WHITE PAPER

OPTIMIZING DOCSIS 3.1 NETWORKS:

The Benefits of Protocol Analysis

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About the Authors

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Executive Summary

Through mounting pressure from network-service competitors and customers, multiple system operators (MSOs) have many challenges, including the need to increase data-transfer rates, meet tighter service-level agreements (SLAs) and ensure network availability. The implementation of the paradigm-shifting DOCSIS® 3.1* specification is slated to solve all of these challenges while opening the door to many other network capabilities. As most MSOs begin to plan their DOCSIS 3.1 deployments, they need to also consider the tools they will require to ensure that maximum network availability and the guaranteed service levels are in place and maintained. These tools will enable operators to not only understand the complexity of the network capability but also how to ensure robust system performance. This paper examines the challenges associated with deploying the next generation of the DOCSIS specification and the tools that can ensure network availability, higher bandwidths and increased data-transfer rates.

1. INTRODUCTION

DOCSIS 3.1's higher bandwidth and higher-speed data communication capabilities will certainly open up new doors for MSOs in a number of areas, including business services, Over The Top (OTT) video, 4K video, and 3DTV. As the network use cases and bandwidth usage continue to change, they bring with them a new set of operator challenges. Understandably, MSOs are asking questions such as "How can we maintain the highest quality of service while also anticipating and handling service-related issues?"

Adding a further layer of complexity to the DOCSIS 3.1 dimension is the existing specification, DOCSIS 3.0. Even though it was launched in 2006, it is still a vibrant entity, with DOCSIS 3.0 equipment deployments continuing to ramp up, including changes such as support for additional bonded channels. That reality, combined with the major changes coming soon due to DOCSIS 3.1, means that there is a need for a new set of analysis tools that will be able to bridge both standards and ensure

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that operators are capable of maintaining their networks and providing satisfactory customer experience.

As with each previous DOCSIS version, the new DOCSIS 3.1 standard will have its own set of complexities, from both implementation and operational points of view. As well as ensuring that the network is being maintained, MSOs will also need to ensure that the protocol is being implemented correctly. This paper discusses some of the key features of DOCSIS 3.1, as well as deployment challenges, and how MSOs and their networks can benefit from new protocol analysis tools.

2. WHAT IS PROTOCOL ANALYSIS?

At a basic level, network operators can perform protocol analysis, often called "packet sniffing," to capture packets and decode them into their component parts, especially for troubleshooting communication issues. While this is the traditional application of protocol analyzers, they can actually do much more than packet sniffing; for example, they can be surprisingly useful in many aspects of network management for analyzing, debugging, maintaining and monitoring local networks and Internet connections.

By providing statistics on network traffic, protocol analyzers can play a valuable role helping MSOs identify trends that may lead to further network problems. Since these tools are versatile, they can be used by a variety of individuals who have network responsibility or by anyone who needs to better understand traffic issues. For example, a protocol analyzer may be used for various scenarios such as:

- Troubleshooting real-time outage and service interruptions
- Analysis of strange network behavior
- Producing real-time and historical statistics to help observe link health and behavior over time
- Lab testing and validation

2.1 A Non-Intrusive Network Monitoring Tool

Figure 1 illustrates how a protocol analyzer can be inserted in a network to act as a passive observer of upstream (US) and downstream (DS) DOCSIS communication between the cable modem termination system (CMTS) and customer premises equipment (CPE) such as modems and set-top boxes. As a non-intrusive probe, a protocol analyzer does not impact the network communication, which will assure that operators receive the most accurate real-time measurements to help them quickly identify and remedy any problems or strange behavior occurring on the network.

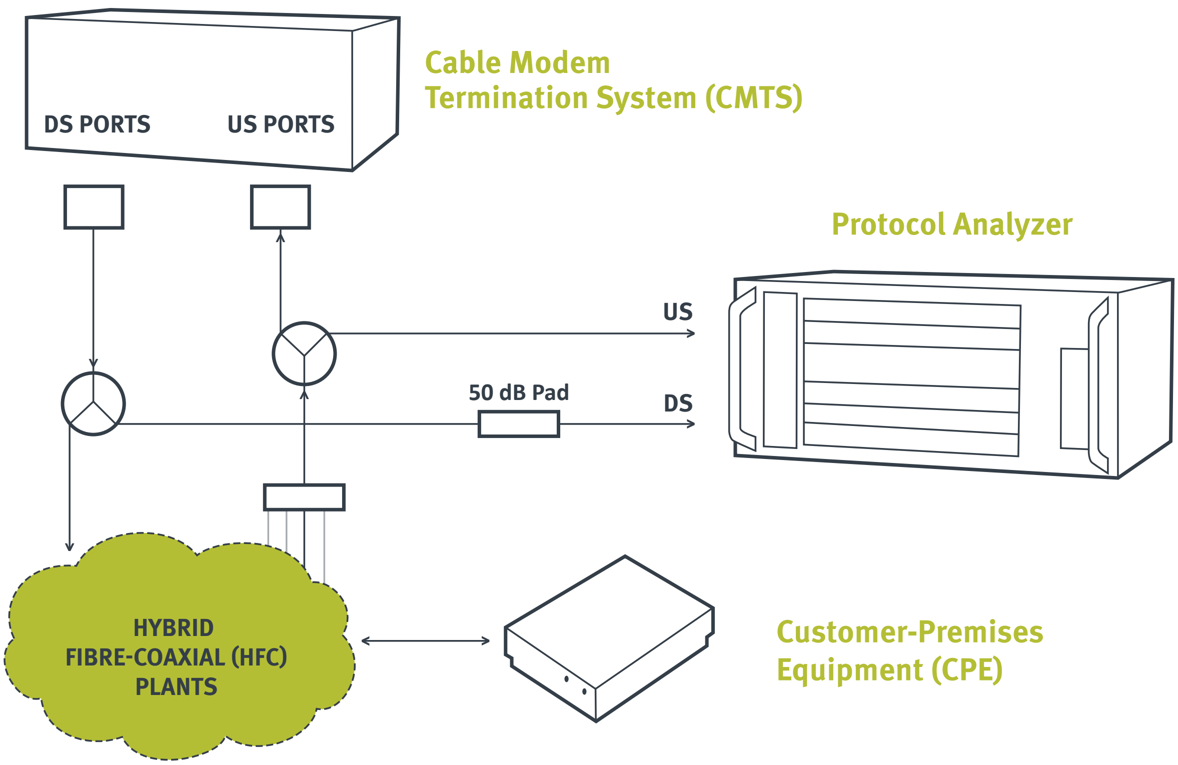

Figure 1 – Protocol Analyzer on a DOCSIS Network

2.2 Typical Protocol Analysis Capabilities

For the past few decades, protocol analysis tools have proven to be effective solutions for debugging and resolving network issues. And due to the changing nature of networks, a protocol analyzer needs to be flexible, upgradable and extendible to handle evolving protocol standards. A protocol analyzer's non-intrusive network-probing – combined with its ability to take RF measurements and perform MAC-level communication analysis – can provide that additional level of monitoring. Important functions of a protocol analyzer include:

- Verification of RF parameters
- Validation of MAC-level communication
- Real-time demodulation
- Triggering capabilities
- Recording capabilities for communication packets
- Support for multiple protocol standards

This section outlines typical functions that a protocol analyzer can perform.

2.2.1 Displaying RF Parameters

A common feature of a protocol analyzer is constellation and spectrum views to display RF parameters and measurements in order for the operator to view and evaluate certain network behavior. These views provide valuable information on network health and why some CPE might not be locking. Such parameters include:

- Input power levels
- Modulation Error Ratio (MER)
- Error Vector Magnitude (EVM)

2.2.2 Troubleshooting MAC-level Communications

Another important aspect of a protocol analyzer is its ability – in real-time or offline – to help validate MAC-level communication and troubleshoot interoperability issues. In addition, a filtering capability can significantly improve analysis time by focusing on specific transactions and messages. These functions enable the operator to perform more effective testing scenarios such as:

- Validating that a message from a CMTS or cable modem (CM) is properly formatted.
- Verifying that some transactions between the CMTS and the CM (e.g., REQ/RSP/ACK mechanisms) properly take place under normal conditions.
- Verifying how the CMTS or CM reacts to some events by analyzing the content of the resulting MAC messages.

2.2.3 Performing Real-time Demodulation and Capture

The ability to perform real-time demodulation and capture is another advantage of a protocol analyzer. Real-time MAC-layer capture, combined with filtering, can provide the operator with valuable information by allowing the efficient identification of network and communication problems without having to wait for the capture to end. Applications for this function include:

- The real-time demodulation and display of the OFDM channel descriptor (OCD) in order to provide useful information for debugging a CMTS and understanding why the CM is not locking.
- Providing additional monitoring capabilities by allowing the operator to enable alarms and threshold alerts.

2.2.4 Configuring Triggers

All protocol analysis tools are aimed at facilitating an operator's daily tasks, such as the ability to configure triggers that can either initiate a capture or inform external equipment to start taking specific measurements. Here are two examples of triggering capabilities that an operator can benefit from:

- A capture trigger, which can be configured for specific types of messages or a destination source (MAC) address.
- A hardware trigger, which can be configured for specific types of messages. This option allows other devices and equipment – such as a spectrum analyzer or even integration into a custom solution – to extend DOCSIS testing scenarios and possibilities.

2.2.5 Evolving with the DOCSIS Standard

As the DOCSIS protocol standard evolves, a protocol analyzer must likewise be capable of evolving, including the ability to:

- Configure and upgrade the protocol analysis system to test different DOCSIS standards (backwards compatibility) and provide additional functions.
- Script and automate the testing of use cases and scenarios by providing access to software components remotely, such as via an application programming interface (API).

3. DOCSIS 3.1 NETWORK CHALLENGES

DOCSIS 3.1 incorporates some new technology for the cable industry that will extend the life of traditional Hybrid Fiber-Coaxial (HFC) plants by providing enhanced and additional services. From a practicality standpoint, DOCSIS 3.1 has the potential to deliver capacity of more than 10 Gb/s in the downstream and 1 Gb/s in the upstream. This section examines the different features of a DOCSIS 3.1 network and how they can benefit from protocol analysis.

3.1 Network Bandwidth and Channel Expansion

Since DOCSIS 3.1 will allow network expansion in both the upstream and downstream as needed by the operators, an important aspect of DOCSIS 3.1 is that it will operate on existing HFC networks and, as needed, those networks can be updated to accommodate more bandwidth, as outlined in the DOCSIS 3.1 specification:

> In the downstream direction, the cable system is assumed to have a pass band with a lower edge of either 54 MHz, 87.5 MHz, 108 MHz or 258 MHz, and an upper edge that is implementation-dependent but is typically in the range of 550 to 1002 MHz. Upper frequency edges extending to 1218 MHz, 1794 MHz and others are expected in future migrations of the plants.
>
> In the upstream direction, the cable system may have a 5-42 MHz, 5-65 MHz, 5-85 MHz, 5-117, 5-204 MHz or pass bands with an upper band edge beyond 204 MHz.[1]

Figure 2 illustrates the current upstream/downstream bandwidth and how the bandwidth may be allocated in the near and longer term.

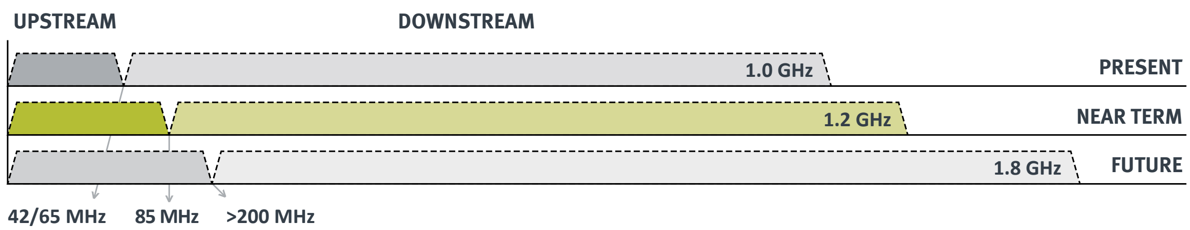

Figure 2 – Current and Future Bandwidth Allocation

3.1.1 Tools and Strategies for Network Bandwidth and Channel Expansion

Planning and implementing these extended bandwidths will, of course, require new tools and strategies. Some elements that will need to be deployed to accommodate the changing frequency spectrum include:

- A protocol analyzer capable of covering the entire frequency band. This will minimize capital expenditures as the operators start to use the upper frequency bands (1.8 GHz).
- Downstream and upstream channel configurations that allow operation in the different bands.
- Modular instruments that enable system capabilities to be upgraded and extended as network needs evolve with additional features and functions using the same hardware and components.
- Multiple systems that can be synchronized in order to offer extended coverage and analysis of the DOCSIS band.

3.2 Orthogonal Frequency Division Multiplexing (OFDM) and Advanced Modulation Formats

Cable networks have become more dependable due to better maintenance and deeper fiber, allowing operators to significantly expand the amount of data that can be transmitted. DOCSIS 3.1 enables operators to take further advantage of these industry developments, including via the deployment of Orthogonal Frequency Division Multiplexing (OFDM).

OFDM is a transmission technique that uses many carriers spaced apart at slightly different frequencies. In the OFDM technique, the allotted bandwidth is divided into a large number of smaller bandwidths, or sub-carriers, as explained below and as shown in Figure 3:

> A large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation) [QAM] at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.[2]

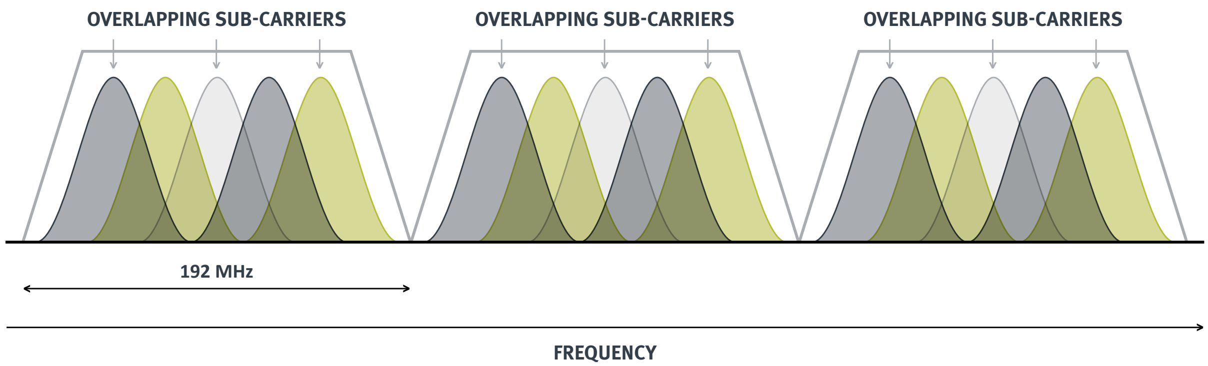

Figure 3 – OFDM Channels on a DOCSIS Network

The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions such as multipath and narrowband interference.

Another feature of DOCSIS 3.1 is its ability to define multiple downstream profiles on a single channel. A downstream profile defines each of the sub-carrier's own modulation formats and amplitude in the OFDM channel. For example, it can define a different modulation order for a different part of the channel so the throughput in the downstream can be optimized according to the signal-to-noise ratio (SNR).

The CMTS defines multiple downstream profiles and assigns some of the profiles to each CM during registration. When the CMTS sends data to a specific CM or group of CMs, it uses one of the downstream profiles assigned to that CM or group of CMs. The CMTS can then effectively react dynamically to a change in network conditions in order to optimize its throughput.

3.2.1 Meeting the Challenge of 4K QAM

In addition, operators will now have to deal with the added complexities of not only a wider OFDM channel (channel bandwidths of 24 MHz to 192 MHz for downstream OFDM, and up to 96 MHz for the upstream) but with the challenges of the new 4K QAM (4096-QAM) compared to 256-QAM, which has been the modulation format of choice for several years. As the SNR decreases, the received symbol has a greater chance of being far from the expected symbol because higher-order modulations mean higher density, which makes them more error-prone on decision-making when the noise level is high.

Figure 4 illustrates the vast differences of 256-QAM and 4096-QAM constellations.

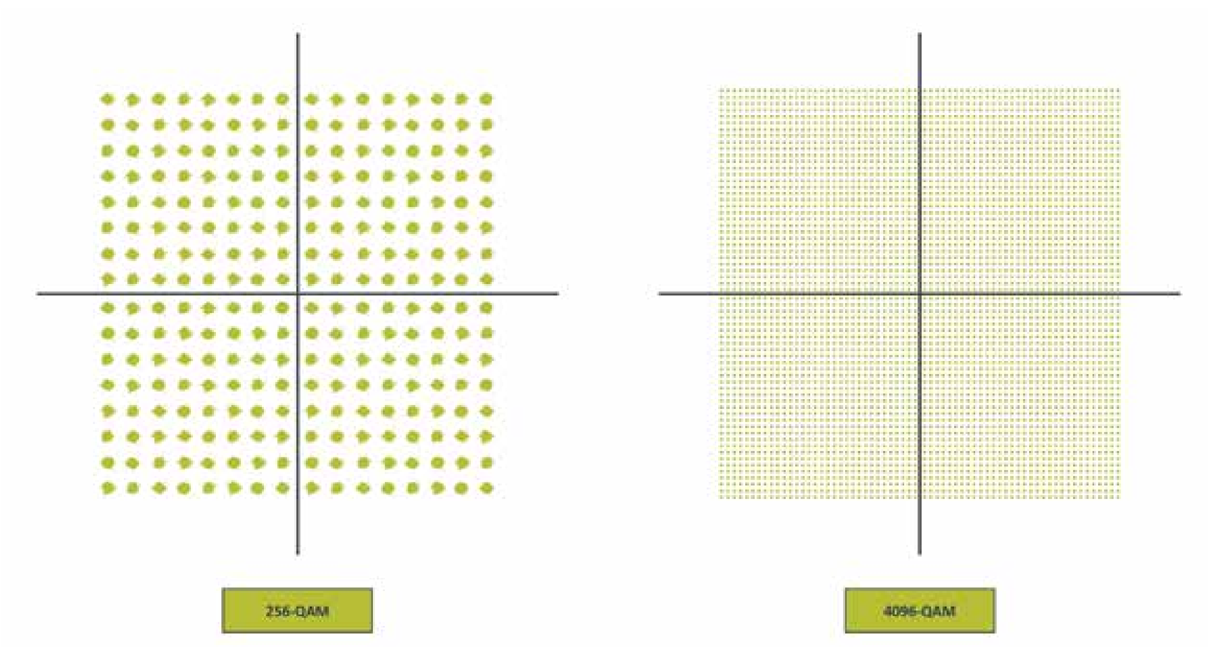

Figure 4 – 256-QAM versus 4096-QAM

3.2.2 Tools and Strategies for OFDM and Advanced Modulation Formats

Considering where the protocol analyzer is placed in the system (i.e., in the RF section of the network), and its ability to demodulate the signal, the following issues need to be taken into consideration for DOCSIS 3.1 deployments:

- OFDM and advanced modulation formats will yield high throughput. Thus, the protocol analyzer will require a tremendous amount of processing power to analyze and monitor how the CMTS and CMs react during specific network conditions.
- Operators will need to cover the 192-MHz channels required for OFDM as well as the resolution needed for valid measurements. This will require real-time demodulation of all sub-carriers and the modulation profile.
- Ability to analyze and monitor only a specific downstream profile, thus concentrating the monitoring effort on a group of CMs under the same network conditions.
- Display a specific downstream profile modulation order versus a sub-carrier for a given channel. By knowing to which CM a profile is intended, operators can dynamically monitor the profile evolution to help them understand how the CMTS handles and reacts to changes in network conditions.
- MER information availability on a per-profile/per-sub-carrier basis or IUC/mini-slot in the upstream. This can be used to debug CMTS algorithms for determining downstream and upstream modulation profiles.

3.3 Mixed Mode Operation

Since the industry's aim is to make DOCSIS 3.1 backwards-compatible with the previous standard, a DOCSIS 3.1 CMTS will be required to support older modems. In reality, despite the constant evolution of network and consumer equipment, legacy data systems may have to support CPE models ranging from the latest high-performance units to ones that are more than 10 years old.

To address these huge client-side technical differences, one of the operating modes that can aid in the migration to DOCSIS 3.1 is enabled by turning off a block of OFDM sub-carriers in the OFDM channel and operating a single-carrier QAM channel within that spectrum. Thus, DOCSIS 3.1 modems and DOCSIS 3.0 modems will be able to operate in the same serving group, with the DOCSIS 3.1 modems using both the OFDM and single-carrier (SC)-QAM channels and DOCSIS 3.0 modems operating in SC-QAM channels. This allows for the use of OFDM across the entire spectrum, while maintaining backwards compatibility.

Figure 5 illustrates a possible channel plan with various mixed-mode operation.

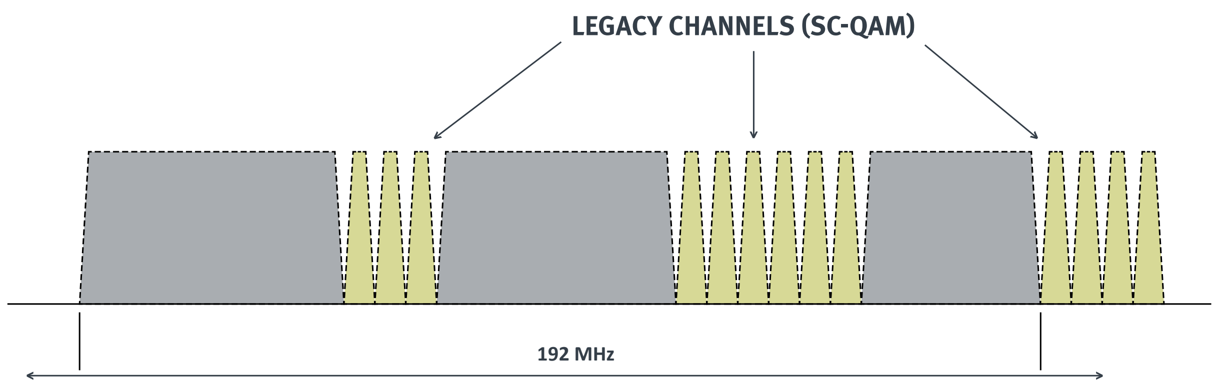

Figure 5 – Mixed Mode Operation

3.3.1 Time and Frequency Multiplexing

Another DOCSIS 3.1 feature is time and frequency multiplexing. According to the DOCSIS 3.1 MAC and Upper Layer Protocols Interface specification[3], the networks must support the following scenarios:

> ...a mix of new OFDMA channels with older legacy SC-QAM channels. DOCSIS 3.1 also allows simultaneous Time and Frequency Division Multiplexing, i.e.:
>
> - OFDMA and SC-QAM can simultaneously operate on separate frequencies.
> - OFDMA and SC-QAM can also operate on the same frequencies, divided in time.

Figure 6 depicts the DOCSIS 3.1 time and frequency multiplexing paradigm for the upstream.

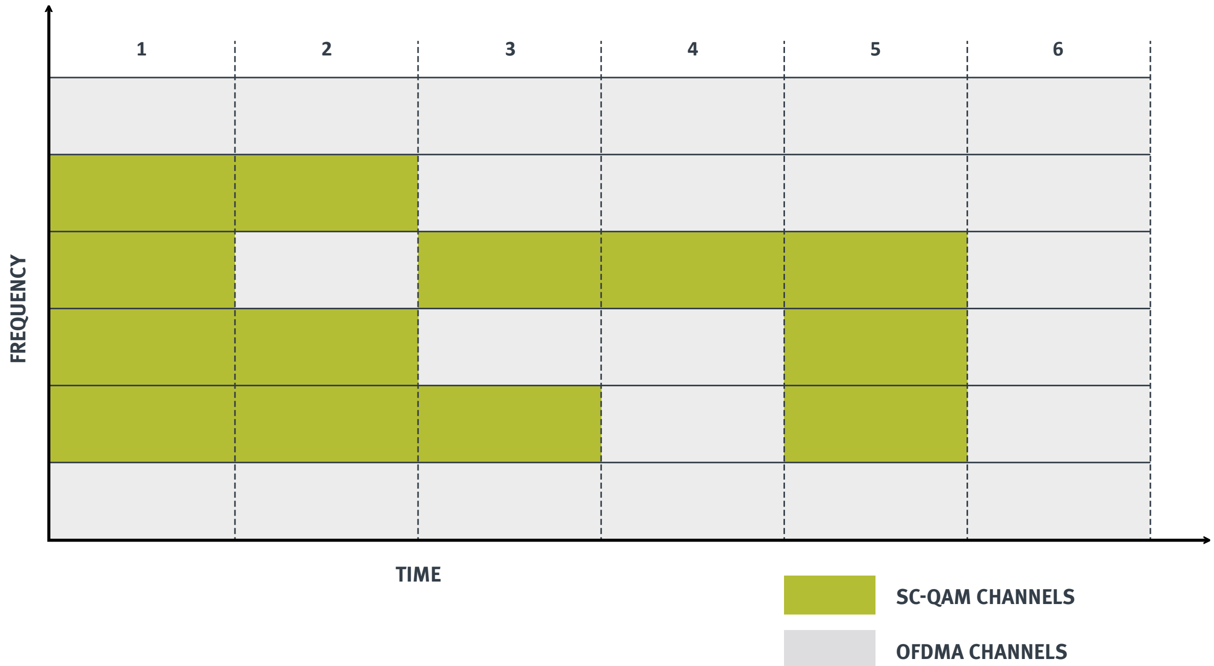

Figure 6 – Upstream Time and Frequency Multiplexing[4]

3.3.2 Tools and Strategies for Mixed Mode Operations

Again, because of the multiple challenges of operating in mixed mode, a flexible protocol analyzer can offer some distinct benefits:

- Support for multiple DOCSIS standards on the same system. At a minimum, the protocol analyzer should be able to analyze both DOCSIS 3.0 and 3.1 at the same time. A mix of downstream and upstream on both standards should be supported as well as the capability to capture both legacy and OFDM channels.
- Ability to use the same hardware for DOCSIS 3.0 or 3.1 with different software configurations and upgrades, which enables extended capabilities in monitoring network configuration.
- Different logical channels (such as a mix of DOCSIS 3.0 and DOCSIS 3.1) can be monitored on the same frequency and analyzed as different channels on the MAC-layer level.
- Multiple systems can be synchronized for a full analysis of legacy and OFDM channel bonding.

4. CONCLUSION

As many MSOs begin evaluating and deploying DOCSIS 3.1 equipment and capabilities, they also have to consider the tools they will need to ensure that maximum network availability and realistic SLAs are in place and maintained. Protocol analysis will enable them to both understand the complexity of their networks and to ensure that their networks perform as expected. This is especially true as the MSOs expand current offerings and deploy new services such as for business, Over The Top (OTT) video, 4K video, and 3DTV.

This paper outlined some of the challenges MSOs will face while implementing, testing and maintaining their DOCSIS 3.1 networks, and how using protocol analysis can complement their traditional network-monitoring methods. This new DOCSIS standard brings its share of complexities, thus next-generation protocol analysis tools should be flexible enough to handle the existing DOCSIS standard, the new DOCSIS standard's strict requirements, and its likely evolution. Such tools will enable operators – both in real-time and offline – to efficiently monitor, analyze and troubleshoot their networks in many practical and beneficial ways.

References

[1] **CableLabs**. "Data-Over-Cable Service Interface Specifications DOCSIS® 3.1 Physical Layer SpecificationCM-SP-PHYv3.1- I03-140610," http://www.cablelabs.com/wp-content/uploads/specdocs/CM-SP-PHYv3.1-I03-140610.pdf

[2] **Anon**. "Orthogonal frequency-division multiplexing," http://en.wikipedia.org/wiki/Orthogonal_frequency-division_multiplexing.

[3] **CableLabs**. "Data-Over-Cable Service Interface Specifications DOCSIS® 3.1 MAC and Upper Layer Protocols Interface Specification CM-SP-MULPIv3.1-I03-140610," http://www.cablelabs.com/wp-content/uploads/specdocs/CM-SP-MULPIv3.1-I03-1406101.pdf.

[4] **Ibid**, page 63.

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