DOCSIS® 4.0
Tools and Readiness

Cable Operator Preparations for DOCSIS 4.0 Technology Deployment

CM-TR-TAR-4.0-V01-230629

RELEASED

Notice

This DOCSIS technical report is the result of a cooperative effort undertaken at the direction of Cable Television Laboratories, Inc. for the benefit of the cable industry and its customers. You may download, copy, distribute, and reference the documents herein only for the purpose of developing products or services in accordance with such documents, and educational use. Except as granted by CableLabs® in a separate written license agreement, no license is granted to modify the documents herein (except via the Engineering Change process), or to use, copy, modify or distribute the documents for any other purpose.

This document may contain references to other documents not owned or controlled by CableLabs. Use and understanding of this document may require access to such other documents. Designing, manufacturing, distributing, using, selling, or servicing products, or providing services, based on this document may require intellectual property licenses from third parties for technology referenced in this document. To the extent this document contains or refers to documents of third parties, you agree to abide by the terms of any licenses associated with such third-party documents, including open-source licenses, if any.

© Cable Television Laboratories, Inc., 2023

DISCLAIMER

This document is furnished on an "AS IS" basis and neither CableLabs nor its members provide any representation or warranty, express or implied, regarding the accuracy, completeness, noninfringement, or fitness for a particular purpose of this document, or any document referenced herein. Any use or reliance on the information or opinion in this document is at the risk of the user, and CableLabs shall not be liable for any damage or injury incurred by any person arising out of the completeness, accuracy, infringement, or utility of any information or opinion contained in the document.

CableLabs reserves the right to revise this document for any reason including, but not limited to, changes in laws, regulations, or standards promulgated by various entities, technology advances, or changes in equipment design, manufacturing techniques, or operating procedures described, or referred to, herein.

This document is not to be construed to suggest that any company modify or change any of its products or procedures, nor does this document represent a commitment by CableLabs or any of its members to purchase any product whether or not it meets the characteristics described in the document. Unless granted in a separate written agreement from CableLabs, nothing contained herein shall be construed to confer any license or right to any intellectual property. This document is not to be construed as an endorsement of any product or company or as the adoption or promulgation of any guidelines, standards, or recommendations.

Document Status Sheet

Document Control Number:	CM-TR-TAR-4.0-V01-230629			
Document Title:	Cable Operator Preparations for DOCSIS 4.0 Technology Deployment			
Revision History:	V01 – Released 6/29/23			
Date:	June 29, 2023			
Status:	~~Work in Progress~~	~~Draft~~	**Released**	~~Closed~~
Distribution Restrictions:	~~Author Only~~	~~CL/Member~~	~~CL/ Member/ Vendor~~	**Public**

Key to Document Status Codes

Work in Progress	An incomplete document, designed to guide discussion and generate feedback that may include several alternative requirements for consideration.
Draft	A document that is considered largely complete but is undergoing review by working groups, members, and vendors. Drafts are susceptible to substantial change during the review process.
Released	A public or gated document that has undergone review. Released technical reports are **not** subject to the Engineering Change process.
Closed	A static document that has been closed to further changes through CableLabs.

Trademarks

CableLabs® is a registered trademark of Cable Television Laboratories, Inc. Other CableLabs marks are listed at http://www.cablelabs.com/specs/certification/trademarks. All other marks are the property of their respective owners.

Contents

1 SCOPE

1.1 Introduction and Overview

DOCSIS 4.0 technology will soon be available, and operators are preparing for future deployments in their access networks and headends, back offices, and processes. SCTE's Engineering Committee has approved a Project Authorization Request (PAR) for Network Operations Subcommittee Working Group 5 (NOS WG5) to work on practices and develop more detailed guidelines for preparations under different beginning states for DOCSIS 4.0 Tools and Readiness. This technical report serves as a summary and early start guidance for operators who are preparing for DOCSIS 4.0 technology deployment now, before the technology is widely available, and specifications are guiding the preparations.

A network operator considering DOCSIS 4.0 technology deployment will want to determine the best network segments to prioritize for deployment. Though market opportunity will be an important factor, and preparation of the back-office systems and work force are critical steps to preparation, we discuss several tasks that operators should complete to help find the best network segments to prioritize and to identify any preparation work that will ease the transition for network operations and customers.

For network readiness, operators will first need to determine whether they plan to implement Frequency Division Duplex DOCSIS (FDD) or Full Duplex DOCSIS (FDX) and the spectrum they plan to utilize for both upstream and downstream traffic. These decisions set the stage for what work will be required to get the network ready for DOCSIS 4.0 deployment. In this technical report, we provide initial review of some of the relevant topics, including network powering requirements, new frequency utilization, new upstream frequencies, bi-directional FDX channels, and new failure modes. We also cover some initial observations on how the requirements around self installation vs. professional installation will change after upgrading a network segment to DOCSIS 4.0 technology.

Generally, the network design translates to target output levels at the tap (which may have lower performance because of implementation issues and impairments), which guide network readiness for a given tap. The drop length and localized impairments dictate home readiness. These two factors combined can provide the basis for determining how many locations would need professional installation vs. which locations may be good candidates for self-installation when offering DOCSIS 4.0 services. If the drop quality is low or if premise wiring is not ideal, professional installation will provide the opportunity to replace those items during installation.

1.2 Purpose of Report

The intent of this technical report is to provide operators with a summary of preparation efforts that they should pursue when preparing to deploy DOCSIS 4.0 technology, before the technology is widely available. The focus is on network and customer readiness, with the assumption that the operator is otherwise ready for DOCSIS 4.0 deployment. For example, the operator is assumed to have addressed any needs for billing and marketing and has determined the financial criteria and readiness for its company.

This report provides initial investigations for the network and customer premise, then deeper assessments of the network segments and customer locations, and finally to considerations of proactive preparations to improve the deployment and operation of DOCSIS 4.0 technology where deployment is committed.

1.3 Starting Positions

Operators that are considering an upgrade to DOCSIS 4.0 technology and services will be transitioning from different starting positions, but the upgrade will lead to changes in the way the spectrum is used. For example, some may be starting with a network utilizing 108 MHz to 684 MHz for downstream data. DOCSIS 4.0 technology requires migrating the downstream channels to higher frequencies to provide more upstream bandwidth. Operators transitioning to FDX implementations will be changing some frequencies to be bi-directional. Some operators also may be using certain frequencies for video-only channels. These current starting positions will impact the information we have about the network, but in many cases, we characterize a downstream frequency to determine its usefulness in the upstream.

1.3.1 DOCSIS 3.0 and 3.1 Backwards Compatibility

The first position on a DOCSIS 4.0 upgrade is that any existing DOCSIS 3.0 or 3.1 network segment can be upgraded with no changes to existing customer services. The existing customer drops, premise wiring, and the DOCSIS 3.0 and 3.1 cable modems are able to exist on the DOCSIS 4.0 network and retain the same services as they had before the network was upgraded. This includes subscribers who utilize Multimedia over Coax Alliance (MoCA) or things like HomePNA Alliance (HPNA), which should be necessary to remove only when an individual subscriber decides to upgrade to DOCSIS 4.0 technology at their location. There is likely to be some service disruption as part of the upgrade process, which requires hardware and software upgrades. However, after the upgrades are complete, the existing customers should not see any degradation in their service unless the upgrade processes introduced a new failure mode. Some of the currently known failure modes are covered later in this report.

1.3.2 DOCSIS 4.0 Vision

Before starting any DOCSIS 4.0 upgrade process, the operator must define what it wants to achieve. DOCSIS 4.0 technology has many options and variations that can be used to support different visions. The hardware and software requirements that support DOCSIS 4.0 solutions are dependent on how an operator plans to implement the upgrade. Upgrades are expected to be done incrementally over time, so an operator should include the incremental steps it wants to take and what hardware and software requirements pair with each of those steps in its vision. Some of the DOCSIS 4.0 upgrade variables to choose from are listed below.

- FDX or FDD—These two choices for DOCSIS 4.0 deployment differ on several factors: trunk amplifier requirements, powering requirements, spectrum frequency performance of passives, field meter requirements, failure mode effects, and software back-end systems requirements.
- Upstream and downstream bandwidth targets—DOCSIS 4.0 technology supports up to a maximum of 10 Gbps downstream and 6 Gbps upstream. However, an operator is not required to design its network to support maximum bandwidth even though the target speeds do impact what changes will be required on a given network segment to achieve that goal. Maxing out DOCSIS 4.0 capabilities will require a very clean and stable network using high-order quadrature amplitude modulation (QAM) constellations.
- Plan a vision for N+0 vs. N+X deployments and upgrades.
- FDX variables
    - The desired maximum spectrum frequency (up to 1.2 GHz) must be determined.
    - Any frequency in the range between 108 MHz and 684 MHz can be used for upstream-only traffic, downstream-only traffic, or bi-directional traffic. Which frequencies does the operator plan to use for upstream, downstream, or bi-directional?
    - N+0 vs. N+X deployment
    - It must be decided whether to target bandwidth density or QAM constellation (each would have different powering and modulation error ratio (MER) requirements).
- FDD variables
    - The desired maximum spectrum frequency (up to 1.8 GHz) must be determined.
    - The frequency range between 108 MHz and 684 MHz can be used for upstream-only traffic or downstream-only traffic.
    - N+0 vs. N+X deployment
    - It must be decided whether to target bandwidth density or QAM constellation (each would have different powering and MER requirements).

1.3.3 DOCSIS 4.0 Technology Not Yet Widely Available

In this report, we assume that DOCSIS 4.0 technology is not yet widely available at the time that the operator is preparing for its deployment. DOCSIS 4.0 technology will become available soon, and operators will have a choice for how they deploy it, for example, starting with CM deployments to strategic customers, then utilizing the

modem's abilities to capture spectrum at higher frequencies and analyzing the data they can collect to characterize the network. Unfortunately, this means that methods such as those outlined in [Thompson2021] and [Howald2021], which place CMs in higher splits to capture spectrum at higher frequencies, will not work when extended directly, at least not until DOCSIS 4.0-capable CMs appear on the market and are deployed. However, the methods shared in this report will help with identification of some technologies that prevent locations from being ready while we wait for general availability of DOCSIS 4.0 CMs and systems.

1.4 Prerequisites

DOCSIS 4.0 technology carries several prerequisites. The summaries in this report guide readiness efforts building from these prerequisites, though many operators may need to begin working on some of these requirements first or as part of their DOCSIS 4.0 technology upgrade efforts. These prerequisites are not necessarily hard requirements, but recommendations based on what we know today. As DOCSIS 4.0 technology becomes more widely available and as operators gain experience with the technology, we will continue to refine these recommendations.

1.4.0 Distributed Access Architecture

R-PHY or R-MACPHY DOCSIS 4.0 specifications assume that a distributed access architecture (DAA) has been deployed first. DOCSIS 4.0 technology, in support of 10G, brings benefits, including capacity and bandwidth improvement, plus additional reliability to services. DAA supports these goals by putting functions closer to the edge to improve scalability and enable digital optics. Though it may or may not be possible to provide DOCSIS 4.0-based services without a DAA architecture, this document assumes DAA is or will be in place. Many operators will want to convert an architecture to DAA as a first step. Qualifying access plant portions for DAA is a separate decision process, but many of the activities called out in this document will also help with that activity.

1.4.1 Profile Management Application (PMA)

PMA is a critical component to have in place before deploying DOCSIS 4.0 technology. PMA creates a series of profiles based on existing network conditions and sets appropriate QAM constellations in each profile. This allows the network to provide reliable service to cable modems with low MER values by using more forgiving QAM constellations while still offering high order modulation profiles and optimal speeds to the cable modems with good MER levels. Without PMA, each node leg must be configured to support the modem with the poorest performance, and the bandwidth capacity for everyone on that network segment is limited by the worst performer.

1.4.2 Digital Optics

Some operators continue to use analog optics in their hybrid fiber-coax (HFC) plants, and some are using a hybrid digital and analog optical solution in their legacy and DAA architectures. Though it may be possible to provide DOCSIS 4.0-based services without all-digital optical links in the access network, this report assumes that digital optics will be in place. Operators that have not completed this upgrade should complete a digital optics upgrade of their choice before conversion to DOCSIS 4.0 technology on that section of the access network.

1.4.3 Spectrum Channel Moves

Operators considering an upgrade to DOCSIS 4.0 technology and services will be making changes in the way spectrum is used. The intent of these changes is to increase network bandwidth and enable new features, such as multi-gigabit symmetrical speed and Low Latency DOCSIS. The first change to spectrum utilization is that DOCSIS 4.0 technology allows upstream transmissions of up to 684 MHz and the option for bi-directional FDX channels within the FDX band of 108 MHz to 684 MHz. To use these frequencies for upstream traffic, operators will be required to move existing channels to make room for those upstream or bi-directional channels. Operators are typically going to have legacy SC-QAM channels, QAM video, and/or downstream ODFM channels utilizing spectrum that the operator will want to transition to upstream or bi-directional. Moving existing channels to a substantially higher frequency can be a non-trivial task and is one of the key tasks that operators can begin looking at today. Each operator will need to look at its existing spectrum utilization and make a plan for how it will move those existing channels in preparation for the DOCSIS 4.0 upgrade.

1.4.4 DOCSIS 3.1 OFDM and OFDMA Operational Practice and Proficiency

The operator should already be operating a DOCSIS 3.1 network with both OFDM and OFDMA channels. DOCSIS 4.0 technology is intended to expand the range of where operators can deploy OFDM and OFDMA, and being proficient with this technology is essential before trying to expand the range. This includes setup, configuration, maintenance, product stability, training, and troubleshooting tools for OFDM and OFDMA, which should all be in place before a DOCSIS 4.0 upgrade.

1.4.5 Mid-Split or High-Split Proficiency

The operator should be proficient with how to upgrade, set up, configure, and maintain a mid-split or high-split network. Operational proficiency with OFDMA is another prerequisite, and operators must also be using a mid-split or high-split network to use OFDMA.

1.4.6 Network Topology and Home to Tap Associations

With some of the new failure modes that come with DOCSIS 4.0 technology and with some of the new configuration requirements, especially when choosing FDX, accurate and accessible topology maps are highly valuable. This includes the association of home to tap, so an operator is able to identify all existing subscribers who are connected to a particular tap. A complete and fully accurate topology map is not mandatory, but it is recommended that operators get serious about a plan to improve their topology data as quickly as they can.

1.4.7 Video Services Provided via Internet Protocol (IP)

Some operators may choose to allow analog video over some frequencies, but the DOCSIS 4.0 services will use IP-based video services, making it a prerequisite assumption.

2 REFERENCES

2.1 Informative References

[Hranac2022]	"How Will Proactive Network Maintenance Change Under DOCSIS® 4.0?," R. Hranac, J. Rupe, Ph.D., D. Torbet, B. Volpe, SCTE•ISBE Cable-Tec Expo 2022 & 2022 Fall Technical Forum, September 19–23, Philadelphia, PA
[Thompson2021]	"Rapid and Automated Production Scale Activation of Expanded Upstream Bandwidth," R. Thompson, R. Howald, J. Chrostowski, D. Rice, A. Vieira, R. Vugumudi, Z. Lu, SCTE•ISBE Cable-Tec Expo 2021 & 2021 Fall Technical Forum, October 11–14, Atlanta, GA
[Howald2021]	"Execute The Upstream Makeover Without Leaving Scars," Dr. R. Howald, L. Wolcott, L. Ellis, SCTE•ISBE Cable-Tec Expo 2021 & 2021 Fall Technical Forum, October 11–14, Atlanta, GA
[CM-GL-PNM-2023]	PNM Current Methods and Practices in HFC Networks (DOCSIS 3.1), CM-GL-PNM-3.1-V04-230213, February 13, 2023, Cable Television Laboratories, Inc.
[CCAP-OSSIv4.0]	DOCSIS 4.0 CCAP Operations Support System Interface Specification, CM-SP-CCAP-OSSIv4.0-I09-230516, May 16, 2023, Cable Television Laboratories, Inc.
[MULPIv4.0]	DOCSIS 4.0 MAC and Upper Layer Protocols Interface Specification, CM-SP-MULPIv4.0-I07-230503, May 3, 2023, Cable Television Laboratories, Inc.
[PHYv4.0]	DOCSIS 4.0 Physical Layer Specification, CM-SP-PHYv4.0-I06-221019, October 19, 2022, Cable Television Laboratories, Inc.

2.2 Reference Acquisition

- Cable Television Laboratories, Inc., 858 Coal Creek Circle, Louisville, CO 80027; Phone: +1 303-661-9100; Fax: +1 303-661-9199; www.cablelabs.com

3 TERMS AND DEFINITIONS

This document uses the following terms and definitions.

cable modem (CM)	A modulator-demodulator at subscriber locations intended for use in conveying data communications on a cable television system.
cable modem termination system (CMTS)	A device located at the cable television system headend or distribution hub that provides complementary functionality to the cable modems to enable data connectivity to a wide-area network.
channel	A portion of the electromagnetic spectrum used to convey one or more RF signals between a transmitter and receiver.
drop	Coaxial cable and related hardware that connect a residence or other service location to a tap in the nearest coaxial feeder cable. Also called drop cable or subscriber drop.
Remote PHY	An architecture in which a CMTS's (CCAP's) media access control circuitry—the electronics that perform DOCSIS processing—remains in the headend or hub, and the physical layer circuitry is relocated to a shelf or an optical node.

4 ABBREVIATIONS AND ACRONYMS

This document uses the following abbreviations and acronyms.

CM	cable modem
DAA	distributed access architecture
DOCSIS	Data-Over-Cable Service Interface Specifications
DS	downstream
FEC	forward error correction
HPNA	HomePNA Alliance, formerly Home Phone Networking Alliance
LLD	Low Latency DOCSIS
MoCA	Multimedia over Coax Alliance
PNM	Proactive Network Maintenance
RF	radio frequency
RxMER	receive modulation error ratio
US	upstream
UTSC	upstream triggered spectrum capture

5 INFORMATION TO UTILIZE

Operators' plans for new products that require DOCSIS 4.0 technology will generate requirements regarding network performance; for example, services that require Low Latency DOCSIS (LLD) will need to have sufficient bandwidth and network quality to support LLD as broadly as is needed for planned product penetration. With that foundation, operators will want to prepare various information sources now.

5.1 Network Readiness and Upgrade Information to Utilize

It is assumed that the network, including optics, vCMTS, R-PHY node, trunk actives and passives, and taps, will be upgraded first. The network upgrades should not require any changes to existing customer drops, premise wiring, or premise equipment. Some operators may benefit from doing pre-work on drops and premise; however, this is not required for a successful DOCSIS 4.0 upgrade. Below are some data points that may be helpful as part of the network readiness evaluation and upgrade process.

- Network design and plant topology records—Details about plant design will be highly valuable when determining readiness. The operator will need to look at its desired target and vision for the DOCSIS 4.0 upgrade and which spectrum frequencies will be used. Any extension of spectrum frequencies will need to be supported by the plant design. This includes powering requirements at the node, power supplies, and amplifiers. It also includes the frequency support of every active and passive in the network, which must support the planned extended frequencies. Operators must also look at the power constraints in the DOCSIS 4.0 specifications for the extended upstream ranges on the cable modem. There is a cable modem transmit power constraint and guidance on maximum tilt, burst power, etc., that must be considered to make sure the transmissions from the cable modem will be received with adequate power at the node in order to utilize the desired QAM constellation(s) for that network leg.
- Outage records, trouble calls, and truck rolls—Outage records, trouble call details, and truck rolls can assist with evaluating network readiness. Significant outages in the network, as well as some customer call issues, may suggest lack of readiness. Assessment of the causes of both is important. Plant issues may suggest work is needed in the plant, whereas customer issues may suggest customers' willingness to adapt to the changes needed. However, other customer call issues may suggest a need for the technology upgrade, suggesting that part of the network may be a good candidate for DOCSIS 4.0 services.
- PNM, Internet Protocol Detail Record (IPDR), and other network telemetry—Existing telemetry data can be very useful when evaluating existing networks. These data can provide information about existing physical impairments that exist today, and data such as spectrum full-band capture can be used to determine existing loss in the network. The access network equipment and DOCSIS equipment provide telemetry and other information that are most important for preparing to deploy DOCSIS 4.0 technology. [CM-GL-PNM-2023] outlines the PNM-related data elements, including how to obtain them and make use of them. DOCSIS 4.0 specifications provide additional measures that can be of use.
- Network measurements—Existing technician tools and data, such as sweep, leakage detectors, and spectrum analyzers, can provide additional measurements and data points about the network.

5.2 Premise Upgrades Data to Utilize

Once a network segment has been chosen to be upgraded, an operator can look at which premise locations are best suited for DOCSIS 4.0 service upgrades, and each premise installation requires a decision as to whether the operator wants to attempt a customer self installation or a technician professional installation. The data described below can be used to assist with the decision on when to attempt a self installation vs. when to schedule a technician to do the installation.

- Current premise activation data—Knowing which existing services are activated at a particular subscriber location provides information on quantity and types of equipment in place. This is useful for helping to provide information about existing splitters installed at that premise and also the presence of interfering technologies like Multimedia over Coax Alliance (MoCA) and HomePNA Alliance (HPNA). This premise data provides information to the operator regarding how to proceed with a recommended professional

installation vs. self installation. On a DOCSIS 4.0 upgrade, every operator will need a process to make sure it handles premise splitter compatibility and power loss and the removal of those interfering technologies like MoCA and HPNA.

- Historical billing records—When an operator has a premise location requesting a DOCSIS 4.0 installation, but where there are no existing services, then historical billing records of previous accounts may be useful to provide some insights into the premise wiring conditions present at that location, such as the presence of splitters.
- Installation and maintenance tickets—Statistics on maintenance tickets collected by network segment, product type, and other breakdowns will be useful when understanding the network quality in certain segments and customer interest in DOCSIS 4.0 services. If existing data are available and trustworthy, an analysis may be helpful. If new data are being considered to be collected, it is important to keep it focused and simple to facilitate high confidence in the data obtained.
- Technician headend and network testing—Existing technician tools, such as sweep, leakage detectors, and spectrum analyzers, will provide additional information about network segments and customer locations that can confirm readiness.
- Drop length and drop cable type—With DOCSIS 4.0 upgrades, the extended use of spectrum frequencies in both the upstream and downstream requires some extra focus on attenuation, and on a DOCSIS installation, it is worth looking at whether a subscriber would benefit from RG11 drop cable. It is important to have data about the total network loss at any given location, including the network loss to the tap port and the loss introduced by the drop. These data are important because they factor into how much transmit power the cable modem will require across its extended frequency range, and it affects how much loss tolerance there is in the premise wiring, including splitters and other passives. For example, in cases where there is low loss on the network and drop, there is more room for loss within the premise wiring. In cases where network and drop loss is high, the premise wiring requirements will be tighter, and a home run may be mandatory to provide DOCSIS 4.0 services.
- Wi-Fi—Information about existing Wi-Fi conditions at a premise location may be useful as part of the premise evaluation process. For example, with a DOCSIS 4.0 upgrade, it is presumed that the subscriber will be upgrading their QAM video set-top boxes to IP video set-top boxes, but if this premise location has a history of a problematic Wi-Fi environment, then there is some risk to the upgrade to IP video set-top boxes that connect to the gateway via Wi-Fi. This may be a case to consider scheduling a technician professional installation to make sure the subscriber does not lose their video services while attempting to do a self installation.

6 TASKS

Network design is one of the first considerations for any DOCSIS 4.0 upgrade. With the extended frequency ranges for upstream and/or downstream comes additional powering requirements. Starting with the vision of what frequencies are planned for deployment, an evaluation of the powering of those frequencies at the node and supporting power supplies and amplifier cascades is required. In addition to the downstream powering requirements, the DOCSIS 4.0 cable modems will also be transmitting at extended frequencies, and the power constraints of the cable modem must be accounted for when evaluating whether the cable modem can transmit in the extended frequencies and still hit at the node with an appropriate target level.

A network operator considering DOCSIS 4.0 technology deployment will want to determine the best network segments to prioritize for deployment. While market opportunity will be an important factor, and preparation of the back-office systems and work force are critical steps to preparation, we discuss in this report several tasks that operators should complete to help find the best network segments to prioritize and identify any preparation work that will ease the transition for network operations and customers.

Operators that plan to deploy downstream channels up to or higher than 1.2 GHz should leverage the existing DOCSIS 3.1 modems on their networks to evaluate the spectrum they support up to 1.2 GHz. If there are no current carriers at 1.2 GHz, it is recommended the operator deploy a carrier at 1.2 GHz to provide a monitoring point for how the network is performing at that frequency range. The existing spectrum tools, field meters, etc., may need software updates to expand visibility to 1.2 GHz. If it is higher than 1.2 GHz, the operator will need to wait for hardware availability of cable modems and field meters that support the desired frequency range higher than 1.2 GHz.

Identification and removal of home splitters, filters, amplifiers, disruptive technologies, and other impairing equipment may at times be needed to provide service, but they are not generally necessary for deployment of DOCSIS 4.0 technology. Part of the readiness effort is to determine which sections of the outside plant are good candidates for DOCSIS 4.0 technology deployment, then to do the necessary steps to enable the portion of the network to provide service using DOCSIS 4.0 technology. Splitter removal may be a desired practice but will be opportunistic. Splitters may introduce loss or may not support higher frequencies, but that may be discovered and addressed after DOCSIS 4.0 technology is deployed in an area. For this early readiness work, estimates of what may be encountered and the impact on the full benefit of the service are sufficient.

6.1 Prioritize Access Network Segments

6.1.1 Utilize Network Telemetry to Prioritize Network Segments

The current architecture of network segments will be a first consideration. The node plus zero (N+0) plant, which has no amplifiers after the node, is a very good candidate to begin with. R-PHY architecture is assumed, and many will be without amplifiers past the node. Further, network segments that have already converted to higher splits are also good candidates for first consideration.

PNM data can reveal impairments and provide performance measures that can identify good plant candidates. RxMER per subcarrier will indicate the quality of the DS channels, whereas full-band capture from cable modems can indicate impairments and overall quality of the spectrum. Unfortunately, an existing cable modem will not capture frequencies above its range, so it will not provide information for the full DOCSIS 4.0 spectrum range. Pre-equalization data can also provide information about the upstream frequency bands. Forward error correction (FEC) statistics will indicate any correctable or unreliable codewords, which can suggest whether the service is high quality or not. When coupled with profiles, the data rates that customers can currently achieve will indicate whether the network segment is a good candidate for DOCSIS 4.0 technology or if additional work may be necessary first.

Note that though downstream data are far easier to obtain on existing DOCSIS 3.0 and 3.1 networks, upstream data are also critical to understanding access network readiness. The most common upstream telemetry includes upstream triggered spectrum capture (UTSC) in free run mode and RxMER upstream data. UTSC data can indicate plant quality through the detected impairments and overall quality. Upstream noise funneling is a known disruption that severely impacts service. Finding upstream noise indicates that work needs to be done before the network segment is ready, but in any case, the impairment should be addressed. Further, upstream RxMER will also indicate quality in the upstream frequencies as described for downstream RxMER per subcarrier.

Many operators utilize node health scores and other measures of network health, which will inform the decision. Taking nodes that have historically been solid performers may be a good starting point for identifying candidate network segments.

Operators have previously used and advocated an approach where they collect RxMER statistics on network segments and plot these on a histogram to determine which network segments have higher RxMER statistics, noting that these often distribute on a bell-shaped curve. The concept here is that higher performing network segments would be good candidates.

The RxMER histogram approach has merits, but it also has weaknesses. RxMER per subcarrier, for the frequencies over which it can be measured, will indicate the signal-to-noise or carrier-to-noise capability of the subcarriers over which it is collected.[1] That measurement does not cover all frequencies, but for the frequencies over which it is collected, it is a good indication of transmission quality. RxMER per subcarrier, when averaged over all frequencies and customers served on a network segment, loses resolution of the variability on that network segment. Likewise, a 2nd-percentile statistic may indicate when there are subcarrier frequencies experiencing lower than desired RxMER; therefore, averaging these for network segments may indicate which network segments are high performing and which may have subcarriers with lower performance. That may be a good indication of the network quality and readiness for DOCSIS 4.0, but there are other measures and factors that should be considered, including those listed below.

- Bin data anomalies (spectrum capture, RxMER per subcarrier)—Spectrum Impairment Detector or Anomaly Detector are example tools available to CableLabs members to use for finding impairments in PNM frequency bin data. Anomaly count and type will indicate network quality, which will weigh into the network's readiness for DOCSIS 4.0 technology.
- FEC statistics—FEC statistics provide information on codeword errors, which can indicate further whether a network segment is high quality. Taking samples that can be normalized across network segments (for example, samples over time that are normalized into percentages of uncorrectables and/or correctables) allows the comparisons to be fair, and, therefore, comparable to determine network segment candidates. Keep in mind these statistics are not indicative of performance at higher frequencies.
- Profile statistics and bit loading—Collecting statistics on the profiles and/or bit loading allocated to channels on the network can help determine the current capabilities over the frequencies in use. Though current downstream frequencies that perform well may not continue to do so when they become downstream frequencies, the information is still a strong indicator of the network quality.

More information about how to obtain and use these telemetry elements can be found in [CM-GL-PNM-2023].

6.1.2 Utilize Truck Rolls to Test Network Segments

Technicians will know the access network condition and, when deployed, can also utilize field meters to test network segments for overall quality. If a technician has a spectrum analyzer that goes into higher frequencies than are currently utilized, they can test the network segment for performance at those higher frequencies. Doing this will require injection of a suitable test signal or signals above the downstream's upper frequency limit. Because existing actives will not pass these higher frequency signals, they will have to be injected locally using a suitable means.

6.1.3 Verify with Additional Information

Network operations readiness factors are also significant. This includes technician expertise, network age, equipment availability, and more factors that should not be ignored when considering access network readiness for DOCSIS 4.0 technology.

Network records are invaluable for understanding the readiness of a network segment. As stated in the assumptions, this report assumes DAA with digital optics has been deployed, but if there are amplifiers in the network or taps that are known to have non-linearities or impaired transmission in higher frequencies than are in use today, or if past

[1] A graph of an OFDM signal's RxMER per subcarrier can give a quick view of an entire OFDM channel and provide hints to the presence of impairments such as LTE ingress.

practices have led to the prevalence of filters in the network, then records may be a good indication of readiness directly.

6.2 Prioritize Customers Within Network Segments

In addition to determining the readiness of the access network, individual customer locations also need to be considered. Though a professional installation can bring most any customer location into one well prepared for DOCSIS 4.0 services, consideration of the current state of these locations can help determine which are going to provide the best service without additional work, or what work will be useful to complete to optimize service.

6.2.1 Utilize Network Telemetry to Determine Customer Premise Condition

Many of the data elements that can be helpful for qualifying a network segment can also be used for determining expected performance of the customer's local network. After identifying candidate sections of the network, the operator should look more closely at the data for individual customer locations served by that network segment. This is where the variation will appear, and those variations will indicate which customer locations may be good candidates that require little or no additional work. A sufficient number of good candidates in a network segment raises the confidence in that segment as a good candidate for DOCSIS 4.0 upgrade.

If an operator has the ability to place a CM into a higher split temporarily to extend the frequencies it can capture, that additional information may help determine whether a residence has unwanted splitters, filters, or drop amplifiers that would need to be removed first. See [Thompson2021] and [Howald2021] for specific guidance on data to collect and how to utilize it.

6.2.2 Utilize Records to Determine Customer Premise Readiness

Existing and past customer services information will suggest whether customer locations are expected to have problematic filters, splitters, drop amplifiers, MoCA, or HPNA. For existing customers, the information should be more reliable; however, experience with determining good candidates for self installations among new customers reveals that qualifying customer premises that are not existing customers will be very difficult.

6.2.3 Utilize Truck Rolls and Installation and Repair Records to Collect Customer Premise Information

Installation and repair events are opportunities to collect useful information and maybe even to prepare a customer location for possible future DOCSIS 4.0 technology, if desired. The records themselves can help if technicians are trained and requested to collect information about location conditions for DOCSIS 4.0 deployment. A quick checklist of what to look for and any proactive preparations that are made (if warranted) will help technicians successfully collect useful information. Further, ticketing systems often allow narratives or supplemental data collection; therefore, proper methods to reliably capture the needed information would be valuable to develop and implement now.

6.3 Assess Digital Optics for Performance and Quality

Though the assumption with DOCSIS 4.0 technology is that digital optics comprise the optical portion of the access network, the reliability and performance of the digital optical portion of the network segment should be verified.

Repair and capacity historical information will reveal if reliability and capacity of the optical link has historically been sufficient. Capacity should be compared to demand forecast in the upstream and downstream directions. Further, keep in mind that penetration models and product offerings need to be factored into the expected future demand on bandwidth after DOCSIS 4.0 deployment is achieved. A model that verifies the amount of penetration for DOCSIS 4.0 services or the amount of capacity that remains after full deployment (or another like measure of expected capacity utilization) will be very critical in the assessment of network segment readiness.

Specific services may require more than an assessment of RF, optical, or a single layer of capacity management. For example, LLD services will require the right capabilities in the network and sufficient capacity at RF, optical, and higher layers to ensure LLD service quality is met.

6.4 Assess Network Quality and Ability to Support DOCSIS 4.0 Performance and Technology

Cable operators that are preparing for DOCSIS 4.0 deployment may need to look at candidate network segments more closely to determine true readiness and assess overall quality before committing to upgrading them.

6.4.1 Network Cable Diameter, Type, and Quality

DOCSIS 4.0 services will require more attention to network loss and attenuation. The correct diameter and type of cable that matches the network design becomes more important with DOCSIS 4.0 because of the high attenuation of signals greater than 1.0 GHz and also the constraints on the transmit power levels from the cable modems paired with a preference for high order QAM constellations (requiring high MER levels). Additionally, older generations of coaxial cable may not perform well at higher frequencies. It is at least prudent and may be required to check the performance of the coax plant before deployment of DOCSIS 4.0 technology. If the age and type of cable is known for a given network segment, samples of the various cable types could be tested for confidence. Operators should expect that some coax may have to be replaced.

6.4.2 Conventional Taps

Existing conventional taps in DOCSIS 4.0 plant will continue to work for DOCSIS 3.0 and 3.1 services. However, any premise that upgrades to DOCSIS 4.0 services will require the tap to support the frequency ranges being deployed with DOCSIS 4.0 technology. The recommendation is that any tap upgrades are included as part of the network upgrade process. Conventional taps are split agnostic; therefore, the biggest concerns will be operational RF bandwidth and return loss characteristics, especially at frequencies above 1 GHz. For operators upgrading to FDX, the expectation is that they will be using up to 1.2 GHz spectrum, which means any existing 1.2 GHz conventional taps should work without any additional work. For operators upgrading to FDD, it is expected that they will be extending spectrum as high as 1.8 GHz, and there is a good chance their existing taps will need replacement tap plates to support those extended frequencies.

Like coax, taps may not perform well at higher frequencies. See [Hranac2022] for more information about test results from taps used at higher frequencies. Keep in mind that even some taps that are specified to perform at higher frequencies may not actually perform well enough for DOCSIS 4.0 services—complete tap upgrades may be needed.

6.4.3 Conditioned Taps

Conditioned taps may need to have new plug-ins installed to accommodate new band splits. In all cases, operators should check with the tap (and other passives) manufacturers to determine whether a faceplate swap is supported for DOCSIS 4.0 FDD/FDX operation and if center conductor seizure mechanisms need to be replaced.

6.4.4 Network Filters

Depending on an operator's practices and earlier efforts, there may be existing filters in the network that may impact DOCSIS 4.0 services. The operator must identify and plan for the filters in place, which most often will be the removal of existing filters.

6.4.5 Trunk Amplifiers

Amplifiers in the access network will still be used with N+X architectures. Any active device, including amplifiers, will need to support the features in each operator's plan. For FDX operation, the operator must deploy FDX-capable amplifiers. For FDD operation, the operator must deploy amplifiers that support the frequency ranges it has planned for, including upstream transmission up to 684 MHz and downstream transmission up to 1.8 GHz.

6.4.6 Network Impairments

After initial identification of a network segment for consideration and assessing the specific capabilities of the components comprising the network segment, it will be important to apply PNM techniques to determine any specific impairments or other RF transmission issues that may stand in the way of a fully performant DOCSIS 4.0

deployment. Network segments with larger numbers of impairments are likely to be older plant in less-than-optimal condition, thus, they may not support DOCSIS 4.0 technology as well as network segments that are newer and better performing. Some impairments such as water in the network will prevent higher frequencies from transmitting well, so those would need to be addressed before higher frequencies are expected to work well. This may be more of a concern with customer locations, as drops are the more frequent location for water in the network.

6.5 Assess Customer Premise Condition (Drop, Inside Wiring, Serving Equipment)

Prioritizing customers within a network segment is the first step to consider customer locations for DOCSIS 4.0 services, but a more detailed look is needed to confirm the absence of specific issues, estimate the risk of uncertain issues existing, or determine what issues may need to be addressed before deployment of DOCSIS 4.0 services. The information outlined in Section 5 will help answer questions about the relevant condition of customer locations. Issues that could impair the full capabilities of DOCSIS 4.0 services are discussed below.

6.5.1 Drop Quality, Inside Wire Quality

PNM data collection can easily help determine drop quality in most cases, but an in-person technician will be able to verify with high assurance when the drop is tested. Remotely, using PNM, the CM can provide spectrum capture to show anomalies, and RxMER can provide detail about the connection quality serving the customer. By comparing to neighbors' data for devices that are on the same tap and/or follow the same network cascade, one can determine whether the issues are with the customers' drop and inside wiring or a whether it is a network issue. Some issues, such as water in the coax, are now easy to determine and are more likely to be in the drop than in the home.

Shield integrity issues can be checked remotely using PNM, but noise funneling is more difficult to attribute to a given customer. Checking for ingress and comparing neighbor modem data will reveal ingress issues that may be isolated to a single customer location, and these issues are likely to be problems in the home. Again, keep in mind some existing tools will not provide visibility above 1 GHz. Likewise, water in the customer's drop would prevent higher frequencies from being transmitted well, so would need to be addressed first; a technician installation can take care of this issue. Ingress problems are expected to impact FDX performance significantly.

6.5.2 Serving Equipment, Splitters, Amplifiers

In many cases, the serving equipment may not be sufficient to provide good remote telemetry for determining the conditions at the customer location in preparation for an upgrade to that home. Some cable modems on the network may not support spectrum full-band capture, for example.

When upgrading a network segment to DOCSIS 4.0 technology, the operator should also review its spectrum utilization plans and make a decision as to which customer premise equipment it may want to stop supporting. The intent of DOCSIS 4.0 technology is to be backwards compatible with prior versions; however, for example, if an operator is still supporting DOCSIS 2.0 devices on the network, it may likely want to get those devices upgraded. DOCSIS 2.0 frequency constraints paired with the movement of channel locations could handcuff an operator's future plans.

Also, some serving equipment may not be compatible with DOCSIS 4.0 technology. For example, a set-top box may have been deployed, and the common practice to add a splitter would potentially impede a DOCSIS 4.0 deployment. DOCSIS 4.0 architectures assume a single connection from the tap to the cable modem without any splitters or other drop components such as amplifiers and filters. This level of assurance may not be enforced by all operators in all cases, so it is important to test the connection's performance to ensure performance is sufficient if not verified or corrected directly.

6.5.3 Transmit and Receive Power Levels

Using the transmit power levels and the receive power levels at both the node and the cable modem is useful in determining total network loss at specific frequencies. There is a theoretical loss that can be calculated based on network design; however, real-world conditions are variable, and the loss at specific frequencies often deviates from the designed levels. By utilizing the measured network loss, an operator can gain insights into what to expect as it shifts which frequencies are used for upstream traffic. With the constraints on the transmit power levels of the cable

modem, an operator can calculate the likelihood of being able to transmit from the cable modem at specific frequencies and receive that transmission at the node with enough power to hold the desired QAM constellation without errors. For cases where the existing transmit and receive power levels show too much loss to support DOCSIS 4.0 upstream frequencies, the operator can expect some work to reduce loss in the network, drop, or premise wiring. Using spectrum full-band capture on existing downstream spectrum provides visibility into power loss across all channel types, including QAM video, SC QAM, or downstream OFDM. In addition to the downstream spectrum data, transmit power levels from the cable modem can be used to evaluate network loss by looking for high transmit power levels on the modem and/or the measured difference between transmit power and receive power levels at the node.

6.6 Improve Network Quality and Its Ability to Support DOCSIS 4.0 Technology

After determining candidate network segments and assessing their readiness, operators will want to determine whether any improvements need to be completed for some of these segments. Segments that require little work may still be good candidates, or eventual candidates after opportunistic improvements can be made.

Cable operators that are preparing for DOCSIS 4.0 deployment may need to perform maintenance or network upgrades. Operating RF transmissions up to 1.8 GHz will likely require upgrades to actives and passives and may require the removal of components put into the network for other purposes. Some of the upgrades will lead to maintenance to correct impairments that DOCSIS devices were otherwise working around or were not an issue because higher frequencies are not in use.

Once the data are collected and plans determined, the necessary preparation work may include any or all of the following.

- Tap and other network passive device updates
- Amplifier updates or removal
- Node and virtual CMTS upgrades
- Optical link upgrades
- Impairment resolution
- Cable replacement
- Power supply upgrades and repowering

For both FDX and FDD implementations of DOCSIS 4.0 technology, the trunk amplifiers will need to be replaced. FDX requires amplifiers that support bi-directional transmissions in the 108 MHz to 684 MHz frequency range and up to 1.2 GHz downstream. FDD will require amplifiers that support upstream or downstream traffic in the 108 MHz to 684 MHz frequency range and up to 1.8 GHz downstream.

For both FDX and FDD, there may or may not be passives that need to be replaced. The requirements of what frequencies must be supported by all network passives is identical to the requirements for the trunk amplifiers above. For example, with FDD it is expected that all taps and other passives must be upgraded or replaced to support 1.8 GHz.

A DOCSIS 4.0 upgrade strategy should include reducing or eliminating QAM video channels and recapturing that spectrum for IP bandwidth.

6.7 Improve Customer Premise Conditions

Operators may choose to roll out DOCSIS 4.0 services on a targeted basis after the technology is deployed. Those subscribers who are the best candidates at highly performant locations might receive the equipment first, whereas those locations that benefit from additional work might need to wait for opportunistic readiness. A good practice would be to update records and maintain information about locations and their readiness before deciding on whether and how to make any improvements to customer locations.

- Impairment resolution—PNM-driven repair is a very cost-effective way to address impairment issues. While doing so, an operator should take the opportunity to make the other needed improvements.
- Drop replacement—In many cases, a drop replacement may be cost effective when deploying technicians to assist in installation of DOCSIS 4.0 equipment at the customer locations.
- Home wiring repair and replacement—Removal of drop/premise amplifiers is critical for any DOCSIS 4.0 upgrade if the home amplifier does not support the frequencies required for DOCSIS 4.0 services at that site. Removal of a drop amplifier as an opportunistic preparation for DOCSIS 4.0 requires an evaluation of the current conditions at the home and if that amplifier is required to boost signal to the equipment installed at that home. Any filter located at the premise should be evaluated for its purpose and its compatibility with the services activated at that location. Splitters located on premise are required to support the frequency ranges required at that location, and the splitter loss must fit the power profile for that location. Because this work requires access to the customer's facilities, it is likely going to happen only if warranted by a technician-assisted installation or repair of DOCSIS 4.0 services. In some cases, customers may be able to do some of these preparations themselves. Determining what can realistically be expected by a customer will depend on the current situation and their abilities.

6.8 Operations Support Systems

Operators will need to update operations support systems, including billing, fault management, and repair. Details are beyond the scope of this report, but it is important for operators to take a good look at the readiness of these systems and decide how to prepare for the transition as they see fit. At the least, additional telemetry and monitoring may be needed, and different data collection in support of DOCSIS 4.0 may require upgrades to fault management, PNM, billing, and general repair.

6.9 Tools Preparation

Operators will need to assess their tools in preparation for DOCSIS 4.0 deployment.

- Field technicians will need to have access to field meters, spectrum analyzers, leakage detectors, and other equipment that can work in frequencies up to and beyond their planned deployment limits; many operators are deploying up to 1.8 GHz or the specific frequencies they have targeted for the upper limit. These instruments will need to be able to analyze multiple QAM and OFDM/A signals, with an ability to do FFT for examining time and frequency domains.
- Technicians will also want to be able to test multi-gigabit symmetrical speeds comparable to planned offerings, but using their field meter or other test equipment.
- A vector signal analyzer will be needed for some tests, again covering frequencies up to and beyond 1.8 GHz. A vector signal generator may be needed to generate specialized test signals in the 1 GHz to 1.8 GHz range. For simplified testing at higher frequencies, a compatible RF signal generator (capable of generating CW carriers) may be sufficient.
- Any centralized monitoring equipment will need to be able to monitor from 1 MHz up to the 2.0 GHz range or the upper limit that the operator has chosen to use.
- Technicians will also want to be able to test multi-gigabit symmetrical speeds comparable to planned offerings, but using their field meter or other test equipment.
- DOCSIS 4.0 CMs will also for the first time support secure shell (SSH) access for technicians, and the appropriate authentication architecture will need to be added.
- It is also critical to be able to detect ingress and egress noise in the 108 MHz to 684 MHz range for those implementing FDX so that echo cancellation problems can be localized. There is a lot of potential noise in those frequency ranges, including UHF and VHF. Today that noise exists, but because it is all in the downstream frequency range, the impact of that noise is usually limited to a single customer or a few customers. When those channels are flipped to upstream, all of that previously isolated noise will funnel up to the node and impact all subscribers on that node.

- FDX amplifiers have a lot of additional complexity. Operators must prepare for tooling that monitors these amplifiers and their performance and how to upgrade software, etc. They must also prepare for training for the network technicians on these new amplifiers.
- Operators must prepare for tool changes that support visibility and troubleshooting of echo cancellation. This will include the ability to monitor baseline noise and separate that background noise from return echoes or reflections.

If these tools can be made ready now or before deployment of DOCSIS 4.0 services, additional verification and certainty can be provided, easing the transition for customers and operators alike.

7 CALL TO ACTION

By no means is this technical report a complete view of the work an operator must do to prepare for DOCSIS 4.0 technology deployment. The references included in this report and other documents will supplement this summary document with additional details and useful preparations. In addition, SCTE NOS WG5 continues to develop more detailed guidelines for operators to follow for smoother preparation and readiness for DOCSIS 4.0 technology and services. The output from that group is forthcoming but anticipated to cover more details, guide from more starting positions, and even help in risk assessment when upgrading operations and networks for DOCSIS 4.0 technology. The work in that group will help the whole community reduce friction on the path to 10G. Go to standards.scte.org to join and learn more.

Appendix I Acknowledgements

We thank the following participants contributing directly to this document.

Contributor	Company Affiliation
Steve Goeringer	CableLabs
Ron Hranac	Retired
Justin Riggert	Comcast
Jason Rupe	CableLabs
Nick Segura	Charter

* * *