Maximizing Returns on the Path to DOCSIS 4.0

A Technical Paper prepared for SCTE by

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1. Introduction

As wireline subscriber demand for increased broadband speed grows, cable operators will have to upgrade their networks to accommodate. Cisco estimates that the average fixed broadband speed in North America will increase 2.5-fold from 2018-2023 [1]. In Canada, strong competition from telco fibre-to-the-premises (FTTP) networks adds to the need for upgrades. Shaw Communications is in the fourth year of a five-year upgrade cycle of its hybrid-fibre coax (HFC) network. This upgrade has allowed Shaw to offer a 1.5Gbps downstream by 100Mbps upstream service tier to most of its footprint and has driven congestion to near zero, all during a global pandemic that has seen network utilization spike by 30% in the downstream and 60% in the upstream. Despite its strong position, Shaw is already planning the next upgrade cycle, which will follow quickly on the heels of the current upgrade. This paper will discuss a strategy to manage network congestion and tier offerings, leveraging available HFC network architectures.

2. HFC Network Status

HFC networks traditionally operate in a frequency division duplex (FDD) mode with upstream spectrum carried below downstream spectrum, separated by a cross-over region. The Data over Cable Service Interface Specification (DOCSIS) supports several different upstream spectrum splits, including 5-42MHz, 5-85MHz, 5-204MHz, and higher, otherwise known as sub-split, mid-split, high-split, and ultra-high-split respectively. Each subsequent version of DOCSIS expands its support of upstream frequencies, always with backwards compatibility as depicted below.

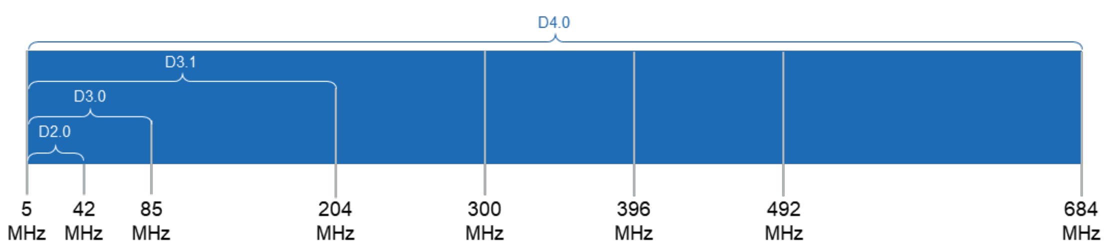

Figure 1 – Upstream Spectrum Band Plans

In the downstream, DOCSIS supports up to 857MHz for DOCSIS 2.0, 1002MHz for DOCSIS 3.0, 1218MHz for DOCSIS 3.1, and 1794MHz for DOCSIS 4.0 FDD [2] – [5]. For simplicity, plant types will be referred to as mid-split, high-split, and DOCSIS 4.0 FDD, describing band plans of 1002/85MHz, 1218/204MHz, and 1794 with an ultra-high-split upstream option.

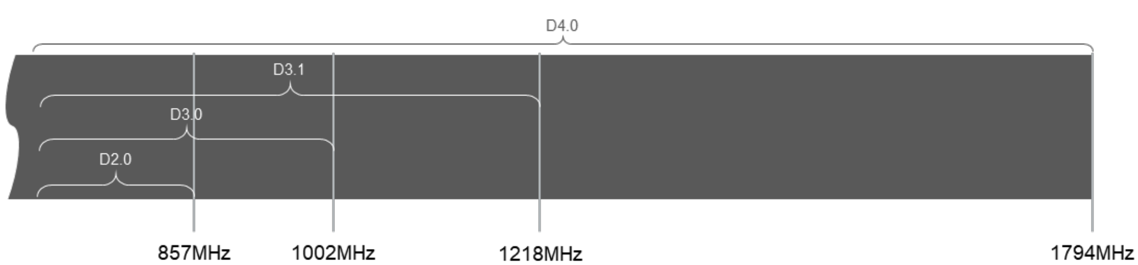

Figure 2 – Downstream Spectrum High Frequencies

Shaw operates an HFC network, that at the time of writing was over 90% mid-split with upstream signals carried from 5-85MHz and downstream signals carried from 108-1002MHz. The approximate spectrum breakdown is shown in Figure 3.

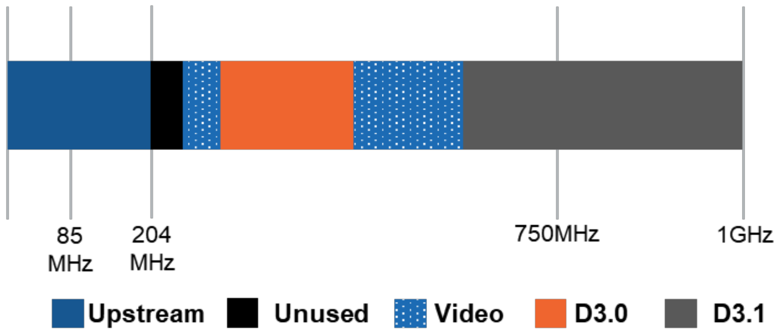

Figure 3 – Shaw Mid-split Spectrum

The HFC network uses analog optical transport from the hub site to the optical node where the transition to coax happens. Plant architectures are measured both by the allowable number of amplifiers in cascade as well as the link budget or spacing between amplifiers. The cascade length is referred to as N+X where N refers to the optical node and the X to the maximum cascade depth. Amplifier spacing refers to the maximum designed frequency, as in 750MHz or 1GHz plant. Shaw's outside plant contains a mixture of architectures, but the average cascade depth is N+4 and, with some exceptions, is designed to 1GHz. A high-level depiction of an HFC network is shown in Figure 4.

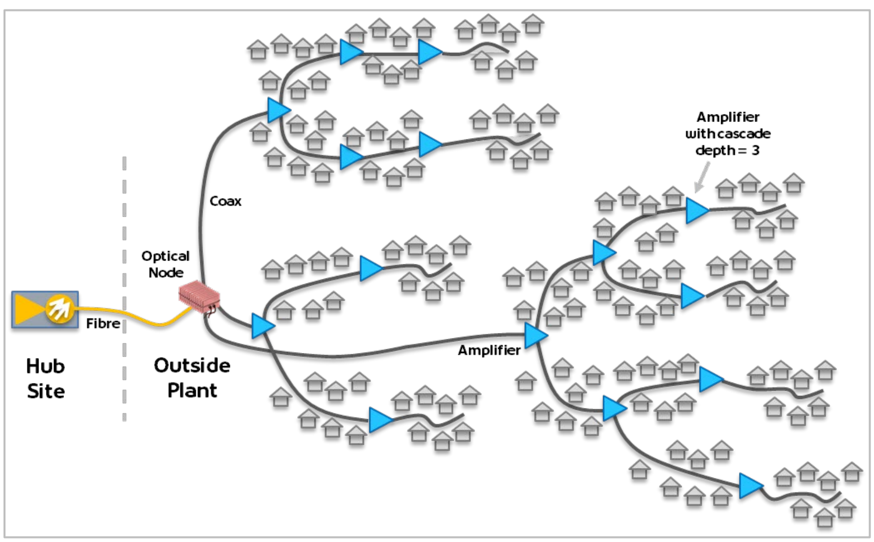

Figure 4 – Hybrid-Fibre Coax Network

2.1. COVID-19 Impact

The COVID-19 pandemic caused a shift in subscriber behaviour unlike anything previously experienced by broadband providers (Figure 5). Restrictions on movement increased subscriber usage of their in-home broadband services in a short time span. In the downstream, this growth was quickly mitigated through a reduction in video bitrates by streaming video providers such as Netflix [6].

Figure 5 – Relative Downstream Traffic During COVID-19

The growth of specific categories of traffic can be analyzed using deep-packet inspection (DPI) systems. In Figure 6, the height of the bars represents the relative amount of added consumption with traffic categories on the left adding the most consumption and categories on the right adding the least consumption. The percentage on top of each bar represents the increase in consumption of that traffic category compared to pre-COVID-19 levels. As can be observed, streaming media, which includes Netflix and YouTube, grew by 30%, which was lower than some of the other traffic categories but accounted for the bulk of increased consumption.

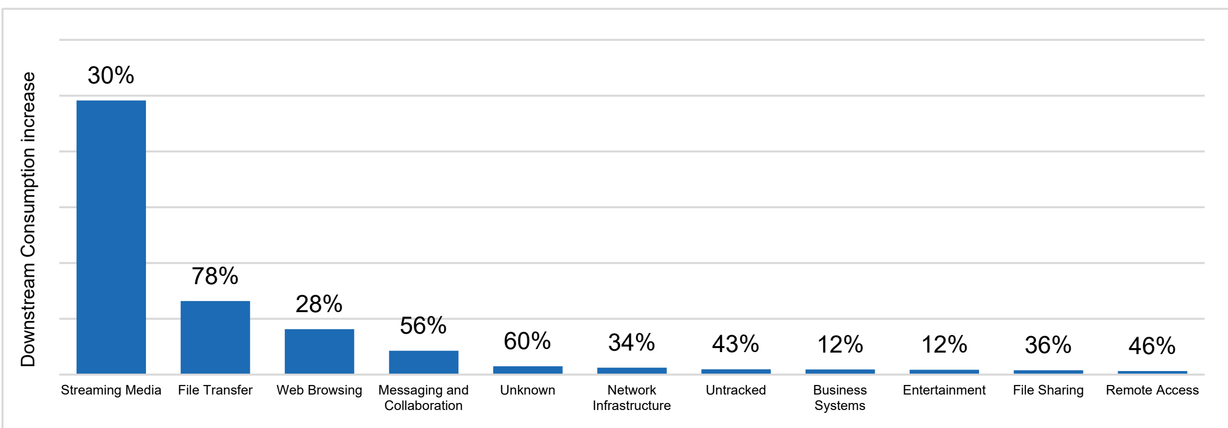

Figure 6 – Downstream Consumption Increase by Application

In the upstream, the shift to remote learning, working from home and the increased use of video calling applications kept upstream traffic higher for a longer period compared to downstream traffic (Figure 7).

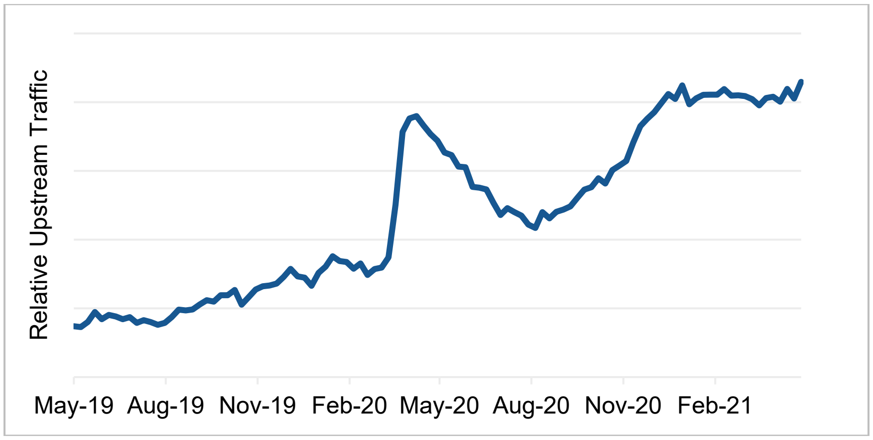

Figure 7 – Relative Upstream Traffic During COVID-19

The largest amount of added consumption, as well as the largest percent increase, came from the messaging and collaboration category, which includes FaceTime and Skype (Figure 8).

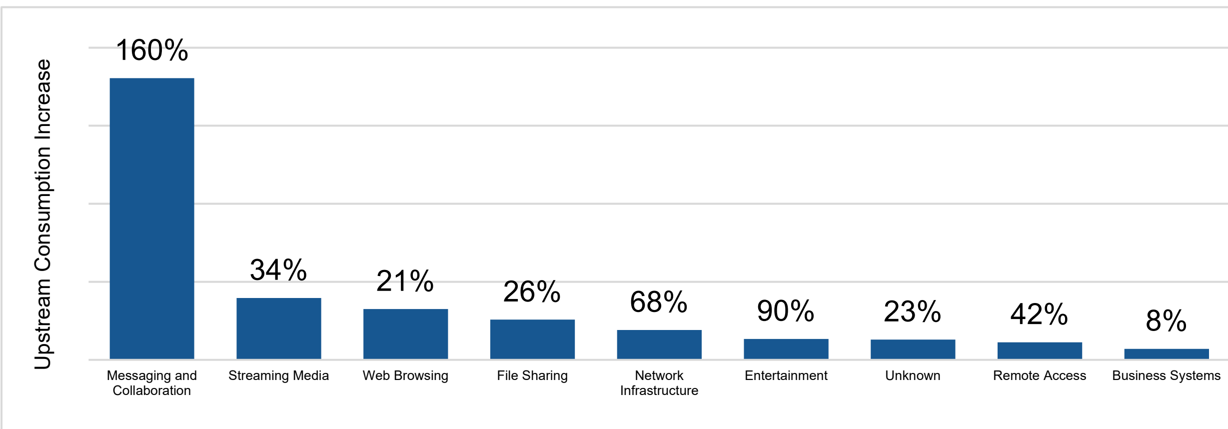

Figure 8 – Upstream Consumption Increase by Application

2.2. Mid-split Journey

Prior to the mid-split upgrade, Shaw's HFC network operated to a high frequency of 750MHz with a sub-split band plan. Increasing demand for broadband services had driven the transition from analog video to the more efficient digital video, freeing up spectrum for DOCSIS carriers. While this provided more spectrum to allocate to the downstream, it did not increase the spectrum allotted to the upstream.

At the time, the downstream-to-upstream ratio was much lower than it is today and there was a concern that upstream congestion would become unmanageable. The decision was made to reserve the downstream spectrum from 54-108MHz for a mid-split upgrade—a decision that was not easy at the time given that downstream spectrum was highly desired for additional broadcast video services.

Mid-split testing began in earnest to ascertain the level of effort required to upgrade the network to 85MHz in the upstream and 1GHz in the downstream. Video set top boxes that used out-of-band communication in the 72.75MHz range had to be re-tuned to a new frequency where possible or retired from the network if necessary. Interference testing was undertaken to see if upstream transmissions in the 54-85MHz range would harm the function of customer premises equipment (CPE) in the same or neighbouring house, and performance of optical transmitters was measured to ensure proper functionality. Lastly, research was undertaken to understand whether the upgrade could be done on a drop-in basis, or whether amplifier respacing was required.

In 2013 the first upgrade of a production node was completed and used to conduct further testing. In the meantime, the network was experiencing unprecedented growth in both the upstream and downstream, driven by increased demand for broadband services. In 2012 upstream year-over-year growth reached a high of 55%, while in 2013 downstream year-over-year growth reached a high of 85%. This demand created increased levels of network congestion, for which a solution was required.

Analysis was undertaken to explore network levers which could be pulled to increase network capacity. Potential solutions included a digital-to-IP video transition to make room for more downstream DOCSIS carriers, node splits in congested areas, an HFC upgrade to N+0 or N+few, and a mid-split upgrade. In comparison to the first three options, a mid-split upgrade was found to be cost effective and could be executed in a relatively short timeframe.

3. Competitive Environment

Canadian telcos are aggressively upgrading their Digital Subscriber Line (DSL) networks to FTTP. As of the end of 2020, Bell's network was 57% FTTP and Telus' network was 81% FTTP [7], [8].

Telus, which operates in much of the same footprint as Shaw, offers a max tier of 1.5Gbps downstream by 940Mbps upstream in its FTTP footprint using Gigabit Passive Optical Network (GPON) technology, as shown in Figure 9. This technology operates at a physical layer (PHY) rate of 2.488Gbps downstream and 1.244Gbps upstream [9].

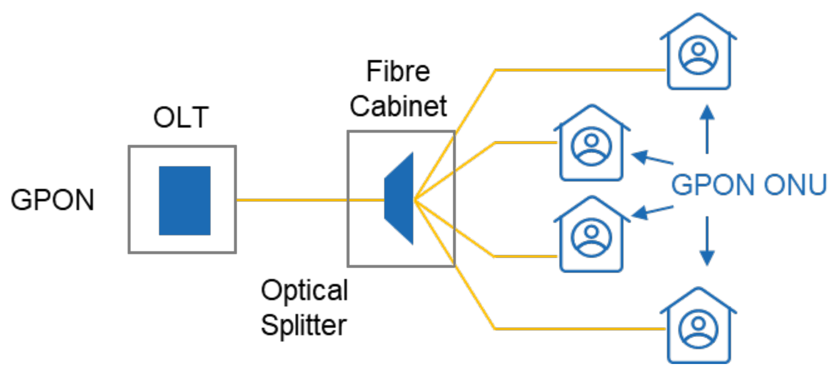

Figure 9 – Gigabit Passive Optical Network

As shown in Figure 10, this Passive Optical Network (PON) architecture allows for the coexistence of GPON and Ten-Gigabit Symmetric PON (XGS-PON) with the addition of Optical Line Termination (OLT) line-cards and additional splitters.

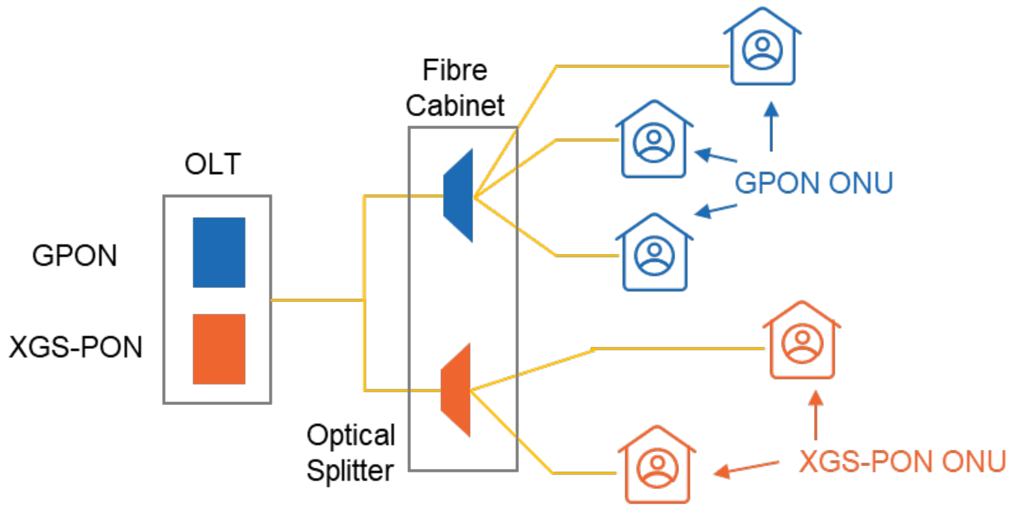

Figure 10 – Passive Optical Network Coexistence

XGS-PON is 10Gbps capable [10] and the max tier supported will depend on the split ratio and how aggressive the operator chooses to be. At the time of writing, Telus launched new 2.5Gbps symmetric services, giving an indication of initial XGS-PON tier offerings. It is important that any upgrade strategy have a roadmap for supporting similar tiers.

4. Upgrade Needs

A mid-split HFC network has similar or greater capacity when compared to a GPON network in the downstream, which allows Shaw to offer a 1.5Gbps downstream tier with options for higher tiers in the future. In the upstream however, a mid-split network has a lower capacity compared to GPON. An HFC network upgrade would be required in order to match the upstream tier.

When network traffic is observed, it is highly asymmetric, with downstream-to-upstream ratios above 15:1 for residential consumers and in the range of 5:1 for business subscribers (Figure 11), even during the COVID-19 pandemic that saw a disproportionate increase in upstream usage, as discussed earlier.

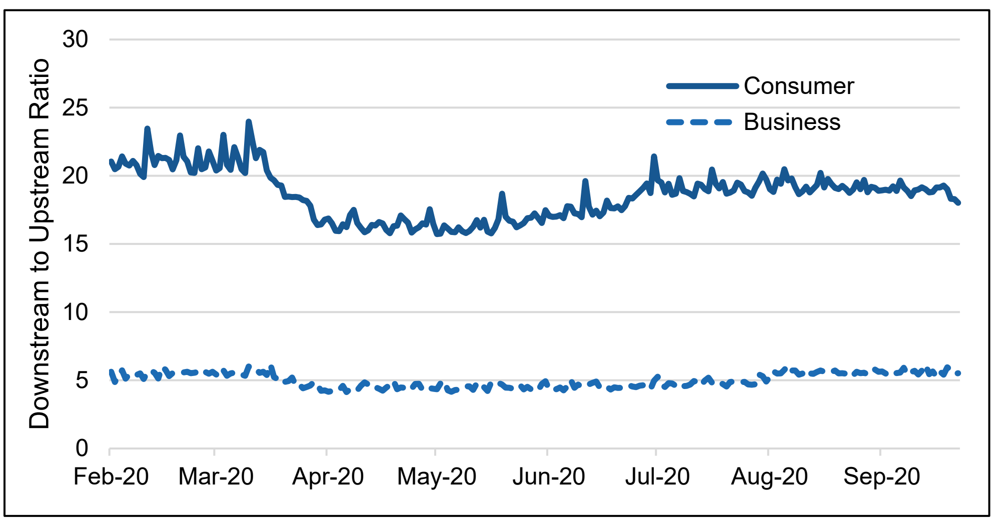

Figure 11 – Downstream-to-Upstream Ratio

Given this relationship, there is a question as to whether subscribers can fully utilize gigabit upstream services, and if so, whether their experience is improved. In looking at the 1Gbps downstream by 100Mbps upstream tier, two interesting phenomena can be observed. Using DPI systems, the max speeds a subscriber is able to reach over the span of a month can be measured. As seen in Figure 12, a significant number of subscribers, likely connected over Ethernet, use their full 1Gbps tier. Many subscribers, however, have a max speed in the 400-500Mbps range due to in-home Wi-Fi limitations.

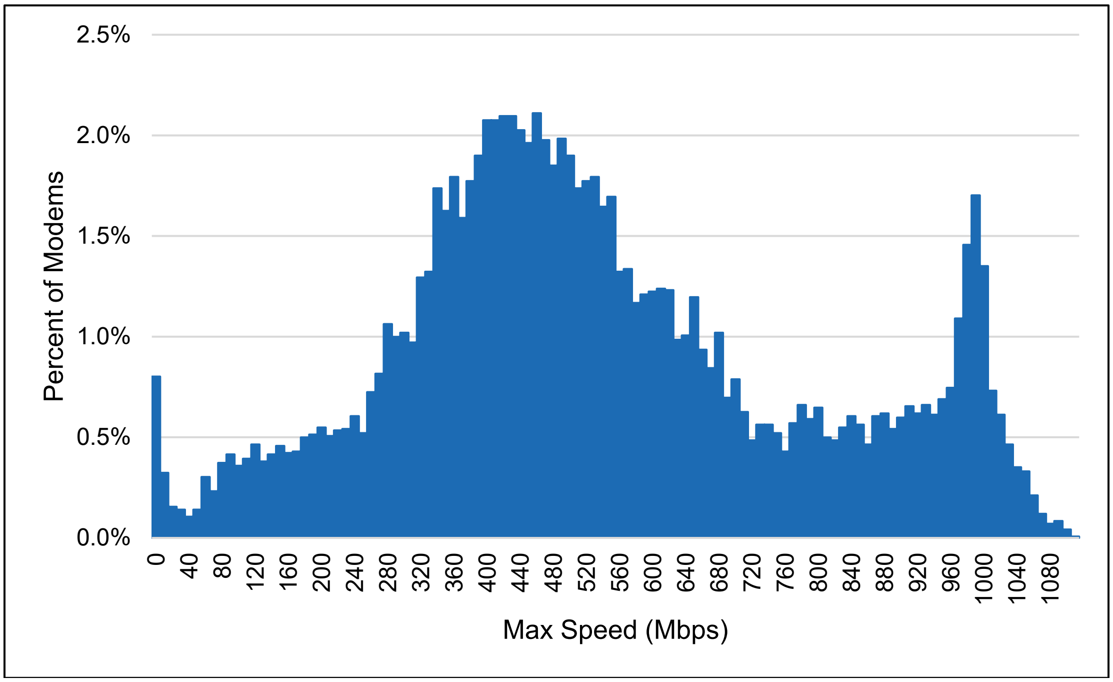

Figure 12 – Downstream Max Speed Distribution (1Gbps Tier)

Wi-Fi 6E will remove current limitations as it introduces new spectrum that will enable gigabit speeds [11]. However, the process to upgrade CPE and end-user devices to Wi-Fi 6E compatible equipment will take time.

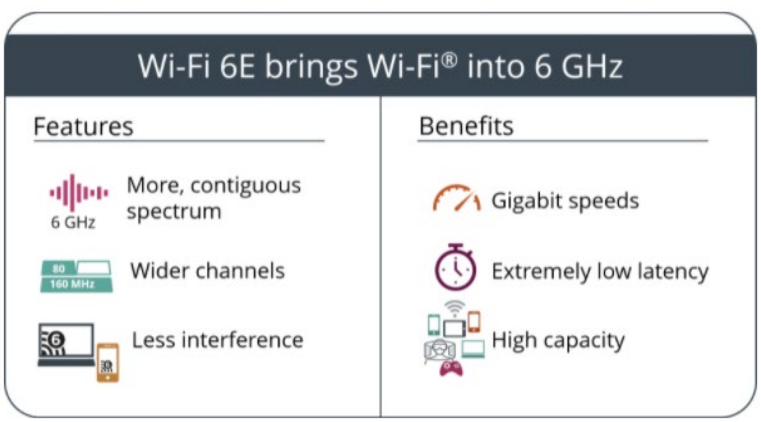

Figure 13 – Wi-Fi 6E Benefits (Source: Wi-Fi Alliance)

The types of applications used during high-speed upstream bursts can be observed using DPI systems. The data shows that the higher the speed, the more the traffic is dominated by backup applications operating in the background, not necessarily noticed by the user (Figure 14).

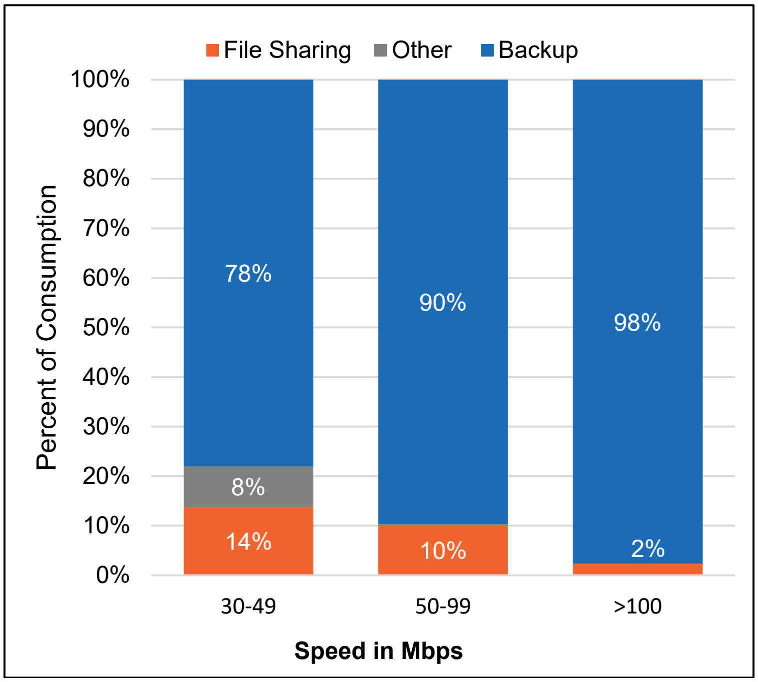

Figure 14 – Median Upstream Consumption by Speed

As mentioned earlier, Shaw is experiencing near zero congestion as the mid-split upgrade cycle approaches completion. Congestion forecasts were produced to estimate when a subsequent upgrade will be required for capacity reasons. Forecasts assume 15% downstream compound annual growth rate (CAGR) in addition to increased IPTV traffic due to customers migrating from older quadrature amplitude modulation (QAM) video hardware to new IPTV video solutions. In the upstream 25% CAGR is assumed. These numbers are in line with recent growth.

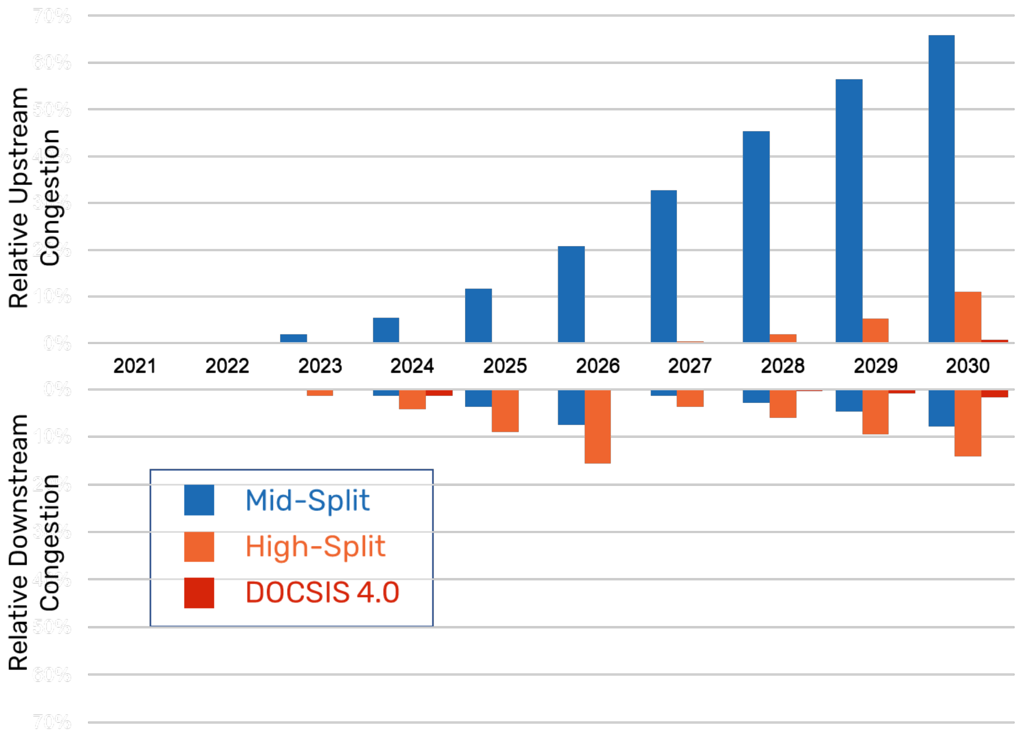

Figure 15 – Congestion Forecast

In Figure 15, congestion is plotted for mid-split, high-split, and DOCSIS 4.0 FDD networks, with upstream in the upper half and downstream the lower half. Low levels of congestion can be resolved with targeted node splits, while higher levels require network-wide solutions. As can be observed, concerns do not arise with mid-split capacity until the latter half of the decade.

In the downstream it is assumed that a high-split plant is operated only to 1GHz, resulting in a net decrease in downstream capacity when compared to mid-split. Downstream congestion grows in 2025 and 2026 but is reduced in 2027 when the transition from QAM to IP video is expected to be complete and more spectrum allocated to DOCSIS traffic. These two topics are discussed further in the following sections. In contrast to the congestion forecasts for mid-split and high-split, a DOCSIS 4.0 FDD upgrade provides enough capacity for the network to run nearly congestion-free through 2030 and beyond.

5. Upgrade Options

With our mid-split upgrade nearly complete, the next network upgrade is being planned. The options currently available are high-split, DOCSIS 4.0 FDD, DOCSIS 4.0 Full-Duplex DOCSIS (FDX), and FTTP.

5.1. High-split

An upgrade of the HFC plant to high-split, with upstream spectrum from 5-204MHz and downstream spectrum from 258-1218MHz (Figure 16), represents a modest increase in spectrum but has the advantage of the required equipment being available now.

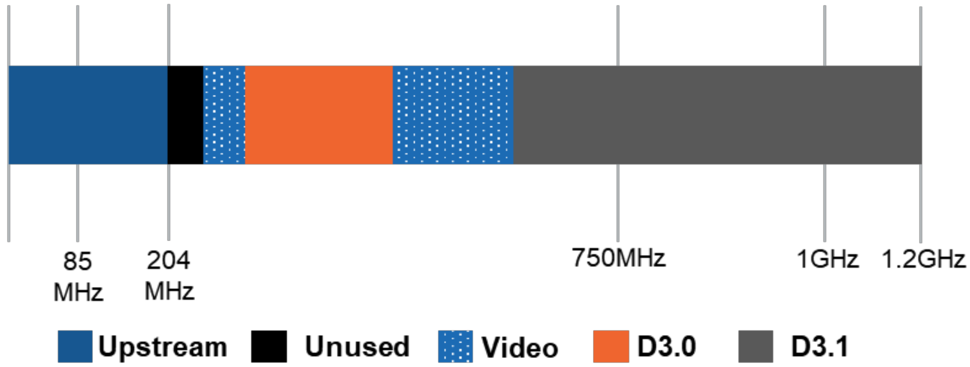

Figure 16 – High-split Spectrum

As displayed in the table below, the increase in spectrum is heavily weighted toward the upstream with 149% additional spectrum, while the spectrum allocated to downstream increases by 7%.

Table 1 – High-split Spectrum Allocation

	Mid-split	High-split	Percent Increase
Upstream Spectrum (MHz)	80	199	149%
Downstream Spectrum (MHz)	894	960	7%

As discussed earlier, the strategic reason to upgrade to high-split is to match the tier capability of GPON, which requires additional upstream spectrum. Another advantage of a high-split upgrade is that the technical considerations are similar to those recently explored with a mid-split upgrade.

Shaw set top boxes that do not have DOCSIS modems use the ANSI/SCTE 55-1 standard for communication. The downstream out-of-band (OOB) transmission frequency range is 70-130MHz [12] in spectrum that transitions to upstream when upgrading to a high-split network. While there are options available to continue OOB operation [13], the decision was made to remove the OOB and all video equipment reliant on ANSI/SCTE 55-1 in the case of a high-split upgrade. Operationally, this means that this equipment must be removed from a service area before upgrade but does not require all equipment to be removed at the system level.

Industry Canada mandates that cable distribution networks do not interfere with international emergency frequencies and that they are monitored for compliance [14]. Monitoring is done by measuring the signal level of an analog television channel chosen by Industry Canada. In a high-split plant these frequencies switch from downstream to upstream and a new method for monitoring is required. There are options available for leakage monitoring in a high-split plant [13], but until commercial solutions are available that range of spectrum will be left unused.

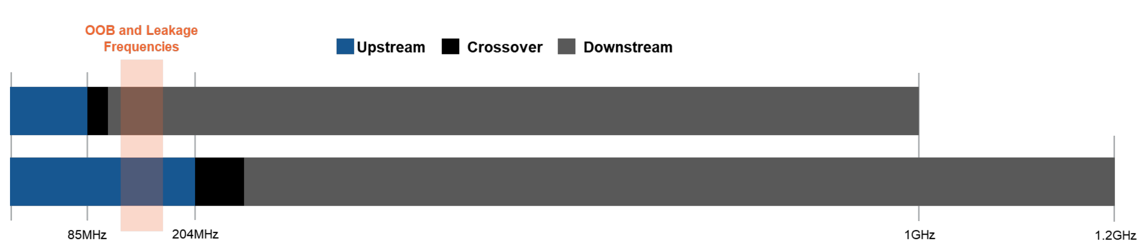

Figure 17 – Out-of-Band and Leakage Frequencies

Another issue to consider in the implementation of high-split is the in-home coexistence of DOCSIS and Multimedia over Coax Alliance (MoCA) signals above 1GHz. MoCA devices use in-home coax wiring for transport of multimedia content, as seen in Figure 18. At Shaw, MoCA is used with whole-home video solutions, allowing a single MoCA gateway to transport video content to MoCA portals over the in-home coax network.

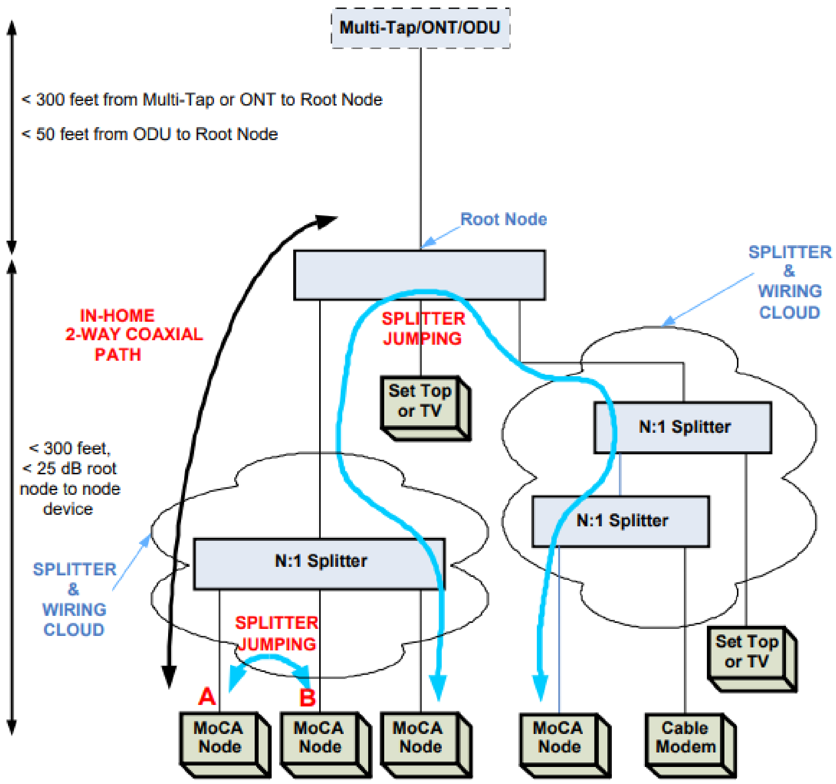

Figure 18 – MoCA Network (Source: MoCA Alliance)

MoCA 1.1 devices operating in an HFC network use 50MHz wide channels in the D-band which is located from 1125MHz to 1525MHz [15], as illustrated in Figure 19. Devices will move to a different channel if received signal strength is not adequate at the current channel.

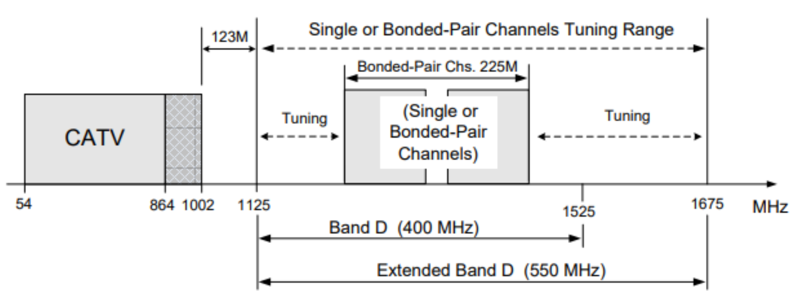

Figure 19 – MoCA Spectrum Use (Source: MoCA Alliance)

A sample of MoCA devices were polled to see what channel they were using. As shown in Figure 20, 46% of devices were using the lowest channel with a centre frequency of 1150MHz, but a significant percentage of MoCA devices had moved to higher spectrum.

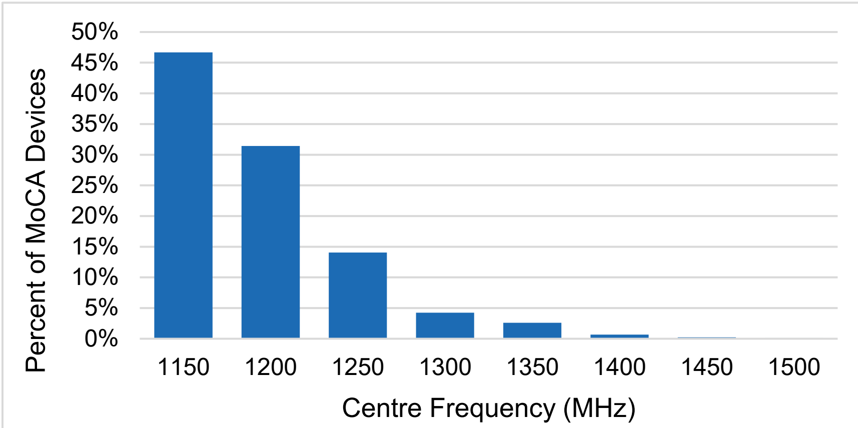

Figure 20 – MoCA Centre Frequencies

Research is required to determine whether MoCA devices can be forced to higher frequencies either through back-office commands or by occupying spectrum to 1218MHz with DOCSIS carriers. If this is not possible, then MoCA spectrum would have to be left unutilized until MoCA devices are removed from the network. In a worst-case scenario, if high-split frequencies are limited to 258-1002MHz downstream, the high-split upgrade would result in 17% less downstream spectrum when compared to mid-split (Table 2). While this is not a preferred outcome, downstream spectrum can also be freed up by the more efficient transmission of video content, or by removing a portion of that content altogether.

Table 2 – High-split Spectrum Allocation when Limited to 1GHz

	Mid-split	High-split (MoCA)	Percent Change
Upstream Spectrum (MHz)	80	199	149%
Downstream Spectrum (MHz)	894	744	-17%

As previously mentioned, a decision was made to remove set top boxes reliant on the OOB for communication. These boxes also happen to be the only ones in the network that do not support MPEG4 video and thus their removal allows for MPEG2 video signals to be carried more efficiently via MPEG4. The amount of spectrum that can be freed up is sufficient to prevent downstream DOCSIS capacity loss during a high-split upgrade.

A high-split upgrade provides the opportunity to move to a Distributed Access Architecture (DAA), although it is not strictly required. DAA allows for scalability and preserves space in hub sites as the number of optical nodes increases. This eliminates the analog optical link as well as any testing that would otherwise have been required to ensure upstream signals could be carried at high modulation rates over the 5-204MHz range. The difference in performance between DAA and analog nodes can be observed by comparing signal-to-noise ratio (SNR) data. A group of approximately ten thousand modems in each type of plant were polled for SNR. As shown in Figure 21, the average downstream SNR of modems in analog nodes was 38.8 decibels (dB) versus 41.4dB in DAA nodes, a difference of 2.6dB.

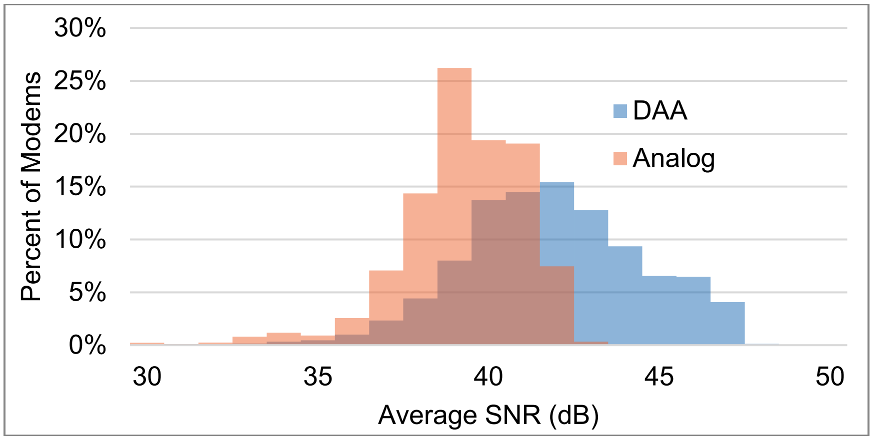

Figure 21 – Downstream SNR DAA vs Analog

As depicted in Figure 22, the average upstream SNR of modems in analog nodes was 33.1dB versus 37.3dB in DAA nodes, a difference of 4.2dB. By using DAA nodes, more modems will be able to make use of the highest modulation profiles, thus increasing capacity.

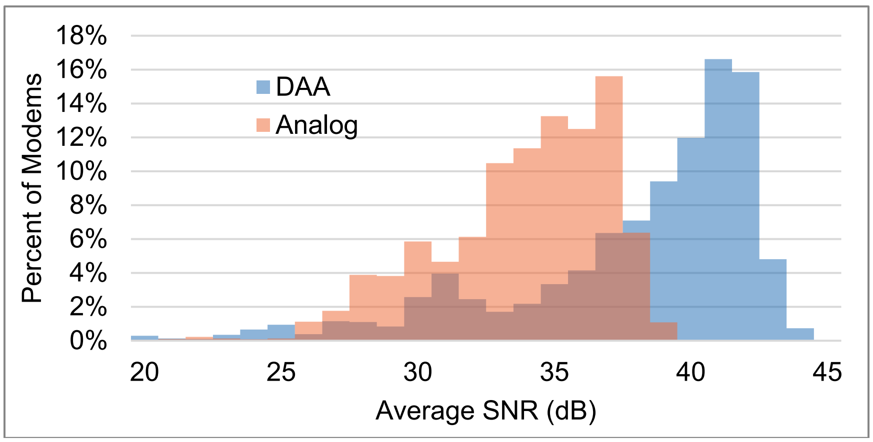

Figure 22 – Upstream SNR DAA vs Analog

As with mid-split, the preferred method for a high-split upgrade is to replace amplifiers in a drop-in fashion. This eliminates the need for plant redesign and amplifier respacing, which would complicate the upgrade. The risk with this method is that signal quality degrades with each additional amplifier in cascade. While adding fibre to the network to reduce cascades to a chosen maximum depth would solve this problem, the time and capital required for such an upgrade is substantial. DOCSIS technology can help in this regard as DOCSIS 3.1 changed the way we think about node capacity. DOCSIS 3.1 introduced the concept of profiles used by orthogonal frequency division multiplexing (OFDM) and orthogonal frequency division multiple access (OFDMA) signals. These profiles allow cable modems with higher signal quality to transmit and receive at higher data rates compared to cable modems with lower signal quality. While the data rate of a cable modem located at the end of line may be lower than other cable modems on the node, there is no issue so long as the data rate is sufficient to enable the service tier. In the case where cable modems at the end of line cannot support service tiers, either tier offerings in that location can be reevaluated, or fibre optics can be deployed to reduce cascade lengths.

During Shaw's mid-split upgrade all passives that were sub-1GHz were upgraded. 1GHz passives could be retained in a high-split upgrade as the top frequency for DOCSIS 3.1 was chosen with 1GHz passives in mind because they were found to continue operation beyond 1GHz. Optionally 1GHz passives could be replaced with 1.8GHz or 3GHz models, which would provide decreased loss from 1-1.2GHz for high-split plant and pave the way for DOCSIS 4.0 FDD.

5.2. DOCSIS 4.0 FDD

Upgrading the HFC plant to DOCSIS 4.0 FDD with a high frequency of 1794MHz represents a large increase in spectrum that comes with several options for upstream frequency range (Table 3). As upstream spectrum increases, downstream spectrum decreases. In deciding which band plan is optimal it is important to look at the downstream-to-upstream ratio and the maximum service tier that can be offered in both directions. DOCSIS 4.0 FDD can materially outperform GPON and compete effectively with XGS-PON, which is capable of 10Gbps symmetric speeds. Depending on which band split is selected, DOCSIS 4.0 FDD can have greater capacity than XGS-PON in the downstream but remains lower in the upstream.

Table 3 – DOCSIS 4.0 FDD Spectrum Allocation

	Mid-split	High-split	UHS-300	UHS-396	UHS-492	UHS-684
Upstream Spectrum (MHz)	80	199	295	391	487	679
Downstream Spectrum (MHz)	894	960	1422	1302	1188	960
DS:US Spectrum Ratio	11.2	4.8	4.8	3.3	2.4	1.4

For capacity planning purposes it is beneficial to have a downstream-to-upstream capacity ratio similar to the downstream-to-upstream demand ratio, which as discussed earlier, is greater than 15:1 for residential subscribers. For competitive purposes however, it may be beneficial to offer symmetric or near symmetric tiers.

Another consideration is the high frequency of current DOCSIS cable modems and video set top boxes. In Shaw's network 100% of CPE currently has a maximum high frequency of 1002MHz. As shown in Figure 23, ultra-high-split options would reduce the available spectrum to current CPE.

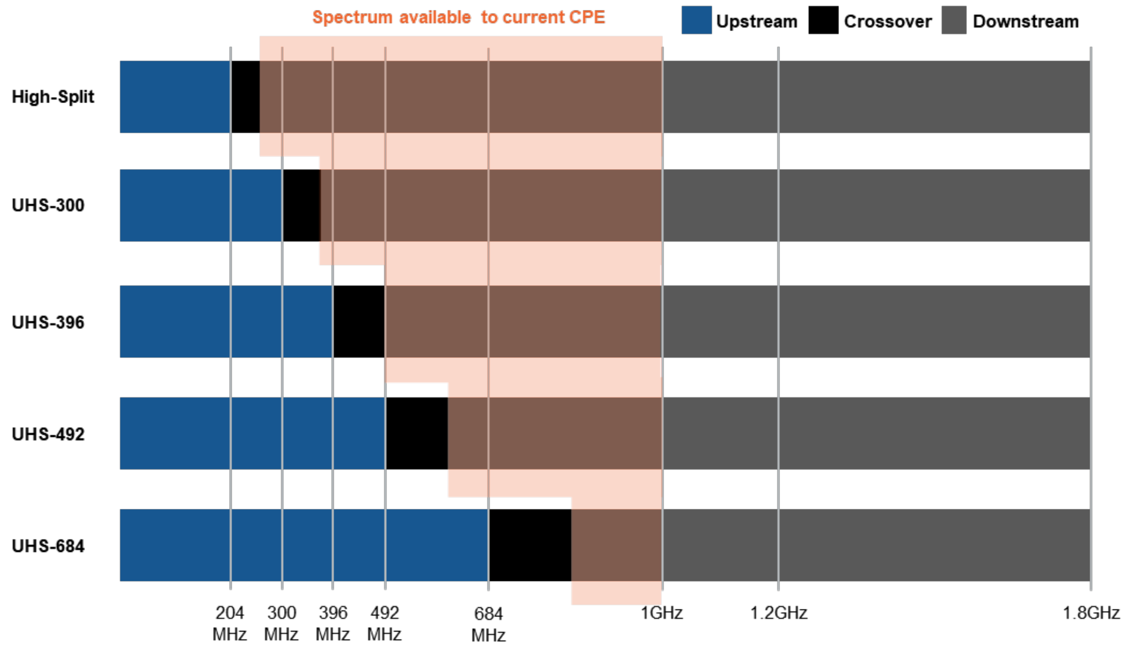

Figure 23 – Spectrum Available to Current CPE

Reducing the capacity available to the installed base of CPE could create congestion until such time as either enough DOCSIS 4.0 FDD cable modems are in the network or QAM video can be retired. One potential strategy is to initially run DOCSIS 4.0 FDD with a high-split band plan and switch to an ultra-high-split band plan in the future, perhaps when the transition to IPTV is complete. UHS-396 is a potential band plan that balances traffic engineering with the need for competitive service tiers.

The mid-split upgrade process at Shaw involved replacing amplifier modules when possible, and the entire amplifier with housing only when necessary. Amplifiers that were 1GHz/42MHz were bench upgraded to 1GHz/85MHz in a properly controlled lab environment as it was not found to be practical to swap diplex filters in the field. DOCSIS 4.0 FDD was designed with multiple band plans in mind, and it is important that new amplifiers have a practical method of changing between them. There are many options for accomplishing this change, ranging from field-swappable diplex filter boards to centrally controlled and dynamic systems that remotely switch band plans depending on instantaneous demand.

As with a high-split upgrade, issues with ANSI/SCTE55-1, leakage detection, and MoCA coexistence arise with a DOCSIS 4.0 FDD upgrade. MoCA coexistence issues are more acute as the overlapping spectrum is greater. The MoCA D-band is 400MHz and the extended D-band used by MoCA 2.0 is 550MHz, which is too much spectrum to forego for long.

Initial tests have been performed on plant segments to confirm operation to 1.8GHz, but as with all HFC networks, signal performance will degrade with increased cascade length. Similar to high-split, the desired upgrade path for DOCSIS 4.0 FDD is a drop-in upgrade. It is expected that a drop-in upgrade will operate in current plant cascades and spacings with performance gains realized as fibre is deployed deeper into the network. Unlike with high-split, all passive devices will require upgrading to 1.8GHz or greater. If available, swapping passives or their housings to 3GHz could future-proof those devices and make any future upgrade easier.

5.3. DOCSIS 4.0 FDX

FDX allows spectrum to be used in both upstream and downstream directions simultaneously, effectively doubling the spectral efficiency for those frequencies (Figure 24).

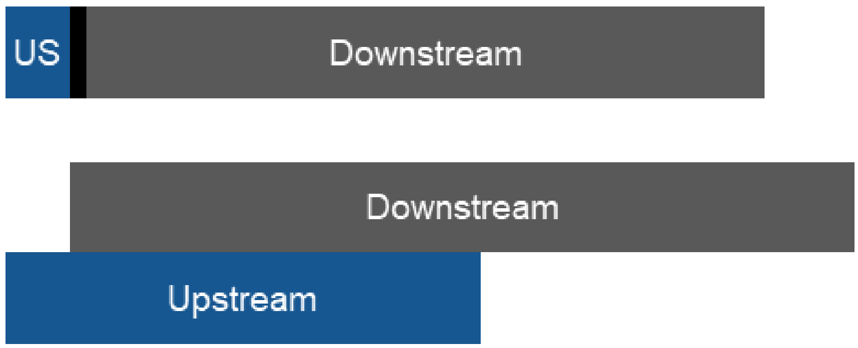

Figure 24 – FDX Spectrum Overlap

The FDX specification supports a high frequency of 1218MHz, and the frequency range from 108-684MHz may be used bidirectionally, leading to a large increase in spectrum (Figure 25).

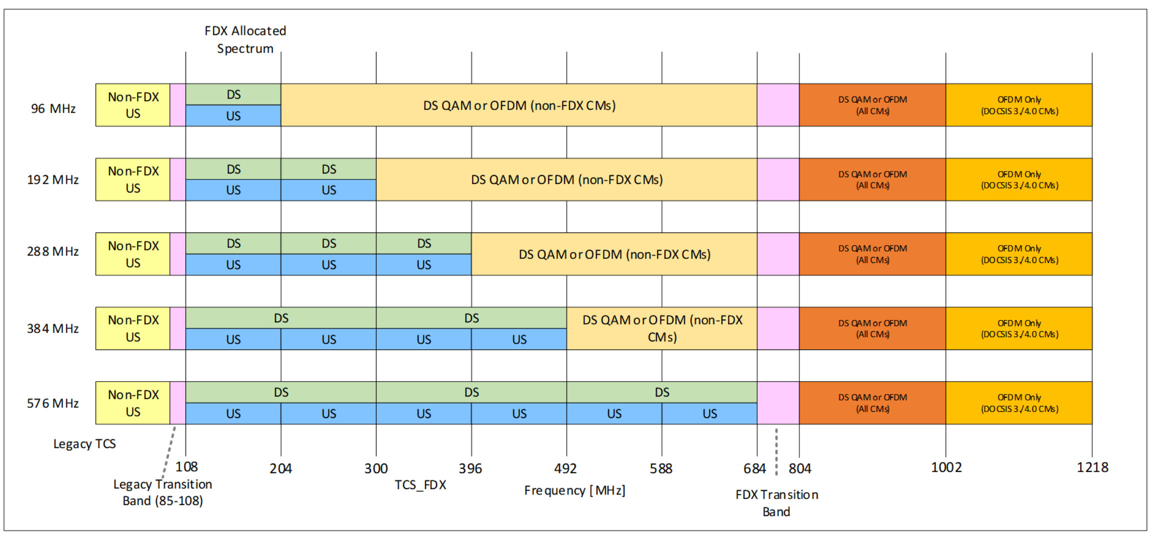

Figure 25 – FDX Band Plans (Source: CableLabs)

The amount of spectrum allocated to upstream and downstream can be delineated by the amount of bidirectional spectrum, as shown in Table 4.

Table 4 – FDX Spectrum Allocation

	Mid-split	96MHz	192MHz	288MHz	384MHz	576MHz
Upstream Spectrum (MHz)	80	176	272	368	464	656
Downstream Spectrum (MHz)	894	1098	1098	1098	1098	1098
DS:US Spectrum Ratio	11.2	6.2	4.0	3.8	2.4	1.7

The quantity of downstream spectrum remains the same for different amounts of bidirectional spectrum. The frequency range between 108-684MHz not used bidirectionally, however, is only available to non-FDX Cable Modems (CMs), as shown in Figure 25.

FDX is designed to be operated in passive, or N+0, plant. This requires the removal of all amplifiers and fibre deployed deep into the network (Figure 26).

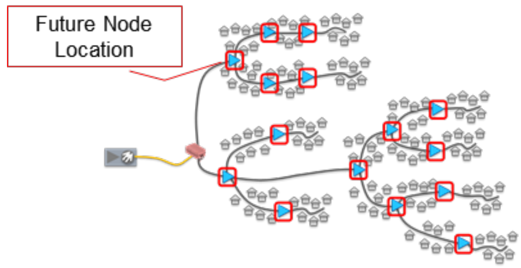

Figure 26 – N+0 Build

In Shaw's network, N+0 represents a small fraction of homes passed, generally in newer areas or especially in Multiple Dwelling Units (MDUs). In these areas, a deployment of FDX is a matter of swapping out the node. In networks with amplifier cascades, however, fibre deployment is required.

The cost and time required to upgrade to N+0 is heavily influenced by the type and ownership of the infrastructure. Owned aerial infrastructure is the easiest to upgrade, with un-owned underground infrastructure the most difficult, with estimates showing upwards of ten times the difference in cost and build time between the two. The mix present in an operator's network will dictate the average cost per home passed as well as the time required to complete the upgrade.

5.4. FTTP

As with FDX, an upgrade to FTTP is heavily impacted by the infrastructure and has the additional requirement to deploy fibre drops, either at the time of upgrade or in a success-based fashion at a later time. One important consideration in moving to FTTP is the lack of backwards compatibility, requiring CPE to be replaced. Depending on infrastructure access agreements there may not be the option to overbuild and transition customers slowly. In a worst-case scenario, the HFC network is removed, a PON network deployed, and all subscribers transitioned within a short period of time. The logistics of such an upgrade would have to be managed diligently.

6. No Regrets Investments

Deploying fibre into the HFC network to decrease coax cable distances and amplifier cascade depths is a no regrets investment beneficial for each upgrade option. Additional capacity is achieved both by decreasing the number of subscribers per serving area and by increasing the spectrum and signal quality available to that group of subscribers.

Outside plant networks can be differentiated by what percentage of the network is fibre optics, with FTTP on one end and N+X on the other. Upgrade strategies that deploy fibre all the way to the subscriber or deep into the network have the advantage of creating a large surplus of capacity. A pragmatic upgrade strategy would be to deploy just as much fibre as is necessary to relieve current network deficits. There are also strategies to reduce the maximum cascade depth in the network, or deploy fibre to an intermediate depth, in areas where congestion is expected. There are reasons to pursue all the above strategies depending on network context. The benefit of a deep fibre strategy is that when work is completed in an area, no network augmentations will be required for a significant amount of time. Any permitting or approval process is done only once, and logistics are concentrated. The drawback of this strategy is that in an environment where capital and time are constrained, the time delay between the first and last subscriber upgrade is significant. A broad fibre strategy, which reduces amplifier cascades to a set depth, would allow capital and time to be spread more evenly throughout the network, increasing the capacity to all subscribers. This approach can be useful in upgrading the network to compete with FTTP offerings in a relatively short time frame.

As shown in Figure 27, upgrade strategies can be placed on a plot of capacity versus fibre depth. Capacity is considered as the sum of upstream and downstream, while fibre depth is subjectively defined, with current HFC networks considered low fibre depth and FTTP considered high. This is a relative judgement as a very high percentage of current HFC networks are fibre.

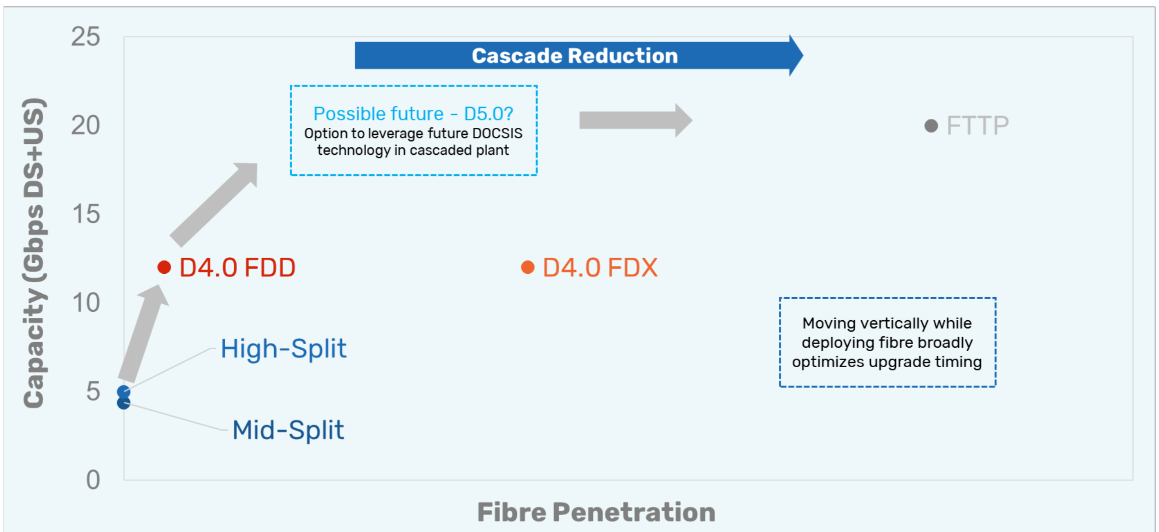

Figure 27 – Capacity vs Fibre Penetration

A deep fibre strategy moves diagonally to the top right on this plot, enabling FDX or FTTP by increasing capacity and fibre depth. A broad fibre approach moves in a near-vertical fashion, reducing cascades over time while using drop-in upgrades to create more capacity. The strategic direction will be influenced by future predictions of the direction of technology, fibre deployment costs, and subscriber demand.

A broad fibre strategy benefits if DOCSIS versions beyond DOCSIS 4.0 FDD are created that continue to operate in cascaded plant. If the direction moves toward passive operation, the deep fibre strategy is optimal. It is best to deploy fibre as quickly as possible if future fibre deployment costs, which are heavily weighted toward labor, increase significantly. An advantage of the broad fibre strategy is that capacity growth can more closely match demand growth, moderating or accelerating as needed.

Another no-regrets investment is the transition of video from QAM to IP delivery. As serving group sizes get smaller, a QAM broadcast video model becomes less and less efficient and the capacity increase achieved by moving to IPTV more compelling.

Lastly, pre-seeding the network with future-proof CPE will ensure that new capacity is available to subscribers as soon as an upgrade is complete. Switchable diplex filters can be used to ensure there is no interference from new CPE.

7. Potential Path

One potential path is to begin upgrading the plant to high-split as soon as the mid-split upgrade is complete. This upgrade would not be undertaken to reduce congestion as mid-split capacity is forecasted to satisfy customer demands for the next few years. Instead, a high-split upgrade would demonstrate HFC's ability to achieve gigabit upstream tiers and could be used to match or exceed an FTTP competitor's high service tier of 1.5Gbps downstream and 940Mbps upstream. A high-split upgrade can also pave the way for future DOCSIS 4.0 upgrades through the development of leakage detection, DAA, QAM reclaim, and other foundational components required for both solutions.

As soon as DOCSIS 4.0 FDD equipment is commercially available, the switch can be made from a high-split upgrade to a DOCSIS 4.0 FDD upgrade but operated with a high-split band plan. In parallel, programs to reduce cascade lengths and retire QAM video hardware will increase the capacity available to subscribers. When QAM video is retired a significant amount of spectrum will be freed up, which can be used for additional downstream capacity or to increase upstream capacity via a change to one of the ultra-high-split band options.

In new developments, FTTP will be the technology of choice, slowly becoming a larger fraction of the overall network. As fibre is deployed into the network to reduce cascades, the amount of work required to upgrade to N+0 or FTTP will be reduced, making such a move more practical in the future.

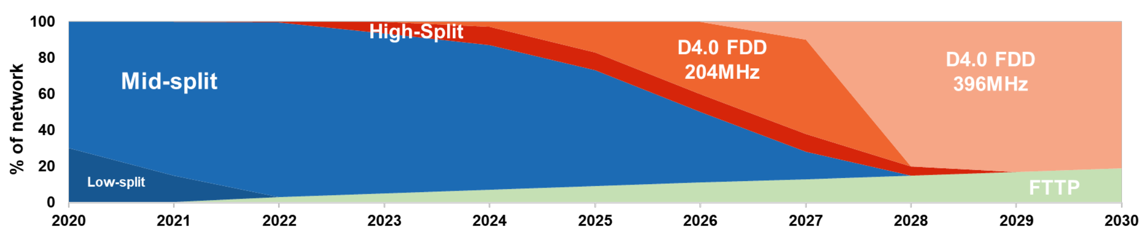

Figure 28 – Potential Network Path

8. Conclusion

Broadband subscriber demand continues to grow, as does competitive pressure, obliging network providers to upgrade their networks. The upgrade strategy network providers choose will impact capital intensity and competitive position. One strategy is to upgrade the HFC network in a drop-in fashion, allowing for a broad increase in capacity while minimizing time and capital spent. This allows time for a measured fibre deployment, slowly bringing the network toward N+0 or FTTP.

While DOCSIS 4.0 FDD is not currently available, starting an upgrade with high-split allows for gigabit symmetric tiers and requires operators to tackle some key issues such as leakage, DAA, QAM reclaim and MoCA coexistence. Once DOCSIS 4.0 FDD is available, focus can shift, initially to a DOCSIS 4.0 FDD upgrade with a high-split band plan and eventually to an ultra-high-split band plan. This strategy maximizes return on investment while efficiently competing with FTTP challengers.

Abbreviations

CAGR	Compound Annual Growth Rate
CM	Cable Modem
CPE	Customer Premises Equipment

DAA	Distributed Access Architecture
dB	decibel
DOCSIS	Data over Cable Service Interface Specification
DPI	Deep Packet Inspection
DS	downstream
DSL	digital subscriber line
FDX	full duplex
FTTP	fiber to the premises
Gbps	gigabit per second
GHz	gigahertz
GPON	Gigabit Passive Optical Network
HFC	Hybrid Fibre Coax
IP	Internet Protocol
IPTV	Internet Protocol Television
Mbps	megabit per second
MoCA	Multimedia over Coax Alliance
MPEG	Motion Picture Experts Group
ms	millisecond
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency-Division Multiple Access
OLT	Optical Line Termination
OOB	out-of-band
PHY	physical
PON	Passive Optical Network
QAM	Quadrature Amplitude Modulation
SNR	signal-to-noise ratio
Tbps	terabit per second
UHS	ultra-high-split
US	upstream
XGS-PON	Ten Gigabit Symmetric PON

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