD module installed in the node.

Upgrading Outside Plant Equipment

As we've already noted, mid-split and high-split upgrades to an existing sub-split network provide optimal D3.1*E* functionality and performance. Since there are several possible sub-split network designs, we can't begin to address all potential upgrade scenarios in this paper. However, we can provide some high-level, generalized information that MSOs can use as a starting point for designing their D3.1*E* network deployments.

Cable providers can easily upgrade 1 GHz sub-split networks to support 85/102 MHz mid-split operation by performing a frequency split upgrade to fielded actives. CommScope's legacy 1 GHz amplifiers and nodes all support mid-split upgrades, typically via a frequency split upgrade kit that enables technicians to upgrade the device's diplex filters to support the higher split.

Product Family	Models Supporting Mid-split Upgrade
STARLINE® 1 GHz Amplifiers	BT100 Trunk/Bridger
	MB100 MiniBridger®
	BLE100 Line Extender
	MBV3
Flex Max® 1 GHz Amplifiers	FM321/FM321e
	FM331LE
	FM601/FM601e Trunk/Bridger
	FM901e Trunk/Bridger
Opti Max® 1 GHz Nodes	OM2741
	OM3100
	OM4100®
Legacy Aurora™ 1 GHz Nodes	NC2 Series
	NC4 Series
Legacy Motorola® 1 GHz Nodes	SG4000

Table 6: 1 GHz CommScope Products Upgradable for D3.1*E* Mid-Split Operation

Cable providers operating a 1 GHz mid-split network will need to upgrade actives and passives to 1.2 GHz models to support 204/258 MHz high-split operation. Doing so, however, doesn't necessarily require cutouts of 1 GHz equipment, unless the equipment is reaching end of life (as discussed in "D3.1*E* Functionality and Aging Plant Considerations" on page 4). For 1 GHz equipment that has not reached end of life, cable providers have the following options for 1.2 GHz upgrades.

Taps and Passives: Install 1.2 GHz faceplates in legacy Regal®, Motorola, and ARRIS® taps and passives. Refer to Table 7 for legacy taps and passives that support this upgrade.

Description	Upgrade to 1.2 GHz Faceplate
BTTF Series 1 GHz Taps	
BTTF2-xxP	Yes
BTTF4-xxP	Yes
BTTF8-xxP	Yes
FFT Series 1 GHz Taps	
FFT2-xxP-R	Yes
FFT4-xxP-R	Yes
FFT8-xxP-R	Yes
SSP Series 1 GHz Passives	
SSP-PIN-R	Yes
SSP-xxN-R Splitters/Couplers	Yes

Description	Upgrade to 1.2 GHz Faceplate
Regal RMT Series 600 MHz, 750 MHz, and 1 GHz wide and narrow body taps	
RMT62-xx	Yes
RMT64-xx	Yes
RMT68-xx	Yes
RMT752-xx	Yes
RMT758-xx	Yes
RMT102-xx/RMT102W-xx	Yes
RMT104-xx/RMT104W-xx	Yes
RMT108-xx	Yes
RMT102BC-xx/RMT104BC-xx/RMT108BC-xx	Yes
RMT102BCP-xx/RMT104BCP-xx/RMT104WBCP-xx/RMT108BCP-xx	Yes
RMT2002-RF-xx/RMT2002W-RF-xx/RMT2004-RF-xx/ RMT2004W-RF-xx	Yes
RMT2008-RF-xx	Yes
RMT2002-CX-xx/RMT2002W-CX-xx/RMT2004-CX-xx/ RMT2004W-CX-xx	N/A
1 GHz Regal Passives	
RLS10-x-15A Series Splitters	Yes
RLDC10-x-15A Series Couplers	Yes
RPI-100SP-20A-90V Power Inserter	Yes
Philips 1 GHz Taps and Passives	
32xx-L-PBT Series	Yes
34xx-L-PBT Series	Yes
38xx-L-PBT Series	Yes
9-TFC-x/17A Couplers and Splitters	Yes
9-LP Series Power Inserters	Yes

Table 7: 1.2 GHz Upgrade Paths for Legacy 1 GHz Taps and Passives

Amplifiers: Install 1.2 GHz RF modules and platform assemblies in legacy Motorola STARLINE amplifier housings. Install 1.2 GHz RF modules legacy ARRIS Flex Max FM331 and FM901 housings.

Description	Part Number
1.2 GHz BLE® Upgrade Parts and Kits	
1.2 GHz BLE Platform Assembly Kit (includes two 1.2 GHz platform assemblies, two barrel castings, and four 6-32 x 3/8 screws)	BLE-120-KIT
1.2 GHz BLE120 RF module, 85/102 MHz split, 24 dB upstream gain, 711 MHz QADU	BLE120-085-SL-XEX
1.2 GHz BLE120 RF module, 204/258 MHz split, 24 dB upstream gain, 711 MHz QADU	BLE120-204-SL-XEX
1.2 GHz BLE120 RF module, 85/102 MHz split, 27 dB upstream gain, 711 MHz QADU	BLE120-085-SL-HEX
1.2 GHz BLE120 RF module, 204/258 MHz split, 27 dB upstream gain, 711 MHz QADU	BLE120-204-SL-HEX
1.2 GHz MB Upgrade Parts and Kits[12]	
1.2 GHz MB120 RF module, 85/102 MHz split, 24 dB upstream gain, 711 MHz QADU	MB120-085-SL-XEX
1.2 GHz BLE120 RF module, 204/258 MHz split, 24 dB upstream gain, 711 MHz QADU	MB120-204-SL-XEX
1.2 GHz MB120 RF module, 85/102 MHz split, 27 dB upstream gain, 711 MHz QADU	MB120-085-SL-HEX
1.2 GHz MB120 RF module, 204/258 MHz split, 27 dB upstream gain, 711 MHz QADU	MB120-204-SL-HEX

12 1 GHz MB100 platform assemblies also support 1.2 GHz MB120 operation. If your MB amplifier is an 870 MHz or lower legacy model, contact your CommScope Sales Representative for more information.

Description	Part Number
1.2 GHz FM332 Upgrade Parts	
1.2 GHz FM332 RF module, 85/102 MHz Split, 27 dB upstream gain, 711 MHz QADU	FML12X085-SHMPA1N
1.2 GHz FM332 RF module, 204/258 MHz Split, 27 dB upstream gain, 711 MHz QADU	FML12X204-SHMPA1N
1.2 GHz FM902 Upgrade Parts	
1.2 GHz FM902 Bridger RF module, 85/102 MHz Split, 27 dB upstream gain, 711 MHz QADU	FMB12X085-SHH6A1N
1.2 GHz FM902 Bridger RF module, 204/258 MHz Split, 27 dB upstream gain, 711 MHz QADU	FMB12X204-SHH6A1N
1.2 GHz FM902 Trunk RF module, 85/102 MHz Split, 27 dB upstream gain, 711 MHz QADU	FMT12X085-SHH6A1N
1.2 GHz FM902 Trunk RF module, 204/258 MHz Split, 27 dB upstream gain, 711 MHz QADU	FMT12X204-SHH6A1N

Table 8: 1.2 GHz Upgrade Parts for Legacy 1 GHz RF Amplifiers

NC4000® Nodes: Install 1.2 GHz mid-split or high-split RF module, 1.2 GHz receiver(s), and DT series Digital Return Transceiver(s) in legacy 1 GHz NC4000 housings.

Description	Part Number
1.2 GHz NC4 RF Module, 85/102 MHz split, supports four downstream outputs and four upstream inputs (factory configured with one downstream output and four upstream inputs), horizontal test points	OA4344SE-85
1.2 GHz NC4 RF Module, 204/258 MHz split, supports four downstream outputs and four upstream inputs (factory configured with one downstream output and four upstream inputs), horizontal test points	OA4344SE-204
1.2 GHz High-Gain Forward Receiver	AR4214E-AS
DT4250 Digital Return Transceiver (for mid-split operation; supports up to 100 MHz operation in the upstream path)	DT4250E-99-00
DT4600 Digital Return Transceiver (for mid-split and high-split operation; supports up to 204 MHz operation in the upstream path)	DT4600N-200-00
150W Power Supply Module (with power connector lead)	PS4101-01

Table 9: 1.2 GHz Upgrade Parts for Legacy 1 GHz NC4000 Nodes

OM4100® Nodes: Install 1.2 GHz mid-split or high-split RF module, 1.2 GHz receiver(s), 1.2 GHz RF cable assembly, and reverse configuration module in legacy OM4100 housings.

Description	Part Number
1.2 GHz OM4120 RF Module, 85/102 MHz split, w/Ingress Control Switches	OM4120 RF-85-ICS
1.2 GHz OM4120 RF module, 204/258 MHz split, w/Ingress Control Switches	OM4120 RF-204-ICS
1.2 GHz OM4120 RF Module, 85/102 MHz split, w/Ingress Control Switches and external test points	OM4120 RF-85-ICS-EXT
1.2 GHz OM4120 RF module, 204/258 MHz split, w/Ingress Control Switches and external test points	OM4120 RF-204-ICS-EXT
1.2 GHz SC/APC Downstream Optical Receiver (supports optical input range of -6 to +3 dBm)	15100054-002
OM4120 Upstream Configuration Module (for standard configurations)	OM4120-RET-STD
OM4120 Upstream Configuration Module (for redundant configurations)	OM4120-RET-RED
OM4120 Downstream RF cable bundle	OM4120-FWD-RF-CAB
OM4120 Upstream RF cable bundle	OM4120-RET-RF-CAB
(Optional) DOCSIS Management Module (DMM) (replaces OM4100 ValueMax/DOCSIS Transponders in 1.2 GHz applications)	1510058-003
(Optional) Status Monitor Card (SMC) (replaces OM4100 daughter card or status monitor card in 1.2 GHz applications)	1510058-001
(Optional) Standard depth OM4120 housing lid. Required when installing 1.2 GHz DMM (p/n 1510058-003) or SMC (p/n 1510058-001) modules	OM4120-HSG-LID

Table 10: 1.2 GHz Upgrade Parts for Legacy 1 GHz OM4100 Nodes

Cable providers currently running a 1.2 GHz mid-split network can easily upgrade CommScope products for high-split operation by again using frequency split upgrade kits. Besides providing the maximum performance improvements from a D3.1*E* deployment, 1.2 GHz high-split operation saves power, provides additional gain, and—with CommScope 1.2 GHz amplifiers configured for high-split operation and operating with a 711 MHz ADU—optimizes downstream and upstream performance. These operational improvements can therefore provide both cost savings and enhanced network performance.

Based on internal analysis performed by CommScope, end-to-end upgrades from sub-split to mid-split or high-split operation to support D3.1*E* operation is more economical on a homes passed basis than a full DOCSIS 4.0 rebuild.

Upgrade Scenario	Estimated Costs per HHP[13] (Dollars)							
	CMTS	Headend Optics	Node	Amplifier	Taps	Modem	Labor	Total Cost
Sub-split to D3.1*E* 1.2 GHz mid-split	~10–15	~5–10	~5–7	~5–15	0	Success Based	~20–25	~50–70
Sub-split to D3.1*E* 1.2 GHz high-split	~15–20	~10–15	~10–15	~5–15	0	Success Based	~20–25	~60–80
1.2 GHz High-Split to 1.8 GHz ESD DOCSIS 4.0	~7–15	0	~10–15	~15–20	~5–18	Success Based	~42	~110

Table 11: Estimated Costs for D3.1*E* Mid-split Network Upgrades, D3.1*E* High-split Network Upgrades, and ESD Network Rebuilds

Conclusion

Next-generation network technologies, such as Node PON, ESD, and FDX, can provide significant operational improvements over traditional HFC cable access networks. But the capital expenditures associated with these technologies—including inside and outside plant equipment upgrades, construction and labor, and software licensing—may be cost-prohibitive for some cable providers. For these cable providers, D3.1*Enhanced* technology can provide significant improvements in downstream speeds and capacities by implementing more cost-effective upgrades to existing inside and outside plant network architectures. Optimizing networks for D3.1*E* functionality provides maximum return on investment while extending the life of current HFC cable access network assets for the foreseeable future. With D3.1*E* technology, cable providers can monetize their existing network assets and offer competitive new speed tiers and services to their subscribers without significant capital expenditures—making it an ideal network optimization solution in today's challenging business environment.

CommScope offers a full, end-to-end portfolio of DOCSIS 3.1 and DOCSIS 4.0 products and solutions for inside and outside plant operation. For further information about the products and solutions discussed in this document, contact your CommScope Sales Representative.

13 Assumes 400 homes passed per node. Price varies by customer size and existing equipment. Ask your CommScope Sales Representative for a detailed analysis.

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