# Data Channel Optimization

## Managing Technology Borders

A Technical Paper prepared for SCTE by

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# 1. Introduction

As Data Over Cable Service Interface Specifications (DOCSIS®) access networks evolve through multiple versions technology Borders have been created. Evolving Hybrid Fiber Coax (HFC) plant upgrades, utilizing different Cable Modem Termination Systems (CMTS), and cable modems also create Borders as well. The evolution of technology within a coax access network has maintained backwards compatibility. However, we do not have forward compatibility through these evolutions. An optimized access networks must find the best balance between maintaining legacy services and building for future offerings.

This paper will define technology borders, and key data elements used in optimization. In addition, it will discuss the CMTS feature impacts, optimization drivers, and calculation methods to optimize an access network. Using case studies are also included which go through examples of utilizing this optimization method. Finally, it will discuss the impacts DOCSIS 4.0 will have in the future to this methodology.

# 2. Identifying Technology Borders

Technology borders can be summarized into two categories HFC and DOCSIS. These two categories are related but evolve independently from each other. Typically, the HFC plant is ready for technology evolution ahead of the needs of new DOCSIS version readiness.

## 2.1. HFC Borders

The HFC plant, utilized for data, is a bi-directional setup. There are two major data points for technology borders: total spectrum capability and diplex filter spectrum location. Total spectrum consists of the highest downstream frequency available, such as 750 MHz, 860 MHz, and 1 GHz. 1.2 GHz and 1.8 GHz. Builds of 1.8 GHz capable HFC plants are just beginning in preparation of DOCSIS 4.0 Frequency Division Duplexing (FDD).

The second data point of technology borders is the diplex filter which in North America is typically at 42, 85 or 204 MHz. With DOCSIS 4.0, operators will have options to ether move the diplex filter higher, with FDD, or use software define spectrum division in Full-Duplex DOCSIS (FDX).

## 2.2. DOCSIS Version Borders

DOCSIS versions have modified spectrum range and offer multiple channel types. Every one of these changes creates a new border. The spectrum boundaries have changed each version on both the downstream and upstream, and the range of options have grown with each version. The range of support may differ between CMTS and cable modem devices. DOCSIS specifications state the following ranges as supported for each version:

 

**Table 1 – DOCSIS Version Borders**

| DOCSIS Version | Downstream Plant (MHz) | Return Plant (MHz) | Full Duplex Plant (MHz) |
|---|---|---|---|
| 2.0 | 54-864 | 5-42 | - |
| 3.0 | 54-1002<br>108-1002 | 5-42<br>5-85 | - |
| 3.1 | 54-1218<br>108-1218<br>258-1218 | 5-42<br>5-85<br>5-204 | - |
| 4.0 (FDD) | 108-1794<br>258-1794<br>372-1794<br>492-1794<br>606-1794<br>834-1794 | 5-85<br>5-204<br>5-300<br>5-396<br>5-492<br>5-684 | - |
| 4.0 (FDX) | 684-1218 | 5-85 | 108-684 |

## 2.3. Cable Modem Borders

Cable modems since DOCSIS 3.0 also have multiple variations of support within the same DOCSIS version. This variation usually revolves around bonding groups sizing and diplex filters. The diplex filters match the spectrum boundaries in the above table (Table 1). The below table (Table 2) shows common bonding group sizing for each DOCSIS version:

**Table 2 – Cable Modem Bonding Capablity**

| DOCSIS Version | Downstream Bonding Group Size | Upstream Bonding Group Size |
|---|---|---|
| 2.0 | 1 | 1 |
| 3.0 | 4<br>8<br>16<br>24<br>32 | 4<br>8 |
| 3.1 | 32 (includes support of up to two OFDM channels) | 12 (includes support of up to two OFDMA channels) |

Table 3 shows the different diplex filter configurations that have typically been used in DOCSIS access networks:

**Table 3 – Cable Modem Diplex Filter Capablity**

| DOCSIS Version | Low-Split (42 MHz) | Mid-Split (85 MHz) | High-Split (204 MHz) |
|---|---|---|---|
| 2.0 | ✓ | x | x |
| 3.0 | ✓ | ✓ | x |
| 3.1 | ✓ | ✓ | ✓ |

These tables do not include DOCSIS 4.0 cable modems yet, but we expect greater number of orthogonal frequency division multiplexing (OFDM) and orthogonal frequency division multiple access (OFDMA) channel supported per cable modem, in addition to the many options of diplex settings available within the DOCSIS 4.0 specification.

# 3. Key Data Elements

As choices are made to modify the capability of the HFC plant or CMTS, data driven optimization decision making becomes necessary. The below data elements provide key information required to make these types of decisions. These data elements focus on each cable modem or DOCSIS channel. Note that service group data elements do not work for boundary optimizations.

## 3.1. Cable Modem Distribution

Looking at a service group's cable modem distribution can provide insight into traffic patterns seen at the service group level. If a certain border is operating below expectations, looking to see if the service group has enough cable modems that can access that capacity can provide a strong reason for this behavior. This can provide further insight into the potential for future capacity additions and can help predict the offloading of current capacity to the new capacity.

**Table 4 – Cable Modem Distribution Example**

| Capacity Type | Count | % Of Distribution |
|---|---|---|
| DOCSIS 2.0 | 5 | 5% |
| DOCSIS 3.0 | 45 | 45% |
| DOCSIS 3.1 | 50 | 50% |

## 3.2. Cable Modem Consumption

Consumption data from each cable modem within a service group can be very useful. This provides information on how much data was used during a given period. Adding the cable modem capabilities to this data allows for an enriched view to the service group's usage in that period, and by cable modem capability. Modifying the period can enable even more insights. For example, obtaining consumption data for certain peak hours and reviewing over a 30 to 90 day period can enable a better understanding of average consumption and overall usage for a particular service group. Using this type of consumption data ultimately enriches the cable modem distribution data set.

**Table 5 – Cable Modem Consumption Example**

| Capacity Type | Count | % of Distribution | Total Consumption (Peak Hour) Gb |
|---|---|---|---|
| DOCSIS 2.0 | 5 | 5% | 10 |
| DOCSIS 3.0 | 45 | 45% | 20 |
| DOCSIS 3.1 | 50 | 50% | 70 |

Table 5 illustrates the information gained form consumption data. In this example, the majority of traffic comes from DOCSIS 3.1 cable modems. Without this detailed view traffic would appear to be even between DOCSIS 2.0/3.0 versus DOCSIS 3.1 cable modems.

 

### 3.3. Capacity by Service Group

Understand the capacity of a service group has long term been a key data element. Understand the capacity you have made available on the downstream and upstream is very important. This is a very common data point historical for capacity planning an access network.

**Table 6 – Capacity By Service Group Example**

| Capacity Items | Achievable Bit-rate (Mbps) |
|---|---|
| Downstream 32 SC-QAM (@256-QAM) | 1216 |
| 192 MHz of OFDM (@1024-QAM) | 1647 |
| Total Downstream Capacity | 2863 |
| Upstream 4 SC-QAM (@64-QAM, 6.4 MHz) | 104 |
| 42 MHz of OFDMA (@256-QAM) | 285 |
| Total Upstream Capacity | 389 |

### 3.4. Capacity by Capacity Type

Understanding the capacity of the service group is very common data element. For this data element, it is important that the focus is on a *per* DOCSIS *channel* capacity level. Single carrier quadrature amplitude modulation (SC-QAM) channels are simple examples to understand; however, OFDM and OFDMA add complexity.

The spectrum location of DOCSIS channels is another important metric that can be used to enrich our data. The ability of the capacity type to be utilized becomes important when it is located within new boundary areas. For example, SC-QAM channel location within mid-split spectrum can only be utilized by mid-split capable cable modems.

**Table 7 – Cable Modem Consumption Example**

| Capacity Type | Capacity (Mbps) |
|---|---|
| 48 Downstream SC-QAM | 1824 |
| OFDM (192 MHz @1024-QAM) | 1647 |
| 4 Upstream Low-split SC-QAM (@64-QAM) | 104 |
| 2 Upstream Mid-split SC-QAM (@64-QAM) | 52 |
| OFDMA Mid-split (25.4 MHz @512-QAM) | 195 |

### 3.5. Peak Traffic

Traffic usage at peak times provides insight into a congestion level of a service group. Breaking down this data into the channel level or channel type can provide insight on the performance of each capacity type.

**Table 8 – Peak Traffic by Capacity Type Example**

| Capacity Type | Capacity (Mbps) | Peak Traffic (Mbps) |
|---|---|---|
| 48 Downstream SC-QAM | 1824 | 590 |
| OFDM (192 MHz @1024-QAM) | 1647 | 940 |
| 6 Upstream SC-QAM (@64-QAM) | 156 | 46 |
| OFDMA (25.4 MHz @512-QAM) | 195 | 87 |

 

### 3.6. Burst Capacity

For service groups that do not have congestion, peak traffic is a powerful data element to understand burst capacity. Burst capacity becomes an output of capacity minus peak traffic. This data can also be organized to boundary focused elements as well. For example, DOCSIS 3.0 downstream burst capacity — which is based on only the SC-QAM capacity can be countered with DOCSIS 3.1 downstream burst capacity that includes both SC-QAM and OFDM capacity.

**Capacity – Peak Traffic = Burst Capacity**

The below table provides an example of utilizing this formula:

**Table 9 – Burst Capacity by Capacity Type Example**

| Capacity Type | Capacity (Mbps) | Peak Traffic (Mbps) | Burst Capacity (Mbps) |
|---|---|---|---|
| 48 Downstream SC-QAM | 1824 | 590 | 1234 |
| OFDM (192 MHz @1024-QAM) | 1647 | 940 | 707 |
| 6 Upstream SC-QAM (@64-QAM) | 156 | 46 | 110 |
| OFDMA (25.4 MHz @512-QAM) | 195 | 87 | 108 |

### 3.7. Spectrum Efficiency

This data point is a powerful indicator of operational issues. For SC-QAM capacity this indicator will show channel impairments and codeword error rates (CER), while for OFDM/OFDMA, this indicator will show low capacity profile use. This data is obtained by collecting information on each cable modems performance on each DOCSIS channel it utilizes and provides data on channel impairment, CER, and active profile/interval usage code (IUC) usage for each of these channels.

This data element is primarily an operational key performance indicator (KPI) but can be used to validate that an operational issue is not causing odd traffic patterns during optimization, avoiding a service group capacity change that impacts customers' services.

### 3.8. Cable Modem Upgrade Churn Rate

For long term planning (or forecasting), it is important to understand the churn rate of cable modems from older version (that have less capabilities) to newer versions that are more capable. Insights from churn rates can allow a more assertive decision making in transitions to new capacity methods. A good example of this is the rate of DOCSIS 3.0 modems upgrading to DOCSIS 3.1 modems. This can provide a better understanding of when OFDM capacity can be added (with a reduction to SC-QAM capacity) when spectrum is limited.

### 3.9. Current Product Offerings/Distribution

Understanding the products that are currently offered to customers can help determine the burst capacity needed per service group. In addition to the max speed, the limitations of the cable modems offered with each product is required. For example, a 1 Gbps product requires a OFDM capable cable modems, whereas a 100 Mbps does not require a OFDM capable cable modem, and DOCSIS 3.0 cable modems can still be used.

## 4. CMTS Capabilities

As each CMTS has differing capabilities, it is important to understand the possible options that can be utilized for managing technology borders, and if any capabilities can impact capacity and traffic patterns.

### 4.1. MAC Scheduler

The MAC scheduler is the controller of the DOCSIS access network and determines what channel a data packet is transmitted over. This functionality can assist or hinder the behavior the technology borders. There are two common schedulers: balanced scheduler and prioritized scheduler.

#### *4.1.1. Balanced Scheduler*

A balanced scheduler provides equally load-balanced traffic across all DOCSIS channels regardless of channel type and is usually based on percentage of utilization. This type of scheduler is effective where a large majority of cable modems have access to all DOCSIS channels. This is especially effective for DOCSIS 3.0 with low-split designed capacity.

As DOCSIS 3.1 was released and operators enabled several new technology borders with OFDM, OFDMA, and different upstream splits issues with type of scheduler started to become evident. Traffic offloading to new technology capacity was held back or legacy capacity was over utilized by more capable cable modems. This limitation forces an increased cable modem churn rate, or a different scheduler type is needed. However, if the new capacity is only dedicated to new product offerings, traffic offloading becomes manageable with this type of scheduler.

#### *4.1.2. Prioritized Scheduler*

While a balanced scheduler can be the most effective solution in certain situations, a prioritized scheduler—which is based on priority of certain channel types or user settings—is the preferred type of scheduler. By allowing priority to lower utilized capacity, the greatest amount of traffic offloaded from older capacity can be achieved. A simple example that most CMTS vendors have adopted is to prioritize OFDM channel traffic. OFDM capable cable modems need to utilize the full capacity of the OFDM channel before their bonded SC-QAM channels. This process offloads the OFDM capable cable modems' traffic from SC-QAM allowing more capacity for legacy services.

Though uncommon in the access network user controlled priority, would be the most powerful example of this type of scheduler. With DOCSIS 4.0 FDD, the expansion of OFDM to new spectrum would make the simple example above less effective. Ideally, a user would set the scheduler to prioritize the new spectrum OFDM channels over current OFDM channels.

Another example of the power of user controlled priority would be in low-split. With upstream channels that tend to have high forward error correction (FEC) error rates due to their location within the spectrum, these channels should be set to a low priority, which would mean that the channel is avoided until the capacity is required.

### 4.2. Dynamic Configuration Features

Dynamic configuration features like upstream agility and profile management application (PMA) can dramatically modify the capacity of a channel. Utilizing spectrum efficiency prevents these features from causing issues during planning.

 

# 5. Optimization Drivers

An understanding of the technology borders and data elements provides the background to start identifying optimization opportunities that can be applied to the access network. With numerous drivers for optimization, this paper will focus on service group capacity, customer experience, and cost reduction. The weighting of each of these drivers will be different for each network operator based on business goals.

## 5.1. Service Group Capacity

Historically the primary driver for access networks was congestion mitigation, achieved by adding additional service group capacity. This was typically done in tandem with segmentation to maintain enough capacity for IP services. However, as operators reach low levels of congestion more weight should be put behind offering higher burst capabilities for customers.

## 5.2. Customer Experience

Customer experience focuses on ensuring each customer in a service group achieves quality services. From the capacity management perspective, customer experience established through the burst capacity for that customer. Note the capacity planning is not focused on plant conditions or in-home issues.

## 5.3. Cost Reduction

When performing capacity management, cost reduction can be achieved through two methods. These methods include license reduction and service group combining.

### *5.3.1. License Reduction*

Depending on the CMTS product, a license is likely utilized for each type of capacity. If the deployment of capacity is in excess, there is an opportunity to reduce the capacity. Each operator will have different agreements with their CMTS vendors, and as a result cost savings will differ from operator to operator.

### *5.3.2. Service Group Combining*

Another option for cost reductions is the combining of two service groups that have low utilization. This reduces the license use by half between those two service groups. Furthermore, it may free up a service group resource for use for another HFC node, though this benefit would not reduce costs.

# 6. Identifying Optimization Opportunities

For long term forecasting our industry commonly utilizes the 2014 traffic engineering formula[1]. This formula is wonderful to forecast capacity needs for a service group going into the long term future.

$$\mathbf{C >= (Nsub*Tavg) + (K*Tmax\_max)}$$

For access network optimization this formula is still interesting for forecasting but utilizing additional formulas to find opportunities. These opportunities are to maximize each serving group for products offered, and to continue to support legacy products. The starting point for optimization identification is burst capacity. The rest of the data elements discussed within this paper are supporting the decision making process around burst capacity.

### 6.1. Legacy Capacity Need Identification

As the access network moves towards new capacity methods, identification of legacy capacity need is beneficial in order to support legacy cable modems. Each access network will have service groups that behave outside of the norm and this process will identify them.

Utilizing burst capacity of legacy capacity, helps create a better understanding of the remaining capacity that is available during peak hours. By taking the highest offered service on a legacy cable modem and subtracting its value from burst capacity, you are left with remaining legacy capacity.

**Legacy Burst Capacity – Highest Legacy Service Tier = Remaining Legacy Capacity**

**Table 10 – Example Data for Legacy Capacity**

| Data Element | Value (Mbps) |
|---|---|
| Legacy Burst Capacity (32 SC-QAM Channels) | 342 |
| Highest Legacy Service Tier | 250 |

As an example, we can use the figures in Table 10 above to calculate the remaining legacy capacity:

342 Mbps – 250 Mbps = 92 Mbps

There is 92 Mbps of remaining legacy capacity at peak burst capacity. We understand that the highest service on legacy services can achieve their burst speeds during peak hours. So, if the remaining legacy capacity was equal to or less than zero, this would reflect a greater need for legacy capacity.

### 6.2. New Capacity Need Identification

Typically, new technology capable cable modems have access to the new technology and legacy capacities. A simple example of this is a DOCSIS 3.1 cable modem would have access to both the SC-QAM and OFDM capacity. Using a similar formula as in the legacy example, you can calculate remaining capacity for new capacity.

**Burst Capacity – Highest Service Tier = Remaining Capacity**

**Table 11 – Example Data for New Capacity**

| Data Element | Value (Mbps) |
|---|---|
| Burst Capacity (32 SC-QAM + 1 192 MHz of OFDM Channels) | 848 |
| Highest Legacy Service Tier | 1000 |

We can apply the figures in Table 11 above to calculate the reaming capacity for new capacity:

848 Mbps – 1000 Mbps = -152 Mbps

From this example we lack 152 Mbps of burst capacity for new capacity modems. A second OFDM channel could be utilized to gain further capacity for the DOCSIS 3.1 cable modems.

# 7. Optimization Cases Studies

In order to bring together the preceding information together thus far, this section will address several case studies. The scenarios presented below are commonly experienced by operators and can provide direction on how to optimize access networks. The cases studies are as follows:

1. Service group congestion
2. Spectrum efficiency congestion
3. Billboard service with low burst capacity
4. Low utilization service group
5. High utilization of legacy capacity
6. Spectrum boundary

## 7.1. Case Study 1 - Service Group Congestion

Congestion of a service group is typically handled by adding more capacity, and this additional capacity can be created by adding DOCSIS spectrum or a segmenting the HFC plant. Due to the state of congestion, using per DOCSIS channel utilization and burst data becomes challenging, but understanding each cable modem’s usage and capability can provide insight into the type of capacity that will be required into the future.

This case study is based Node 14A, which is capable of 1 GHz with an 85 MHz return. The current DOCSIS configuration and utilization is:

**Table 12 – Capacity – Case Study 1**

| Capacity Type | Capacity (Mbps) | Peak Utilization (Mbps) | Peak Burst Capacity (Mbps) |
|---|---|---|---|
| 32 Downstream SC-QAM | 1216 | 1,140 | 76 |
| OFDM (114 MHz @256-QAM) | 774 | 644 | 130 |
| 6 Upstream SC-QAM (@64-QAM) | 156 | 61 | 95 |
| OFDMA (25.4 MHz @512-QAM) | 195 | 77 | 118 |

The CMTS’ MAC scheduler prioritizes OFDM traffic on the downstream and tries to balance traffic on the upstream.

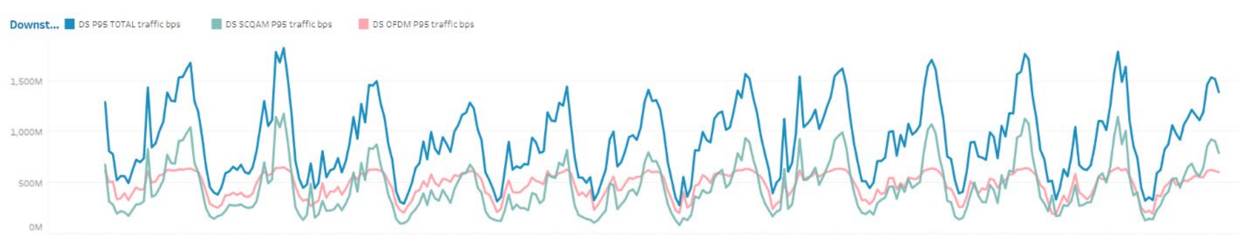


**Figure 1 – Hourly Downstream Traffic Graph – Case Study 1**

Because the upstream is not congested, the current configuration looks strong. However, on the downstream there is heavy usage on both channel types. At its current configuration, the downstream channel configuration only reaches 750 MHz, so spectrum expansion is recommended.

The Internet/IPTV cable modem distribution is:

**Table 13 – Cable Modem Distrabution – Case Study 1**

| Capacity Type | Count | % Of Distribution |
|---|---|---|
| DOCSIS 2.0 | 0 | 0% |
| DOCSIS 3.0 | 160 | 36.5% |
| DOCSIS 3.1 | 278 | 63.5% |

This cable modem distribution and the OFDM channel flatline illustrates that adding OFDM capacity will also lower SC-QAM usage.

After expanding OFDM spectrum to 192 MHz and adding 1024-QAM flat profile, 873 Mbps of capacity was added to OFDM. The new DOCSIS configuration and utilization is as follows:

**Table 14 – Updated Capacity – Case Study 1**

| Capacity Type | Capacity (Mbps) | Peak Utilization (Mbps) | Peak Burst Capacity (Mbps) |
|---|---|---|---|
| 32 Downstream SC-QAM | 1216 | 694 | 522 |
| OFDM (192 MHz @1024-QAM) | 1647 | 1136 | 511 |
| 6 Upstream SC-QAM (@64-QAM) | 156 | 53 | 103 |
| OFDMA (25.4 MHz @512-QAM) | 195 | 58 | 137 |

The CMTS' MAC scheduler prioritizes OFDM traffic on the downstream and tries to balance traffic on the upstream.

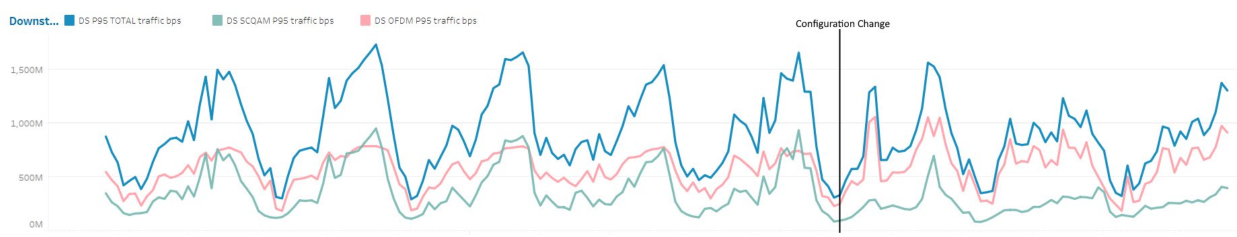


**Figure 2 – Updated Hourly Downstream Traffic Graph – Case Study 1**

These updates have eliminated congestion; in addition, we can support the current product offerings. As seen in figure 2 a significant behavior change on the SC-QAM capacity can be observed.

## 7.2. Case Study 2 – Spectrum Efficiency Congestion

When dealing with multiple boundaries it is possible for legacy capacity to reach congestion without impact to the entire service group. This example shows how spectrum efficiency can cause congestion that appears like scenarios such as poor cable modem distribution. The root cause can be hidden and difficult to identify if the data elements being used are too few. In the example below, the problem presents as a legacy capacity issue but is an OFDMA channel performance issue.

This case study is based Node 3435B, which is capable of 1 GHz with an 85 MHz return. The current DOCSIS configuration and utilization is:

 

**Table 15 – Capacity – Case Study 2**

| Capacity Type | Capacity (Mbps) | Peak Utilization (Mbps) | Peak Burst Capacity (Mbps) |
|---|---|---|---|
| 48 Downstream SC-QAM | 1824 | 127 | 1697 |
| OFDM (168 MHz @1024-QAM) | 1438 | 134 | 1304 |
| 6 Upstream SC-QAM (@64-QAM) | 156 | 153 | 3 |
| OFDMA (25.4 MHz @512-QAM) | 195 | 72 | 123 |

The CMTS' MAC scheduler prioritizes OFDM traffic on the downstream and tries to balance traffic on the upstream.

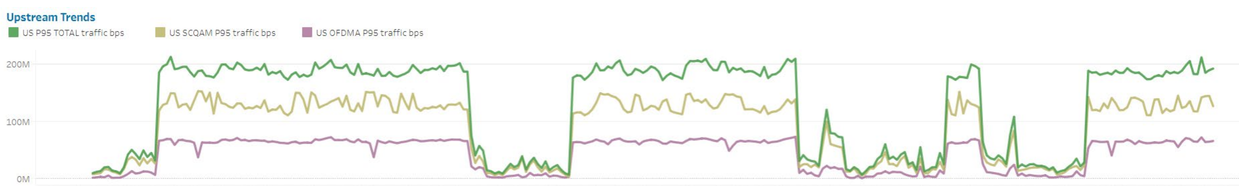


**Figure 3 – Hourly Downstream Traffic Graph – Case Study 2**

The downstream capacity is strong for this service group, but upstream SC-QAM burst capacity is very close to zero. This appears to be a cable modem distribution issue. The Internet/IPTV cable modem distribution is:

**Table 16 – Cable Modem Distrabution – Case Study 2**

| Capacity Type | Count | % of Distribution |
|---|---|---|
| DOCSIS 2.0 | 0 | 0% |
| DOCSIS 3.0 | 68 | 54.4% |
| DOCSIS 3.1 | 57 | 45.6% |

Upon closer examination, the majority of the codewords on OFDMA are passing at 16-QAM, a much lower modulation order then 512-QAM. This service group also has several cable modems that are currently impaired on OFDMA. At 16-QAM the OFDMA channel can only achieve 86 Mbps. Correcting this upstream performance issue could restore 109 Mbps of upstream capacity back to this service group. As seen in the information below, correction of this issue also initiated the correction of the traffic pattern.

**Table 17 – Updated Capacity – Case Study 2**

| Capacity Type | Capacity (Mbps) | Peak Utilization (Mbps) | Peak Burst Capacity (Mbps) |
|---|---|---|---|
| 48 Downstream SC-QAM | 1824 | 395 | 1495 |
| OFDM (168 MHz @1024-QAM) | 1438 | 991 | 447 |
| 6 Upstream SC-QAM (@64-QAM) | 156 | 72 | 84 |
| OFDMA (25.4 MHz @512-QAM) | 195 | 108 | 87 |

 

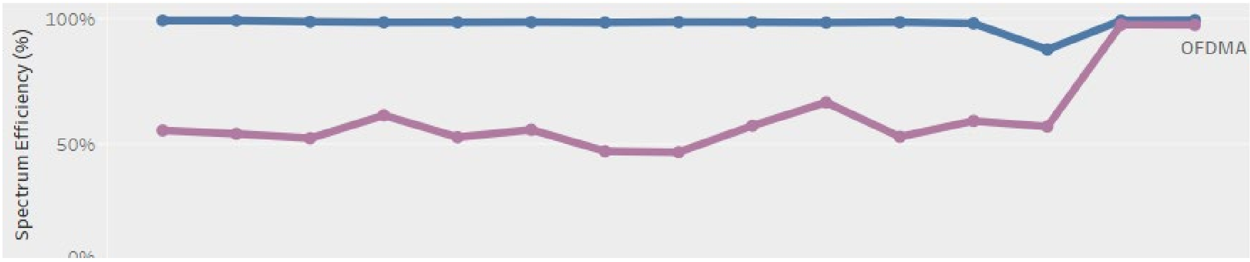


**Figure 4 – Spectrum Efficency – Case Study 2**

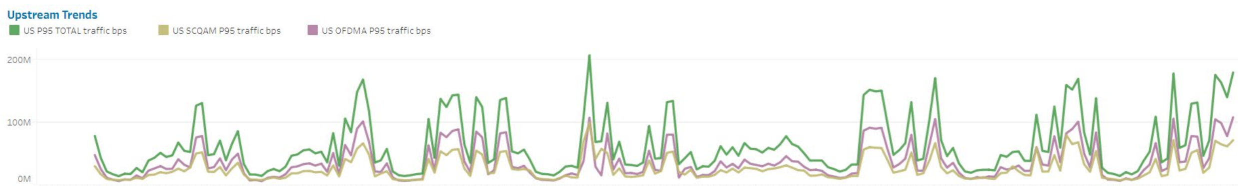


**Figure 5 – Updated Hourly Downstream Traffic Graph – Case Study 2**

### 7.3. Case Study 3 - Billboard Service with Low Burst Capacity

If service group congestion is not an issue, the focus moves to the next highest priority - supporting the highest service levels. Users of the highest services are generally heavier users, though in the majority of cases, the maximum service rate is rarely used. Ensuring efficient burst capacity for these services will enable the customer to achieve their max speeds during all hours. This will drive higher customer happiness as their service is capable during all hours.

This case study is based Node 402A, which is capable of 1 GHz with an 85 MHz return. The current DOCSIS configuration and utilization is:

**Table 18 – Capacity – Case Study 3**

| Capacity Type | Capacity (Mbps) | Peak Utilization (Mbps) | Peak Burst Capacity (Mbps) |
|---|---|---|---|
| 32 Downstream SC-QAM | 1216 | 899 | 317 |
| OFDM (112 MHz @256-QAM) | 774 | 624 | 150 |
| 6 Upstream SC-QAM (@64-QAM) | 156 | 46 | 110 |
| OFDMA (25.4 MHz @512-QAM) | 195 | 87 | 108 |

The CMTS' MAC scheduler prioritizes OFDM traffic on the downstream and tries to balance traffic on the upstream.

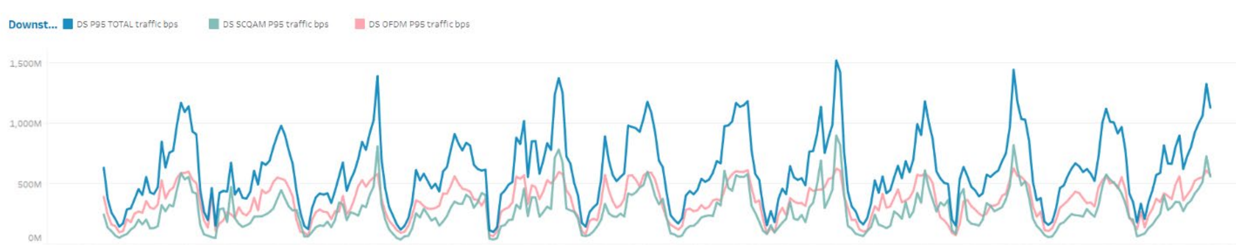


 

**Figure 6 – Hourly Downstream Traffic Graph – Case Study 3**

The upstream is not congested so the current configuration looks strong. On the downstream, despite heavy usage on OFDM, there is room on SC-QAM channels. The Internet/IPTV cable modem distribution is:

**Table 19 – Cable Modem Distrabution – Case Study 3**

| Capacity Type | Count | % Of Distribution |
|---|---|---|
| DOCSIS 2.0 | 3 | 1% |
| DOCSIS 3.0 | 92 | 32.1% |
| DOCSIS 3.1 | 278 | 66.9% |

This service group has a high DOCSIS 3.1 distribution which explains the high OFDM usage and low SC-QAM usage. The top service tier for this service group today is 1 Gbps/100 Mbps, and the current burst capacity on the downstream is 803 Mbps, and most of it is on SC-QAM channels. Because the 1 Gbps service tier is only offered on DOCSIS 3.1 cable modems, increases to OFDM capacity would be the best path forward. In this example, reclaiming SC-QAM capacity for OFDM is not required since additional spectrum for OFDM is available.

After expanding OFDM to 192 MHz and adding 1024-QAM flat profile, 873 Mbps of capacity was added to OFDM. The new DOCSIS configuration and utilization is:

**Table 20 – Updated Capacity – Case Study 3**

| Capacity Type | Capacity (Mbps) | Peak Utilization (Mbps) | Peak Burst Capacity (Mbps) |
|---|---|---|---|
| 48 Downstream SC-QAM | 1824 | 590 | 1234 |
| OFDM (192 MHz @1024-QAM) | 1647 | 940 | 707 |
| 6 Upstream SC-QAM (@64-QAM) | 156 | 46 | 110 |
| OFDMA (25.4 MHz @512-QAM) | 195 | 87 | 108 |

The CMTS' MAC scheduler prioritizes OFDM traffic on the downstream and tries to balance traffic on the upstream.

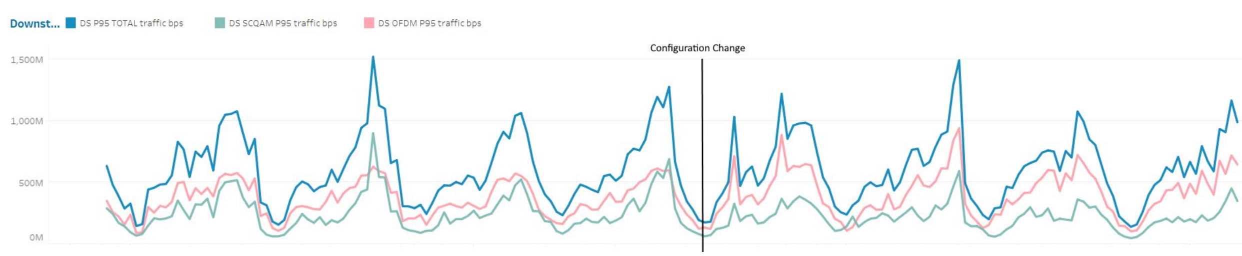


**Figure 7 – Updated Hourly Downstream Traffic Graph – Case Study 3**

This configuration change has provided considerably more burst capacity, but due to the OFDM priority of the MAC scheduler the greatest usage change occurred to OFDM not SC-QAM capacity. Now, not only does this service group now have the burst capacity to support the 1 Gbps product, it can also support a higher service offering if offered.

 

### 7.4. Case Study 4 - Low Utilization Service Group

This case study applies to situations in which operators must reclaim capacity in order to reduce licensing costs. Licensing agreements with each multiple system operators (MSO) can vary from vendor to vendor. If reduction of DOCSIS spectrum can yield a license cost savings this case study provides a good example.

This case study is based Node 236A, which capable of 1 GHz with an 85 MHz return. The highest service tier offered is 1.5 Gbps/100 Mbps. The current DOCSIS configuration and utilization is:

**Table 21 – Capacity – Case Study 4**

| Capacity Type | Capacity (Mbps) | Peak Utilization (Mbps) | Peak Burst Capacity (Mbps) |
|---|---|---|---|
| 48 Downstream SC-QAM | 1824 | 100 | 1724 |
| OFDM (192 MHz @256-QAM) | 1647 | 154 | 1493 |
| 6 Upstream SC-QAM (@64-QAM) | 156 | 72 | 84 |
| OFDMA (25.4 MHz @512-QAM) | 195 | 87 | 108 |

The CMTS' MAC scheduler prioritizes OFDM traffic on the downstream and tries to balance traffic on the upstream.

This service group is efficient in its upstream capacities. However, the downstream is very much over built. Because this is an economic choice there is some difficulty in determining the "right" direction. Assuming cost savings were the same between SC-QAM and OFDM reductions, the most sensible option would be to reduce SC-QAM capacity by 50%. Pushing more capacity towards the ideal conditions for capacity per hertz.

### 7.5. Case Study 5 - High Utilization of Legacy Capacity

After the deployment of new capacity legacy capacity customers maybe impacted *if* their capacity was reduced during the process. Even with extensive planning, abnormal service groups can appear to have congestion or high utilization of legacy capacity.

This case study is based Node 1, which is capable of 1 GHz with an 85 MHz return. The highest service tier offered is 1.5 Gbps/100 Mbps. The current DOCSIS configuration and utilization is:

**Table 22 – Capacity – Case Study 5**

| Capacity Type | Capacity (Mbps) | Peak Utilization (Mbps) | Peak Burst Capacity (Mbps) |
|---|---|---|---|
| 48 Downstream SC-QAM | 1824 | 366 | 1458 |
| OFDM (192 MHz @256-QAM) | 1318 | 604 | 714 |
| 6 Upstream SC-QAM (@64-QAM) | 156 | 116 | 40 |
| OFDMA (25.4 MHz @512-QAM) | 195 | 63 | 132 |

The CMTS' MAC scheduler prioritizes OFDM traffic on the downstream and tries to balance traffic on the upstream.

 


**Figure 8 – Hourly Downstream Traffic Graph – Case Study 5**

The Internet/IPTV cable modem distribution is:

**Table 23 – Cable Modem Distrabution – Case Study 5**

| Capacity Type | Count | % of Distribution |
|---|---|---|
| DOCSIS 2.0 | 5 | 1.8% |
| DOCSIS 3.0 | 124 | 43.5% |
| DOCSIS 3.1 | 156 | 54.7% |

The downstream is distributed very well and can support top tier packages, and the downstream SC-QAM has a significant amount of capacity to support legacy capacity customers. The problem shows up on the upstream, where there is low burst capacity on SC-QAM channels. While the highest upload package sold for this service group for legacy capacity is 30 Mbps, and there is sufficient burst capacity to support that package, this is playing very closely to the edge.

The legacy capacity could be increased by adding an SC-QAM channel and reducing OFDMA by 6.4 MHz. This would increase the legacy capacity by 26 Mbps to 66 Mbps, but reduce the OFDMA capacity by 36-37 Mbps.

### 7.6. Case Study 6 – Spectrum Boundary

As the industry moves towards DOCSIS 4.0 the possible net increase of new capacity becomes significant. Recently, high-split upgrades were completed that can provide insight into a scenario with a marked increase in poor cable modem distribution of capable modems. This is an interesting case study that showcases what can occur with an activation of a new spectrum boundary.

This case study is based Node 7518, which is capable of 1 GHz with an 85 MHz return. The current DOCSIS configuration and utilization is:

**Table 24 – Capacity – Case Study 6**

| Capacity Type | Capacity (Mbps) | Peak Utilization (Mbps) | Peak Burst Capacity (Mbps) |
|---|---|---|---|
| 32 Downstream SC-QAM | 1824 | 68 | 1756 |
| OFDM (192 MHz @256-QAM) | 1318 | 140 | 1178 |
| 6 Upstream SC-QAM (@64-QAM) | 156 | 23 | 133 |
| OFDMA (25.4 MHz @512-QAM) | 195 | 39 | 122 |
| OFDMA (64 MHz @512-QAM) – High-split | 476 | 52 | 458 |

The CMTS' MAC scheduler prioritizes OFDM traffic on the downstream and tries to balance traffic on the upstream.

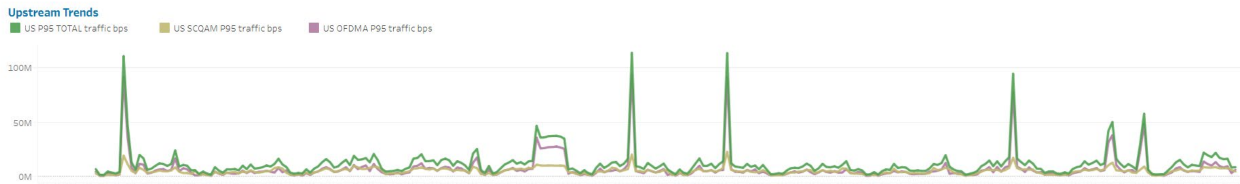


**Figure 9 – Hourly Downstream Traffic Graph – Case Study 6**

The Internet/IPTV cable modem distribution is:

**Table 25 – Cable Modem Distrabution – Case Study 6**

| Capacity Type | Count | % Of Distribution |
|---|---|---|
| DOCSIS 2.0 | 0 | 0% |
| DOCSIS 3.0 | 7 | 24.1% |
| DOCSIS 3.1 (Mid-split) | 21 | 72.4% |
| DOCSIS 3.1 (High-split) | 1 | 3.5% |

Even with this service group having very low utilization it still shows inefficient use of the high-split OFDMA channel. Given there is no congestion, immediate actions to rectify spectrum inefficacy from occurring is not required. Traffic distribution could normalize if more high-split capable modems were added. Another option to increase efficiency would be to prioritizing the high-split OFDMA channel over the remaining capacity, which would drive all high-split modem traffic to the high-split OFDMA channel until full. This would require fewer cable modems to be switched out to maintain capacity below the high-split spectrum addition.

# 8. Looking Forward to DOCSIS 4.0

As we move towards DOCSIS 4.0, what changes in the ways we manage technology borders to optimize access networks? The methods above can be applied, like an example reduction of legacy capacity in place of new capacity. DOCSIS 4.0 increases the importance of understanding the necessary planning in the reduction of legacy capacities, which has the potential to impact legacy services. DOCSIS 4.0 comes in two major designs: FDD and FDX. These designs will have different impacts on their technology borders from each other.

## 8.1. FDD Changes

For FDD DOCSIS 4.0 access network will largely have the same types of boundaries discussed in this paper. However, there is greater risk to legacy services due to the conversion of forward spectrum to return spectrum. Strong pre-planning is required to avoid poor legacy services post upgrade. After the upgrade is completed, the operator is able to return to modem upgrades and spectrum management as before. Given that is the largest spectrum upgrade that has occurred so far, operators will need to be aware of a number of important considerations - from spectrum efficiency for each customer to identified plant condition issues - to maintain capacity for each customer. Each OFDM channel representing a large chunk of capacity, cable modems that are unable to utilize most OFDM channels could have poor experiences, but a single OFDM impairment can be non-impacting. DOCSIS 4.0 FDD will require the management of the reduction of SC-QAM capacity. The continual forward progression towards OFDM/OFDMA only networks will require the application of the above optimization approaches in optimization to know when to take the next step forward.

### 8.2. FDX Changes

With FDX, the change for DOCSIS 4.0 access network is greater than that of FDD. Despite FDX having the advantage of software upgraded spectrum (up to 684 MHz), this capacity is *not* available to the whole service group, but is shared between interference groups (IG). This creates an additional technology boundary to manage. Due to the capacity gains achieved by this upgrade interference groups will not be an issue at the inception of this technology, as time goes forward it has the potential to restrict product offerings and capacity management options.

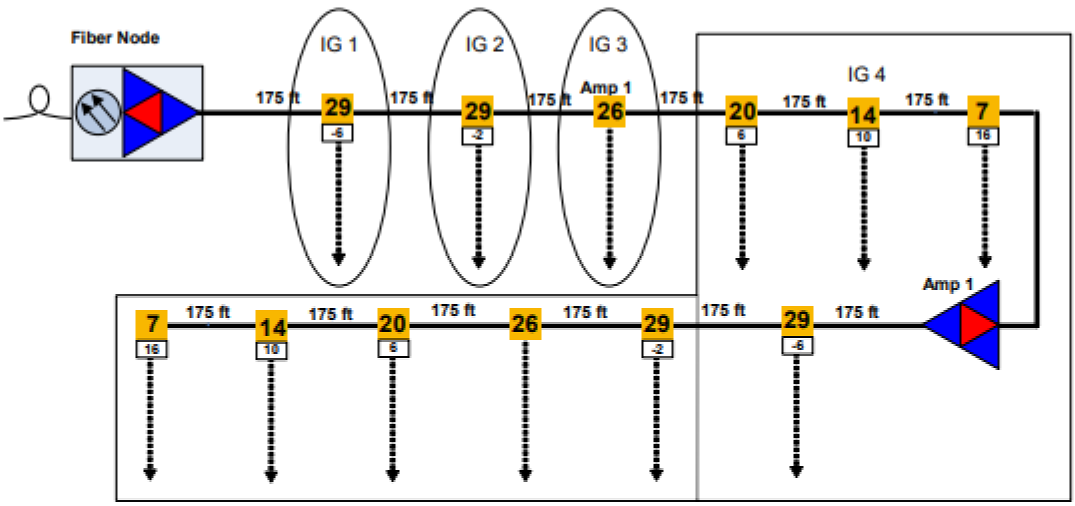


**Figure 10 – DOCSIS 4.0 FDX N+1 Interferance Groups[2]**

In the diagram above, an N+1 FDX setup and corresponding interference groups are displayed. For capacity issues with IG 4, segmenting Amp 1 to its own Fiber Node is a logical solution. However, congestion on IG 1-3 how is this managed? Do you segment between these IG to management congestion? As is evident, the new technology boundary of interference groups will be challenging to overcome, but challenges can be overcome.

## 9. Conclusion

Operators will be required to build processes to manage capacity by channel or capacity type, in addition to the service group level moving forward. This is a key steppingstone as we move forwards towards mature DOCSIS 3.1 access networks, and to the path forward to DOCSIS 4.0. Other key steppingstones are distributed access architecture (DAA), PMA, and multiple OFDM/OFDMA channel configurations. The next few years will bring a lot of change to access networks, but the industry is ready to manage this. Enjoy the road towards 10G.

# Abbreviations

| | |
|---|---|
| CER | Codeword error rate |
| CM | Cable modem |
| CMTS | Cable management termination systems |
| DAA | Distributed access architecture |
| DOCSIS | Data over cable service interface specifications |
| FDD | Frequency division duplexing |

 

| | |
|---|---|
| FDX | Full-duplex DOCSIS |
| FEC | Forward error correction |
| Gbps | Gigabits per second |
| GHz | Gigahertz |
| HFC | Hybrid fiber coax |
| IG | Interference group |
| IPTV | Internet protocol television |
| KPI | Key performance indicator |
| Mbps | Megabits per second |
| MHz | Megahertz |
| MSO | Multiple System Operators |
| OFDM | Orthogonal frequency-division multiplexing |
| OFDMA | Orthogonal frequency-division multiple access |
| PMA | Profile management application |
| SC-QAM | Single carrier quadrature amplitude modulation |

# Bibliography & References

[1] SCTE 2014: *Traffic Engineering in a Fiber Deep Gigabit World;* John Ulm and Tom Cloonan; Society of Cable Telecommunications Engineers

[2] SCTE 2021: *Developing The DOCSIS 4.0 Playbook For The Season Of 10g;* Dr. Robert Howald and John Williams; Society of Cable Telecommunications Engineers

 