Preparations for Deploying & Lessons Learned from Deploying High Split (204 MHz) on I-CCAP, R-PHY, & R-MACPHY

High Split as a Steppingstone Towards DOCSIS® 4.0

A Technical Paper prepared for SCTE by

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1. Introduction

Vendors who make equipment for hybrid fiber-optic & coaxial cable (HFC) networks and cable service providers (also known as "cable operators") have been discussing high split (HS)—moving the upstream (US) frequency split to 204 MHz—for quite some time now. Over the last few years, vendors have made available the various components required for high-split operation, and they continue to add features and capabilities to simplify the introduction of high split by operators into HFC networks.

The time for talk is over! Some operators have recently taken the brave plunge in deploying high split, while others are busy preparing to migrate to high split in the near-term. This paper will explore the drivers for pursuing high split (204 MHz) on an HFC network. The paper will explore what it takes to deploy high split, including the consideration of architectural issues that need addressing to support high-speed data (HSD), video, and voice over internet protocol (VoIP) services on high-split HFC networks for both residential and commercial services. Furthermore, the paper will explore the considerations for each of the services and the features that are required in the products that comprise the end-to-end solution that enables high split.

The paper will present a unique cross-industry view of a cable operator who is actively deploying high split as well as a vendor who is providing most of the elements to enable this type of migration. The paper will explore the considerations for three of the most popular HFC access architectures today, including Integrated CCAP (I-CCAP) as a Centralized Access Architecture (CAA) as well as the two leading Distributed Access Architectures (DAAs): Remote PHY (R-PHY) and Remote MACPHY (R-MACPHY). There is value in deploying high split in all three of these architectures, and the technology is available today. The paper will explore the main issues which must be addressed in preparation for deployment, as well as key lessons learned from both the preparations and deployments. This paper will position high split as an important steppingstone to DOCSIS 4.0 and explore an HFC network's evolution through this lens.

2. High Split & Cable Acess Architecture Overview

This section will provide an introduction and overview on what exactly high split is, what are the market drivers for high split, and what does high split gain for cable operators in order to lay the groundwork for reviewing the architectural and operational considerations for implementing high split.

2.1. High Split Overview – What is It?

The current return spectrum in HFC networks, typically allocated between 5 MHz and 42 MHz (65 MHz for some geographic regions), has been a critical resource over the years to support the enablement and growth of interactive services. The Data Over Cable Service Interface Specification (DOCSIS) specification versions that define how to provide standards-based high-speed data service up to and including DOCSIS 3.1 have traditionally used frequency division duplex (FDD) to split the upstream (US) and downstream (DS) bands and their associated traffic with a guard band in between the two to prevent interference.

The technology behind the HFC upstream path has grown in complexity and efficiency over time. More recently, DOCSIS 3.1 brought orthogonal frequency domain multiple access (OFDMA) digital modulation technology to the return path along with a higher 204 MHz split. OFDMA improved resiliency to return path noise and impairments, which has resulted in support for even higher speeds and capacities without the need for physical expansion of the return bandwidth spectrum.

However, the 42/65 MHz upstream has become cable's Achilles Heel. With gigabit downstream tiers, it becomes very difficult to pair a complimentary upstream tier with it. This creates the need for upstream bandwidth augmentations which is achieved through implementation of higher frequency splits. DOCSIS 3.1 technology introduced an upstream spectrum of 5-204 MHz, also referred to as a high-split (HS) configuration, with downstream spectrum starting at 258 MHz. The latest DOCSIS 4.0 specification provides an extended FDD option to enable FDD upstream spectrum up to 684 MHz while also providing for incremental downstream bandwidth capacity to offset the expansion of the upstream spectrum.

The vast majority of HFC networks today were built to either 750 MHz or 860 MHz as the maximum DS frequency with sub-split returns in the 5-42 MHz range (5-65 MHz range for some other regions). Expanding services are driving consideration for network expansions to address growing capacity needs in both the downstream and upstream directions. Past expansions were focused on expanding the downstream, while leaving upstream spectrum mostly untouched. As upstream bandwidth expansions are planned, particularly for sub-split and mid-split architectures evolving the return to 204 MHz, a phased approach should be considered that not only considers the impact on downstream bandwidth and services, but also considers the impact of future DOCSIS 4.0 technology options. This will be further explored later in the paper.

In comparison to the upstream spectrum, the downstream spectrum has stretched from 54 MHz (or approximately 87 MHz in other regions) up to 550 MHz, 760 MHz, 860 MHz or, more recently, 1,002 MHz or 1,218 MHz. Whichever is the maximum DS frequency, the DS spectrum clearly has much wider spectrum and supported bandwidth and capacity than the US has. It has been clear for some time that cable operators would need to eventually expand the utilized US spectrum in order to meet the needs of their subscribers as well as to compete in the broadband access market. The drivers for expanding US spectrum will be further described in Section 2.2.

Over time, both the DOCSIS standards and the equipment that implements these standards enabled an ability to expand the upstream spectrum. Up through the DOCSIS 3.1 standard, cable operators can expand the US spectrum to two additional levels:

(1) Mid split (MS): US spectrum of 5-85 MHz with DS spectrum starting at 108 MHz
(2) High split (HS): US spectrum of 5-204 MHz with DS spectrum starting at 258 MHz.

Eventually, as DOCSIS 4.0 technologies are widely adopted, additional Ultra-High Splits (UHS) will open the door to even greater upstream bandwidths and capacities with splits that can reach 300 MHz, 396 MHz, 492 MHz, or 684 MHz. However, regardless of which upstream expansion option is selected, operators must recognize certain technical challenges and be prepared to address them as will be explored in the rest of this paper.

An example of the raw total throughput that a cable operator could send in the downstream and receive in the upstream for each service group (SG) is instructive of the relative throughputs that each of the splits outlined above could potentially provide. Table 1 shows three separate implementations, one for each of low split, mid split, and high split. For this example, a mixture of DOCSIS 3.0 single carrier QAM (SC-QAM) and DOCSIS 3.1 orthogonal frequency-division multiplex (OFDM) channels was assumed in the DS, and likewise, a mixture of DOCSIS 3.0 advanced time division multiple access (ATDMA) SC-QAM and DOCSIS 3.1 orthogonal frequency-division multiple access (OFDMA) channels was assumed in the US, as outlined in Table 1.

Table 1 – Raw Throughput Examples for Low/Sub Split, Mid Split, & High Split

US Frequency Split	US Spectrum Usage (MHz)	DS Spectrum Usage (MHz)	US Raw Throughput (Mbps)	DS Raw Throughput (Mbps)
Low/Sub Split	Total: 5-42 ATDMA: 18-42 OFDMA: N/A	Total: 54-860 SC-QAM: 54-588 OFDM: 588-860	87	5380
Mid Split	Total: 5-85 ATDMA: 18-42 OFDMA: 42-85	Total: 108-1,218 SC-QAM: 108-642 OFDM: 641-1,218	575	7812
High Split	Total: 5-204 ATDMA: 18-42 OFDMA: 42-204	Total: 258-1,218 SC-QAM: 258-642 OFDM: 642-1,218	1302	6912

In this example, the maximum DS frequency when operating in low/sub split is assumed to be 860 MHz, a starting point for many cable operators today, and the example also assumes that the operator is utilizing DOCSIS 3.0 SC-QAMs only at this stage in the US, representing yet again another common starting point for cable operators. When moving to high split, the DS loses its lower 204 MHz of spectrum, and a move to 1,218 MHz in the DS is assumed to maximize total spectrum allowed when using DOCSIS 3.1-capable equipment. The example in Table 1 just assumes raw throughput to and from the SG, independent of whether the channel is used for MPEG or DOCSIS QAM.

For the US in this example, usable bandwidth was assumed to be starting at 18 MHz due to noise that typically exists in the 5-18 MHz range caused by noise funneling from the cable plant. However, operators can and have harvested this lower bandwidth utilizing the capabilities of the newer DOCSIS 3.1 OFDMA channels, but that is not explored in this example. Figure 1 shows an overview of the low split, mid split, and high split spectrum and the estimated raw throughput from Table 1. The migration to services that are closer to symmetric is a key driver for cable operators to compete with operators who offer services over a fiber-to-the-home (FTTH), fiber-to-the-premise (FTTP), fiber-to-the-building (FTTB), or generally, a fiber-to-the-X (FTTx) architecture. The competitive drivers for a migration to high split will be covered in Section 2.2.

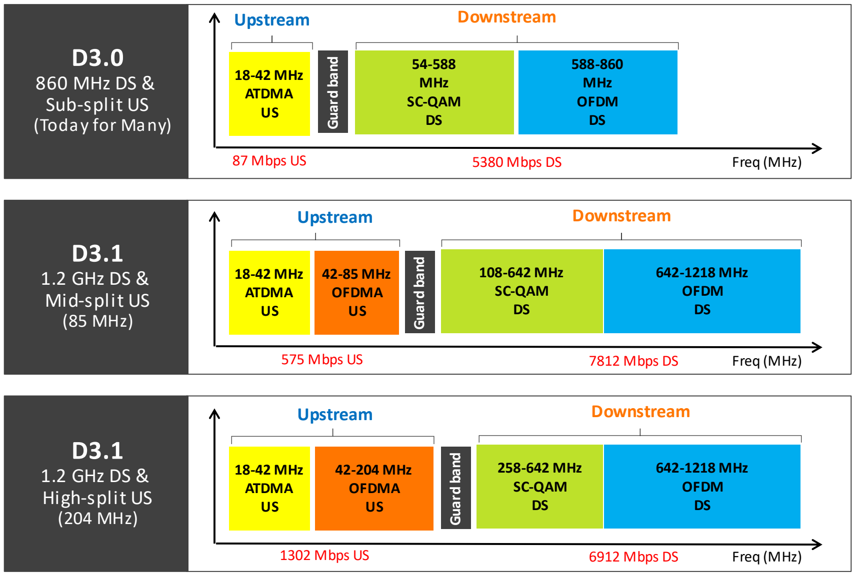

Figure 1 – Example Spectra & Overview of Low/Sub Split (42 MHz), Mid Split (85 MHz), & High Split (204 MHz)

2.2. Market Drivers for High Split

Cable operators face different levels of competition that vary by market. Historically, cable operators had competed against the legacy telecommunication providers (also known as the "telcos"), who initially offered high-speed data utilizing digital subscriber line (DSL) service over twisted-pair copper lines Many telcos and other alternative operators have opted to implement a fiber passive optical network (PON) for FTTx services. Service providers who are utilizing PON are offering service tiers up all the way up to 5 to 8 Gbps, with many offerings currently in the range of 2 to 3 Gbps as of the writing of this paper. Deploying some versions of PON for FTTx service offerings enables symmetric services, and this distinguishes these offerings from service offerings over HFC.

While cable operators do face tough competition from service providers that utilize DSL, satellite, and fixed wireless access (FWA), the services offered on these technologies generally compete with only specific segments of the broadband internet market either based on location or service availability as well as services that generally fit the lower end of the bandwidth speeds offered, which generally also align with lower cost. Cable operators face much tougher competition from service providers who offer services over FTTx PON due to the higher speeds, potential for symmetrical services, and lower latencies that this technology provides. Therefore, the existence of service providers using FTTx technologies overbuilt on an HFC network and/or the threat of a service provider overbuilding an FTTx network on an HFC network are two of the main market drivers for operators moving their DOCSIS deployments to high split.

Due to the actual or potential competition from FTTx, cable operators need to increase their DS SLA speeds, and when they do this, they also need to increase the US SLA speeds for two main reasons: (1) to have enough bandwidth in the US to support the required Transmission Control Protocol (TCP) Acknowledgements (ACKs) to sustain the offered DS speed and (2) to offer US speeds that may be required or desired by a subset of their subscribers, most notably business/commercial subscribers as well as gamers and video uploaders.

Deploying FTTx services typically comes at high cost whether it is done by cable operators, telcos, or other service providers. Cable operators generally have a key advantage, especially against the potential for a new fiber optic overbuilder: the advantage is the cable network they already have in place! One of the hallmarks of DOCSIS has been the ability to enable cable operators to expand services in an evolutionary manner with incremental investments while maintaining backward compatibility for existing services, as is explored in a separate paper entitled "Network Migration to 1.8 GHz – Operational "Spectral Analysis" Measured in nano-Hertz, a 30-Year Perspective" [Maricevic_2022]. This ability afforded by DOCSIS is a key reason why cable operators are now at the point of implementing or seriously considering a move to high split (204 MHz) in the US and 1.2 GHz in the DS. The decision for an operator to deploy PON or expand with DOCSIS is not an "either/or" situation but can many times be a coexistence story where the operator deploys PON in strategic portions of its network where it makes business sense in addition to high split with 1,218 MHz on HFC. Each operator needs to evaluate its own economic, competitive, cost, strategic, etc. situation to decide which path to go relative to expanding capacity with a pure HFC network implementation, or with a hybrid HFC / PON type deployment.

2.3. Historic & Projected Service Group Capacity of DOCSIS Versus PON

Since FTTx PON competition is a key market driver for cable operators to implement high split, it would be instructive to show how DOCSIS has evolved service group bandwidth over the years and to project how it might grow. This section explores a couple of potential evolutions of an HFC network SG with both spectral changes and channel lineup changes and how that impacts the raw bandwidth per service group (SG) in the DS and US.

Figure 2 shows an example of how SG bandwidth capacity has changed over the years, illustrative of the general DS and US SG bandwidth trends over time. The example only shows an expansion up to DOCSIS 3.1 technology and maximizing out at 1.2 GHz DS and 204 MHz US.

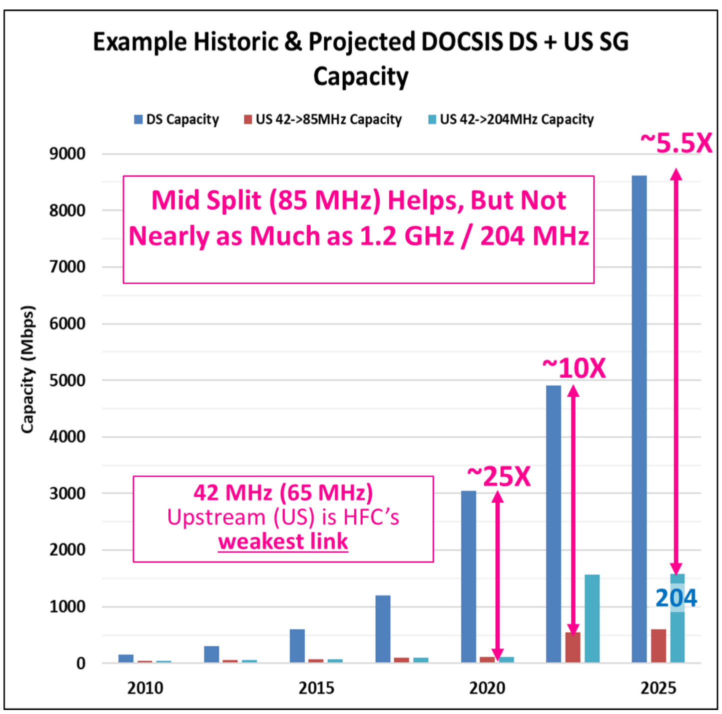

Figure 2 – DOCSIS Service Group Bandwidth Over the Years Utilizing DOCSIS 3.1 Technology

In this example, by 2020, the operator had grown to utilize 32 SC-QAM channels and a single 192 MHz OFDM channel in the DS while the upstream remained at low split (42 MHz). The operator in this example utilized a single 3.2 MHz and four 6.4 MHz ATDMA SC-QAM channels in the US. This yielded just over 3 Gbps per SG DS, which was roughly 25 times what could be achieved in the US.

In 2022, this example added another 192 MHz block of OFDM in the DS and opted to go to mid split (85 MHz). The DS SG throughput grew to nearly 5 Gbps, while adding OFDMA to fill up the remaining 85 MHz of spectrum grew the US SG throughput to approximately 540 Mbps. This reduces the DS:US SG bandwidth ratio to about 10x. Had the operator instead opted to move to high split (204 MHz) and fill the remaining spectrum up to 204 MHz with OFDMA channel capacity, they would have increased the US SG throughput to approximately 1.5 Gbps, further dropping the DS:US SG bandwidth ratio to about 3x. While moving to high split brought the operator closer to symmetrical in DS versus US, the move did not appreciably increase the DS throughput nor efficiently utilize the spectrum that was available.

The final step in this sample HFC SG evolution has the operator moving to 1.2 GHz of spectrum in the DS and 204 MHz in the US, yielding approximately 8.6 Gbps throughput in the DS and 1.5 Gbps in the US with the ratio of DS:US at approximately 5.5x.

By way of comparison, PON offers both asymmetrical and symmetrical offerings, depending on the version of PON in use. Gigabit passive optical networking (GPON) provides 2.5 Gbps DS with 1.2 Gbps US for a 2:1 ratio. The Institute of Electrical and Electronics Engineers (IEEE) specifies a 10 gigabit per second Ethernet passive optical networking (10G EPON) downstream that can be deployed with either a 1 Gbps or a 10 Gbps upstream for either a 10:1 or a 1:1 ratio. The International Telecommunication Union (ITU) Telecommunications Specifications Sector (ITU-T) specifies 10 Gbps PON (10G-PON), which is also known as XG-PON, that pairs 10 Gbps DS with 2.5 Gbps US at a 4:1 ratio and 10 Gbps symmetrical PON (XGS-PON) that provides symmetric 10 Gbps in both DS and US for a 1:1 ratio.

When including the impact of forward error correction (FEC) on throughput, XGS-PON (and other 10G PON technologies) net capacity is ~8.5 Gbps to the SG. Considering traffic engineering, average throughput per user, and a SG size of 64 subscribers, the maximum service level agreement (SLA) that XGS-PON technology can offer at a reasonable subscriber quality of experience is ~7.5 Gbps. Therefore, the 7.5 Gbps potential SLA from XGS-PON sets the bar for the near-term future evolution of DOCSIS and HFC networks to strive for.

Figure 3 below shows an alternative SG bandwidth evolutionary path along with providing a longer future projection of the HFC network SG bandwidths. The example includes those from Figure 2 above through year 2020. In 2022 in the new example, the operator has chosen to jump straight from an 860 MHz DS and low split (42 MHz) cable plant to a 1.2 GHz DS and high split (204 MHz) cable plant, taking a larger leap in an earlier timeframe and skipping the work associated with implementing a mid-split cable plant. Starting from 2025 and later, the operator has chosen to implement D4.0 FDD, which is also known as Extended Spectrum DOCSIS (ESD), to further increase the DS and US SG bandwidth.

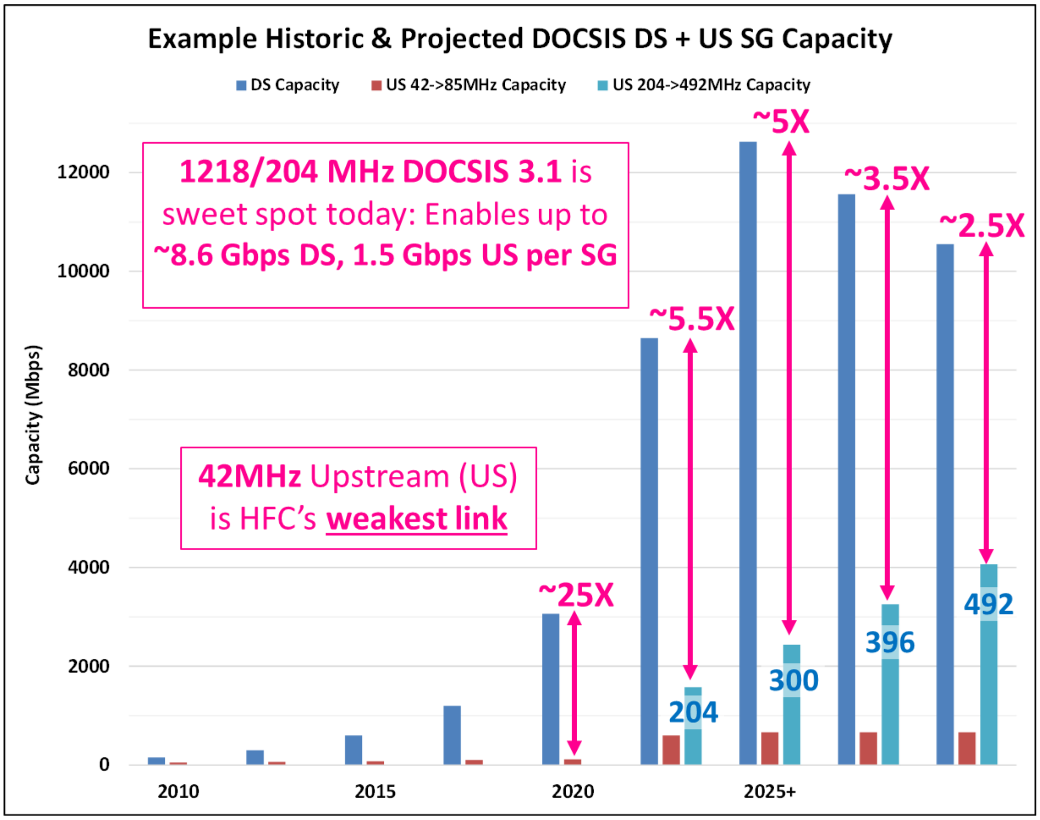

Figure 3 – DOCSIS Service Group Bandwidth Over the Years, Including Future Expansion Using DOCSIS 4.0

When the operator moves to D4.0 FDD, even though the maximum DS frequency can be moved up to as high as 1.8 GHz, the DS bandwidth in this example does not grow as much relative to the high split implementation from 2022 because some of what had been DS spectrum is now allocated to the US. The example shows that as the operator moves the UHS to higher frequencies, the US bandwidth grows while the DS bandwidth shrinks as the operator allocates more spectrum to the US at the expense of the DS. In this example, the operator moves through three different UHS settings: 300, 396, and 492 MHz. The example in Figure 3 shows the following:

1. DOCSIS 4.0 can achieve greater than 8.5 Gbps throughput per DS SG, more than what XGS-PON can provide
2. DOCSIS 4.0 can enable the HFC network to offer services that are much closer to symmetrical than prior implementations of DOCSIS
3. Implementing 1.2 GHz DS and high split (204 MHz) US is a clear steppingstone on the path to DOCSIS 4.0 and provides a significant amount of value with equipment that is available today.

The example in Figure 3 focuses the future steps to DOCSIS 4.0 as following the extended spectrum FDD path. A similar story could be laid out for operators who choose to implement DOCSIS 4.0 Full Duplex DOCSIS (FDX). One of the key technical differences between D4.0 FDD and D4.0 FDX is that D4.0 FDX utilizes some portions of the spectrum for both DS and US transmission while keeping the maximum DS frequency set at 1.2 GHz. An operator could chart a bandwidth evolution course to high split and then on to either D4.0 FDD or D4.0 FDX and, in theory, achieve similar results. The factors for deciding between D4.0 FDD and D4.0 FDX are beyond the scope of this paper, but regardless of that future path, making the step to high split now puts the operator in a better position to compete and set up for the next phase of its network evolution.

At the January, 2019 Consumer Electronics Show (CES), the Internet & Television Association (NCTA), CableLabs®, and Cable Europe announced an industry initiative generally called 10G™, which was defined as "the cable industry's vision for delivering 10 gigabit networks" and "a powerful, capital-efficient technology platform that will ramp up from the 1 gigabit offerings of today to speeds of 10 gigabits per second and beyond – to consumers in the United States and across the globe in the coming years" [NCTA 10G]. DOCSIS 4.0 is clearly one of the key technologies that enables 10G™, and as high split is a logical steppingstone to DOCSIS 4.0, it is also clearly also one of the smartest steps an operator can take on the Path to 10G™.

2.4. What Does High Split Buy the Cable Operator?

CommScope has been modeling HFC network operator bandwidth trends for well over a decade now and has utilized this data to project how operators can evolve their plants to meet the projected bandwidth demands of their end subscribers. A separate paper entitled "Broadband Capacity Growth Models – Will the end of Exponential Growth eliminate the need for DOCSIS 4.0?" by John Ulm, Dr. Zoran Maricevic, and Ram Ranganathan [ULM_2022] provides some excellent insights about what implementing high split actually buys the cable operator that will be summarized here.

The completed study performed modeling of a high (21% CAGR), moderate (16% CAGR), and low (linear) DS average busy hour user throughput (Tavg) growth rates on a 1,218/204 MHz plant offering a 5 Gbps DS, 1 Gbps US SLA. It analyzed SG size and the maximum number of subs supported over a 10-year window. The results are shown in Figure 4.

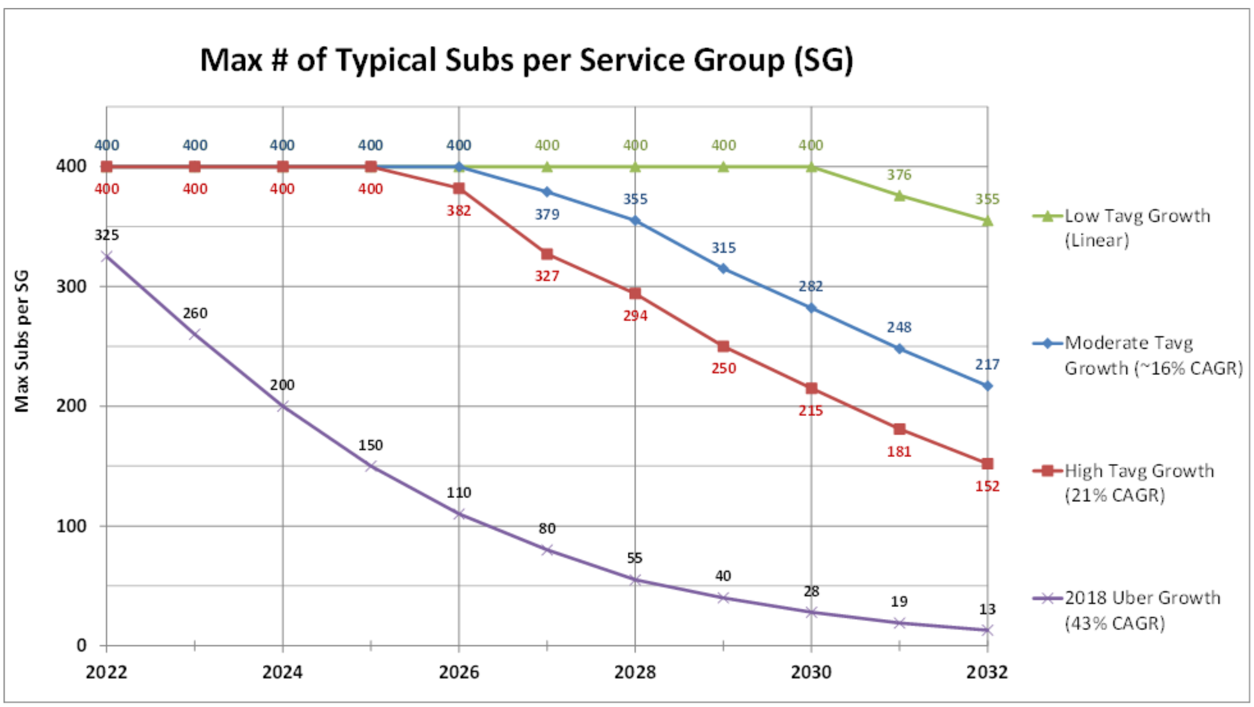

Figure 4 – Max Subs per SG for Low, Moderate & High DS Tavg growth, 1,218/204 MHz

For comparison purposes, Figure 4 also includes the 2018 projections of 43% CAGR "uber growth" – CAGR much higher than the more recent tapering of DS bandwidth growth. The 2018 projections show the max subs per SG supported would drop to 28 subs by 2030. This drove many people to think that FTTx would be required by 2030. However, the reality is that a 1,218/204 MHz plant supporting 5G x 1G tiers can easily last into the next decade, maybe even further if the slower growth projections hold.

In this case, the operator moves to high split in 2024 while simultaneously completing its migration to IPTV in the same year, reducing the legacy MPEG QAM video spectrum to zero. In 2025, the 5G DS tier is introduced and fills up most of the available 1,218 MHz of spectrum. Note that the SG size is still at 400 subs. After 2025, the SG size is reduced as needed to keep within the allotted 1,218 MHz.

Perhaps the key point of this 1,218/204 MHz case study is that a node with 150+ subs can be upgraded to 1,218/204 MHz and support a service tier of 5 Gbps x 1 Gbps for the next decade and beyond. There is no pressing near-term need to push the HFC to very small (and inefficient!) SG sizes, that could be, for example, achieved in N+0 systems. Even if the throughput follows high growth rates, the cable operator is not stuck and can node split further to a smaller SG size to meet the needs of their subscribers and/or migrate to DOCSIS 4.0.

3. Architectural Considerations for High Split

3.1. CMTS Architectures: I-CCAP, R-PHY, & R-MACPHY

There are three predominate Cable Modem Termination System (CMTS) / Converged Cable Access Platform (CCAP) architectures in the market today:

1. **Integrated CCAP (I-CCAP)**
2. **Remote PHY (R-PHY)**
3. **Remote MACPHY (R-MACPHY)**

I-CCAP is a Centralized Access Architecture (CAA) whereby an I-CCAP provides DOCSIS Media Access Control (MAC) and physical layer (PHY) functionality in a single, integrated, highly available chassis that provides high-speed data, voice, and video services on HFC networks. Figure 5 shows an example of an I-CCAP deployment in an HFC cable network.

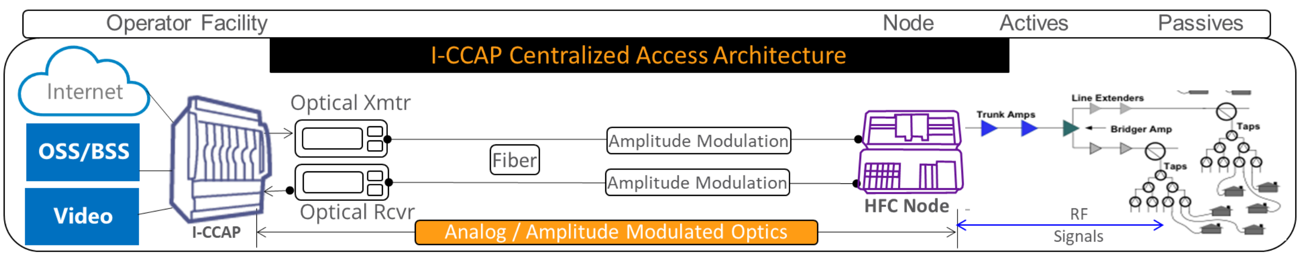

Figure 5 – I-CCAP Centralized Access Architecture

R-PHY is a DAA whereby the PHY component of the CCAP is moved from a centralized location (in an I-CCAP) and out to a Remote PHY Device (RPD), which is housed in a shelf or a fiber node. Figure 6 shows an example R-PHY architecture implementation. The RPD handles the RF generation and reception of the signals that traverse the cable plant. The CCAP MAC functionality is provided by either a physical CCAP Core, which is typically an I-CCAP that has been evolved to support R-PHY operation, or a virtualized CCAP Core that runs on common off-the-shelf (COTS) servers in the headend. From headend to RPD, the signals typically traverse an Ethernet network and over digital optics. The migration from analog / amplitude modulated optics as utilized in an I-CCAP CAA architecture to digital optics provides benefits by reducing the noise introduced on the HFC plant by the analog optics. Given the reduction in noise on the HFC network and the pushing of the RF signal generation to the edge of the network, the channels can be received typically with higher modulation error ratio (MER) than in an I-CCAP architecture, and this results in the ability to utilize higher modulation orders and a more efficient use of the RF spectrum.

Furthermore, moving the PHY function to a fiber node can reduce the cable operator's rack space, power, and cooling requirements for the cable headends and operator facilities. In this architecture, the RPDs are aggregated by a Converged Interconnect Network (CIN), which is comprised of switches/routers that connect the RPDs to the cores, software systems, and the internet to round out the network.

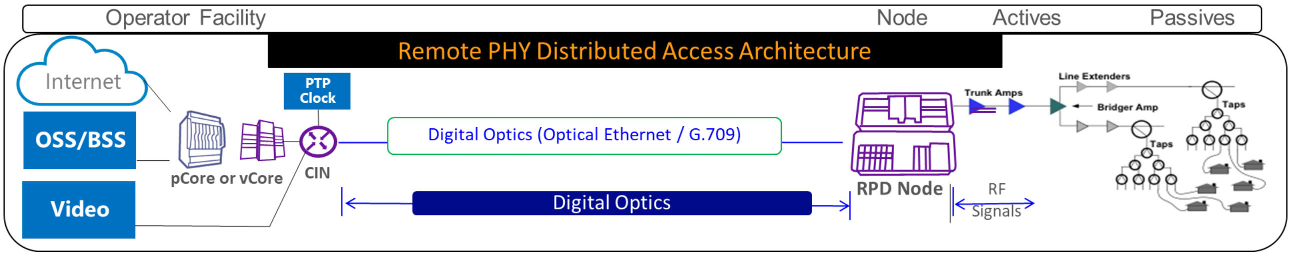

Figure 6 – Remote PHY Distributed Access Architecture

R-MACPHY is another DAA whereby both the MAC and PHY components of the CCAP are located in a Remote MACPHY Device (RMD), which can also reside in a shelf or a fiber node. Figure 7 shows an example R-MACPHY architecture implementation.

Like R-PHY, R-MACPHY also utilizes Ethernet and digital optics for the fiber optic distribution network and has similar benefits as R-PHY. With R-MACPHY, both the MAC and PHY functionality are moved to the remote location—typically in a fiber node—and this colocation has some additional benefits including better latency performance and, depending on the application and implementation, the potential to remove the need for the IEEE 1588 Precision Timing Protocol (PTP) grandmaster clock and associated timing network, further simplifying the network.

Similar to R-PHY, RMDs are also aggregated via a CIN. In the cable operator headend and similar to R-PHY, the RMDs connect to OSS/BSS, a video core, and, in the newer Flexible MAC Architecture (FMA) as defined by CableLabs, an FMA Core and/or MAC Manager. RMD is the main access component, which is an intelligent device performing the following functions, among others:

- Support DOCSIS MAC functionality, including DOCSIS signaling functions
- Provide all PHY-related circuitry such as downstream QAM & OFDM modulators and upstream QAM & OFDMA demodulators
- Convert downstream MEPG video received from a video core and downstream legacy out-of-band signals received over a digital transport link, such as Ethernet, into analog for transmission over RF
- Convert upstream legacy analog out-of-band signals received over RF into digital for transmission over a digital transport link, such as Ethernet.

R-MACPHY deployments arguably consume less total system power than either the I-CCAP or R-PHY alternatives.

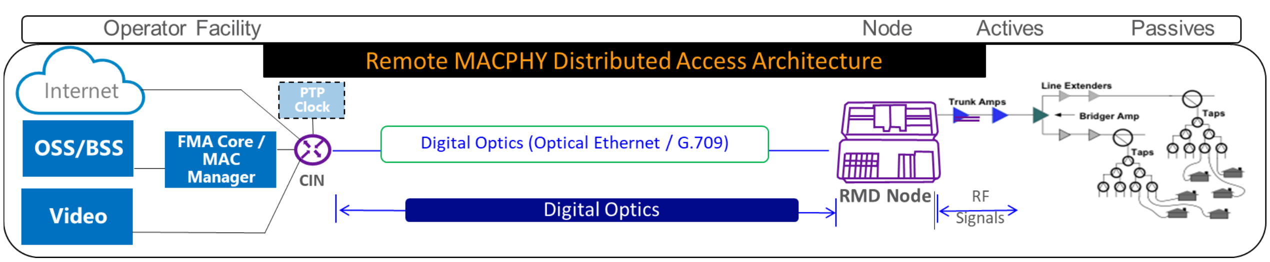

Figure 7 – Remote MACPHY Distributed Access Architecture

The great news for cable operators is that a migration to high split is both possible and can make sense for any of these architectures, and high split deployments are currently in the field on all three architectures using today's technology!

When an operator upgrades the HFC network to high split, the main components that get upgraded in all of these architectures are the actives in the cable plant, including the fiber node and RF amplifiers (line extenders (LEs) and bridger amps (MBs)). Whether deploying a CAA or DAA, the RF tray in the node needs to be upgraded to support high split (204 MHz) operation. Operators may typically want to leverage the fiber node visit to also move the downstream to support up to 1.2 GHz. With a CAA, the amplitude modulated optics can be implemented as analog in the return path, but the use of digital optics in the return path as offered by some vendors provides significantly improved performance. Generally, analog return path is better suited to shorter fiber links (approximately 10 miles or less) while digital return provides even more pronounced benefits at longer fiber links. When implementing a DAA, then the fiber optic link is handled by Ethernet links and digital optics.

Independent of implementing a CAA or DAA, the considerations for the upgrades to the actives and passives in the cable plant between the fiber node and the subscribers are the same. Generally, the RF amplifiers (actives) need to be upgraded to support 204 MHz operation in the upstream path, and most of the options already include support for 1.2 GHz operation in the downstream path as well. These upgrades to the amplifiers typically allow for the housing to remain in place while the active part of the product is swapped out. This saves time and cost and reduces the potential for problems to arise from cutting out and replacing products. Regarding passives, if taps currently deployed are limited to 1 GHz operation, the operator may choose to upgrade these to support 1.2 GHz via a tap faceplate swap while working on the cable plant. When operators implement the upgrade to high split, they will generally need to upgrade the node and subtended amplifiers at the same time or avoid using a portion of the spectrum while making the switch. If an operator is using conditioned taps, then the conditioning in place—whether via attenuation, equalizers (EQs), or cable simulators—may need to be adjusted to handle the new frequencies in use.

There are some considerations for implementing high split when looking at these three main CMTS/CCAP architectures. When embarking on an HFC network evolutionary step like high split, it is helpful to look out a couple potential steps ahead to leverage the work that needs to happen to better prepare the operator for a step beyond the high split. A DOCSIS 4.0 system, whether FDD or FDX, is generally predicated on implementing a DAA. For D4.0 FDD, a DAA is required to be in place because the HFC access technologies vendors are not currently planning on implementing analog / amplitude modulated optics that can support beyond 1,218 MHz. For D4.0 FDX, the spectrum that is shared between downstream and upstream can only really function well if the PHY is located near the edge of the network. Therefore, given that the operator will likely need to move to a DAA as the next evolutionary step to DOCSIS 4.0, it may make sense to leverage the planned node visit for doing the high-split upgrade to also implement a DAA at the same time. However, the great news is that moving to a DAA is definitely not required. Moving to a DAA requires additional coordination and work by the operator, so the operator may choose to implement high split with I-CCAP CAA first to get the benefits for some portions of the network and then subsequently upgrade to a DAA later in time. Products in the market today provide the flexibility to support multiple evolutionary steps that include a migration to high split!

One of the most common locations for RMDs and RPDs is in the optical fiber node. An RMD will contain network interfaces, such as Ethernet, and perform DOCSIS MAC and PHY functions, QAM video PHY functions, and RF functions including upstream analog signal receive and processing, all contained within a single module. As such, operators will want to ensure that legacy HFC node housings currently deployed can be initially upgraded to a high split configuration and are later upgradeable to FDD-, FDX-, and/or FMA-compliant nodes via installation of RMD or RPD modules.

Production hardware capable of 1.8 GHz D4.0 FDD or 1.2 GHz FDX operation is not yet available as of the writing of this paper. However, many operators have either already deployed or are trialing D3.1 RMD and RPD solutions and planning for eventual production deployments. Therefore, initial high split deployments must be part of larger initiatives that lay the groundwork for higher frequencies and bandwidth in both downstream and upstream directions. This strategy ensures support for future migrations to DAA solutions that will lead to improved RF signal quality and greater efficiencies in speed, reliability, latency and security.

Operators may need to support more symmetrical gigabit upstream speeds on their I-CCAP infrastructure. The initial phase of a transition to a high-split architecture includes the RF amplifier upgrades and may continue to leverage traditional analog optics for downstream signal transport if the lasers are already 1.2 GHz-capable. For the upstream, digital return optics based on sampling and digitization of return analog TDMA and OFDMA carriers at the node transport those signals back to the I-CCAP at the hub or headend facility. An upgrade to 5-204 MHz modules is necessary, both for the node transmitters and the headend digital receivers. Legacy analog return optical links, typically capable of supporting expanded return bandwidths, can continue to be used but care must be taken to ensure their set operating points are adjusted for the expanded high-split bandwidth load to maintain desired signal-to-noise ratio (SNR) and MER performance targets.

As DAA architectures further mature, deployment of DAA (RMD and/or RPD) technologies can start in select areas as the next rollout phase supporting the migration to a high-split HFC network. At that point, new bi-directional digital Ethernet links will replace traditional analog optics and legacy digital optics as nodes are converted to DAA. Legacy nodes upgraded with RMDs or RPDs remain in place supporting DOCSIS 3.1 services over upgraded high-split coaxial networks, enabling operators to benefit from significant improvements in RF signal quality and ready to support a future transition to D4.0 FDD or FDX operation.

3.2. Spectral Considerations

When operators implement high split (204 MHz) in the upstream, operators need to clear out the spectrum from 54 MHz to 258 Mhz that had typically been used in the downstream and will now be repurposed. A simultaneous migration to 1,218 MHz can help by increasing the overall spectrum in use on the cable plant and enabling operators to shift the downstream spectrum up in frequency. However, this may not be enough to free up the desired spectrum. Therefore, the operator may need to implement additional strategies to free up spectrum, some of which include the following:

- Harvesting / removal of video channels that have a low subscriber watch rate
- Implementation of Switched Digital Video (SDV) for MPEG QAM video
- Migration of QAM video from MPEG-2 to MPEG-4 for greater compression
- Evolution from MPEG QAM video to IP video delivery.

When moving to high split, if an operator has legacy MPEG QAM set-top boxes (STBs) deployed, then one of the legacy STB out-of-band (OOB) is typically utilized, either SCTE 55-1 [SCTE 55-1] or SCTE 55-2 [SCTE 55-2]. While these protocols have served cable operators well in providing interactive video services to subscribers for years, the signals that are used in the downstream for these implementations typically fall between 85 MHz and 204 MHz and are thus now in the upstream direction once a cable plant is migrated to high split. Two popular methods of dealing with this issue when evolving to high split include the following:

1. Migrate to STBs with embedded cable modems (CMs), potentially also compliant with the DOCSIS Set-Top Gateway (DSG) specification [DSG]. Note that some legacy STBs can be field upgraded from supporting legacy STB OOB to supporting DSG.
2. Migrate to all IP video delivery with IP STBs.

When employing one of the two strategies above, operators should take care that any STB upgrades that take place truly remove the need for any legacy STB OOB signaling as some STB implementations still required legacy STB OOB to either boot-up or for specific functions that required subsequent STB software upgrades to disable.

Cable operators may have some additional signals on the plant that need to be either disabled, relocated, or specially handled, especially when moving to a DAA. For example, cable operators in Europe who have previously operated frequency modulation (FM) radio application on the cable plant will likely need to shut this service down in order to support high split. When moving to a DAA, some of the plant alignment tones can be locally generated by the RPD or RMD. For other narrowband signals that may need to be preserved, the operator can implement Narrowband Digital Forward / Narrowband Digital Return (NDF/NDR) [R-OOB].

In summary, the cable operator needs to explore the entire spectrum in use today and ensure that all services are accounted for in some way when migrating to high split and/or a DAA. Products and features are available to help ensure that nearly all of the services can be available after the migration, but the operator may need to make some decisions on specific services to impact in order to get the greater benefit of improved upstream and downstream bandwidth.

3.3. Leakage Detection

Migration to high split and ultra-high split systems will require moving the upstream/downstream split further up into and potentially above the aeronautical band. Figure 8 below illustrates how the migration to a high-split architecture today—and migrations to even higher splits in the future—will incrementally turn legacy downstream spectrum currently within the aeronautical bands into new upstream bandwidth. This will require new approaches from operators to continue to monitor and repair signal leakage in compliance with existing United States Federal Communications Commission (FCC) and other international governing body rules. Some of the approaches being explored include:

1. Leveraging OFDMA Upstream Data Profile (OUDP) test bursts
2. Implementation of exclusion zones
3. Upgrading legacy leakage meters to detect downstream OFDM pilots.

With OUDP, upstream OFDMA signals will be generated by all cable modems that are provisioned for HS mode to allow new test equipment to detect egress from coaxial plant and accurately measure it for enterprise reporting. The concept involves cable modems that are instructed to generate OUDP test bursts in open timeslots and using specific CMTS configurations and OFDMA parameters that are considered optimum for accurately detecting leakage when driving either slowly or quickly past an RF leak. Specific parameters include subcarrier spacing, cyclic-prefix, roll-off-period, symbols-per-frame, data IUC modulation, pilot pattern, transmit burst gap between CMs, transmit duration and the frequency transmit location(s). Each modem will be instructed to repeat transmissions in a round-robin fashion, so RF Leakage detectors are not reliant on customer upstream data traffic. The primary benefit of using signals from cable modems is that their RF level is the same amplitude as the OFDMA signal which allows for a much higher capture resolution and accuracy when a vehicle is in motion. A further exploration of this strategy can be found in a prior SCTE paper, “Leakage In A High Split World – Detecting and Measuring Upstream Leakage Levels in a One Gbps Symmetrical High Split Hybrid Fiber Coax Network” by John Chrostowski, et. al. [Chrostowski 2020].

Implementation of exclusion zones carved out of downstream OFDM carriers would allow the insertion of tag signals which would allow the continuous use of legacy leakage detection field meters.

Upgraded meters would allow detection of OFDM pilots within a large bandwidth range.

Interoperability testing to refine and evaluate the effectiveness of these proposed approaches, and their variations, is currently under way. Results today are encouraging, and options to support leakage monitoring obligations are within reach.

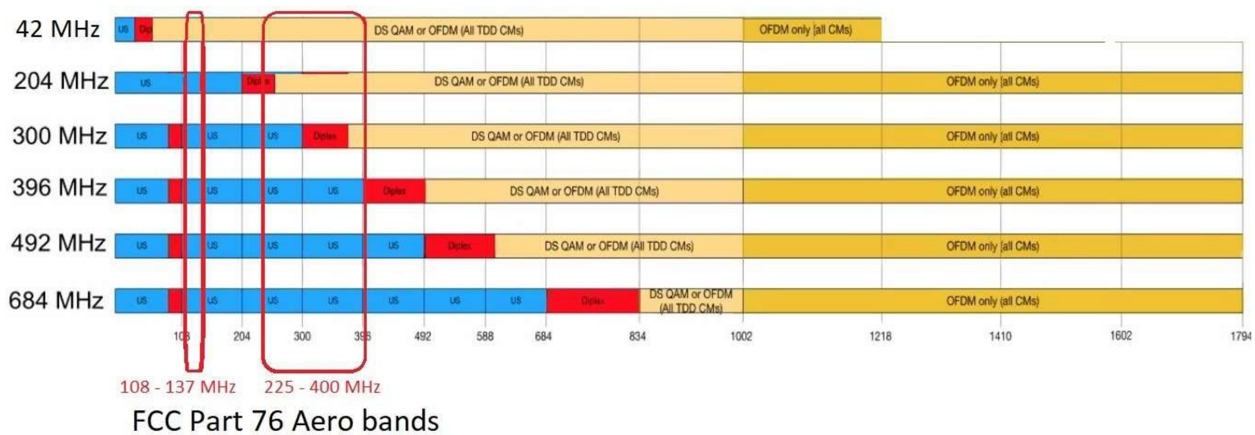

Figure 8 – DOCSIS 4.0 Frequency Split Roadmap vs. FCC-governed Aeronautical Bands

3.4. Customer Premise Equipment (CPE) Considerations

When operators decide to move to a high-split implementation, one of the first steps they need to take is to start pre-seeding the market with customer premise equipment (CPE) / CMs that have a selectable diplex filter that is remotely switchable to support the current split—low split (42 MHz or 65 MHz) or mid split (85 MHz)—in addition to high split (204 MHz). Having a large set of modems already in the field that are capable of high split will make it easy to take full advantage of the benefits of high split once the rest of the network elements have been evolved to make it a reality. Therefore, it is imperative for cable operators to start deploying cable modems that have the desired high-split diplexer capability early in time so that the market has enough critical mass of modems in use to justify and take advantage of the upgrade to high split.

After the operator has deployed enough high-split-capable CPE and enabled high split in the network, remotely forcing the CPE to use the new US and DS spectral ranges is critical. There are two main methods for this. One method involves configuring the MAC Domain in the I-CCAP, CCAP Core (for R-PHY), or RMD to tell the modems to start using the high split diplexer setting. This is then communicated down to the cable modems through the MAC Domain Descriptor (MDD) as type-length-value (TLV) 21 as defined in the D3.1 MAC and Upper Layer Protocols Interface Specification [DOCSIS 3.1 MULPI]. This implementation is relatively easy since it is down at the MAC domain level and not at the individual CM level. An alternate method is to set the diplexer setting via the CM config file, and this utilizes TLV 84 in the config file as defined in the same specification and which supersedes any TLV 21 setting in the

MDD [DOCSIS 3.1 MULPI]. While more difficult to manage down to the CM level, TLV 84 provides operators with more granular control of CMs that utilize high split and may become useful. With these two methods, operators have the ability to more broadly implement or to specifically pinpoint high split on the installed CPE as required for the given implementation.

When implementing high split, cable operators may need to address the legacy video CPE that are on the network due to the legacy STB OOB signals that would traditionally be in the downstream spectrum that is now utilized in the upstream. This topic has been explored in more detail in Section 3.2 and will also be explored in Section 5.2.2 but is listed in this section for completeness.

3.4.1. Potential High-Split CPE Interference on Legacy CPE

When implementing high split on CPEs, it is also possible that the upstream transmissions from the CMs may interfere with other legacy CPE, such as video STBs and legacy D2.0 and D3.0 CMs, that may not be high-split capable. In short, the transmissions in the upstream band from 54 MHz to 204 MHz may overlap with the downstream spectral window for the legacy CPE, and given that the high-split CM and legacy CPE are close to each other on the cable plant, the transmissions will be relatively high power and may cause issues.

There are two typical potential scenarios that have been considered relative to the potential interference of US transmit signals from high-split CPE on legacy video STBs and legacy D2.0 and D3.0 CMs: single home interference and neighbor-to-neighbor interference, as shown in Figure 9. Testing conducted by CableLabs, vendors, and multiple cable operators across a large set of legacy STBs has shown that STBs generally cannot handle an adjacent D3.1 transmit interference level known as the Carrier-to-Adjacent Carrier Interference Ratio (CACIR) where the interfering US transmission signal is 20 dB higher than the downstream video QAM receive level. Above this level of interference leads to MPEG video data corruption and resulting in an impacted video signal, including tiling and other potential artifacts. D2.0 or D3.0 legacy modems may also experience packet loss. The impacts are generally caused because the automatic gain control (AGC) functional blocks in the legacy CPE devices may be overdriven due to the relatively high-power US transmissions coming from the nearby D3.0 high-split CPE.

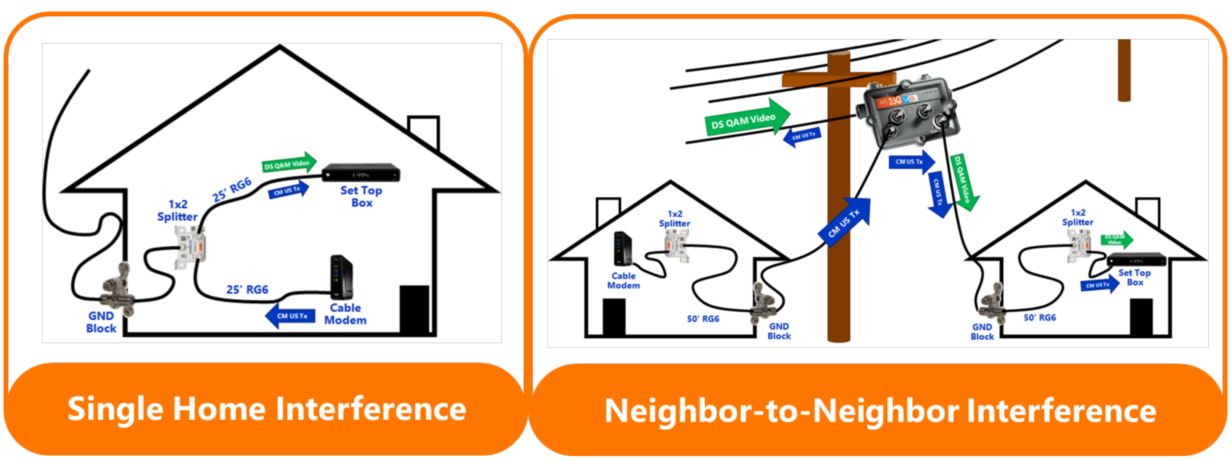

Figure 9 – Two Potential High-Split CPE Interference Scenarios

Luckily for both cable operators and end subscribers, interference that has a CACIR of 20 dB or higher is generally very uncommonly seen by operators in the field. Studies have shown that the neighbor-to-neighbor interference would require an extremely rare set of conditions for both neighboring premises to have. Typically, the scenarios that have impacts are with single home interference for a small set of subscribers who have significant RF losses either in the drop to the premise or in the premise. For these scenarios, the DS signal level into the video STBs will already be quite low while the D3.1 modems running with high split enabled will be operating near the top of their RF output power range to overcome the losses within the in-home cable network. These subscribers have typically already been highlighted as needing improvements by typical cable plant monitoring and maintenance efforts. Additionally, operators can use the monitoring of STB receive power levels and D3.1 high-split CPE transmit levels to identify premises that might be at risk of experiencing such interference and then take steps to correct these scenarios.

Cable operators can mitigate cases of potential or actual interference through several potential solutions, including the following:

- Improving the in-premise cable network and/or drop to the premise to decrease the signal attenuation
- Reconfiguration of the in-premise cable network to better isolate the D3.1 high-split CPE by not placing them on the same RF splitter as legacy CPE that may be impacted by interference
- Replacing in-premise RF splitters with RF splitters that have higher isolation
- Installing band-stop RF filters to filter out the 54 MHz to 204 MHz spectral range for the legacy CPEs. Note that this solution should be used sparingly as the band-stop RF filters need to be very strategically placed within the subscriber premise, and the subscriber potentially moving such filters could cause issue with the high-split CPE deployments.

4. Operational Considerations for High Split

4.1. Upstream Level Considerations

4.1.1. Levels Out of Cable Modem (CM)

In DOCSIS 2.0 (D2.0), quadrature phase shift keying (QPSK) modulation remained as one of the constellations for the return path, and was assigned higher maximum power than the max power for the higher-level constellations, such as 16QAM and 64QAM, as shown in Table 2 from the DOCSIS 2.0 Radio Frequency Interface (RFI) specification [DOCSIS 2.0 RFI]. At first glance, this specification may appear as an error because the higher-level constellations do require a higher signal to noise and as such, would benefit from higher power transmission – provided, that the underlying noise is thermal / white Gaussian in nature.

Table 2 – Upstream Cable Modem Levels from D2.0 RFI Specification

Table 6-6 Constellation Gains and Power Limits

Constellation	Constellation Gain G_{const} Relative to 64QAM (dB)	P_{min} (dBmV)	P_{max} (dBmV) TDMA	P_{max} (dBmV) S-CDMA	P_{min} - G_{const} (dBmV)	P_{max} - G_{const} (dBmV) TDMA	P_{max} - G_{const} (dBmV) S-CDMA
QPSK	-1.18	8	58	53	9.18	59.18	54.18
8QAM	-0.21	8	55	53	8.21	55.21	53.21
16QAM	-0.21	8	55	53	8.21	55.21	53.21
32QAM	0.00	8	54	53	8.00	54.00	53.00
64QAM	0.00	8	54	53	8.00	54.00	53.00
128QAM	0.05	8	N/A	53	7.95	N/A	52.95

But there was no error in Table 2, because QPSK, even though not very bit-per-second-per-hertz efficient, remained to deal with the presence of sizable ingress interference. Table 3 gives further clarification – QPSK was needed for those situations when carrier-to-interference plus ingress was in the mid-20 dB range, and as pointed to in Note 2 from the table, those time-varying ingress bursts could be as high as 10 dB below the signal. Therefore, there was a desire and need to keep QPSK as one of the options and to keep its max power high.

Table 3 – Assumed Upstream RF Channel Characteristics from D2.0 RFI

Table 4-2 Assumed Upstream RF Channel Transmission Characteristics (see note 1)

Parameter	Value
Frequency range	5 to 42 MHz edge to edge
Transit delay from the most distant CM to the nearest CM or CMTS	<= 0.800 msec (typically much less)
Carrier-to-interference plus ingress (the sum of noise, distortion, common-path distortion and cross-modulation and the sum of discrete and broadband ingress signals, impulse noise excluded) ratio	Not less than 25 dB (Note 2)
Carrier hum modulation	Not greater than -23 dBc (7.0%)
Burst noise	Not longer than 10 μsec at a 1 kHz average rate for most cases (Notes 3 and 4)
Amplitude ripple 5-42 MHz:	0.5 dB/MHz
Group delay ripple 5-42 MHz:	200 ns/MHz
Micro-reflections – single echo	-10 dBc @ <= 0.5 μsec -20 dBc @ <= 1.0 μsec -30 dBc @ > 1.0 μsec
Seasonal and diurnal reverse gain (loss) variation	Not greater than 14 dB min to max

2. Ingress avoidance or tolerance techniques may be used to ensure operation in the presence of time-varying discrete ingress signals that could be as high as 10 dBc. The ratios are guaranteed only within the digital carrier channels.

How high? As high as 58 dBmV per single QPSK channel of D2.0 as sourced from a cable modem. Then, the DOCSIS 3.0 Physical Layer Specification [DOCSIS 3.0 PHY] takes it a step higher, as shown in Table 4: a D3.0 cable modem must be able to generate a QPSK channel with a minimum of 61 dBmV if using a single channel and the same total power if distributed across 2 or 4 QPSK channels.

Table 4 – D3.0 per Channel Power Levels Out of Cable Modem, with Highlighted Max Points

Table 6–21 - Electrical Output from CM[46]

Parameter	Value
Level range per channel (Multiple Transmit Channel mode disabled, or only Multiple Transmit Channel mode enabled with one channel in the TCS)	TDMA: P_{min} to +57 dBmV (32-QAM, 64-QAM) P_{min} to +58 dBmV (8-QAM, 16-QAM) P_{min} to +61 dBmV (QPSK) S-CDMA: P_{min} to +56 dBmV (all modulations)
Level range per channel (two channels in the TCS)	TDMA: P_{min} to +54 dBmV (32-QAM, 64-QAM) P_{min} to +55 dBmV (8-QAM, 16-QAM) P_{min} to +58 dBmV (QPSK)
Level range per channel (three or four channels in the TCS)	TDMA: P_{min} to +51 dBmV (32-QAM, 64-QAM) P_{min} to +52 dBmV (8-QAM, 16-QAM) P_{min} to +55 dBmV (QPSK)

With the introduction of D3.1 [DOCSIS 3.1 PHY], no per-channel max power increases take place; however, the total composite power is nudged up, from 58 dBmV for D2.0, and 61 dBmV for D3.0, to 65 dBmV, as shown in Figure 10. D3.1 also increased the maximum US spectrum to 204 MHz. The latest

DOCSIS spec, D4.0, stays with the same 65 dBmV total composite power (TCP) limit, provided the whole D4.0 upstream spectrum, up to 684 MHz, is utilized [DOCSIS 4.0 PHY].

7.4.12.2 Transmit Power Requirements

The transmit power requirements are a function of the number and occupied bandwidth of the OFDMA and legacy channels in the TCS. The minimum highest value of the total power output of the CM P_{max} is 65 dBmV, although higher values are allowed. The total maximum power is distributed among the channels in the TCS, based on equal power spectral density (PSD) when the OFDMA and legacy channels are fully granted to the CM. Channels can then be reduced in power from their max power that was possible based on equal PSD allocated (with limits on the reduction). This ensures that each channel can be set to a power range (within the DRW) between its maximum power, $P_{1.6hi}$, and minimum power, $P_{1.6low}$, and that any possible transmit grant combination can be accommodated without exceeding the transmit power capability of the CM.

Maximum equivalent channel power ($P_{1.6hi}$) is calculated as $P_{1.6hi} = P_{max}$ dBmV $- 10\log_{10}(N_{eq})$.

For a CM operating with a DOCSIS 3.1 CMTS, even on a SC-QAM channel, the CMTS MUST limit the commanded $P_{1.6hi}$ to no more than 53.2 dBmV+ (P_{max} - 65) if the bandwidth of the modulated spectrum is $\leq$ 24 MHz. This enforces a maximum power spectral density of P_{max} dBmV per 24 MHz. This limit on power spectral density does not apply for a CM operating with a DOCSIS 3.0 CMTS, where the fidelity requirements are the DOCSIS 3.0 fidelity requirements and not the DOCSIS 3.1 fidelity requirements.

SC-QAM channels that are 6.4 MHz in BW have a power of $P_{1.6r\_n}$ + 6 dB.

Figure 10 – D3.1 PHY Spec Snippets, Requiring TCP of 65 dBmV Out of the CM

Figure 11 shows how the above TCP-focused specs translate to per-channel levels with the upper left-most green line showing D3.1 high-split levels and the other lines/colors showing various levels of D4.0 FDD ultra-high splits. Please note that the vertical y-axis shows power per 1.6 MHz-wide channel, the method used in the PHY specs. For power per 6.4 MHz-wide channel, one should add 6 dB to all the per-channel powers.

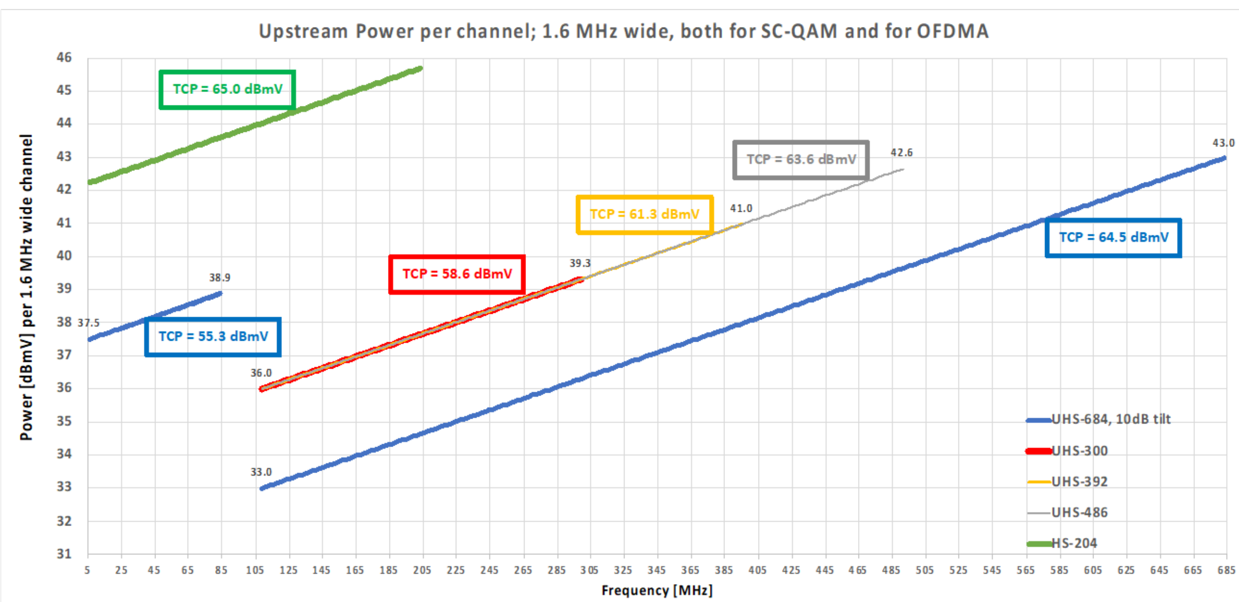

Figure 11 – Max HS CM Levels (Green) with Various Ultra-High-Split Options of D4.0 FDD

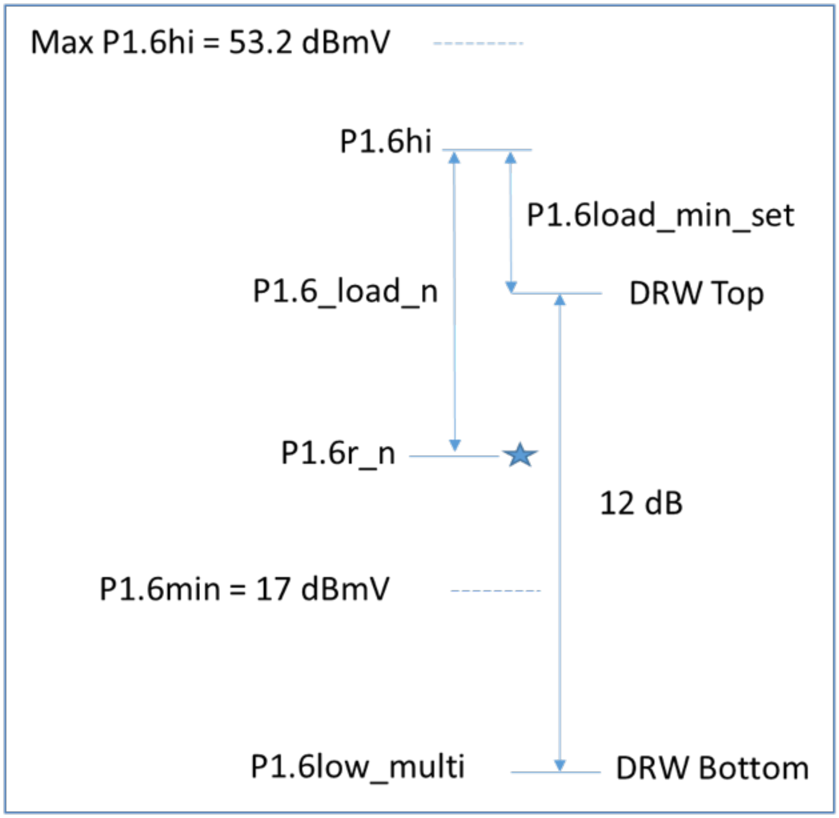

Figure 3.2.7-4. Transmit power at the CM

Figure 12 – Dynamic Range Window (DRW) Considerations from D3.1 PHY

Thus, in comparison to US levels specified in previous DOCIS versions, both TCP and per-channel D3.1 levels are high enough – which gives plenty of room to overcome whatever spurious noises the upstream plant may present. In comparison with the D4.0 levels, the maximum D3.1 high-split levels are also higher—about 6 dB higher and range from ~48 to ~52 dBmV per 6.4 MHz-wide channel, as can be seen in Figure 11. Operators, however, should exhibit caution in approaching the maximum levels, for several reasons as outlined below.

The first reason is that cable modem termination systems (CMTSs) "normally administers dynamic range window (DRW) of 12 dB." Exact dynamic range window (DRW) details per D3.1 PHY spec are shown in Figure 12. One way to think of this aspect is that HS CM shall not be commanded a TCP higher than 59 dBmV, which corresponds to ~44 dBmV/6.4 MHz channel. If reached, this TCP range is often denoted as a "red zone" by the operators.

The second reason is outlined in Section 4.1.2 below.

4.1.2. Levels into RF Amplifier Upstream Ports

The second reason operators should exhibit caution in approaching the maximum modem transmit levels when operating high split is that the upstream power into the return RF amplifiers should fall into a "Goldilocks" (also known as "just right") range recommended by the amplifier manufacturers: not too low so as to get affected by thermal noise and the amplifier's noise figure, and not too high so as to get distorted in the upstream gain stage. Per CommScope's MB120 amplifier data sheet [MB120 data sheet], as an example, the high-split configuration upstream distortion specs are shown for 33 upstream channels at 5 dBmV per 6.4 MHz at the amplifier's upstream input port.

Figure 13 shows an in-between RF amplifiers section of HFC plant, as a backdrop for various levels discussed. For completeness, the tap values were selected in order to set the customer-premise downstream levels to fit within -6 to +8 dBmV per 6 MHz-wide downstream channel range, as shown in Figure 14.

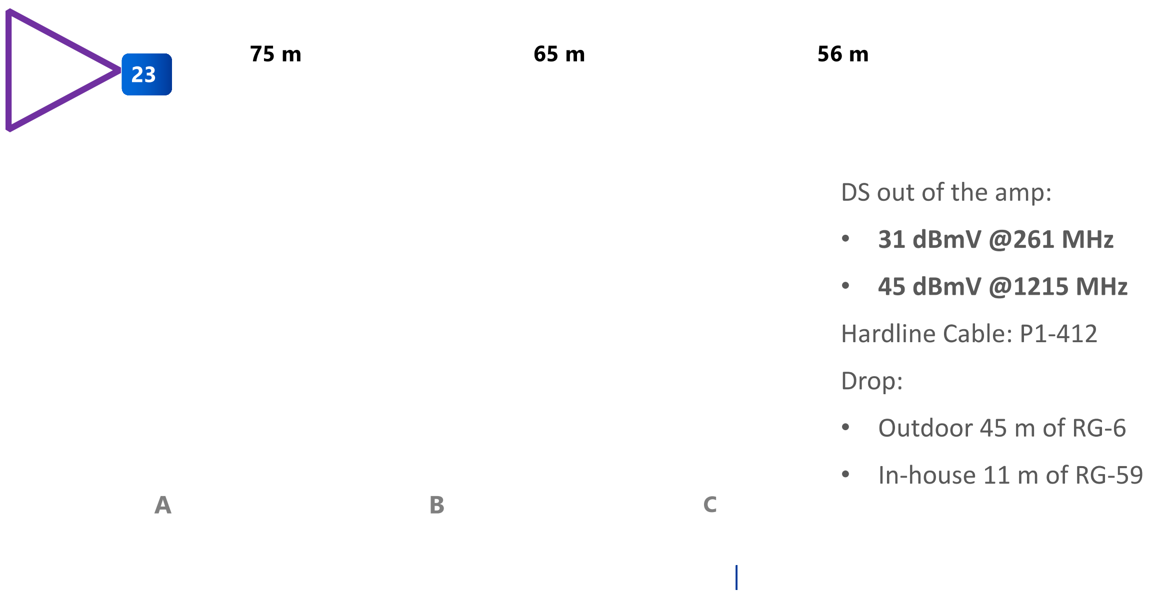

Figure 13 – An Example Section of HFC Plant in Between Two RF Amplifiers

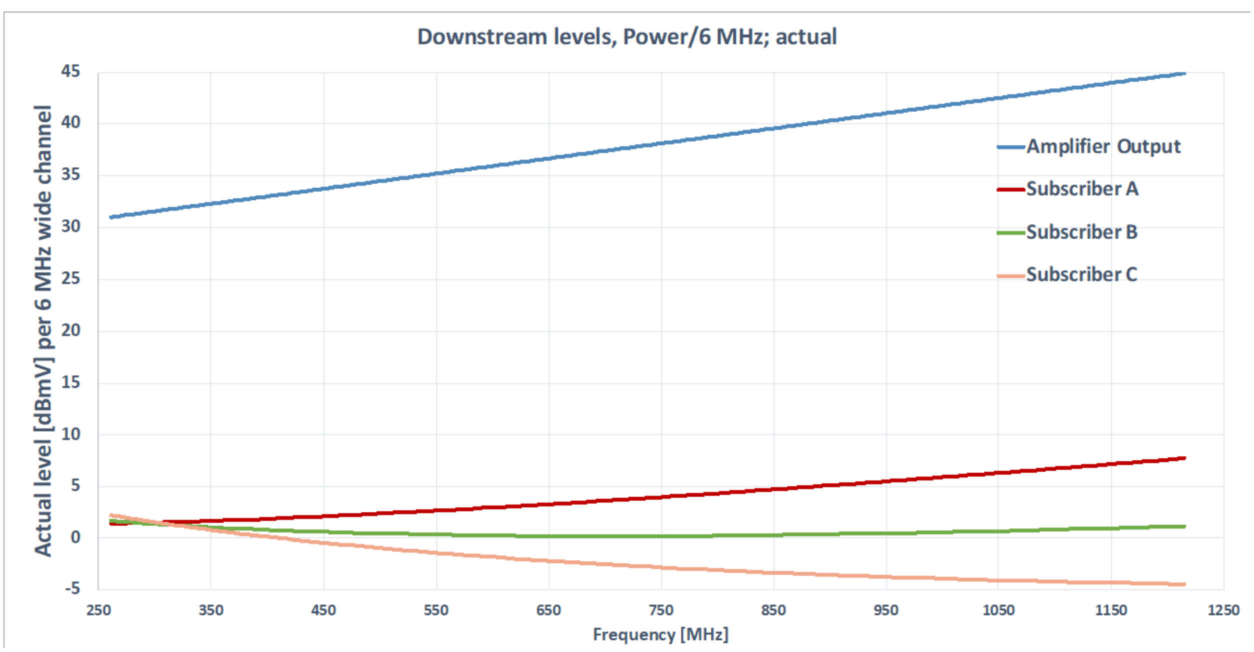

Figure 14 – Actual Per-channel DS Levels, at an RF Amplifier Output and at Customer Premises

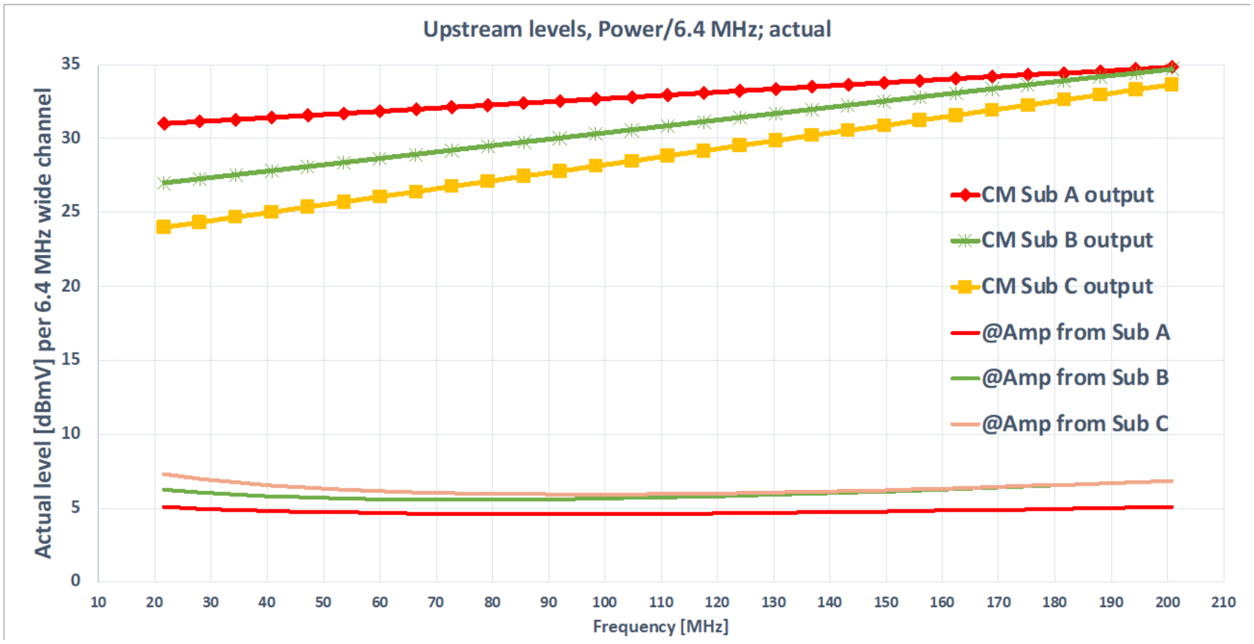

Figure 15 – CM Upstream Levels, and the Resulting Input-into-RF Amp Levels

The upstream levels into the RF amplifier, driven by the CM's 31/35, 27/35, and 24/34 dBmV at lowest/highest upstream channel at premises A, B, and C, respectively, are shown in Figure 15. The "smile" shape in the 3 "@Amp" curves is due to the cable loss signature, driven by the selected linearly-up-sloped CM output. The CM TCP comes to 48, 46, and 44 dBmV at premises A, B, and C, respectively.

A more exacting method of DS/US alignment can be carried if "conditioned taps" are used in place of the regular ones. In Figure 16, the first tap, with the original 23 dB value, is replaced by a 17 dB tap with an internal 6 dB cable simulator plugin. Similarly, the third tap with the original 11 dB value, is replaced by a 4 dB tap with an internal 6 dB cable equalizer plugin. As a result, the downstream levels at the conditioned A and C drops will match those of B; and similarly, as shown in Figure 16, the same CM levels out of A, B and C cable modems will produce an identical level into the upstream RF amplifier input port.

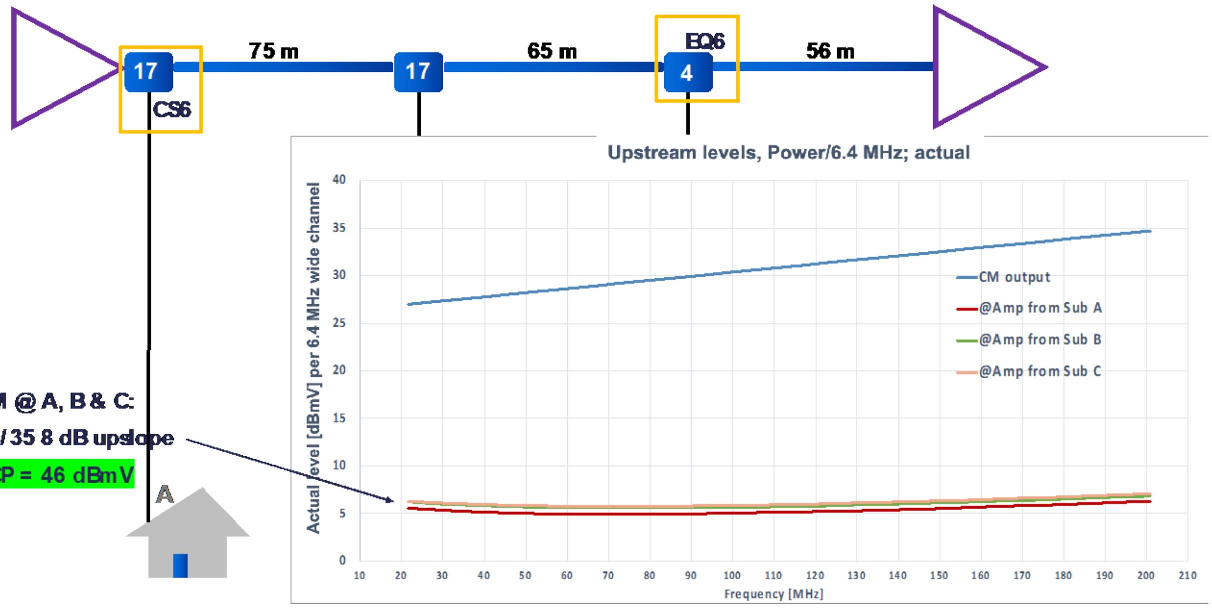

Figure 16 – Conditioned Taps Example for an Even Further Optimized Plant Section

The effort required to perform this level of balancing does not appear to produce enough improvement in the high-split plant to pay for itself, and is hereby mentioned as an option, although rarely employed operationally. That may, however, change with introduction of D4.0 and ultra-high splits.

4.2. Field Components Upgrade Considerations – "Rip and Replace" or "Modules Only?"

At minimum, high-split upgrades affect the fiber node and RF amplifiers. In some cases, the RF taps and passives may get a refresh as well. One of the key decisions to consider when upgrading nodes and amps is whether to "rip and replace" the whole housings or to just upgrade the modules inside.

The modules-only approach has several advantages, such as:

- Faster to complete – which leads to less down time
- Crews are more efficient – get more nodes done in a shift
- Fewer opportunities for the things to go wrong (such as broken fiber pigtails, cracked coaxial cable, bent connectors) – thus avoiding "opening a can of worms"
- Lower cost of labor encountered – by eliminating re-connectorization of coaxial cable and/or fiber splicing.

There are, however, several reasons where it makes sense to "rip and replace":

- If the new device offers future-proof options not available in the old one
- Is the old housing in acceptable shape? If not, replacement is the only option
- Is the old device type an unsupported product? If yes, cut out and use the "standard" product.
- If standardization driven – even if the old device is a supported product, it may get replaced because of standardization.

Standardization does matter as it improves inventory management and thus reduces overall inventory needs. Fewer spares are carried on a technicians' trucks, and tech training is simplified, which further minimizes opportunities for human error.

Figure 17 and Figure 18 show details of the node replacement process, in support of and as an illustration of how involved it may get, especially if executing the “rip-and-replace” strategy.

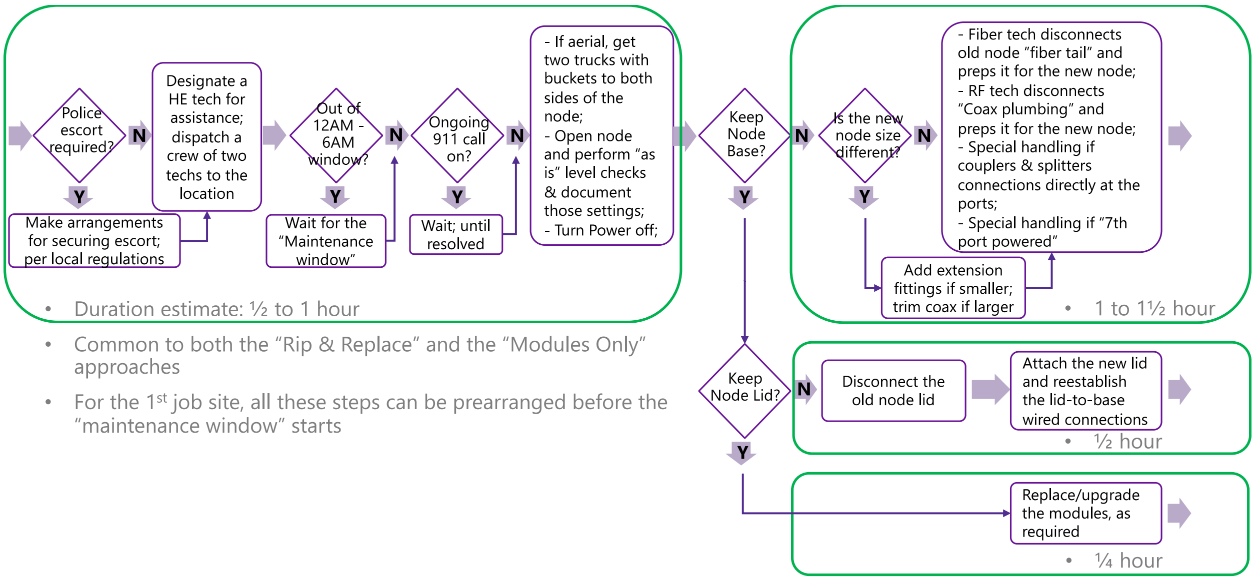

Figure 17 – How to Replace a Node – Initiation and Replumbing Part of the Process

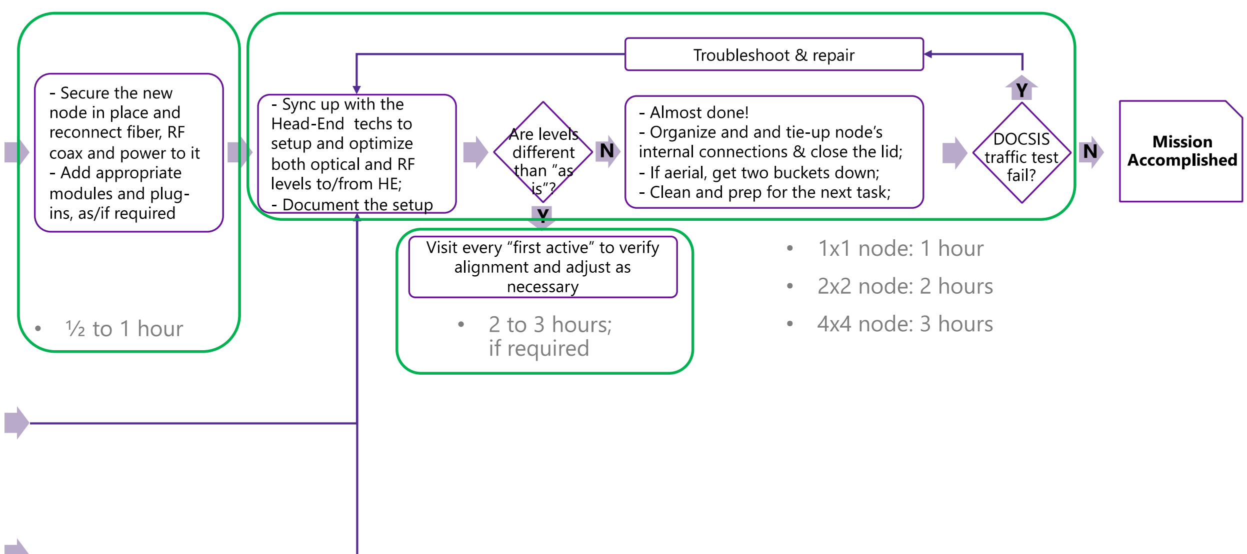

Figure 18 – Setup & Wrap-up Part of the Node Replacement Process

5. Shaw Communications – High-Split Lessons Learned

Shaw Communications has embarked on deploying both mid split (85 MHz) and high split (204 MHz) along with 1,218 MHz downstream in their HFC network. This section describes thoughts behind the upgrade, key considerations, potential future migrations, and lessons learned.

5.1. Why the Need to Modernize the Network Beyond Mid Split?

Mid-split deployments are becoming more and more common for great reasons. With the sudden rise in upstream traffic during the COVID-19 pandemic, mid-split deployment plans for most operators have increased in priority and scale. Mid-split upgrades provide a rapid, cost-effective method for immediate congestion relief. However, for most operators the business case for mid-split upgrades has been primarily focused on congestion mitigation while the benefits of broadband tier enablement are usually discounted. As a result, the broadband speeds offered in the marketplace are typically defined solely by an operator's congestion management strategy. Competitive FTTx deployments will force many operators to shift this thought process.

In many markets around the world, cable operators are facing more competition from well-funded players (typically quadruple-play telco operators) who are aggressively deploying FTTx networks at scale. Even operators with significant mid-split deployments (such as Shaw) face substantial market pressures from the aggressive advertising on the purported advantages of a pure fiber network, along with very aggressive speeds tiers in market. In the Canadian market, Shaw is already seeing competitive 2.5 Gbps symmetrical tiers become broadly available as of the writing of this paper.

While broadband tiers enabled by a mid-split network have been very successful in competing against GPON offerings, these tiers will not be as competitive once FTTx deployments shift to 10 Gbps-capable PON technologies, such as 10G EPON and XGS-PON. As a result, it is paramount that cable operators think beyond mid split and look towards future technologies such as high split and D4.0 to ensure they remain relevant in a very competitive marketplace.

5.2. Key High-Split Readiness Activities (with a Mind Towards DOCSIS 4.0)

Operators who have D4.0 FDD deployment ambitions can utilize high-split deployments as an opportunity to set themselves up for success by dealing with some of the foundational readiness activities early. The following is a summary of key activities an operator can undertake within their high-split programs to assist a future D4.0 transition.

5.2.1. Network Architecture Readiness

As noted, Section 3.1, there are multiple architecture options that can enable high-split deployments. If an operator has D4.0 deployment ambitions, starting down the DAA path is critical. It is recommended that operators include the following architectural considerations when defining their high split upgrade program:

- DAA to implement: R-PHY or R-MACPHY
- Node fiber availability to support analog-to-digital optics conversion
- Proactive cascade reductions
- HFC power supply upgrades
- Elimination of 3x3 and 4x4 (DS-SG x US-SG) node configurations (to ensure compatibility with DAA upgrades given the capabilities of the RPDs and RMDs in the market today).

5.2.2. Set-Top Boxes with Legacy Out-of-Band Signaling

Most operators have set-top boxes deployed in their networks that require SCTE 55-1 or 55-2 out-of-band (OOB) signals to operate. As noted previously in this paper maintaining these signals requires some extra efforts in a high-split network.

Shaw elected to fully reclaim these legacy set top boxes and only support DOCSIS Set-Top Gateway (DSG) or IPTV video set-tops in Shaw's high split network deployments. Note that DSG STBs utilize an embedded cable modem and thus preclude the need for the legacy SCTE 55-1 or 55-2 STB out-of-band signaling. This approach operationally simplifies the deployments while ensuring Shaw is effectively managing the lifecycle of legacy equipment in the network.

It should be noted that should an operator elect to leverage DSG set-top boxes with high split, it is critical that they test this equipment to ensure the capability of operating in a mode where the legacy OOB signals are not present. Some of the DSG STB equipment requires the legacy OOB to come online to function correctly. In this situation, these DSG STBs are not compatible with a high split deployment and will require software updates to eliminate the dependency on the OOB carrier. The potential issue is solvable by working with the STB vendor, but it is good to plan ahead so the operator is not caught off-guard waiting for a vendor STB software update that was unexpected.

5.2.3. On-Premises Architecture

When looking at the on-premises network architecture, operators need to consider the following when defining their go-to-market strategy for implementing high split:

5.2.3.1. On-Premises Interference Risk

Many operators deploy multiple coaxial cable-based customer premises equipment (CPE) in the same premises network to support high-speed data, voice, and video services. There is a risk when high-split and sub/mid-split CPE deployed in the same in-home network that a high transmit level on high split CPE can overload the tuner of the sub/mid split CPE in the same home. If this were to occur services supported by the sub/mid split CPE could be intermittent.

5.2.3.2. Wi-Fi & Ethernet Distribution

With the advancement of next generation Wi-Fi technologies (Wi-Fi 6, 6E) and the proliferation of structured Ethernet wiring (Cat 5E/6), the home IP network is becoming more capable and easier to use than ever. In addition, the market scale of these technologies will drive future capabilities and cost optimizations that are not easily replicated on the coaxial networks in the premise.

5.2.3.3. Future Access Network Considerations

To minimize future re-work, it is important to align HFC install practices with future FTTx, and D4.0 considerations. In these use cases, coaxial cable-based in-home networks are not ideal, and customers are best supported by Wi-Fi and wired Ethernet systems.

Operators should strongly consider moving to a point-of-entry style modem install for their high-split customer activations. This type of installation eliminates the use of on-premises coaxial networking and leverages a converged services gateway (broadband, voice, & video) with Wi-Fi and Ethernet for on-premises signal distribution. This will provide the operator the following benefits:

- Leverages future-proof in-home networking technology (Wi-Fi and Ethernet)
- Simplifies on premises networks and reduces operational support costs
- Improved customer experience
- Supports easy future FTTH and D4.0 upgrades.

5.2.3.4. Spectrum Readiness

The upgrade of existing low-split or mid-split plant to high split does require the reallocation of downstream spectrum to use in the upstream. Shaw had to identify 25 downstream carriers to be reclaimed in its mid-split nodes to enable a seamless transition to high split. This reclaim was enabled primarily through optimizations to the legacy QAM video package. These optimizations included the following:

- MPEG-2 to MPEG-4 conversions (high definition (HD) and standard definition (SD))
- Legacy VOD QAM carrier reclaims
- Improved closed-loop stat multiplexing of linear video services.

To enable the radio frequency (RF) spectrum for high-split deployments, Shaw developed the capability to build a distinct channel lineup that is used for high-split nodes deployments. This distinct channel lineup is delivered by the DAA node via an auxiliary video core. This configuration allows an operator to target any spectrum reclamation activities to the node level and minimize the operational impact of large-scale video STB swaps while eliminating the cost and complexity of managing multiple channel lineups through analog head ends and hub sites.

5.2.3.5. Modem Pre-Seeding

Deployment of modems with capabilities to support future plant configurations is a great way for operators to set themselves up for future success. Shaw was able to leverage a very high penetration of mid-split-capable modems to provide immediate congestion relief and large-scale broadband tier upgrades as nodes were upgraded to mid split.

When looking at high-split upgrades, operators should include the pre-seeding of high split-capable CPE into their overall network upgrade programs. With high-split-capable CPE available today, this is a “no regrets” investment!

High-split modem pre-seeding benefits include the following:

- The full-band capture capability of the modem can be used to validate performance of newly activated downstream spectrum (1-1.2 GHz)
- Investments in high-split CPE are fully leveraged in D4.0 FDD (and also D4.0 FDX) deployments
- Immediate traffic offload to newly activated upstream and downstream spectrum once high-split upgrades have been completed
- Future broadband tier upgrades can be done without a modem swap.

5.2.3.6. Back-office Software Readiness

Back-office software (BSS) updates are often overlooked and undervalued when operators consider network upgrades such as high split. However, the definition of node-level serviceability flags is a key enabler to a successful upgrade. These types of flags tell the billing system what the service capabilities of the node are and what equipment variants are to be allowed on the node. The following are examples of node service availability flags that an operator could implement in support of high-split investigations:

Table 5 – Node Serviceability Flags for Back-office Software in Support of High Split

Flag	Function
Legacy STB Reclaim Underway (Hybrid)	Informs the customer service representative that a legacy STB reclaim is underway and warns them that activation of new legacy OOB video CPE should not be done on the customers node.
Legacy STB Reclaim Underway (All IP)	Informs the customer service representative that a legacy STB reclaim is underway and warns them that activation of new legacy QAM video CPE should not be done on the customers node.
Legacy STB Reclaim Completed (Hybrid)	Informs the customer service representative that the customer's node has completed all required legacy OOB video CPE reclaims and implements a provisioning rule to deny all activations of non-DSG and non-IPTV hardware.
Legacy STB Reclaim (All IPTV)	Informs the customer service representative that the customer's node has completed all required legacy video CPE reclaims and implements a provisioning rule to deny all activations of non-IPTV hardware.
High Split Completed (Hybrid)	Informs the customer service representative that the customer's node has completed a high-split upgrade and informs them of the new high-split-enabled broadband service catalog. In addition, informs the access network configuration systems of which RF channel lineup to apply to the DAA node (i.e., high split legacy QAM video lineup + high split DOCSIS configuration).
High Split Completed (All IP)	Informs the customer service representative that the customer's node has completed a high-split upgrade and informs them of the new high-split enabled broadband service catalog. In addition, informs the access network configuration systems of which RF channel lineup to apply to the DAA node (i.e., full spectrum high split DOCSIS configuration).

5.3. A Potential Evolution Path to DOCSIS 4.0

For a cable operator to be successful in a market where there is an aggressive FTTP builder, they will need to have the ability to rapidly deploy competitive speeds to 10G PON technologies, while at the same time increasing focus on service reliability, service experience, and customer service. D4.0 FDD technology gives operators the necessary tools to compete in this type of marketplace. D4.0 FDX technology also gives operators the necessary tools to compete and may be preferred by some operators. Focusing in on D4.0 FDD, it provides operators the following benefits:

- Highly economical upgrade
- Fastest path to compete with 10 Gbps-capable PON technologies
- Enough capacity to reduce focus on speed (i.e., take speed "out of the conversation")

- Improved network reliability
- Ability to leverage previous high-split investments.

Shaw has developed their network upgrade strategy with a view on the most efficient path to D4.0 FDD. In this context, high split is an important and logical steppingstone in setting the stage for future D4.0 FDD deployments.

The following is a potential four step process that operators who are currently deploying mid split could implement to enable a seamless transition through high split and to D4.0.

Step 1: D3.1 High Split (204 MHz / 1 GHz)

In this phase as shown in Figure 19, the operator begins deploying high split using an architecture that can evolve gracefully to D4.0 FDD deployments. This configuration will allow operators to compete in highly competitive markets with gigabit symmetric services while setting the stage for future upgrades.

The following elements are included in this initial step:

- Reclaim of all legacy OOB STBs
- Upgrade any taps and passives with less than 1 GHz capabilities to 1.2 GHz while keeping 1 GHz-capable taps in place
- Resolution of any plant architecture issues (e.g., plant powering upgrades, elimination of 3x3 (DS-SG x US-SG) and 4x4 node configurations, proactive cascade reductions)
- DAA node deployment (Remote PHY or Remote MACPHY) coincident with an upgrade to 204 MHz / 1.2 GHz
- Reclaim legacy QAM video channels to support the high split conversion.

Figure 19 – Step 1: D3.1 High Split (204 MHz / 1 GHz)

Step 2: D3.1 High Split with 1.8 GHz Taps

In this phase as shown in Figure 20, the operator will include a full upgrade of taps and passives into the high-split upgrade efforts. In this phase a sweep of the plant will be completed to upgrade all taps and passives housings to be 3 GHz-capable, and 1.8 GHz-capable faceplates.

Adding a full tap and passive swap enables the operator to achieve the following benefits:

- Minimizes future rework to enable full D4.0 FDD capacities
- Allows the operator to gain experience and optimize full scale tap and passive swaps
- Enables additional plant hardening by allowing the inspection and resolution of craft issues that can cause ingress and RF performance issues
- Improves plant stability issues that are caused by seizure screw related issues

- Improves DAA node uptime by ensuring power bypasses are included in all taps and passives
- Enables 1.2 GHz plant operation and allows the deployment of an additional 200 MHz of downstream capacity.

Figure 20 – Step 2: D3.1 High Split with 1.8 GHz Taps (in 3.0 GHz Housings)

Step 3: D3.1 High Split with 1.8 GHz Taps and 1.8 GHz Amplifiers

In this phase as shown in Figure 21, the operator will include a full upgrade of the HFC amplifiers to be 1.8 GHz-capable equipment (compliant with [SCTE 279 2022]).

Adding a full amplifier upgrade enables the operator to achieve the following benefits:

- Gaining experience with 1.8 GHz amplifiers in production environments
- Improved compliance of amplifier level setup by leveraging auto-setup capabilities of 1.8 GHz amplifiers
- Minimizing operational complexity by using soft-selectable pads and EQs
- Minimizes future rework to enable full D4.0 FDD capacities.

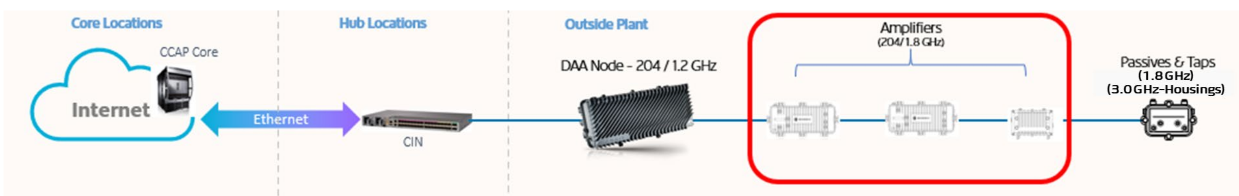

Figure 21 – Step 3: D3.1 High Split with 1.8 GHz Taps (in 3.0 GHz Housings) and 1.8 GHz Amplifiers

Step 4: DOCSIS 4.0 High Split

In this final phase as shown in Figure 22, the operator will include the deployment of a D4.0-capable node and shift to a RMD to enable the full D4.0 FDD capacities.

Adding a D4.0 RMD enables the operator to achieve the following key benefits:

- Enables full D4.0 FDD capacities
- Improves network resiliency by fully separating the data and control planes on the DAA node
- Reduction of technical facility power and cooling requirements.

Figure 22 – Step 4: DOCSIS 4.0 High Split

5.4. Summary of Lessons Learned

As part of Shaw's high-split deployments and Shaw's overall D4.0 readiness activities, the following are some key lessons learned:

1. **The Frequency Modulation (FM) and Very High Frequency (VHF) Bands are unproven for upstream usage**

   These portions of the spectrum have historically been used for downstream signals; their use for upstream has not been proven out. Over the air broadcasts can significantly impact the quality of these channels. It is important that operators have a plan on how to validate the impacts of ingress and how much DOCSIS capacity this spectrum can provide.

2. **The performance of DAA deployments is amazing!**

   DAA deployment will be required for DOCSIS 4.0; however, there are significant performance benefits that operators can achieve by including DAA deployments in their high-split programs. Shaw has seen an average downstream modulation error ratio (MER) improvement of up to 8.2 dB and an upstream MER improvement of 5.2 dB.

3. **Pre-seeding modems is an effective way to prepare for the future**

   Having modems pre-deployed in the network that are immediately able to utilize the new spectrum created by deploying high split is a key element to the high-split business case. These modems enable immediate congestion mitigation, tier upgrades without modem swaps, as well as enabling the operator to use the full-band capture capability to test and validate the new spectrum before customer use.

4. **Avoid "big bang" changes**

   A successful D4.0 deployment involves many changes that can be highly impactful to operational teams. It is important to layer these changes in over time to allow for effective change management. High split represents an opportunity for operators to begin their D4.0 journey today and prove out and harden technology changes one at a time.

5. **Plan for measuring and minimizing customer impact when deploying high-split change events**

   As has been highlighted by the COVID-19 pandemic, the reliability of the home's broadband connection has never been so important. Due to the sheer number of changes required to deploy high split and ultimately D4.0, it is critical that the operator has a plan on how to measure and optimize the deployments to ensure customer impacts are minimized.

6. Conclusion

Subscribers' growing bandwidth demand and increased competitive pressures, especially from internet service providers deploying 10G PON technologies, are driving cable operators to expand upstream (and downstream) capacity. In addition to these market factors, operators may upgrade plant actives (RF amplifiers) due to reaching the end of their typical 10-20-year lifetime—an opportune time to make the change to 1,218/204 MHz actives.

High-split (204 MHz) operation in the upstream—especially when paired with an upgrade to 1,218 MHz in the downstream—can provide quite the improvement in the HFC network service group capacity of up to 8.6 Gbps capacity in the downstream and 1.5 Gbps capacity in the upstream. Some projections show high split and 1,218 MHz providing enough bandwidth for a service group of at least 150 subscribers with 5 Gbps down x 1 Gbps up speed tiers / SLAs for the next 10 years.

Moving to high split is not only a steppingstone on the path to 10G and to DOCSIS 4.0, whether moving to FDD or FDX, but a huge step in terms of benefits to both operators and end subscribers. Luckily for cable operators, technologies and products in the market—deployable today—enable operators to confidently move forward with high split in the three leading CMTS/CCAP architectures: I-CCAP, R-PHY, and/or R-MACPHY. A node visit, required for the high-split upgrade, is also the opportune time to upgrade to a DAA, whether R-PHY or R-MACPHY. However, a simpler and faster high-split upgrade with I-CCAP, is still a strong option to consider, especially when the bandwidth and market drivers demand an earlier move to high split—before the operator can migrate to a DAA. High split on I-CCAP can have even better performance when utilizing digital return in place of analog return on the fiber optics link.

In planning to implement high split, several potential architectural considerations must be taken into account, such as strategies on how to free up the high-split spectrum, like implementing SDV, reducing the video channel line-up, migrating from MPEG-2 to MPEG-4, or moving to IPTV. Tools and solutions exist that support leakage detection, which in the high-split world now must detect signals in the reverse path. Operators must develop a CPE strategy that aligns with high split, including pre-seeding the market with high-split-capable CPE, migrating legacy video STBs to STBs with embedded cable modems (DSG-capable or otherwise), and dealing with potential interference from high-split-capable CPE with other legacy CPE in the home or in close neighbors. Operators need to consider the cable modem RF levels and the inputs to the RF amplifiers when making the move to high split. Operators also need to consider whether to take a "rip-and-replace" or a "module-only" upgrade path for the RF components, with each one having benefits and drawbacks.

Shaw Communications shared some considerations and lessons learned from embarking on a high-split upgrade. Shaw explained the Canadian market dynamics that drove them to deploy mid split and then high split to compete against FTTx service providers. Shaw explored some of the key architectural considerations for moving to high split, including network architecture readiness, strategies for handling legacy STB out-of-band signals, preparing for the spectral shift, pre-seeding high-split-capable modems, and back-office software readiness, among others. Shaw provided a step-by-step potential evolutionary path to high split and then to DOCSIS 4.0 FDD-capable DAA devices in preparation for the next step of enabling D4.0 FDD. Finally, Shaw shared some of their key lessons learned, including the unproven nature of the FM and VHF bands for upstream usage, the amazing performance of DAA (average MER improvements of 8.2 dB down and 5.2 dB up), the importance of pre-seeding modems with high split support, avoiding making major changes at the same time, and the importance of minimizing subscriber impacts during the upgrade through proper monitoring.

In short, the time for talk is over, and there is no better time like the present to embark on the journey to implement high split as a key step on the path to 10G!

Abbreviations

10G EPON	10 Gbps Ethernet passive optical networking
10G-PON	10 Gbps passive optical networking (also known as XG-PON)
ACK	acknowledgement (typically from Transmission Control Protocol)
AGC	automatic gain control
BSS	business support system
BW	Bandwidth
CAA	centralized access architecture
CACIR	carrier to adjacent carrier interference ratio
CAGR	compounded annual growth rate
CAPEX	capital expense
CCAP	Converged Cable Access Platform
CDF	cumulative distribution function
CES	Consumer Electronics Show
CM	cable modem
CMTS	Cable Modem Termination System
COTS	common off-the-shelf
CPE	customer premises equipment
D2.0	Data Over Cable Service Interface Specification 2.0
D3.0	Data Over Cable Service Interface Specification 3.0
D3.1	Data Over Cable Service Interface Specification 3.1
D4.0	Data Over Cable Service Interface Specification 4.0
DAA	Distributed Access Architecture
dB	Decibel
dBmV	decibel-millivolts (decibels relative to 1 millivolt)
DCA	Distributed Cable Architecture
DOCSIS	Data Over Cable Service Interface Specification
DRW	dynamic range window
DS	Downstream
DSG	DOCSIS Set-top Gateway
DSL	digital subscriber line
DTA	digital terminal adapter
EOL	end of line
EPON	Ethernet Passive Optical Network (aka GE-PON)
EQ	Equalizer
ESD	extended spectrum DOCSIS
FCC	Federal Communications Commission
FDD	frequency division duplex
FDX	full duplex DOCSIS
FM	frequency modulation
FMA	Flexible MAC Architecture
FTTB	fiber to the building
FTTH	fiber to the home
FTTP	fiber to the premise

FTTx	fiber to the ‘x’ where ‘x’ can be any of multiple option for subscriber locations, including home, premise, building
FWA	fixed wireless access
Gbps	gigabit per second
GHz	gigaHertz
gNMI	Google Network Management Interface
HD	high definition
HEO	head end optics
HFC	hybrid fiber-coax
HP	homes passed
HS	high split (204 MHz)
HSD	high-speed data
HW	hardware
I-CCAP	Integrated Converged Cable Access Platform
IEEE	Institute of Electrical and Electronics Engineers
IP	internet protocol
ITU	International Telecommunication Union
ITU-T	International Telecommunication Union Telecommunications Specification Sector
kbps	kilobits per second
LDPC	low density parity check (FEC code)
LE	line extender (amplifier)
LS	low split (42 MHz or 65 MHz, depending on region)
MAC	media access control
MB	multi-port bridger (amplifier)
Mbps	megabit per second
MDD	MAC Domain Descriptor
MDU	multiple dwelling unit
MER	modulation error ratio
MHA	Modular Headend Architecture
MHz	megaHertz
MPEG	Moving Picture Experts Group
MPTS	multi-program transport stream
MS	mid split (85 MHz)
MSO	multiple system operator
MULPI	MAC and upper layer protocols interface
N+0	node+0 actives
NCTA	The Internet & Television Association (formerly National Cable & Telecommunications Association)
OFDM	orthogonal frequency-division multiplexing
OFDMA	orthogonal frequency-division multiple access
OPEX	operating expense
OSP	outside plant
OSS	operational support system
PHY	physical interface/layer
PON	passive optical network
PSD	power spectral density
PTP	(IEEE 1588) Precision Timing Protocol

QAM	quadrature amplitude modulation
QoE	quality of experience
QPSK	quadrature phase shift keying
R-MACPHY	remote MACPHY
R-PHY	remote PHY
RF	radio frequency
RFI	radio frequency interface
RMD	remote MACPHY device
RPD	remote PHY device
SCTE	Society of Cable Telecommunications Engineers
SDV	switched digital video
SG	service group
SLA	service-level agreement (also known as speed tier)
SNR	signal-to-noise ratio
SS	sub split (42 MHz or 65 MHz, depending on region)
STB	set top box
Tavg	average bandwidth per subscriber
TCP	total composite power
TCP	Transmission Control Protocol
Tmax	maximum sustained traffic rate – DOCSIS Service Flow parameter
TX	Transmit
UHS	ultra-high splits (300 MHz, 396 MHz, 492 MHz, or 684 MHz)
US	upstream
VOD	video on demand
VoIP	voice over internet protocol
VHF	very high frequency
XG-PON	10 Gbps passive optical networking (also known as 10G-PON)
XGS-PON	10 Gbps symmetrical passive optical networking

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