DOCSIS® 4.0 Technology Realizing Multigigabit Symmetric Services

Migration Scenarios for Multigigabit Return Services

A Technical Paper prepared for SCTE•ISBE by

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Introduction

DOCSIS® 4.0 technology is being designed to support symmetric multigigabit services. In order to achieve these, the Hybrid fiber-coax (HFC) network will need to evolve to support both more return and more forward spectrum, all while maintaining existing services. To support more return speed, DOCSIS 4.0 technology will support expanded forward capacity on the HFC network to 1.8 GHz. Cable can already offer gigabit service in the downstream and providing upstream gigabit service will enable new symmetric multigigabit cable Internet products. However, there is still a set of legacy digital video services that need to be maintained for the foreseeable future. This paper will discuss options for maintaining legacy digital video services, while changing the HFC network to support symmetric multigigabit Internet services.

Content

1. Coaxial Cable Spectrum

1.1. Forward (Downstream) Spectrum

This first section explains some history of cable television, and how both the network and services have evolved over time. Readers that want to get right to multigigabit symmetric services can move to the next section.

Cable has been expanding the capacity of the coaxial network pretty much since it was invented. Originally it was a few analog TV channels. Then it was 20 channels, then 40, then 60, then 80. Then additional capacity for high definition television (HDTV). Then it was more capacity for both digital video, Internet and digital voice services. And when even more capacity was needed for expanding Internet service, systems started reclaiming analog television signals and converting them to digital television.

The cable system is generally referred to as the upper frequency supported. For example, it is common to refer to cable networks as 550 MHz, 750 MHz or even 1 GHz (1,002 MHz). Each of these upper limits has a place in cable history as shown in Table 1 below.

Table 1 – Historical Cable Plant upper limits

System limit	When state of the art	Why
220 MHz	1960	20 analog channels
330 MHz	1970	40 analog channels
450 MHz	1980	60 analog channels
550 MHz	1985	80 analog channels
750 MHz	1995	80 analog channels + room for digital services. Primarily intended to be digital television but soon also used for Internet service.
870 MHz	2000	Ditto, plus more high definition analog channels, digital television channels, and even more digital services.
1,002 MHz (a.k.a. 1 GHz)	2006	Ditto with room for lots of digital services including high definition television and data capacity.

There have been programs to reclaim spectrum. For example, the digital terminal adapter (DTA) was used to reclaim analog channels by converting them to digital channels, thereby reclaiming spectrum which could be used for other services, primarily Internet service. As a rule of thumb, one analog standard definition television channel would take 6 MHz of spectrum. In that same 6 MHz of spectrum it is possible to put up to 17 digital television channels using the Moving Picture Experts Group (MPEG-4) standard.

1.2. Return (Upstream) Spectrum

The forward system limit is only part of the story. The coaxial cable is generally split into both forward and return spectrum; also known respectively as downstream and upstream. And whereas the forward capacity has been growing for decades, the return capacity has generally stayed the same. And this will be a key topic of this paper, to expand the upstream capacity of the cable plant.

North America generally ended the return path at 42 MHz in order to start the forward path at 54 MHz, which was the off-air location of channel 2. Europe ended the return path at 65 MHz, which allowed their forward to start at 86 MHz to carry the FM radio band.

With a nod to colleagues in the rest of the world, the rest of this paper will focus on North American cable plant. Even in the best cases in rest of world application where a 65 MHz or even an 85 MHz return path is in use, expanding the HFC network to 1.8 GHz will allow a return path to span up to 684 MHz, which is a 10x increase over the current standard return paths, and will allow for multigigabit return capacity as well as a multigigabit forward capacity.

1.3. Spectrum, Capacity and Speed

The words spectrum, capacity and speed have specific meanings.

Spectrum, also sometimes referred to as bandwidth, is allocated on the coaxial cable. For example, on a North American 750 MHz system the forward spectrum runs from 54 MHz to 750 MHz, a total of 696 MHz of spectrum. The return path runs from 5 – 42 MHz for a total of 37 MHz of return spectrum. And here is a simple observation, that today's typical 750 MHz HFC network has 20 times the forward spectrum as return spectrum. This is because the early cable business was delivering television programming, and the more the better. However, with the business shifting toward both Internet service and IP service delivery, it is now a focus to grow both the forward and return to offer symmetric services. A 750 MHz HFC network can support a 1 Gbps downstream speed tier (and maintain legacy video services), however, the relatively small upstream spectrum supports a speed tier on the order of 40 – 50 mbps.

Spectrum is turned into bits by sending Sine waves over it. Coaxial cable is a fabulous medium to send sine waves over. Without going into the Physics behind it, at a certain time and amplitude and phase, a sine wave represents some number of digital bits which can be built up into IP packets and used for Internet services. Really, really fascinating stuff, but beyond the scope of this paper.

And the more spectrum there is, the more sine waves that can be sent and therefore more bits that can be carried. Simple as that. The more spectrum there is, the more Internet service capacity there can be.

Capacity is managed. Speed is an offered service. There has to be at least as much capacity as the highest speed tier. For example, in order to offer a 1 Gbps speed tier, there had better be at least 1Gbps of capacity. And since there are usually multiple customers sharing that capacity, there should be even more capacity available than the highest speed tier to ensure the customers are getting their advertised speed tiers. As a rule of thumb, a speed tier should be supported by twice the capacity. So, a 1 Gbps speed tier would be backed up by 2 Gbps of capacity. A 2 Gbps speed tier would be back by 4 Gbps of capacity, and so forth. This rule of thumb is generous, and actual numbers depend on the number of customers using that capacity, their usage, etc.

1.4. Traditional 750 MHz cable plant

A 750 MHz HFC network was state of the art in the late 1990s, and was used for plant upgrades through the mid 2000's. With digital television service, it supported a competitive triple-play offering that my home used for almost 2 decades. In North America, a 750 MHz HFC network is still the largest percentage of plant in use; decreasing for sure, but still the majority.

As shown in Figure 1, on a North American 750 MHz HFC network the return path runs from 5 – 42 MHz, and the forward from 54 – 750 MHz. Note this figure starts to introduce the new top end of 1.8 GHz (1,794 MHz), which is shown to scale for reference to allow the reader to start getting a feel for the new spectrum allocations discussed later in this paper.

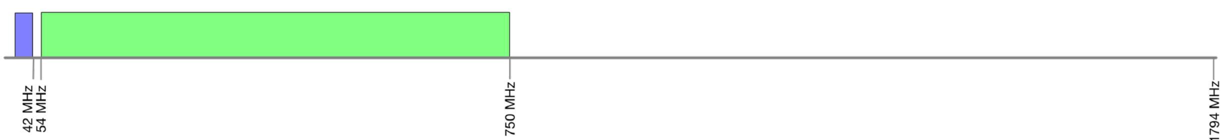

Figure 1 – North American spectrum usage; 42 MHz return split and forward to 750 MHz

Figure 1 shows graphically how much return and forward spectrum is available; the color blue is used for return path spectrum and green is used for forward path spectrum. The issue has become the return path which is short on spectrum and hence can support only a minimal return speed and as can be seen, clearly the network is not symmetric in terms of capacity.

For decades this HFC network supported all the services that were needed including the move from analog TV to digital TV, the advent of high definition television, the introduction of Internet and digital phone services, etc. Now, it's time to look at something different.

1.5. 1.8 GHz, Return Spectrum and Symmetry

Why 1.8 GHz? There is nothing special about it per se, rather, about a decade ago this value was chosen when a company made HFC network equipment that could work to 1.8 GHz. For the detail-oriented reader, the actual number is 1,794 MHz and is referred to as 1.8 GHz.

With DOCSIS 3.1 technology, the top end of cable plant is 1.2 GHz (1,218 MHz), and the move to 1.8 GHz (1,794 MHz) allows an additional three downstream DOCSIS OFDM carriers, each 192 MHz wide.

The key reason for moving the top end of the spectrum to 1.8 GHz is not to increase the downstream capacity per se, rather, this change is to allow an increase in the return spectrum. In fact, a key tenet of DOCSIS 4.0 technology is to allow the HFC network to flexibly operate on any of six return path splits as listed in Table 2 below.

Table 2 – Return splits for 1.8 GHz plant

Return split end (MHz)	Diplex Region (MHz)	Forward spectrum start (MHz)	Forward spectrum available (MHz)	Ration of downstream to upstream capacity
204	54	258	1,536	7 : 1
300	78	378	1,416	5 : 1
396	102	498	1,296	3 : 1
492	120	612	1,182	2 : 1
588	150	738	1,056	1.7 : 1
684	174	858	936	1.3 : 1

Table 2 shows a couple of things. The first column shows the amount of return spectrum available. Since most current North American systems today support only 42 MHz of return spectrum, the move to support up to 684 MHz of spectrum is a greater than 10x increase in return capacity and is essentially the same amount of forward spectrum (696 MHz) available with a 750 MHz HFC network today.

The second column shows the amount of spectrum used by the diplex filter, which separates the return spectrum from the forward spectrum.

The fourth Colum shows the amount of forward spectrum available with a 1.8 GHz HFC network, based on the return split, and should be compared with a 750 MHz HFC network that supports only 696 MHz of forward spectrum.

The fifth column shows the ratio of downstream to upstream capacity, and the trend to symmetry (1:1) as the total spectrum is partitioned for more upstream capacity. It is both the increase in spectrum and the trend toward symmetry which enables multigigabit symmetric data services and provides a new way to think about the HFC network.

A key item is that a DOCSIS 4.0 modem will be capable of all the splits listed in Table 2. This is very important because a DOCSIS 4.0 modem can be initially deployed when the network supports one return split, and later on the return split can be changed (increased to provide more return capacity and more symmetry) and that same DOCSIS 4.0 modem can stay in place and take advantage of the new return.

Figure 2 shows a comparison drawn to scale between the traditional 750 MHz HFC network (from Figure 1) and a 1.8 GHz HFC network using the highest return split from Table 2.

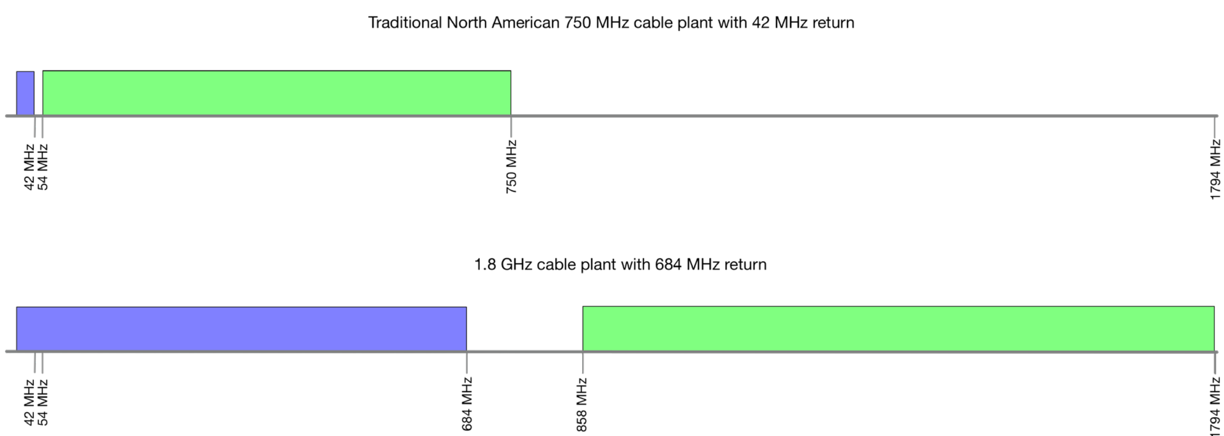

Figure 2 – Comparison of 750 MHz and 1.8 GHz HFC Networks

As can be seen in Figure 2 the 1.8 GHz HFC network has both significantly more return spectrum, and more forward spectrum. The goal is the migration from a broadcast television service, to more symmetric Internet services. The coaxial cable already out there is capable of this, though there will be operational issues to deal with when the switch occurs; however, making this switch to being predominantly an Internet services provider is the future of the business.

In summary, this next move to 1.8 GHz will allow symmetric multi-gigabit services. Internet services are the basis for the majority of communications these days, even the delivery of entertainment. What were once analog television channels are now carried over the digital technology. This conversion began in the late 1990s when cable began offering Internet Protocol (IP) services. Digital voice was originally offered as a legacy service too, before voice over IP (VoIP) was enabled. Now television services are going over IP too. Home automation, distance learning, health care, your favorite app's, etc., all these services are offered over IP.

While it is not possible to predict the services that will be used 5 years from now, it is a pretty good bet those services will be offered over IP. Hence this paper, discussing a method to increase IP capacity and move to symmetric multigigabit services, while maintaining the legacy video services.

1.6. DOCSIS 4.0

To support multiple HFC network scenarios, DOCSIS 4.0 supports two types of plant operation:

- Full Duplex (FDX) operation using the full duplex spectrum defined between 108 MHz to 684 MHz.
- Traditional operation using separate forward and return spectrum separated by a diplex filter, with multiple return splits available.

In both cases, the splits are as listed in Table 2 and the intent is to add more upstream capacity for Internet service. Operating in either case depends on how the operator chooses to configure their HFC network for this future view of services.

2. Enabling Technologies

The previous section discussed the increases in spectrum that are made available with a move to 1.8 GHz. This section looks at how the spectrum is currently being used for today's services including limits on those services imposed by existing network equipment and customer premise equipment (CPE). An important part of moving to 1.8 GHz will be ensuring that existing services still fit, based on how they fit into the available spectrum.

2.1. Legacy Service and Spectrum Limits

When expanding the return path spectrum, the forward path spectrum has to be moved further up. That is, with a legacy 42 MHz return, the forward path started at 54 MHz. If the return path is move up to end at say 396 MHz, based on Table 2 the forward path now starts at 498 MHz. That means that all the downstream services that used to start at 54 MHz now need to start at 498 MHz, and the question becomes can the deployed modems and set-top boxes still receive those services?

The examples given in this paper assume legacy CPE can receive signals up to 1 GHz (1,002 MHz) as discussed in the following sections. Operators should check with their systems to learn the limits of deployed CPE.

2.1.1. Digital Video Set-top Box Spectrum

Modern digital set-top boxes support spectrum to 1 GHz (1,002 MHz). Older set-top boxes will support lower limits, for example, both the Motorola DCT 2000 and Scientific-Atlanta Explorer 1850 set-top boxes operate to only 860 MHz. Operators should check their inventory of deployed set-top boxes and plan digital video spectrum appropriately.

If the return path is moved up, the digital video spectrum will also have to move up but cannot be moved beyond the limit of the deployed set-top boxes to receive that spectrum.

2.1.2. DOCSIS 2.0 and Earlier Spectrum

DOCSIS 1.0, DOCSIS 1.1 and DOCSIS 2.0 modems only operate to 857 MHz. To keep these modems operational, a single downstream 6 MHz DOCSIS channel needs to be kept below 857 MHz.

2.1.3. DOCSIS 3.0 Spectrum

DOCSIS 3.0 downstream technology in practice operates to 1 GHz (1,002 MHz) based on supplier implementations. Again, DOCSIS 3.0 spectrum will need to be kept below 1 GHz and will be seen in some cases to be a limiting factor.

2.1.4. DOCSIS 3.1 Spectrum

DOCSIS 3.1 downstream technology is specified to operate to 1.2 GHz (1,218 MHz); hence, the existing DOCSIS 3.1 spectrum can be moved above 1 GHz but must stay below 1.2 GHz (1,218 MHz).

DOCSIS 3.1 modems can also use all the DOCSIS 3.0 spectrum. Because of that higher spectrum limit available for DOCSIS 3.1 modems, a program for migrating customers from DOCSIS 3.0 to DOCSIS 3.1 modems is a positive step when considering a move to 1.8 GHz.

2.1.5. DOCSIS 4.0 Spectrum

DOCSIS 4.0 modems are anticipated to support all the return splits listed in Table 2 (up to 684 MHz) while also supporting downstream spectrum up to 1.8 GHz (1,794 MHz) which will make the DOCSIS 4.0 modem the first to be capable of symmetric multigigabit services.

DOCSIS 4.0 modems can also use all of both the DOCSIS 3.0 and DOCSIS 3.1 spectrum.

2.2. Switched Digital Video

Switched Digital Video (SDV) provides a method to reclaim spectrum for video delivered using MPEG transport. This includes both linear television programming as well as video on demand (VOD) programming. SDV delivers programs only when and where requested by viewers, unlike broadcast digital video systems that deliver all programming all the time even if no viewer is watching.

With broadcast digital video, HFC capacity is consumed even if no one is watching. With SDV, HFC capacity is only consumed when a viewer is watching. SDV optimizes capacity and without dedicating spectrum to programming that is not being watched.

Additionally, by switching some, or all, of the broadcast video tier it is possible to significantly increase the amount of programming offered. The so-called "long tail effect" demonstrates that there is a large aggregate demand when many specialized offerings are made available.

It should be noted that both IPTV and over-the-top video providers are doing the same thing, using IP transport instead of MPEG transport. Imagine if Netflix broadcast their entire programming catalog all the time to all subscribers and allowed the subscriber to just tune to whichever "channel" they wanted. This would be a huge waste of capacity. Rather, Netflix content is only placed on the network when there is an active viewer consuming that content.

SDV and IPTV are both examples of a switched model where spectrum is only allocated when content is being watched. Several references are provided about the statistics of SDV and the evidence is clear it conserves HFC network capacity. This information will be used when providing examples of migrating existing services to HFC network with a higher return split.

2.3. 750 MHz spectrum example

This section will show an example of how the spectrum is used to support today's services. A 750 MHz HFC network was chosen because this is the most prevalent in North America. These examples can be considered representative of a 750 MHz HFC network and different operators can do different things.

On a 750 MHz HFC network, the forward path starts at 54 MHz and ends at 750 MHz which provides a total of 696 MHz of spectrum to support all the forward path services offered today, including television, Internet and all the IP services that run over the DOCSIS spectrum.

This example assumes all services are digital, and that analog television has been removed. Digital television uses the MPEG-4 standard which allows compressing more television channels into a given amount of spectrum than for example the MPEG-2 standard. Table 3 lists conversion factors used to convert services into spectrum.

Table 3 – Digital Service to Spectrum conversion

Digital Service	Spectrum
17 standard definition digital television channels (MPEG-4)	6 MHz
9 high definition digital television channels (MPEG-4)	6 MHz
1 DOCSIS downstream channel capable of 38 mbps total capacity	6 MHz
DOCSIS 3.1	Variable

In North America the downstream channelization was traditionally built on 6 MHz of spectrum which is based on the NTSC analog television standard. (Other regions of the world use the PAL standard which uses 8 MHz of spectrum per analog channel, and these regions can also use 8 MHz DOCSIS channels.)

Digital technology allows more service to be carried in the spectrum than analog. Digital has been used to make the most of the available spectrum by compressing more services into it and is the reason that such devices as the DTA have been used to carry televisions in digital format on the cable plant.

2.3.1. 750 MHz with SDV

Table 4 shows an example spectrum allocation for a 750 MHz HFC network and how the forward spectrum is used. There is a total of 115 Consumer Technology Association (CTA) channels available on this plant, each 6 MHz. With SDV in use, all the digital television services can be offered in 40 CTA channels, using 240 MHz of spectrum. The remainder of the spectrum is allocated for DOCSIS service, including both DOCSIS 3.0 (and earlier) and DOCSIS 3.1 spectrum.

Table 4 – Downstream Spectrum Allocation to Digital Services with SDV

Service	CTA channels (@ 6 MHz)	Spectrum
Digital Television (SD and HD)	40	240 MHz
DOCSIS 3.0 (and earlier)	32	192 MHz
DOCSIS 3.1	32	192 MHz
Total	104	624 MHz

The spectrum listed in Table 4, with SDV in use, is shown in Figure 3.

Figure 3 – 750 MHz plant spectrum allocation with SDV

Note that all the services fit within the forward path that starts at 54 MHz and ends at 750 MHz. An astute reader will realize that 696 MHz of spectrum divided into 6 MHz channels works out to 116 channels, however, just below the FM band there is a discontinuity in the channelization resulting in 115 CTA channels.

2.3.2. 750 MHz without SDV

Table 5 shows the corresponding spectrum usage for a plant without SDV. Note that without SDV, more CTA channels are needed for the digital video services including SD channels, HD channels and VOD service. Specifically with SDV as shown in Table 4, a total of 40 CTA channels are needed for digital television whereas Table 5 shows that without SDV a total of 60 CTA channels are needed for digital television. But there are only 115 total CTA channels available on a 750 MHz HFC network, therefore with more CTA channels allocated to video there will be fewer CTA channels available for DOCSIS spectrum. Note that Table 5 shows half the DOCSIS 3.1 spectrum that is available in Table 4. On the cable plant there is only so much spectrum to be allocated between services, and this is an example of traditional broadcast digital television without SDV requiring more capacity and hence less capacity is available for DOCSIS service.

Table 5 – Downstream Spectrum Allocation to Digital Services without SDV

Service	CTA channels (@ 6 MHz)	Spectrum
SD digital television (425 channels)	25	96 MHz
HD Digital television (207 channels)	23	192 MHz
VOD	12	72 MHz
DOCSIS 3.0 (and earlier)	32	192 MHz
DOCSIS 3.1	16	96 MHz
Total	108	648 MHz

The spectrum listed in Table 5 is shown in Figure 4.

Figure 4 – 750 MHz plant spectrum allocation without SDV

In both Figure 3 and Figure 4, all the services fit within the 750 MHz limit of a traditional cable plant. A North American 750 MHz HFC network supports 115 forward CTA channels (each 6 MHz wide) and the example with SDV uses 104 CTA channels whereas the example without SDV uses 108 CTA channels (albiet with less DOCSIS capacity). No system fills every channel and it is appropriate to not show every CTA channel being used.

3. MultiGigabit Return Examples

A key point of this paper is that an operator can take their 750 MHz HFC network today, and without any changes to existing services, migrate the spectrum to a 1.8 GHz HFC network with more return path and provide symmetric multigigabit data services. And do this without running into legacy CPE limits as discussed in section 2.1. This is not straightforward since most legacy CPE operate to only 1 GHz (1,002 MHz), and increasing the return path means that the start and end of the forward path is also moved up.

In this section, information from the proceeding sections will be synthesized to show how this works.

This section focuses on the return path and a forward path example using a 1.8 GHz HFC network is given in section 4.

3.1. 3 Gbps Return Example

A 396 MHz return will support up to 3 Gbps of upstream capacity using DOCSIS 4.0 technology.

With a 396 MHz return, the forward path starts at 498 MHz which means the legacy services which used to start 54 MHz will now start at 498 MHz, and end correspondingly higher in the spectrum too.

3.1.1. 3 Gbps Return Example with SDV

Applying the information from Table 4 to a 1.8 GHz HFC network with a 396 MHz return path yields the information shown in Figure 5.

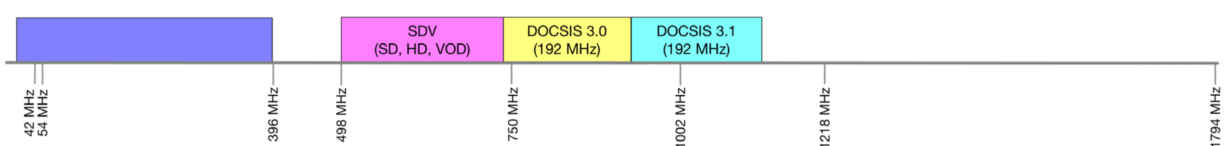

Figure 5 – 3 Gbps return with legacy spectrum allocation with SDV

This figure shows that legacy services on a 750 MHz HFC network with SDV will fit on a new plant with a 396 MHz return. The key is that the legacy SDV services and DOCSIS 3.0 services all fit below 1 GHz (1,002 MHz). This means that even though the services have been moved up in the spectrum that the legacy CPE should still be able to receive these services.

Note that the DOCSIS 3.1 spectrum has moved above 1 GHz (1,002 MHz) but remains below 1.2 GHz (1,218 MHz). From section 2.1.4 the existing DOCSIS 3.1 CPE will operate up to 1.218 MHz meaning they will get the same service and perhaps even better service since additional DOCSIS 3.1 spectrum could be added up to 1.2 GHz (1,218 MHz).

3.1.2. 3 Gbps Return Example without SDV

Applying the information from Table 5 to a 1.8 GHz HFC network with a 396 MHz return path yields the information shown in Figure 6.

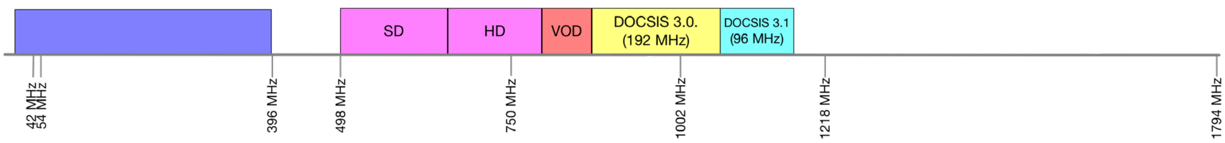

Figure 6 – 3 Gbps return with legacy spectrum allocation without SDV

This figure shows that legacy services on a 750 MHz plant without SDV will not fit on a new plant with a 396 MHz return. The legacy video spectrum is okay, it all fits below 1 GHz (1,002 MHz) and the issue is that a portion of the DOCSIS 3.0 spectrum falls above 1 GHz (1,002 MHz). DOCSIS 3.0 CPE will not receive spectrum above 1 GHz (1,002 MHz) and the operator has a choice to make which will be discussed in the next paragraph. Also in Figure 6 note that the DOCSIS 3.1 spectrum has moved above 1 GHz, however, from 2.1.4 the existing DOCSIS 3.1 CPE will operate up to 1,218 MHz meaning those CPE will get the same service and perhaps even better service since the DOCSIS 3.1 spectrum could be extended to 1.2 GHz (1,218 MHz).

To make the DOCSIS 3.0 spectrum fit below 1,002 MHz, either the spectrum for legacy video services need to be reduced, which is likely not possible, or the DOCSIS 3.0 spectrum needs to be reduced. As shown in Figure 7, if the DOCSIS 3.0 services are reduced from 32 to 24 CTA channels then the DOCSIS 3.0 service will end right at the upper limit of 1 GHz (1,002 MHz) and the existing DOCSIS 3.0 CPE will operate with a somewhat reduced capacity. To plan for this move, the operator can begin replacing DOCSIS 3.0 CPE with DOCSIS 3.1 CPE and can expand the DOCSIS 3.1 spectrum.

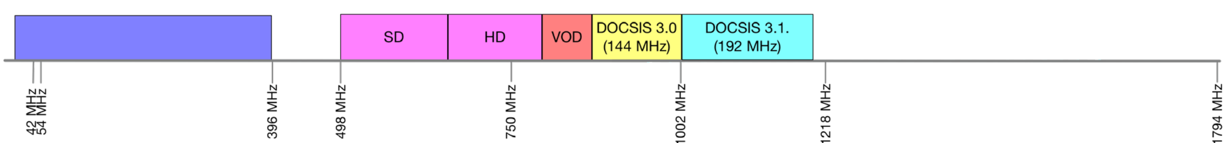

Figure 7 – 3 Gbps return with modified legacy spectrum allocation without SDV

Also, in Figure 7 the DOCSIS 3.1 spectrum has been doubled to 32 CTA channels (192 MHz) which fits below the limit of 1.2 GHz (1,218 MHz). Whereas there was a reduction of DOCSIS 3.0 spectrum, there can be an increase in the DOCSIS 3.1 spectrum with an overall increase of spectrum available to DOCSIS 3.1 modems since DOCSIS 3.1 modems can also use the DOCSIS 3.0 spectrum. This is an example of how a proactive swap to DOCSIS 3.1 modems will position an operator for DOCSIS 4.0.

3.2. 4 Gbps Return Example

A 492 MHz return will support up to 4 Gbps of upstream capacity using DOCSIS 4.0 technology.

With a 492 MHz return, the forward path starts at 612 MHz which means there is only 390 MHz of spectrum up to the legacy services limit of 1 GHz (1,002 MHz).

3.2.1. 4 Gbps Return Example with SDV

Applying the information from Table 4 to the plant with a 492 MHz return path yields the information shown in Figure 8.

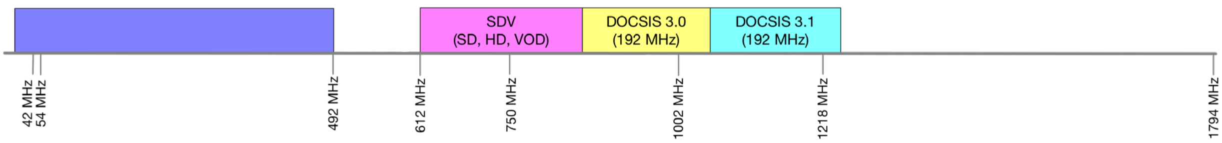

Figure 8 – 4 Gbps with legacy spectrum allocation with SDV

Much like the example from section 3.1.2, this figure shows that legacy services on a 750 MHz plant with SDV will not fit on a plant with a 492 MHz return without some tweaking, because a portion of the DOCSIS 3.0 services fall above 1 GHz (1,002 MHz). As a result, the DOCSIS 3.0 spectrum would have to be trimmed somewhat, from the original 32 CTA channels (196 MHz) down to 25 CTA channels (150 MHz) as shown in Figure 9.

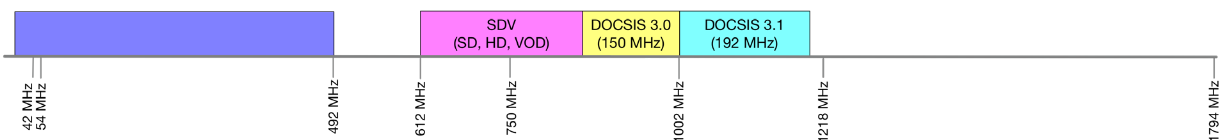

Figure 9 – 4 Gbps with legacy spectrum allocation with SDV

With this reduction in the DOCSIS 3.0 spectrum, all the legacy services will fit on a plant that now supports 4 Gbps capacity in the return. Note also that all 192 MHz of spectrum for DOCSIS 3.1 modems also fits below the 1.2 GHz (1,218 MHz) limit, therefore, the DOCSIS 3.1 modems will continue to have all that capacity available.

3.2.2. 4 Gbps Return Example without SDV

This particular example does not work well. Applying the information from Table 5 to the plant with a 492 MHz return path yields the information shown in Figure 10 below and shows that legacy services (without SDV) on a 750 MHz HFC network will not easily fit on a new plant with a 492 MHz return.

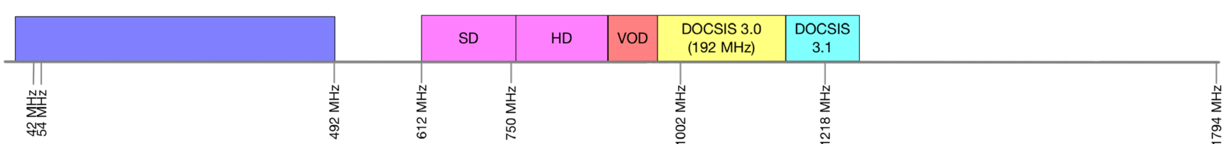

Figure 10 – 4 Gbps return with legacy spectrum allocation without SDV

The key is that almost all of the DOCSIS 3.0 services fall above 1 GHz (1,002 MHz) which means that the legacy DOCSIS 3.0 CPE will not have enough spectrum to maintain services; only 30 MHz of downstream spectrum would be available for DOCSIS 3.0 modems, down from 192 MHz, which is not enough.

There are ways to make this work, depending on the steps an operator wants to take. Without impacting legacy video services, an operator could swap all DOCSIS 3.0 and earlier modems for DOCSIS 3.1. If the operator was OK with reducing video services to expand Internet services, they could cut back on traditional video programming. There are options and the benefit of getting to 4 Gbps of return capacity (and in fact 4 Gbps of symmetric capacity) could be a catalyst for change.

3.3. Other Return Examples

Table 2 lists 6 new return splits available with DOCSIS 4.0 technology including 300 MHz, 396 MHz, 492 MHz, 588 MHz and 684 MHz. The previous examples only addressed two of these: 396 MHz and 492 MHz.

What is envisioned is the operator choose one of the new DOCSIS 4.0 return splits, one that is easy to achieve while maintaining legacy services and make that change. The new HFC network should support enough capacity to get started with symmetric gigabit service. Then the operator can begin addressing legacy services with an eye of transitioning to one of the even higher return splits to offer even more upstream capacity and move to symmetric multigigabit services.

4. Multigigabit Forward Example

The previous sections have discussed multigigabit return services, specifically looking at fitting in existing services when the return spectrum is increased. Now let's look at the forward path.

Any of the multigigabit return examples in section 3 can also have a multigigabit forward, making for multigigabit symmetric capacity. This section builds on the example in section 3.2.1 by adding DOCSIS 4.0 downstream capacity to the HFC network which then has a downstream capacity of 6 Gbps and an upstream capacity of 4 Gbps, which would easily support a 2 Gbps symmetric service tier.

With DOCSIS 4.0 technology the forward path extends to 1.8 GHz (1,794 MHz), up from 1.2 GHz (1,218 MHz) with the DOCSIS 3.1 specifications. This increase of 0.6 GHz (600 MHz) is planned for just DOCSIS services. Couple this with the fact that DOCSIS 4.0 modems will be able to use all the DOCSIS 3.0 and DOCSIS 3.1 spectrum, it's possible to envision a multigigabit forward service with spectrum to spare, all below 1.8 GHz.

Figure 11 shows an example where 384 MHz of additional downstream is added for DOCSIS 4.0 services. Note that only up to 1.576 GHz is used, not even the full 1.8 GHz.

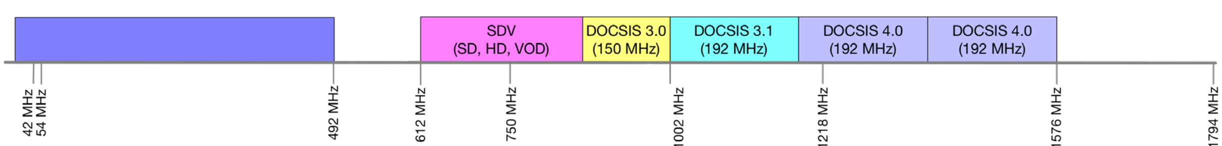

Figure 11 – Symmetric Multigigabit Service Example

A DOCSIS 4.0 modem would be able to bond all of the DOCSIS 3.0, DOCSIS 3.1 and DOCSIS 4.0 spectrum. Combined all this DOCSIS spectrum is about 6 Gbps of capacity. And the return in this example supports up to 4 Gbps capacity. These types of numbers should easily support a 2 Gbps symmetric services, with the possibility for even higher tiers.

Figure 12 is simply Figure 11 redrawn to show the downstream DOCSIS spectrum all in same color.

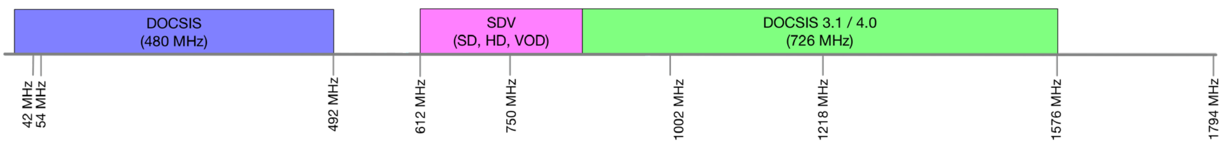

Figure 12 – Symmetric Multigigabit Service Example

The result of the scenario in Figure 12 is over 6 Gbps of downstream capacity (726 MHz of downstream spectrum) and 4 Gbps of upstream capacity (480 MHz of upstream spectrum), all while maintaining legacy video services using SDV technology. It's a beautiful picture, all this capacity available for Internet services while gracefully maintaining legacy video services for some time into the future.

As mentioned in section 3.3, once the plant has been consolidated on an easy-to-achieve new return split that maintains both legacy video and Internet services, the operator can then consider migrating to one of the even higher return splits defined in Table 2, as well as perhaps extending the forward spectrum all the way to 1.8 GHz (1,794 MHz).

Figure 13 below shows the spectrum that will ultimately be available with DOCSIS 4.0 technology and includes a return path up to 684 MHz and a forward path consisting of 858 MHz of spectrum, ending at 1.8 GHz (1,794 MHz).

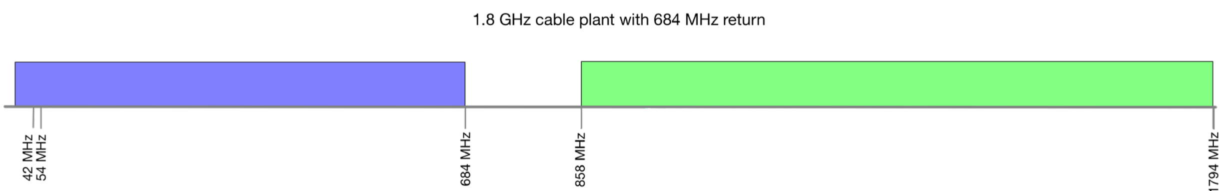

Figure 13 – DOCSIS 4.0 Technology Spectrum Plan

Configuring the plant in this way will support over 7 Gbps of downstream capacity and 5 Gbps of upstream capacity, which will set the stage for the existing HFC network to provide Internet services for many years to come.

Conclusion

DOCSIS 4.0 technology is being designed to both enable symmetric multigigabit services and to provide operators with options for migrating their HFC networks to achieve this goal. Specifically, DOCSIS 4.0 technology includes adding both upstream and downstream capacity and the tools necessary to support symmetric multigigabit services.

DOCSIS 4.0 technology also includes flexible options for increasing the return capacity in steps, following either the full duplex path or by following the flexible split path. DOCSIS 4.0 will allow operators choices as the network is migrated to symmetric Internet service. DOCSIS 4.0 modems can initially be deployed on one return, and later the HFC network can be changed to another (increased) return split and that same modem can stay in service.

Depending on how the HFC network is operated today, there is the possibility to retain all existing legacy video services while the DOCSIS capacity is expanded. Scenarios were provided in section 3 that illustrate several high-runner cases, and the analysis is flexible enough to be applied to other scenarios.

Preparing the HFC network for DOCSIS 4.0 technology includes the same process the cable industry has been following from the 1960s as shown in Table 1. The capacity of the HFC network has always been expanding, and it has even more room to grow beyond what is envisioned for the DOCSIS 4.0 specifications. Coaxial cable has turned out to be a fabulous medium for broadband services.

An interesting point for discussion is upgrading the DOCSIS 3.0 modems to DOCSIS 3.1 modems. Not all DOCSIS 3.0 modems need to be replaced; the goal is to reduce dependence of the DOCSIS 3.0 spectrum such that if the amount of DOCSIS 3.0 spectrum needs to be reduced to fit below 1 GHz (1,002 MHz) that customers using DOCSIS 3.0 modems will not be adversely affected. This is an area for additional study; however, reducing dependence on the DOCSIS 3.0 spectrum will facilitate a transition to a higher return split.

DOCSIS 4.0 modems will support multiple return splits. This capability was first introduced in DOCSIS 3.1 technology where two return splits were envisioned, and this capability has turned out to be useful.

And with the availability of multiple, flexible return splits, operators have choices in how their HFC network is operated. When first moving to DOCSIS 4.0 technology, the HFC network can be moved to a first new higher split that supports legacy services, and later on the HFC network can be moved again to support an even higher split all while using the same DOCSIS 4.0 modem.

Abbreviations

CPE	Customer Premise Equipment
CTA	Consumer Technology Association
DOCSIS	Data Over Cable Service Interface Specifications
DTA	digital terminal adapter
FDX	full duplex
FEC	forward error correction
FM	frequency modulated
GHz	Gigahertz, or billions of cycles per second
HFC	hybrid fiber-coax
HD	high definition
Hz	hertz
IP	Internet Protocol
ISBE	International Society of Broadband Experts
MHz	Megahertz, or millions of cycles per second
MPEG	Moving Picture Experts Group
NTSC	National Television System Committee
PAL	phase alternating line
SCTE	Society of Cable Telecommunications Engineers
SD	standard definition
SDV	switched digital video
VOD	video on demand
VoIP	voice over Internet Protocol

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