

DOCSIS Migration Methodology

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The DOCSIS network is continuing to be pressed to deliver more throughput and speeds as more users and services are added. Without a systematic way to analyze and plan the upgrades, this process can be costly and time consuming.

It's possible, however, to analyze and plan a successful network migration. Knowledge is the first step. You'll need to understand your product roadmap, the benefits of each generation of DOCSIS technologies, and the current state and architecture of your DOCSIS network.

As a detailed example will make clear, the migration strategy itself comes from analyzing the service requirements and network capacity. Product roadmap The development of a long-term technology roadmap is the key to avoiding the continual "rip out and replace" cycle of DOCSIS hardware and associated systems. Before we can do this, we must have an understanding of the services we want to deliver and associated timeline – a product roadmap.

The product roadmap can be categorized by parameters, such as type of services (high-speed Internet, voice, video over IP), service penetration, speeds for each tier, security and reliability.

For example, the desire for operators to launch voice services was a major driver for the deployment timeline of DOCSIS 1.1. Privacy and theft of service were another set of requirements that drove the need for the deployment of DOCSIS 1.1. Competitive trends such as the need to boost downstream speeds may drive the need to upgrade to downstream channel bonding, which is part of DOCSIS 3.0.

Therefore, a set of high-level end objectives from marketing is very useful in helping determine the various technology options and the deployment timeline. These objectives should be documented as sets of features along with dates showing when each objective needs to be met. Note: The marketing objectives discussed in this article are examples only and do not reflect Comcast's plans for future DOCSIS services.

A five-year goal of increasing downstream and upstream speeds while continuing to push out voice services might include the following objectives:

- 30 Mbps down, 2 Mbps up; standard tier
 - 50 Mbps, down, 5 Mbps up; premium tier
 - 5 percent growth, annual penetration rate, data
 - 40 percent growth, annual penetration rate, voice
 - 1 percent penetration, premium tier
 - 20 percent annual speed acceleration
- DOCSIS technologies Given those requirements, let's analyze what technology pieces are needed. The first step should be an assessment of what each version of DOCSIS offers and the current network capacity.

DOCSIS 1.0: This version, standardized in 1996, was mainly designed to provide high-speed Internet access.

DOCSIS 1.0 requires several back office and operational support systems (OSSs). For example, dynamic host configuration protocol (DHCP) and trivial file transfer protocol (TFTP) servers are needed to provision the cable modem. The DHCP systems have to be capable of handing out Internet protocol version 4 (IPv4) addresses for the cable modem, the TFTP servers, and time-of-day servers. The TFTP servers have to provide a configuration file to each modem when it boots up.

Based on the size of the network, these servers have to be capable of handing out hundreds of IPv4 address and configuration files a second. The cable operator typically uses a tool to create a cable modem configuration file for each service tier. The tool converts human readable parameters into the binary format file per DOCSIS.

DOCSIS 1.1: Because it enabled the launch of voice services, most operators have upgraded to DOCSIS 1.1. This is a major upgrade to features and capability.

DOCSIS 1.1 adds a rich set of quality of service (QoS) features, enhanced speeds because of media access control (MAC) layer improvements, and more security features to the capabilities of DOCSIS 1.0.

In many ways, the features present in DOCSIS 1.1 are what most people associate with DOCSIS today. This version is widely deployed across the world. Because of the depth of the upgrade and wide nature of the impact, migrating to DOCSIS 1.1 requires careful planning.

The key issue in deploying DOCSIS 1.1 systems is interoperability with existing DOCSIS 1.0 customers. Services for existing DOCSIS 1.0 customers, however, should not be affected by deploying DOCSIS 1.1 systems.

Some DOCSIS 1.0 modem designs may be capable of supporting individual DOCSIS 1.1 features via a software upgrade. Similarly, some DOCSIS 1.0 cable modem termination systems (CMTs) may be capable of supporting individual DOCSIS 1.1 features.

DOCSIS 2.0: Contrary to the numbering scheme, DOCSIS 2.0 is more confined in the areas that it impacts than DOCSIS 1.1. The major additions to DOCSIS 2.0 include the following:

- Upstream physical layer
- Faster symbol rates (5.12 Msymbols/sec)
- More modulation types, such as 64-QAM (quadrature amplitude modulation)
- Advanced time division multiple access (A-TDMA)
- Synchronous code division multiple access (S-CDMA)
- Logical upstream channels
- Autonomous load balancing

DOCSIS 2.0 can provide nearly three times the upstream throughput of DOCSIS 1.x. In addition, upstream robustness is improved because of the stronger forward error correction (FEC) and larger pre-equalizer. However, the downstream data rate remains the same as DOCSIS 1.0 (maximum rate = 38.8 Mbps post-FEC).

DOCSIS 3.0: This is a major enhancement to the capabilities of DOCSIS and as such touches every aspect of the specifications. See Figure 1 for a summary. The feature most associated with DOCSIS 3.0 is channel bonding. Channel bonding is specified for both upstream and downstream directions. Channel bonding provides speeds of 160 Mbps downstream and 120 Mbps upstream as the minimum capability.

DOCSIS 3.0 is different from other versions in that there is no set maximum speed. Instead, what limits speeds are the available number of channels in the HFC plant and the implementation of the CMTS and modem.

Channel bonding works by taking multiple physical channels and aggregating the speed of multiple DOCSIS 2.0 channels. Logically, the set of bonded channels is treated as one. The net effect is that the data rate is increased by a factor of N , where N is the number of bonded channels. For example, with three bonded channels in the downstream, a data rate of $38.8 \text{ Mbps} \times 3 = 116.4 \text{ Mbps}$ is achieved.

One other related specification is worth noting. The modular CMTS (M-CMTS) set of specifications provides for a decoupled architecture where the downstream physical layer (PHY) is separated from the media access control (MAC) layer. The main motivation for this is to share the QAM signals and the HFC downstream RF spectrum with video services. The edge QAM modulator used to deliver video has the same signal format and feeds the same transmit lasers as the downstream DOCSIS channels. Because of this, a common element that can serve DOCSIS and video can be deployed.

In addition, the architecture advocates a separation of the downstream and upstream channels to allow for flexible association of downstream channels to upstream channels (MAC domains). Previous implementations of CMTS had a fixed ratio of upstream channels to downstream channels. For example, a common implementation had one downstream

QAM channel with six upstream QAM channels on a single line card. Current network
Before we can develop the migration strategy, we need to understand the current traffic utilization and architecture of our deployed network. The key items we need to know are:

- Node size—number of homes passed per node
- User concurrency—number of simultaneous users active on a channel

Concurrency is a difficult parameter to measure directly. Very few tools exist that can gather the data for DOCSIS traffic. However, we can estimate simultaneous usage by observing average network usage and peak user data rates.

For example, on the downstream we observe the average usage is 40 kbps per sub when individual user speeds are 6 Mbps. Therefore, we have one out of 150 users active (0.67 percent) at any one time. Data from other cable operators indicate concurrency values in the range of 0.5 percent to 1 percent. A conservative estimate of 1 percent concurrency for the downstream figures in our analysis to follow.

Similarly for the upstream, we observe the average usage to be 20 kbps per user with the individual user speeds of 384 kbps. This yields a concurrency of 5 percent. The following detailed example serves to illustrate how these metrics might be used to develop a plan for future upgrades. Detailed example Note: The scenarios discussed in this article are examples only and do not reflect Comcast's plans for future DOCSIS migrations.

This example will use the example marketing requirements and concurrency factor presented earlier.

We start with taking the homes passed and multiplying by the penetration rate to yield the number of users on a fiber node. We then take the number of users and multiply by the concurrency value to find the number of users active at any one time on that fiber node. Finally, we take the number of active users and multiply by the speed per user to yield the capacity.

Capacity is expressed as either bits per second or the number of channels. This will dictate how we split/combine the channels with RF splitters/combiners. Table 1 provides this calculation for each year of our plan for both data service tiers. We also need to make sure that we have enough channels per fiber node to achieve the peak speeds. Table 2 provides the number of bonded channels needed to meet the peak speed needs based on our marketing requirements for the downstream. From Table 1, we initially need to deliver a capacity of about one downstream channel per fiber node. This grows to ~2.6 downstream channels by Year 5. From Table 2, we need two channels in Years 1 and 2 and three channels in Years 4 and 5 to meet the peak speed requirement.

We also need an RF combine network for Year 1 that has at least two channels going to each fiber node and a capacity of 1 Ch/FN. Similarly in Year 2, we need to have a capacity of 1.3 channels per fiber node with each fiber node having at least two channels reaching it.

From Table 3, we see that initially we need to deliver a capacity of less than one upstream channel per fiber node. This grows to ~1.7 upstream channels by Year 5; assuming each channel is running at 16-QAM, 5.12 Mbaud. With a more aggressive modulation like 64-QAM, we barely miss meeting the capacity need using only one channel. However, a typical scenario is that we will have DOCSIS 1.x modems that will not be able to run at 64-QAM. Therefore, it is more likely that we will need one DOCSIS 1.1 channel and one DOCSIS 2.0 channel running at 5.12 Mbaud, both running 16-QAM.

Note that no upstream channel bonding is needed even in Year 5 because the highest peak rate is less than 20.48 Mbps. The combine for this case is simple, a one-to-one combine from the fiber node to the upstream port.

Also note that we have ignored voice services from our analysis because it has only a minor impact to the end results in addition to simplifying the analysis. Equipment needs Because the marketing requirements call for peak speeds > 38.8 Mbps in the downstream, we have to deploy DOCSIS 3.0 modems now for our premium tier customers. In addition, we should be planning to upgrade all future modems no later than Year 3 to DOCSIS 3.0 for the same reason. Historically, cable modems have been left in the network for 5 to 7 years after initial deployment.

Based on the cost of the DOCSIS modem, we should carefully examine if we should switch to all DOCSIS 3.0 modems sooner than Year 3 even though we will not initially need this capability for the standard tier customers.

Looking at the needs for Year 5, we will need modems with peak speeds of ~100 Mbps for the premium tier and ~60 Mbps for the standard tier in the downstream. Since we want to avoid buying different types of modems over the life of our marketing timeline, we need to purchase modems that can channel bond at least $100 \text{ Mbps} / 38.8 \text{ Mbps} = 3$ channels. Note that the minimum capability of DOCSIS 3.0 is four-channel bonding, so any compatible DOCSIS 3.0 modem is acceptable.

On the CMTS, we need to upgrade all the downstream ports to support bonding. This is because of the downstream channels being shared with the non-bonded modems and our need to offer premium tier service to all nodes in Year 1. Since downstream channel bonding can be done in software, we can deploy the service without any hardware upgrades if the capacity constraint can be met. If more downstream capacity is needed, then we should only buy blades that have downstream channels; that is, we should not buy blades that have a fixed number of downstream ports and upstream ports.

For the upstream side of the CMTS, a DOCSIS 2.0 upstream is sufficient because the peak speeds are ~10 Mbps even in Year 5. In addition, since upstream bonding will most likely need hardware upgrades, we don't want to pay for this capability when it is not needed. This allows us to keep our existing upstream blades. Conclusions Cable operators will need to plan and spend time designing their DOCSIS networks to ensure that technical functions meet the marketing service definitions. Aligning the marketing objectives and service definitions with the capabilities of a DOCSIS network must be factored when developing the network architecture.

Planning a DOCSIS network usually includes work on IP address allocation, design of a cable modem provisioning system, writing DOCSIS-compliant configuration files to match the quality of service (QoS) specified in the service definitions, design of a backhaul IP network, RF characterization of an HFC plant, creating a network management platform, and maintaining a customer database for billing purposes. DOCSIS 3.0 will include all these tasks, plus defining the number of channels needed to support bonding.

DOCSIS upgrades can enable cable operators to increase revenues and profits, offering valued-added services to consumers not possible before. Training, planning, and close network management are essential to ensure that the costs to deliver the solution do not become more than the increased revenue. Saifur Rahman works in national engineering and technical operations for Comcast. Reach him at saifur_rahman@cable.comcast.com.