Preparing for DOCSIS® 3.1

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Introduction

As the service provider community migrates to Gigabit services over HFC, DOCSIS® 3.1 is seen as the key enabler. The conversation around DOCSIS 3.1 is typically centered on the question, "How do I make sure I'm ready?" Because DOCSIS 3.1 benefits are many, so too are the steps to prepare.

Since DOCSIS 3.1 impacts so many points in the network, the task of making preparations can be overwhelming. The migration requires significant change throughout the service provider network: the wide area network (core and backhaul); distribution hub or headend; operations support systems; business support systems; physical layer and CPE devices. Therefore, it is critical for service providers to have a guide so they can understand important considerations as they embark on the **journey to DOCSIS 3.1.**

Before service providers can take the first step in the network evolution process, there must be a methodology that begins with a thorough assessment of the service provider's architecture. This paper provides the framework that guides service providers through assessing network readiness in the first stage of DOCSIS 3.1 evolution. This stage includes inventories, measurements and analyses that provide the baseline needed to architect a phased evolution that ensures service continuity, bandwidth gains, operational efficiencies and minimized costs.

Methodology

Realizing the full benefits of DOCSIS 3.1 without disrupting existing subscribers during the migration, requires a proactive, methodical approach to planning for network transformation. Failure to do so will result in jeopardizing much-needed bandwidth gains, wasting capital investment dollars and/or complicating operations. A readiness assessment is the first step.

This paper outlines the assessment in the following four phases:

1. Identifying service provider delivery goals
2. Assessing current network characteristics and capabilities
3. Evaluating architectural evolution plans
4. Making your network ready for DOCSIS 3.1

This paper will explore this assessment process in detail, using a real-life customer example to help illustrate the common scenarios that service providers may face as they prepare their networks.

Identifying Subscriber Delivery Service Goals

The first and most critical consideration in planning a DOCSIS 3.1 network upgrade is to determine the service provider needs and business goals for deploying a DOCSIS 3.1 network. This includes the growing need for symmetrical services, how much bandwidth will be offered to each service group and at what rate the bandwidth utilization is expected to grow. Business considerations such as implementing tiered service packages, data only and bundled data/ video packages will drive these architectural requirements. Expanded business services with data rates and network security features above the highest residential offerings will also drive changes to the architecture. In addition to IP data, service providers will need to plan for a future of IP video delivery and Over the Top (OTT) video. The service provider's plans and timelines to bring IP video onto the network will strongly dictate its approach to DOCSIS 3.1 transformation.

DOCSIS 3.1 transformation does not require that all network changes be made at the same time. In fact, service providers can implement DOCSIS 3.1 on an existing plant (e.g. 750 MHz downstream, 42 MHz upstream) without having to embark on a major outside plant upgrade. Because DOCSIS 3.1 is backwards-compatible with DOCSIS 3.0, the technology offers even more flexibility by enabling a DOCSIS 3.1 downstream to operate alongside a DOCSIS 3.0 upstream, and a DOCSIS 3.1 upstream to operate in parallel with a DOCSIS 3.0 downstream.

Service providers can develop a gradual, cost-effective network migration strategy to accommodate the increased traffic demand using one or a combination of the following approaches:

- Upgrade the existing HFC plant, including:
  - Extending the downstream spectrum to 1 GHz or beyond
  - Changing the upstream split to a 85 MHz mid-split or 204 MHz high-split
  - Splitting nodes and pushing fiber deeper as needed to improve plant and reduce service group (SG) sizes
- Reclaim spectrum to be used for DOCSIS 3.1 by leveraging switched digital video (SDV)
- MPEG-2 to MPEG-4 linear video migration, migrating to IP video services and/or reducing SG sizes
- Deploy DOCSIS 3.1 modems now in 3.0 mode to seed the market with DOCSIS 3.1 capable devices
- Add DOCSIS 3.1 OFDM channels with enhanced LDCP forward error correction technology
- Increase downstream modulation rates
  - Support in the downstream for 512 QAM, 1024 QAM, 2048 QAM and 4096 QAM with optional/future 8192 QAM and 16384 QAM support
- Increase upstream modulation rates
  - Support for 128 QAM, 256 QAM, 512 QAM and 1024 QAM added with optional support for 2048 QAM and 4096 QAM
- Migrate to a Distributed Access Architecture that supports Remote PHY or Remote MACPHY devices

Tables 1 and 2 illustrate the capacity gains that service providers can achieve with DOCSIS 3.1.

DS Spectrum (MHz)	D3.1 DS Throughput (Gbps)	MAX D3.0 DS Throughput (Gbps)	Gain %
108-1002	7.27	5.66	28
108-1218	9.02	5.66	59
108-1794	13.71	5.66	142

Note: DOCSIS 3.0 downstream spectral efficiency = 6.33 bps/Hz
MSO SNR operating margin for DOCSIS 3.1 = 2 dB
8K FFT size for DOCSIS 3.1 signals, DOCSIS 3.1 spectral e ciency = ~8.13 bps/Hz
32 DOCSIS 3.0 SC-QAM bonded channels generate a capacity of 1.22 Gbps and DOCSIS 3.1 192 MHz OFDM channels generate a capacity of 1.56 Gbps
• DOCSIS 3.1 capacity on a clean fiber deep plant might reach 1.8-2.0 Gbps

Table 1 – Capacity Gain Offered by DOCSIS 3.1 – Downstream[1]

US Spectrum (MHz)	D3.1 US Throughput (Gbps)	D3.0 DS Throughput (Gbps)	Gain %
5-42	0.25	0.15	64
5-65	0.41	0.25	64
5-85	0.54	0.33	64
5-204	1.35	0.33	309

Note: DOCSIS 3.0 downstream spectral efficiency = 4.15 bps/Hz
MSO SNR operating margin = 2 dB
4K FFT size for DOCSIS 3.1 signals, DOCSIS 3.1 spectral efficiency = 6.77 bps/Hz
The capacity of a DOCSIS 3.0 6.4 MHz QAM64 SC-QAM channel is 26.6 Mbps and the capacity of a 96 MHz DOCSIS 3.1 OFDMA channel is 650 Mbps
• DOCSIS 3.1 capacity on a clean fiber deep plant might reach 750-850 Mbps

Table 2 – Capacity Gain Offered by DOCSIS 3.1 – Upstream[1]

Example of a Service Provider's Delivery Goals

In the real-life customer example, the service provider wants to transform its existing network in order to provide a significant increase in available bandwidth per subscriber. As part of the network transformation, the service provider wants to use the most suitable HFC and DOCSIS technology, and where possible, reuse existing operational support systems, only upgrading as needed. The service provider also has a business objective that requires any network transformation to drive toward an all-IP network.

Over the last several years, the service provider's network has undergone a continual re- segmentation of nodes as capacity requirements demanded. As a result, the average node has between 250-500 homes passed. A primary objective for the service provider is to deliver the following tiers of service over the next five years, requiring a DOCSIS 3.1 network transformation to achieve the following service level goals.

Required Service Levels (Mbp/s)	2016	2018	2021	2024
Premium Service	600/100	1000/100	2000/1000	5000/1000
Mid-Tier Service	100/60	250/100	500/500	1000/1000
Regular Service	50/25	100/100	200/200	500/500

Table 3 – Required Service Levels to Deliver Multiple Tiers of Service

The service provider must account for continued bandwidth utilization growth. In early 2018, we saw average subscriber downstream usage during peak busy hour reach 1.6 Mbps, while upstream usage during peak busy hour was 0.14 Mbps. Service providers may choose to use an industry compound annual growth rate (CAGR) for bandwidth growth such as 25% in the upstream and 35% in the downstream, or customize it based on their own experiences.

Assessing Current Network Characteristics and Capabilities

Once the service provider has identified its service delivery goals to successfully meet subscriber demand, the next step is to assess its network assets and capabilities.

CMTS Capabilities

Service providers will need to review the capabilities and current configuration of the CMTS. It begins with the conditions of the existing CMTS where the service group sampling is being done. As part of this review, the service provider will be able to determine the ability of the CMTS to upgrade to a DOCSIS 3.1 capable CCAP device, as well as gain an understanding of its supplier's hardware and software roadmap. This process will unearth the options for hardware, software and configuration changes that may be necessary to bring the CMTS network to a state of readiness, to operate in compliance with the DOCSIS 3.1 specifications.

In the real-life customer example, in order to provide the bandwidth required for the existing services, as well as the required HSD rates, each service group will need to be configured with:

- 8 video on-demand QAMs 36 broadcast QAMs
- 32 DOCSIS 3.0 SC-QAMs
- 24 MHz of DOCSIS 3.1 OFDM
- 8 DOCSIS 3.0 US SC-QAMs

The service provider's existing CMTSs are limited to DOCSIS 3.0, and in some remote locations they are limited to DOCSIS 2.0. Therefore they will require an upgrade to DOCSIS 3.1 CCAP devices. The service provider will need to determine which CCAP solution is capable of providing the mixture of QAM/OFDM required, and will also need to perform detailed spectrum planning to provide the requested service levels.

Core to Edge Routing Capabilities

Service providers will need to conduct a comprehensive assessment of their core router's capabilities and backhaul capabilities. The assessment will also need to encompass hardware capability and availability, software functionality and port utilization/capacity.

During this process, the configuration of the core routing capabilities should be audited, port utilization determined and port capacity upgraded, if required. At this stage, the service provider should have a better understanding of the impact of migration to CCAP on the bandwidth and routing protocol requirements of the core to edge IP routing components. In order to fully understand bandwidth requirements, service providers need to examine sample service group design plans to effectively provide an adequate mix of video and HSD services, delivered over IP from the core router to the edge. They will also be able to project future growth and plan for capacity management by reviewing routing capacity.

In the real-life customer example, there were a sufficient number of ports available on the router for growth. Port utilization was less than 50%, additional XFP ports were available, fiber raceways were unobstructed and the system software was up to date on all devices.

OSS/BSS Assessment

An assessment of the service provider's OSS/BSS system's capabilities should be conducted to ensure DOCSIS 3.1-capable CMTS support, RF plant health monitoring, inclusion of video services into CCAP service groups and end-of-line performance in CPE devices. An evaluation of the OSS/BSS can review existing DOCSIS provisioning systems, fault performance and security management systems for DOCSIS 3.1 functionality. In this stage of the network assessment, software and hardware versions should be reviewed and all contributing vendors' solutions should be evaluated to ensure full DOCSIS 3.1 capability. This capability can be in either the current version or in a pending upgrade version. This part of the network assessment should also address any known interoperability concerns raised by new DOCSIS 3.1 elements and OSS/BSS vendors.

In the real-life customer example, a detailed review of the service provider's fault management systems, DOCSIS provisioning systems and HFC health monitoring systems, determined that all software/hardware platforms are capable of monitoring DOCSIS 3.1 service levels. All SNMP- based devices have been reviewed and confirmed to be capable of continuing to monitor existing hardware, and all proposed new hardware is compatible with SNMPv3. Individual OSS component vendors have confirmed continuing support and compatibility with the DOCSIS 3.1 standards.

Inside Plant Assessment

This assessment is an inspection and review of components in the RF path of the inside plant to determine DOCSIS 3.1 upgradability. It encompasses a review of the CMTS to the optical transmitters and receivers, existing power-levels and level requirements. The analysis also includes combining options and loss/gain due to recombining or elimination of elements.

The service provider will also need to review the existing design documentation to determine the physical layout of the path of IP and RF traffic in the hub/headend where the assessment is being conducted. The assessment should include detailed reviews of the power levels at each coaxial combining point, attenuation levels and input/output levels at optical receivers and transmitters. Alignment of the high-speed data (HSD) and video serving groups must be noted. Any differences in group sizes, power levels or alignments need to be taken into consideration.

The assessment must also include a review of the downstream and upstream RF carriers in use on the network, a review of the upstream RF bandpass characteristics of the network and a review of the description and expected behaviors of the headend optical transmitters and headend return optical receivers. It should also include a review of the manufacturer's specifications of the headend optical transmitters/receivers.

In the real-life customer example, one headend site and one hub site were audited. On average, sites were determined to be capable of supporting new or upgraded equipment allowing a DOCSIS 3.1 upgrade. The inside plant assessment yielded the following findings:

- Both audited sites had adequate electrical power, including sufficient backup generator capability required for new high-density headend optical platforms and CCAP devices.
- Although RF and fiber optic cabling was installed within and over the top of rack in cable trays, there was separation between different cables in the cable trays, providing the required space for new cable installation.
- Equipment racks were appropriate size with 13 racks in use for headend optical, RF combining/splitting, CMTS, eQAM and other management functions.

Outside Plant Assessment

The outside plant (OSP) assessment is a detailed audit of the HFC infrastructure from the fiber node to the first available customer premises in the RF path. The assessment must include all RF active and passive devices, a determination of which devices require upgrade or replacement and the capacity of these devices to support the basic DOCSIS 3.1 configuration of 1 GHz+ forward spectrum and 85 MHz+ return spectrum. The average cascade length and basic design architecture should also be reviewed as part of this assessment.

A physical audit of the designated service groups should also be performed. The service provider must compare the existing OSP design plan to what is visually observed during the audit. Each active and passive component, from node to end of line, needs to be visually inspected and documented. In this assessment, information on the make and model of each device is to be overlaid on the supplied OSP design plan.

It is also important to assess the OSP with a review of the system architecture encompassing; fiber distance to node, fiber architecture, amplifier cascade, subscriber tap values and output levels, drop length and cable type, in-home losses, splitters, direct currents, number of outlets, modems, set-top boxes and converters. The service group sizing and any potential change to reduce size (and increase available bandwidth per service group) should be reviewed at this time.

In addition, the OSP assessment should include a review of electrical supply and bonding and grounding practices to be performed. It encompasses the following: a determination of local electrical code requirements; a review of practices for electrical bonds at pole, bonding and grounding inspection processes; and a review of procedures related to termination of unused tap ports and amplifier output ports.

Longer cascades of amplifiers introduce additional noise which will become problematic at higher frequencies. Careful planning of the required number of amplifiers in a cascade will be required to ensure the tilt created between power levels at different frequencies is acceptable.

In the real-life customer example, it was analyzed whether longer cascades in the network needed to be reduced. Simulations indicated that a 42dB MER could be maintained up to a maximum of N+5. A review of existing HFC plant designs indicated there were 1460 cascades of N+6 and a desktop review suggested that 486 extra nodes would be required to redesign at a N+5 level. The total number of amplifiers and devices containing diplex filters requiring replacement was estimated at 245,000.

Evaluating Architectural Evolution Plans

Once service providers make the decision to begin a network transformation that involves the transition to DOCSIS 3.1, they need to start making plans to evolve their existing architecture.

Pushing fiber deeper into the network is critical to this type of evolution because fiber-based services can help o set bandwidth constraints. The key is for the service providers to make this decision as soon as possible and then determine which course of action is most e cient for them, their network and their customers.

One approach would be to deploy PON to deliver services to select service groups right away, and gradually use the PON architecture to bring the other service groups into the fold. Another approach would be to use PON to deliver services to businesses alongside a DOCSIS network assigned for residences. A third approach would be to deploy a hybrid PON approach that utilizes RFoG (radio frequency over glass) to carry DOCSIS-based services over a fiber infrastructure.

Once the service providers determine which approach to take in evolving their architecture, there are many other factors that they must also consider, such as centralized access architecture vs. distributed access architecture. A traditional HFC plant is, by its very nature, a centralized access architecture, with electronics housed in the headend or hub, and amplitude modulated optical systems used to distribute signals to a receiving node. HFC networks require that the CMTS/CCAP and edge QAM MAC & PHY be in the headend in a centralized access architecture. Although this technology has served well for the last two decades, a shift to digital optical transport will change the design of HFC networks to a distributed access architecture.

Using digital optical transport creates a digital fiber coax (DFC) network, which allows the DOCSIS PHY and MAC to be separated, creating a distributed access architecture. DFC networks allow the CCAP MAC and PHY, or just the PHY element to be placed in a node, closer to the customer premises which enables selective subscriber migration.

When service providers are embarking on a plant upgrade, they must take into consideration their goals and plans for the next three to five years. As such, they should only install components and technologies that meet the engineering standards of these longer term plans. For example, if a mid-split is in the plans, such as moving the return from 50 MHz in North America to a higher frequency, all active and passive electronics being installed as part of that upgrade must be taken into account. Similarly, the forward spectrum allowed through any active and passive electronics should take into account plans for forward spectrum of at least 1200 MHz, and potentially up to 1800 MHz.

The DOCSIS 3.0 specifications support an upper frequency edge for the upstream band of up to 85 MHz, also known as mid-split. While the newer DOCSIS 3.1 specification supports an upper frequency edge of up to 204 MHz, also known as high-split. If there are plans for forward spectrum to move past 1 GHz, that also needs to be carefully considered prior to making any upgrades in the plant. The decision for mid-split or high-split spectrum allocation is dependent on what upstream service offerings are required and if the forward is moved out to 1.2 GHz or more, and if a full 96 MHz OFDM channel is required.

Selective Subscriber Migration

DOCSIS 3.1 allows for increased service levels, however in some cases there will be segments of the HFC plant where upgrades are either not cost-effective, or greenfield construction lends itself best to the use of all-optical solutions. Migrating select subscriber groups to alternative technology approaches such as xPON or RFoG can help make the plant upgrades more efficient.

PON networks carry digital data over fiber from the headend/hub to the customer premises. PON networks are attractive because they are passive, which increases reliability and lowers operational and maintenance costs. However, they don't support legacy video services and are often associated with a migration to IPTV. Hybrid PON networks can provide a video overlay to support legacy video systems for additional complexity. PON networks may also require a PON extender to address issues with network reach and adding capability for higher split ratios in the optical network.

RFoG networks carry RF signals to the customer premises over fiber. This requires pushing fiber optic cable deeper into the network, but allows any type of packetized data and/or any RF modulated signal for the delivery of subscriber services. Hence, it provides compatibility for existing DOCSIS modems and legacy video set-top boxes.

Optimized Node Segmentations and Splits

As the demand for more bandwidth continues, service providers are constantly reviewing the utilization of service groups, and evaluating when and where to split nodes. Node splits reallocate or add more bandwidth to service groups. There are two ways to split nodes. Logical node splits reallocate more bandwidth to areas of greater usage. Physical node splits light up dark fiber or add new fiber to increase capacity. The method depends on the size of the groups on each node and the amount of bandwidth being utilized.

However, regardless of the method of node segmentation and splitting, the bottom line is that the number of customers per node must decrease. Some major service providers are currently planning for as few as 50 homes per node in order to deliver high-quality, feature-rich services over time.

Spectrum Utilization

It's imperative that the service provider is utilizing available spectrum efficiently, in order to maintain high-quality subscriber services during DOCSIS 3.1 evolution. This approach includes management and reclamation for channel realignment and the removal of any analog services. Where possible, analog services should be removed or consolidated. Channel realignment should include provisions to allow two contiguous (or mostly contiguous) 192 MHz carrier blocks for OFDM modulation in the forward path. The use of OFDM and/or QAM modulated carriers to support legacy devices should be carefully planned in order to maximize the number of contiguous or near-contiguous carriers for channel bonding by DOCSIS 3.0 modems.

Regardless of the migration path service providers take, they will likely need to synchronize the introduction of next-generation capabilities with a phase-out of legacy services. One strategy that enables service providers to strike this delicate balance is the deployment of switched digital video (SDV). This approach helps to utilize spectrum as efficiently as possible by enabling service providers to scale back the amount of spectrum that is allocated to legacy QAM channels, without reducing the number of channels available to subscribers. By sending less-frequently watched channels over the network only when a viewer requests them, service providers can achieve a significant bandwidth savings for their legacy broadcasting capabilities and reclaim valuable spectrum. The SDV strategy can save up to 90% of the Broadcast Digital Video spectrum, permitting MSOs to offer virtually unlimited programming in a fraction of the amount of spectrum.

The diagram below is an example of a spectrum evolution plan for a DOCSIS-based service provider network.

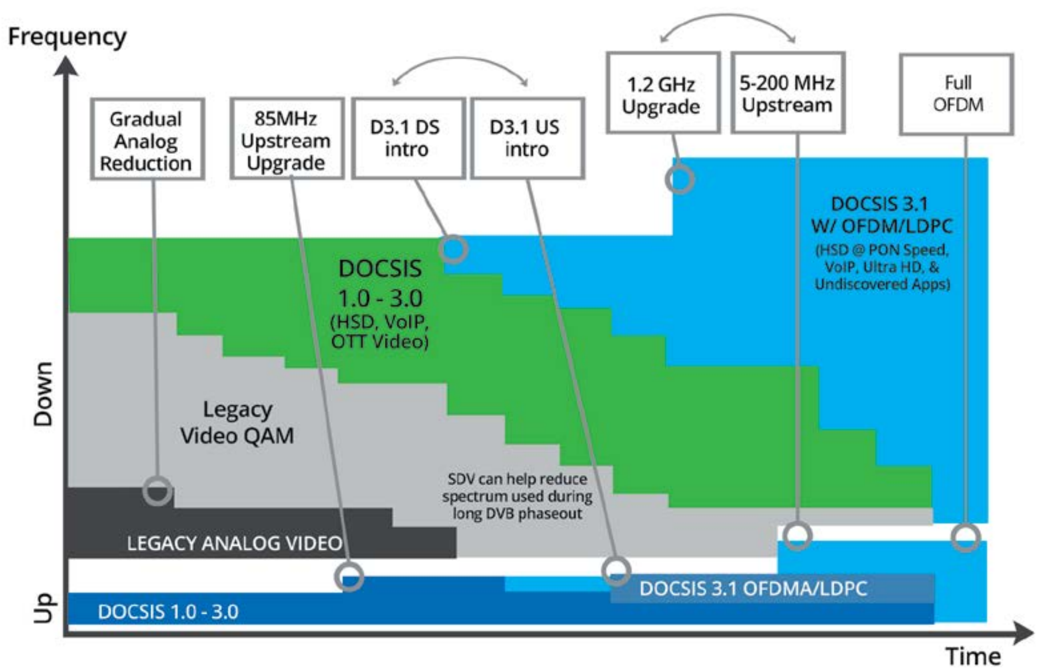

Figure 1 – Future Cable Spectrum Evolution[2]

Getting Your Network Ready for DOCSIS 3.1

Once service providers have gone through the process of identifying subscriber delivery service goals, measuring network characteristics and capabilities and evaluating architectural evolution plans, they are now ready to identify the network changes that need to be made to support their goals.

Based on centralized CCAP with future support for R-PHY deployments, the service provider will have to deploy I-CCAP for brownfield networks based on traditional DOCSIS 3.1, 1.2 GHz HFC solutions. R-PHY will need to be deployed for greenfield networks and small serving group density hub locations with R-PHY shelf solutions. This evolution path is illustrated below.

However, a key benefit of DOCSIS 3.1 is its ability to operate in existing plants (e.g. 750/42MHz) to deliver Gigabit services without requiring costly outside plant upgrades. service providers have the flexibility to upgrade to 1.2GHz/204MHz after DOCSIS 3.1 is introduced, if they so choose, in order to create more spectrum for additional bandwidth growth.

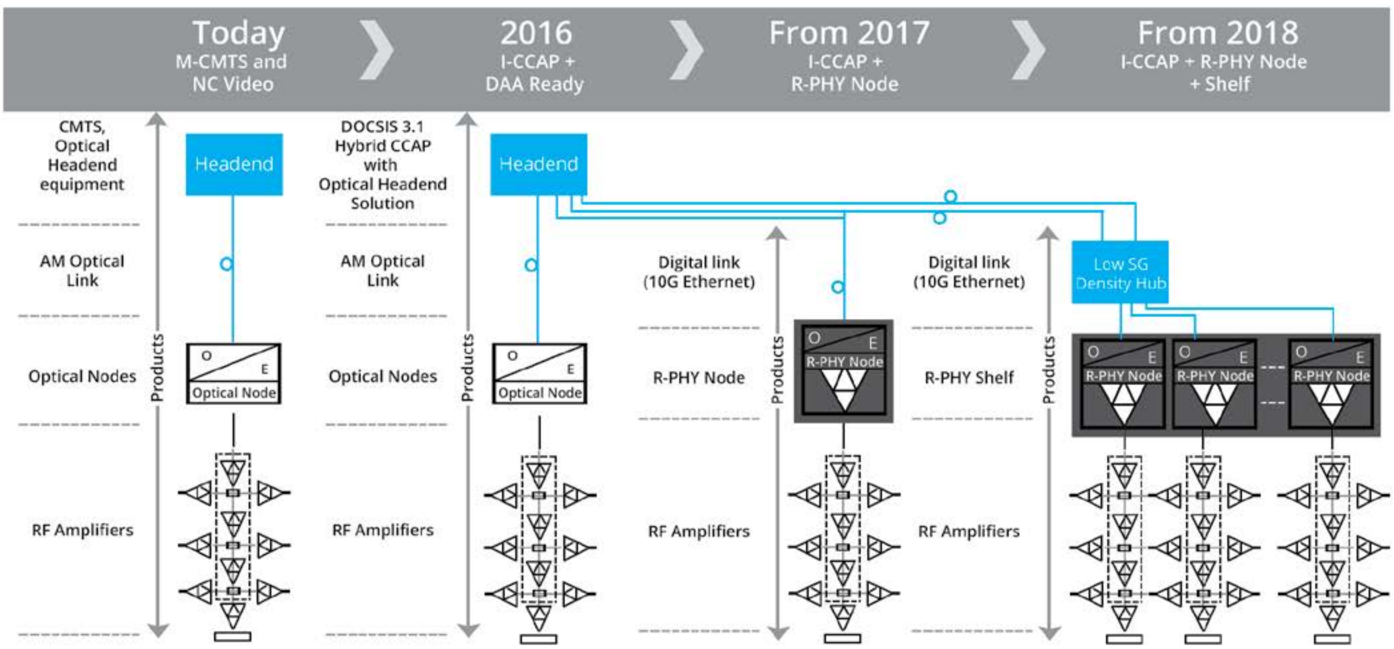

Figure 2 – Final Analysis of the Real-life Customer Example – A Multi-stage Evolution to DOCSIS 3.1

In order to provide the desired services and data rates, it was determined that the service provider customer should begin a multi-year upgrade process. This would require deployment of HFC technology targeted toward higher service group density hub locations based on integrated-CCAP, new head end optics, nodes, amplifiers and passives. In a second stage, deployment of Remote-PHY nodes within a Distributed Access Architecture (DAA) would be targeted to low service group density locations. Overall, distributed architectures with either R-PHY or R-MACPHY should be supported.

Conclusion

In the end, it all comes down to the service provider delivering the optimal quality of experience (QoE) while supporting its business model. The methodology outlined in this paper guides the service provider to overcome certain technological challenges with regard to capacity, efficiency and cost. The business case for any network evolution project needs to be solid, with the return on investment taking place in a meaningful and reasonable timeframe. No matter what the service provider's goals are for the types of service to offer, amount of bandwidth to deliver or upgrades to the network to perform, the primary objective is to ensure the network is capable of satisfying subscriber demand, now and throughout the next decade.

Related Readings

Managing the Evolution to DOCSIS® 3.1 – This paper reviews the advanced features of DOCSIS 3.1 that increase network capacity, and then presents a technical network migration process that helps service providers prepare for the DOCSIS 3.1 era.

Managing the Evolution to DOCSIS® 3.1, Part II – This paper identifies several operational considerations associated with a DOCSIS 3.1 transition. It reviews several unique requirements of DOCSIS 3.1 and examines multiple paths on which service providers may choose to embark as they ready their networks, while minimizing operational disruption along the way.

Network Migration Demystified in the DOCSIS® 3.1 Era and Beyond – This paper explores a gradual network migration strategy that accommodates the traffic demand in a cost- effective manner, with a decision tree that helps select the appropriate technology enablers. Downstream and upstream migration to DOCSIS 3.1 is described and long-term network evolution scenarios are provided.

References

1 Ayham Al-Banna, Ph. D. "What Spectral Efficiency Gain Can DOCSIS 3.1 Offer to MY Network?" ANGA Cable 2016, Cologne, Germany.

2 Cornel Ciocirlan "Migrating to IP Video over DOCSIS®"

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