Bringing the Mid-Split Factory Online to Rapidly Produce Terabytes

An Operational Practice prepared for SCTE by

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Table of Contents

Title **Page Number**

List of Figures

List of Tables

1. Abstract

Cable operators are actively addressing upstream capacity with their most powerful tool – new spectrum. Mid-Split and High Split architectures satisfy long-term capacity and speed requirements, and are further empowered by DOCSIS 3.1 OFDMA. While capacity gains and speeds are straightforward to predict, the "how" of upstream spectrum migration requires careful planning.

At the 2021 SCTE Expo, in a paper entitled Executing the Upstream Makeover without Leaving Scars, a newly developed, remotely automated, in-Home Assessment Tool (iHAT) was unveiled. This tool was designed to manage large-scale activation of new Mid-Split spectrum while ensuring minimal customer disruption.

That was then! One year later, iHAT is fully integrated into production and technical operations workflows. The new spectrum is delivering up to 5 times more capacity. Technical training has been developed and deployed, and new care processes have been created and implemented. The iHAT tool itself has evolved – the production code is now 'iHATv3' – to make activation more efficient, automated, and less disruptive.

It is now timely to share the learnings along the path from tool development to production in scale. In this paper we will describe that journey. Technology, tools and processes for execution of large scale Mid-Split activation have been developed, launched, and scaled. Attendees will understand the spectrum activation journey from start-to-finish – system engineering, technical solutioning, operationalizing, and best practices – from the experts that made it happen.

2. The What and Why of iHAT

2.1. Background

Network upgrades of spectrum have historically targeted extending the Downstream from, say 550 MHz, to 750 MHz, 860 MHz, 1 GHz, or even 1.2 GHz. The outcome was fresh new fields of Bandwidth to seed with new and/or expanded video and data services. For the upstream, the spectrum has changed significantly less, based on consistently lower upstream demand and upgrades addressing upstream needs consisted primarily of adding additional DOCSIS channels and splitting nodes to prevent them from being congested.

Over the years, the spectrum has become fully occupied – albeit there is still capacity upgrade levers available by moving from DOCSIS 3.0 to DOCSIS 3.1. Furthermore, with the spectrum fully occupied, upstream traffic growth continuing, and mass CPE device swaps difficult and costly for modest capacity gains in the available upstream spectrum, node splits have become the primary tool of managing upstream, and as a result have been accelerating. The time to add more spectrum to the upstream has arrived, and Comcast, along with other MSOs, have made the decision to migrate to the 85 MHz Mid-Split architecture.

2.2. Purpose

Unfortunately, unlike the downstream, however, the "how-to" of spectrum migration gets more complicated in the upstream. The 42/54 MHz split has been in place for decades, and devices that adhere solely to it, particularly set-top boxes (STBs), are in many millions of homes. These devices support services that will remain active, and large scale swap outs of devices in homes, or processes that require large scale physical visits to homes, should be avoided in order to cost effectively and efficiently deploy Mid-Split spectrum at scale.

Therefore, production-scale tools, techniques, and processes must be developed to ensure that a new, wider upstream path can be efficiently operationalized, while being transparent to customers. This the purpose of the iHAT tool. It is the foundational kernel of the Mid-Split activation process, allowing remote diagnosis of the drop-home environment necessary to activate seamlessly and create processes to activated ubiquitously and harmlessly to customers.

2.3. Theory of Operation

The problem statement for Mid-Split activation, highlighted in Figure 1, is to develop a way to unobtrusively discover the state of a home with respect to these two criteria:

- Potential for video interference
- Ability to support DOCSIS upstream pass-through in the Mid-Split band

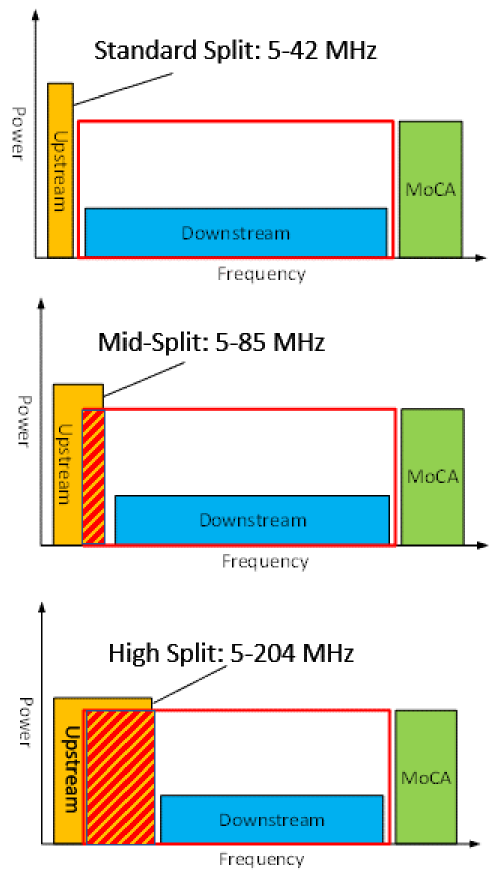

Figure 1 – New Spectrum Split vs Standard Split Deployed Equipment

To enable this home-by-home assessment in scale, an automated in-Home Assessment Test – aka iHAT – was developed to enable a seamless migration of capable CMs to utilize Mid-Split when conditions 1 and 2 above are satisfied, as shown in Figure 2

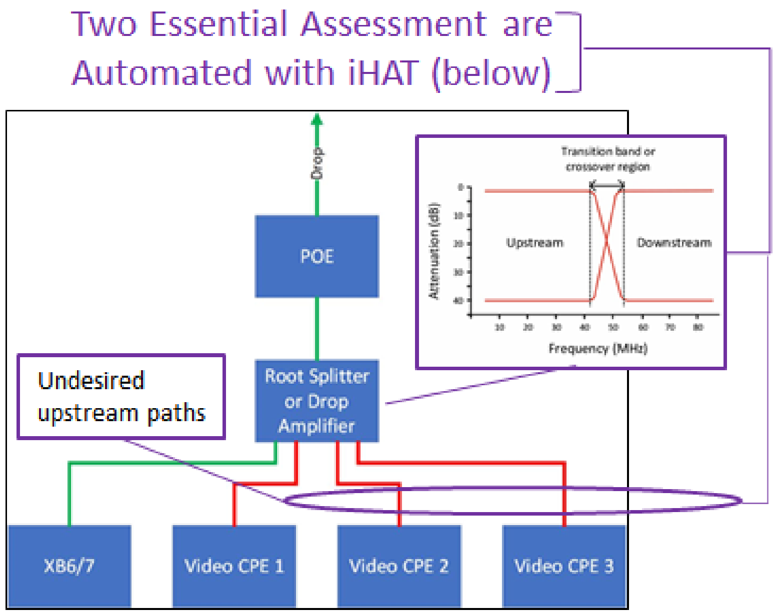

Figure 2 – The Two Basic RF Assessments Evaluated by iHAT

2.3.1. Video Interference Risk

With the decades of spectrum split in North America being set at 42 MHz/54 MHz, all QAM video STBs deployed are configured this way. They were built to receive video channels beginning at 54 MHz. When the network is NOT configured this way, and instead is upgraded to enable the diplex split to expand the upstream and activate new spectrum above 42 MHz, the QAM STB's point of view for Mid-Split or High-Split changes. This is shown in Figure 1.

The red cross-hatched areas in Figure 1 represent the spectral overlap imposed on a QAM STB by a Mid-Split capable cable modem when utilizing that band. Any signal energy that appears above 54 MHz can be seen by the STB downstream receiver, because it is built expecting to operate on downstream signals that begin at 54MHz. Unfortunately for the STB, in a home that also contains a Mid-Split capable cable modem (CM), the CM sees that band as "eligible" for placing carriers when the CMTS is configured to allow CMs to use it.

Note that the STB is not acting on any specific signal type – it is simply adapting its Automatic Gain Control (AGC) function to deliver the ideal level to the A/D converter. AGC measures the total energy in the downstream band and doesn't care about its origin. Thus, if new Mid-Split upstream energy on the STB receiver is very high, the STB receiver will add attenuation. When this happens, the *desired* video channels will inadvertently be pushed lower through a phenomenon called "Adjacent Channel Interference" or ACI. If it attenuates too much, then the QAM video signals can be low enough to cause low SNR in these channels, and video pixelization could ensue.

Note the above description is a "static" or time-fixed snapshot view of upstream energy and spectral overlap with signals moving downstream to a STB. Actual upstream traffic is "bursty." This is important because the AGC function has dynamic characteristics, but they tend to be slow acting. As a result, the duty cycle (off/on ratio) and burst duration is a factor that can impact the AGC implementations differently in different STBs.

As represented in Figure 1, the nature of the levels is not favorable – the downstream receive level is low (DS Rx), while the upstream transmit level (US Tx) is high. Until now, there was a diplex filter to separate them, but now, between 54-85 MHz, this is no longer the case. Fortunately, between a CM and a QAM STB there will be an RF splitter, the design of which will inherently isolate the port of a CM from the port of a STB by some amount. This scenario is illustrated in Figure 3, showing just one isolation path between modem (MTA) and a STB's RF inputs.

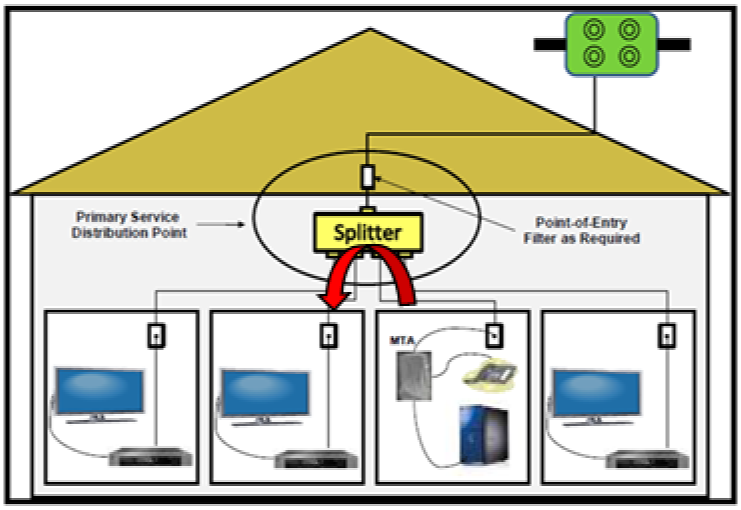

Figure 3 – Mid-Split Band Energy Isolation Path Across RF Splitter

How much energy leaks through to the STB? That question depends directly on the splitter and home wiring shown in Figure 3. Home wiring has a very predictable dB/loss per foot and is easily modeled. The most important factor with respect to the ACI phenomenon is the splitter(s) used to distribute RF to devices for video and data services.

2.3.2. Drop Amplifiers

In addition to OSP and traditional CPE devices that provide residential services that only know the 5-42MHz split, many homes also use drop amplifiers. These are also built with a Low-Split diplexer.

These devices must come out…eventually…. but because they may or may not be customer-impacting, they do not *necessarily* have to be tackled coincident with the activation of Mid-Split spectrum. From a capacity perspective, every drop amplifier that can be removed is good for capacity. The operations perspective depends on the percentage of homes that include a drop amplifier – estimated at 15-20% but can cluster depending on geography and practices. Methodically removing in-home drop amps over a period of time may make more sense than dealing with amplifiers transactionally as part of a service call or product upgrade. A proactive plan to address drop amps will eliminate the perpetual limbo state that is mixed-mode devices working in mixed-mode spectrum.

With capacity and product in mind, we can itemize home amplifier management into two buckets:

- Capacity-driven – All DOCSIS 3.1 CMs at Comcast are Mid-Split-capable, and all DOCSIS 3.0-only CMs are not. CMs are migrating to DOCSIS 3.1 steadily, so in time the majority will be installed and capable of Mid-Split upstream connectivity. However, even if a Mid-Split-capable CM is present, any home that cannot allow the spectrum to pass out of the home reduces capacity gain and upstream lifespan is compromised. Over time, these amplifiers must be removed to deliver on the full capacity promise. How quickly this must be done is a mathematical analysis of utilization vs penetration trajectory.

- Product-driven – One of the key benefits of the Mid-Split is the ability to deliver HSD speeds in the upstream such as 100 Mbps, 200 Mbps, 300 Mbps, and higher. Once such products are made available, customers with home amplifiers will be (self)-blocked from receiving them. Interest in speeds that require Mid-Split would trigger immediate action, to remove the blocking amplifier. The challenge is how to manage this efficiently and, more importantly, in a way that minimally impacts the customer. The good news is these blocking devices (amplifiers or any filtering within the band that may have been installed inline) can be discovered remotely and in real-time. While the customer cannot get the new upstream speed immediately, a rapid and transaction-based process can serve to notify the customer that additional steps are required to support the speed upgrade.

2.3.3. Issues with Legacy Systems

Some of the lessons learned from production deployments are that we now have the ability to uncover modifications made on the network over time to keep it operating and delivering services, but that have not been historically documented, or at least well-documented. Drop amplifiers are of course a case where documentation has been limited, but other scenarios exist:

- Noise and/or trap filters
- Frequency selective in-line equalizers
- RF Amplifiers added for plant extensions after initial build

Filters installed, such as for ingress, that impact upstream transmission bandwidth are somewhat obvious candidates to be found. AS scale is built, we are able to begin putting numbers around the likelihood of these types of devices effecting the ability to fully activate Mid-Split. The percentage is low, but not negligibly so. Incorporating processes to detect and locate these devices during the upgrade and activation will be incorporated. Not all cases need immediate remediation, but all cases where a customer is looking to achieve higher upstream speeds that only Mid-Splt can provide, will. However, this can be a transactional process on product order.

The last category – RF Amplifier – may be less obvious. Over time, single amplifiers may have been added to a complex HFC network cascade to capture, for example, a new development at the end of a block. If these were not properly documented and put into the spatial database, then they could be missed in the upgrade process when existing amplifiers are swapped out for Mid-Split capable devices. The result is a Mid-Split blocker in a sea of newly upgraded Mid-Split capable actives Fortunately, manifests itself as a cluster of localized iHAT failures that indicate more of a systemic issue than a home-by-home situation. Additional tools are then able to pinpoint the most likely ancestor device – which will be identified as a device close to the “missing” amplifier, a from which the actual location can quickly identified for remediation.

2.4. Evolution

A "Black Box" view of iHAT that includes the core functions of the initial design core is shown in Figure 4.

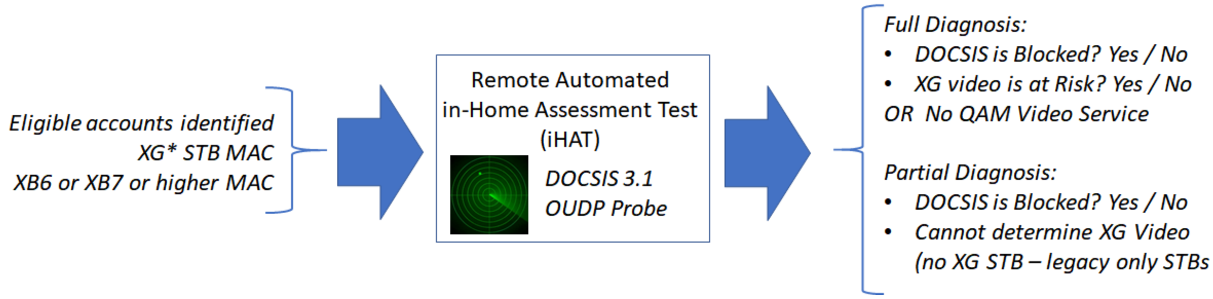

Figure 4 – The iHAT "Black Box" Method and I/O

2.4.1. iHATv1 – Proof of Concept and Functional Validation

With the introduction of the "N+0" architecture [Howald fiber frontier/2016, surf conditions/2018], Comcast began the upgrading of its HFC plant to an 85 MHz upstream. This has continued unabated, and is now on an accelerated path to cover more footprint, faster, by also upgrading in-place N+x HFC footprint to be Mid-Split capable. The system engineering and development of operational practices began at this time, and the mathematical basis for the potential for ACI due to Mid-Split quantified theoretically. Further lab testing was performed to assess the sensitivity of different STB models to ACI as a function of RF level and On/Off duty cycle of US traffic. The next step was to observe performance in the field against these projected impacts.

The first version of iHAT (iHATv1) was very much a trial-worthy, proof-of-concept (PoC) approach to facilitate learning about the drop amplifier and video interference deployment challenges. The approach used had high customer impact – multiple reboots to switch the CM diplexer between Low Split and Mid-Split, and a proprietary MIB managed. Fortunately today we have standardized MIBs via DOCSIS 3.1.

The method to evaluate readiness of a home for Mid-Split was to increase the upstream burst rate – i.e. change the speed tier to be higher to exercise the full Mid-Split spectrum and ensure the CM upstream signal would overlap with STB receivers, so the effect on the receiver could be observed when it did. Speed tests were then used to simulate utilization, while simultaneously measuring the effect on STB fidelity by observing modulation error ratio (MER) and uncorrected codeword error rate (UCER).

FEC-free range of operation for 256-QAM is MER ≥ 34 dB and BER ≤ 1E-8. Through lab measurements, we observed that video experience degrades – visible pixelization occurs – for 256-QAM when ACI ≤ -20dBc for the most sensitive of STB makes and models. By reading the MER and UCER during a speed test, a home could be identified as being at risk for video interference or not. Furthermore, the ability to demodulate the Mid-Split signals at the CMTS would identify that the bandwidth was not being blocked by a drop amplifier.
While this tool was a significant simplification of the in-home measurements that preceded it, where technician had to go to a home and take measurements and make a visual and RF diagnosis, it was still too limiting as a tool for use in scale:

- It could only be run during maintenance windows, at times when customers would be minimally impacted
- Test duration in a single home was long, due to multiple device reboots. For large node this would translate to several hours of MW down time for each node.
- Multiple APIs were required to orchestrate configuration, speed testing, and data collection

All the above led to a semi-automated engineering tool suitable for trial learning with 10s to 100s of customer assessments during a given maintenance window.

2.4.2. iHATv2 – Ecosystem Automation and Transition to D3.1 OUDP Test Probe

The iHATv1 tool validated the general premise that devices in the home and the tools available to activate and monitor them could be programmed for new functionality that would enable home-by-home diagnosis of Mid-Split activation readiness. The evolution to iHATv2 was driven by the need to become less disruptive to customers, less burdensome for the operations teams, more efficient in test duration and results availability, and more scalable for a production environment. Automation of the manual processes of pre-selecting customers and of launching iHAT itself
As shown in Figure 4, iHAT retrieves a list of devices, by account, on a particular Mid-Split-enabled RemotePHY Device (RPD) node, after the node is cutover, activated, and services restored. When an account is identified as having a Mid-Split-capable CM – for Comcast, this includes the DOCSIS3.1 gateway family of XB6, XB7, and XB8 – it is deemed eligible for an iHAT test. With one of those devices present, it will be possible to place the CM in Mid-Split mode to determine whether its upstream transmissions in the Mid-Split band are able to be seen and received by a Mid-Split enabled vCMTS and DAA node, or if they are blocked.
When an account also includes the "XG" class of QAM STB, the iHAT evaluation will look both for DOCSIS Mid-Split pass-through and the potential for video interference. This XG family, the majority of QAM STBs in the Comcast network, supports the proactive network maintenance (PNM) and SpectraCM functionality needed to capture RF measurements that are the basis for iHAT scoring of video interference potential. Older QAM STBs do not support this capability. In a home that includes an XG class STB, that measurement is a reasonable proxy for the expectation for other non-XG STBs with respect to their isolation from Mid-Split spectrum energy. If there is no XG-class STB present at all, but "legacy" QAM STBs are present, then no iHAT assessment can be made with respect to the potential for video degradation. At the outset, these homes default to Mid-Split activation. This policy will be revisited as production scale assessment can be made. This risk is low – single digit percentage [Howald MUSL 2021 paper]. By NOT defaulting to activating, the alternative is to roll a truck to each of these homes and take "iHAT" style isolation measurements manually.

2.4.2.1. OUDP Test Probe

The method iHAT uses to make its determination is based on the DOCSIS 3.1 OFDMA Upstream Data Profile (OUDP) feature, which allows a pre-defined "probe" signal to be scheduled by a CMTS and generated as a test signal. The probe can be defined by center frequency, bandwidth, and duration. When iHAT runs, it schedules this probe signal, home by home, to be burst into a portion of the Mid-Split spectrum.

Figure 5 shows the probe signal centered at about 80 MHz. It is 1.6 MHz wide (a common reference bandwidth for OFDMA bandwidth used in the DOCSIS 3.1 requirements), has a PSD at the ranged OFDMA power, and lasts 3-5 seconds. These are empirically-derived values through trial-and-error testing and optimization in the lab.

Figure 5 – Probe Signal Used in iHAT via DOCSIS 3.1 OUDP Feature

When the probe is fired, the time stamp is used to instruct the XG STB when to execute a Full Band Capture (FBC), and with that capture, samples are returned to that include levels of the OUDP probe and the first few downstream QAM channels. By determining the relative levels of these components and comparing them to an interference threshold value, making offset adjustments that account for the test probe not occupying the Mid-Split band completely, the home can be classified as to whether it needs remediation.

The OUDP method provides three major advantages:

1) It is part of the DOCSIS 3.1 specification, so a required featured to be compliant to the specification (when asked for!)
2) It can be a scheduled event within a system's normal operation, and therefore is very non-intrusive, happening without a customer's awareness or service interruption
3) As a scaled down (in total power) representation of an actual upstream signal, it does not actually create enough interference to impact video. Instead, it emulates what a small portion of the filled spectrum would look like and extrapolates mathematically to draw the proper pass/fail conclusion.

Iterative optimization of the parameters yielded a repeatable, reliable result that correlates well as a mathematical extrapolation with the video threshold testing that forms the foundation of ACI analysis.

The probe signal can also be used to evaluate blocking of the Mid-Split upstream by a drop amplifier, because if this is so, the CMTS will not be able to observe the probe. However, as part of the iHAT test, Mid-Split becomes active on a modem prior to an OUDP probe being launched, once the CMTS has a configuration that supports it. Ranging information of the OFDMA band (DOCSIS 3.1 ranging) is available to determine if the upstream was successfully sounded. If not, this is typically sufficient cause to identify a home with a drop amp issue, at which point the CM can remain in partial service or reverted to Low Split mode. In either case, the home state is logged as "remediation required."

An further benefit of the OUDP approach, looking to the future, is that it has a lot in common with the Sounding function that is part of DOCSIS 4.0 FDX.

2.4.3. iHATv3 – "Hitless" Implementation and Operation

While iHAT v2 provided significant improvements in the implementation of the test itself, in particular with respect to the execution of the core RF function itself, it still represented significant disruption because of the direct management of filters in the CM to be switched into one position or another. Modem resets that were required and device implementation differences for going back between filter settings, and onsite remediation challenges were among the obstacles. These ideas begat iHATv3, which was focused on "hitless" – or a substantially less intrusive iHAT operation sequence. A key change made to move in this direction was the use of the DOCSIS-standardized (and thus enforceable for all manufacturers) MAC Domain Descriptor (MDD) broadcasts to configure switchable diplex filters. Two major advantages to this approach are

- MAC re-initialization to Mid-Split is owned by configuration of the vCMTS and RPD, and not an iHAT function itself
- Dedicated boot files for the purpose of switching diplexers to assess Mid-Split serviceability is eliminated, removing a major disruptive step and minimizing boot file redundancy

An important element introduced by the integration of the vCMTS into iHAT's functionality is the powerful role the vCMTS has in managing the broadband network. It puts much more capability at iHAT's disposal, far above and beyond the initial simple iHAT functionality originally defined. iHAT is able to take advantage of this but moving away from diplex filter-based split configuration to manage whether a device is in Low Split or Mid-Split. With the vCMTS now an API away from iHAT, it is called upon instead to configure the bonding group of the modem to Low-Split or Mid-Split utilization, rather than move a switch in a CM. Referring to Figure 4, if iHAT finds that the device should remain in MS mode for either failure case it will dynamically adjust the bonding channel configuration (DBC) to Low Split so that there is no energy in the Mid-Split band, avoiding a drop amp blockage that could result in partial services flags at the vCMTS, or protecting a STB in the home.

2.4.4. Future Roadmap of iHAT

The iHAT tool has been launched, but as with any new launch and particularly in an agile SW-based environment, the road does not end at initial launch, it is just the beginning. Lessons learned will be rolled into future patches and releases, but also new use cases discovered and features needed to support those use cases developed, tested, and integrated into the production code.

Some of the use cases known at this time and part of the iHAT development backlog include;

- Low-Split amplifier, OFDMA blocker scenarios that extend beyond the home drop amp:
    - Use for outside plant amplifier cascades

    - Cases of “missed” plant amplifier upgrades
    - Hidden multiple dwelling units (MDUs) riser amplifiers
- In-line frequency-selective (and low-split) equalizers
- Enhanced orchestration between device APIs to minimize CM/STB communication failures
- Periodic iHAT results home health and maintenance checks
- Event-driven iHAT re-tests (for example, triggered by metrics in home or a new device in the home)
- Systemic failure results detection and automation
- Various iHAT dashboard filters and optimizations
- Extension to “nHAT” – detection of potential neighbor interference issues due to split changes, supporting expected phenomenon in both High Split and DOCSIS 4.0 FDX system

The features and capabilities will be addressed and rolled out in future software sprints.

3. From Lab to the Field

The mission statement for the original definition of iHAT in 2020 was to remotely go into a home with a test that would determine its readiness to be activate the home immediately with Mid-Split spectrum, and if it was not able to, diagnose why not. Now, two years hence, its fundamental technology has improved, it has been hardened, its capabilities and role expanded, and, more importantly, its APIs built out to turn it into a system that can be part of a large scale production operational step.

3.1. Completing the Ecosystem

Consider Figure 6 below, where iHAT is depicted at the heart of a broader upgrade workflow.

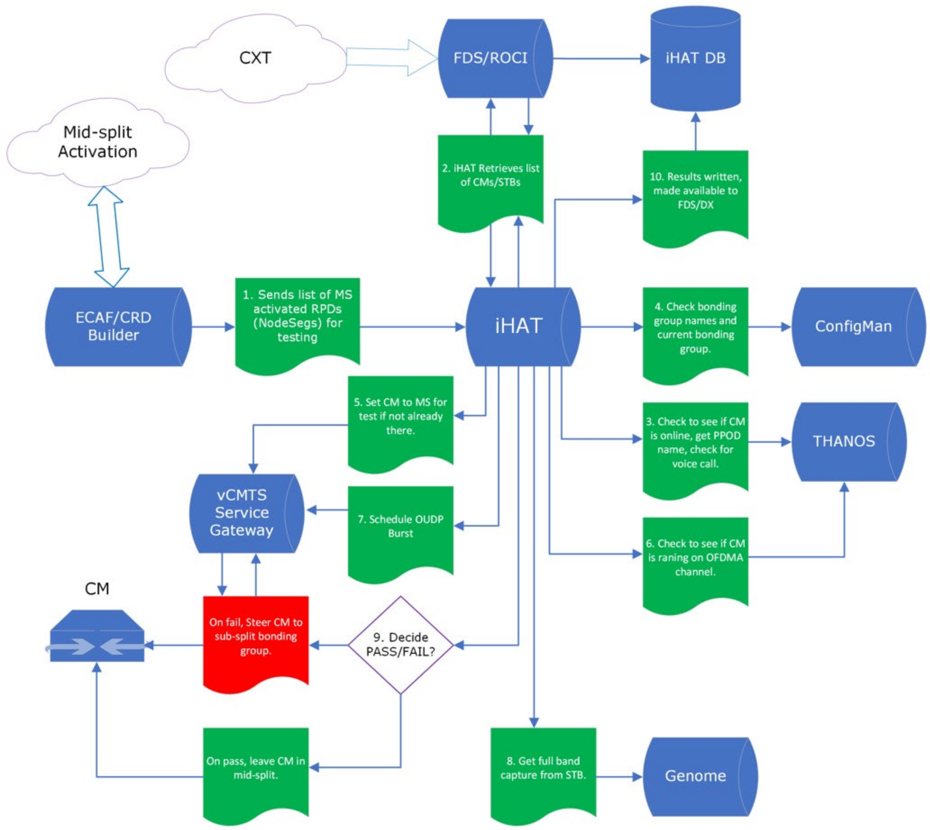

Figure 6 – iHAT as Part of a Production Upgrade Workflow

With a commitment to upgrade millions of HHP per year to mid-split capability, the tool cannot be operated in isolation, or be part of a workflow that has a "Stop" sign until human intervention to push a button. Automation is required to meet the pace required to cover the footprint target. Figure 6 contains a lot of homegrown names and acronyms associated with Comcast operations. The decoder ring is below, along with a description of their functionality as it pertains to Figure 6:

CXT = Customer Experience Technologies, the name of an organization within Comcast focused on systems and tools built for, and to maintain and support, the customer experience

FDS = Federated Data System. For iHAT purposes, it acts as an attribute and information sharing database for reading of essential information from the home and publishing ouf iHAT outcomes for subsequent disposition, processing and to other APIs. For example, what devices exist at this address? What type of device is it? What is the MAC address? What was the result of the iHAT test? The **iHAT DB** next too FDS/ROCI is where the output is pushed for other applications to use, in particular technician tools.

ROCI = An ML-based spatial tool that maps logical connectivity of devices to physical network architecture to the level of an individual Tap in the field. What modems are connected wo which RF amplifier? Which node leg? Which RPD?

ECAF = A tool within the automated workflow managing construction projects. For iHAT purposes, ECAF signals when a Mid-Split RPD and HFC network upgrade project has been

completed in the field, triggering that the spectrum activation via iHAT can begin (there are some timing nuances to exactly when but the functional trigger is closure of ECAF ticket)
CRD = Configuration of an RPD is determined by the CRD it is programmed with. Its function in the iHAT workflow is to prepare the vCMTS to accept OFDMA upstream carriers for the iHAT testing and for data carriage itself after successfully passing the test.
ConfigMan = Configuration Manager. AS described, this tool keeps track of the channel bonding configurations deployed and their state in the devices. Its role in iHAT is associated with the disposition of an iHAT result, whereby a "Pass" results in bonding if US SC-QAM and OFDMA carriers across the Mid-Split band for that home or business, and a "Fail" bonds only the 4 SC-QAM channels.
THANOS = A popular Marvel character, but for iHAT iHAT purposes it is an information store of vCMTS DOCSIS information of status, state, and logical connectivity.
Genome = A application that obtains metrics and data from devices and subsequently used to build dashboards and views in tools that maintain and support the RF network. Its role here in iHAT is to get the snapshot of the STB spectrum during the iHAT test to measure the isolation in the home.
vCMTS Service Gateway – An external application that in the iHAT application drives the vCMTS operation and the functions required to execute during the period that iHAT is running
It is apparent from Figure 6 that, while iHAT is at the heart of this flow, it is dependent upon a range of ecosystem software components to scale Mid-Split activation rapidly through the footprint. As part of the qualification of iHAT, a disciplined Integration and Test (I&T) process was developed to bring this full system to maturity and harden it for production. This process included phases of pairwise testing of relevant components to verify the APIs were communicating properly, exchanging the proper information, acting as expected on the information - reporting results, creating notifications or alarms, kicking off additional processes, etc., and executing cleanly and consistently before moving to the next phase of integration as the system was brough online component-by-component.

4. Integration with Production Ecosystems

While advancements in our network are necessary and important we have to be mindful about customer service interruptions. Minimizing the times we interrupt the customer's service is crucial to limiting customer frustration, churn and sentiment. With the customer experience top of mind, we developed a roadmap for a customer's journey and the touchpoints along their journey. We broke out the customer journey in three parts, as shown in Figure 7: Preparation, construction and appreciation.

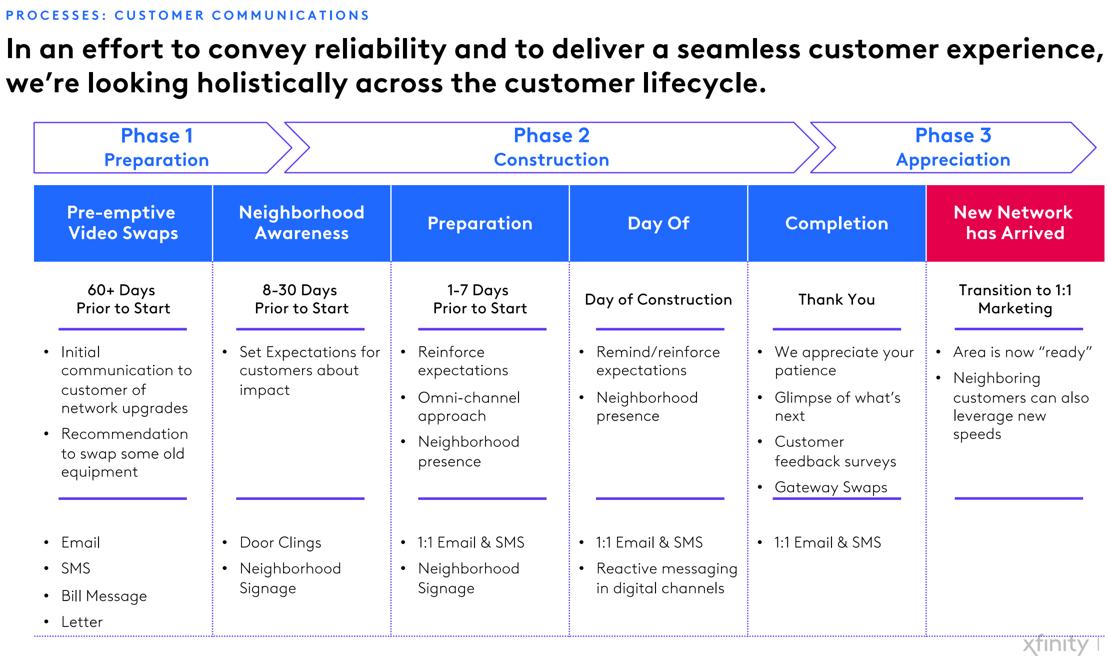

Figure 7 – Customer Journey During Upgrade

Along the customer journey we make it a point to notify them of upcoming service interruptions at least sixty days in advance. We reach out through multiple methods both physical and digital to ensure they are aware and have alternative options for connectivity during the times of interruption. During the construction phase our goal is to not have a customer hard down more than 180 minutes on average. Should we exceed 180 minutes hard down then credits and other forms of acknowledgment will be offered to the customer. When their journey is complete, we thank them and share our appreciation for their patience. We also share with them the new opportunities and capabilities offered to them with the upgraded network. This process is summarized in Figure 8.

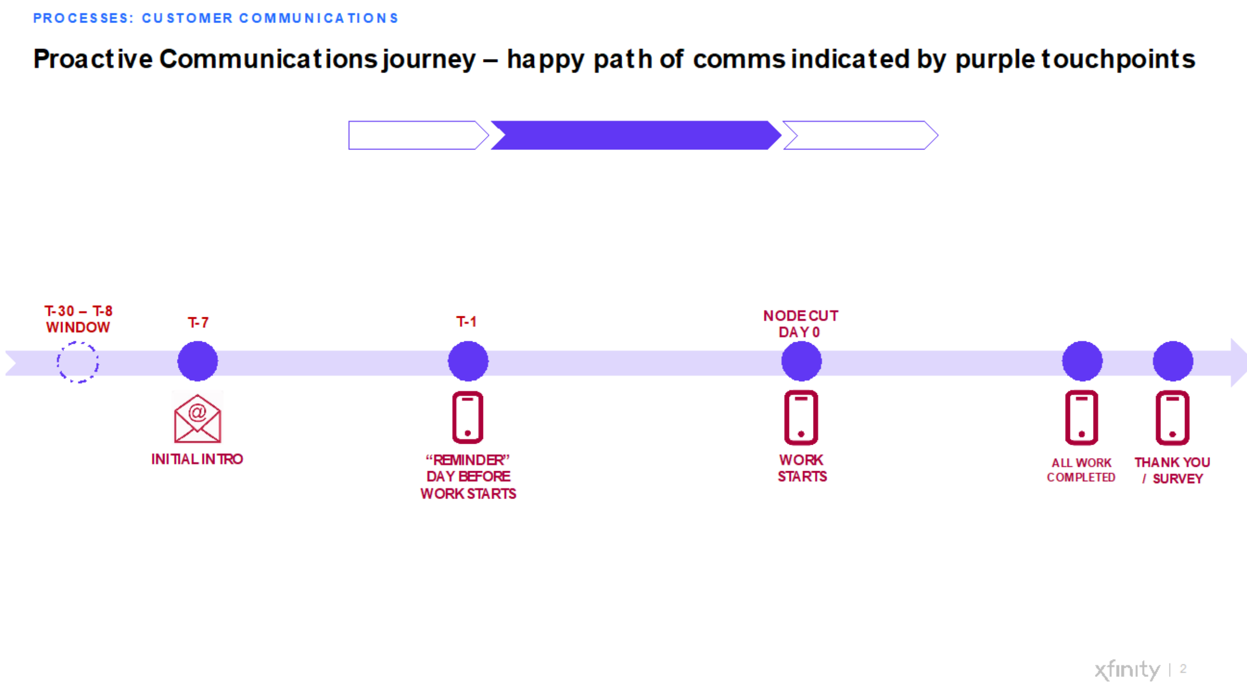

Figure 8 – Commincations Strategy During Upgrade Cycle

From a CARE perspective we have also built-in the automatic detection of Mid-Split customers so that the moment they call us we know and meet their unique wants and needs. Furthermore, we integrate the intelligence of iHAT within our interactive troubleshooting guide to determine whether a truck roll is necessary to remediate an issue specifically caused by the enablement of the OFDMA spectrum. With both Mid-Split identification when a customer reaches out and quick diagnosis as to whether their issue is Mid-Split related will set us up for success in the future. This flow is shown in Figure 9**.**

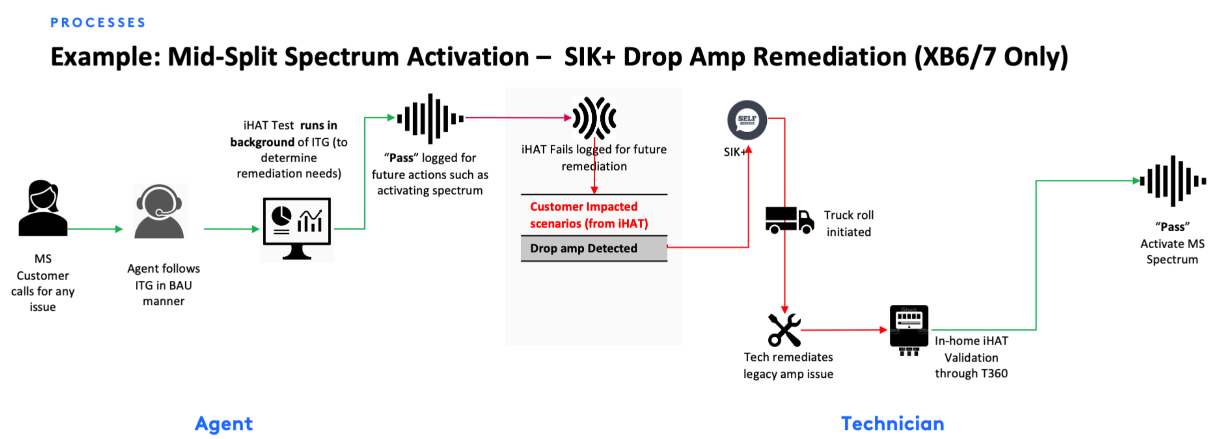

Figure 9 – Customer Care Workflow

5. Technical Operations Best Practices

Cross-functional teams across all Divisions and HQ are involved in executing the Mid-Split architecture at scale while caring for the end-to-end customer experience. A major advantage of our network architecture is that we can quickly and continuously evolve it with minimal disruption to customers — without digging up their yards and neighborhoods, as laying fiber to their homes would require. In most cases, customers should only be down for a few hours while our teams cut over to the enhanced technology on a neighborhood-by-neighborhood schedule. Through neighborhood signage, SMS, email, and more, we will proactively and fully communicate to customers throughout the journey – well before work begins, during down time, and after the job is done.

In Field Operations, technicians will need to understand the importance of the work we're doing to prepare our network for the future. They will also be responsible for:

- Preparing homes and businesses to use the new Mid-Split frequency range
- Identifying and removing hindrances preventing modems from leveraging the new frequencies

Due to the dynamic nature of Mid-Split deployment we've had to be very strategic about how, when and where we communicate. While technicians in a popular and competitive metro area would likely see activity in their market first it is equally important, we also communicate to their peers in more rural areas in a timely manner. **Table 1** is an example of the recommended communications timeline and tactics from both a national perspective to a small, localized trial.

Table 1 – Communications Timelines and Tactics

	Item	Audience	Key Message	Delivered By	Approximate Timing
	Final Comms Package and Templates	Division Communicators	Ensure the messaging is aligned and consistent across the enterprise with peer review	National Communications	
	Training Materials	Division Teams	Ensure the training is aligned and consistent across the enterprise with peer review	National Communications	
1	Leader Update	Supervisors+	Awareness to leaders that customers may start seeing advanced comms, program introduction & awareness	Launch Area Specific	Launch minus 3 weeks (or as determined by division)
2	Team Deck	Supervisors to use in team meetings	High level overview of Path to 10G	Launch Area Specific	Launch minus 2 weeks (or as determined by division)
3	Tech Awareness	All Technicians, Supervisors	High level overview of Path to 10G	Launch Area Specific	As Determined by local leadership
4	Tech Awareness	All Technicians, Supervisors	High level refresher of Path to 10G	Launch Area Specific	As Determined by local leadership

5.1. Hardware

Our network has evolved over the last few years to require less QAM set-top boxes in favor of QAM-less IP set-top boxes. The benefit of having less QAM set-top boxes in the premise means there is less of a need for in-home amplifiers in the home. For this reason we have been on a journey to bring field awareness about keeping the premise as passive as possible. Doing so sets us up for success and cost savings by not needing to return to the premise to remove a Mid-Split amplifier when we move to High-Split or any unforeseen challenges when we go to DOCSIS 4.0.

An additional hardware consideration is the field meter necessary to support troubleshooting both OFDM and OFDMA in the field. Most of us are very familiar with how quickly technology can evolve so being prudent about which meter we deploy and when is crucial to our success. Furthermore, knowing the make and model technicians have with them is crucial to effectively route the ones with fully capable meters to a home that is leveraging the Mid-Split architecture. Lastly, the speed testing capabilities of the meter are very important for customer speed validation.

Training materials to onboard technicians for these challenges are shown in Figure 10 and Table 2.

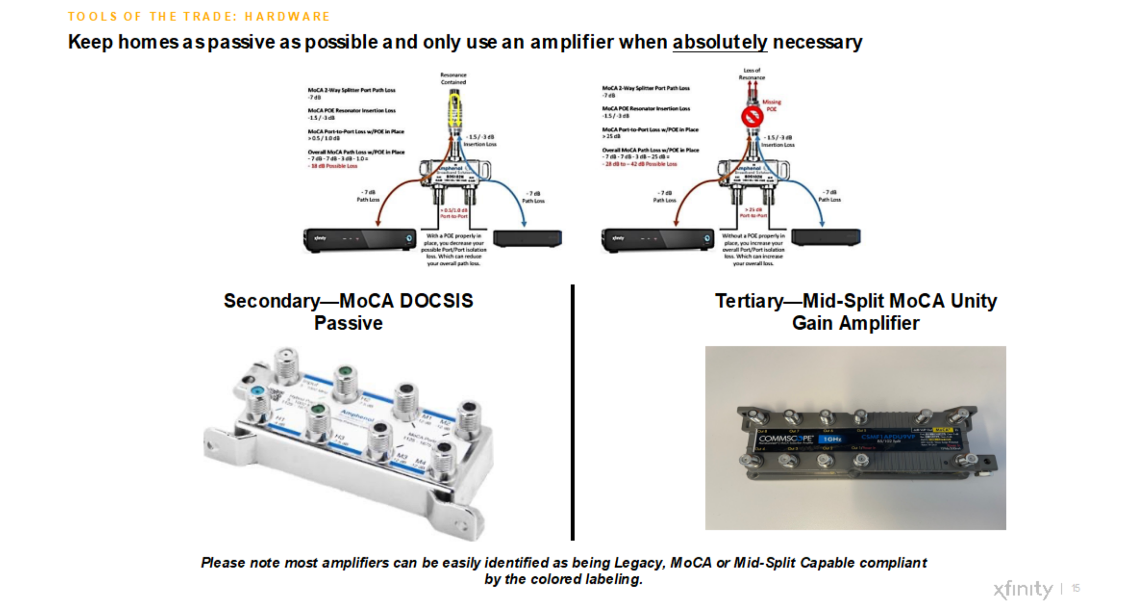

Figure 10 – Hardware Recommendations in the Home

Table 2 – Field Meters and Capabilites

TOOLS OF THE TRADE: HARDWARE

XM Capabilities Matrix

	XM1 - 2016	XM2 - 2019	XM2M - 2021
DOCSIS Ds Capability	D3.0 4x SC QAM	D3.1 32x SC QAM + 2 OFDM	D3.1 32x SC QAM + 2 OFDM
Ds Spectrum Visibility	50-1002 MHz	50-1212 MHz	50-1212 MHz
DOCSIS Us Capability	4x SC QAM	8x SC QAM + 2 OFDMA	8x SC QAM + 2 OFDMA
Us Spectrum Diplex	5-65 MHz Fixed	5-42 / 5-85 MHz Diplex	5-42 / 5-85 / 5-204 Triplex
Ingress Widget Bandwidth *	5-125 MHz	5-125 MHz	5-204 MHz
Speedtest Bootfile	N/A requires XMT Odroid side car	d11_m_cgndp3_2g250m_c05.cm	d11_m_cgndp3_3g2g_c05.cm
Ethernet Capability	100Mbit	1000Mbit	2500Mbit

XM2 recommended for Mid-Split areas

*Noise and Ingress can be measured across the entire meter bandwidth using DS Spectrum widget

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5.2. Software

Software is equally as important as the hardware because in many instances it can save a technician time by calling out impairments and opportunities ahead of their arrival. The software also serves as a be a second point of validation by confirming what the meter reads as opposed to a gateway. We've integrated tools like iHAT to help technicians be aware of previous conditions or impairments with a premise. The context enables them to know what they're likely going to a premise to remediate. Once they've remediated the issue we provide them the ability to force the gateway to start leveraging the OFDMA carrier.

Understanding enough about iHAT is important for technician to efficiently support the roll-out of Mid-Split and OFDMA. Figure 11 is a slide from the training material associated with this new software tool.

TOOLS OF THE TRADE: SOFTWARE

What is iHAT?

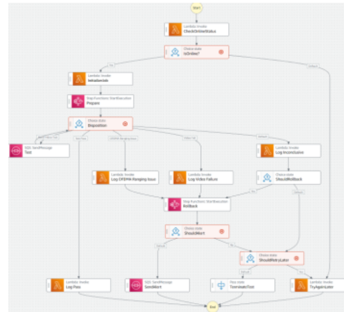
iHAT is a NGAN tool developed to help us determine whether a premise can support Mid-Split

How does it work?

When a node has been converted to Mid-Split, iHAT will be run by NGAN to determine which homes can activate MS spectrum without interruption and which homes may need remediation

What is iHATv3?

iHATv3 is an updated version of iHAT that will not require a device reset to perform a test



Identified Issue	Definition	Solution
OFDMA Ranging Issue/ Blocked Carrier	iHat is unable to reach DOCSIS Device	Most likely cause is a drop amplifier in the way and will require a TC to remove or replace with Mid-Split Drop Amplifier
Video Interference	iHat identified Video interference from one of the XG devices in the home	This is caused by low port-to-port isolation in the soft drop system TC will be required to ensure passive drop network meet Comcast specifications. (other solutions available depending on market availability)
No XG Devices		iHAT can preform a test but will not be able to provide video interference information
XB3/ BWG or older model		Customer does not meet minimum requirements to preform test

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Figure 11 – iHAT Definitions

6. The Terabyte Factory is Online

Comcast has been installing digital Mid-Split capable nodes for over 5 years as part of our "Fiber Deep" DAA network upgrade strategy using Remote PHY nodes (RPDs). Up until recently these deployments were exclusively in areas upgraded to "N+0," which eliminates all RF amplifiers in the plant between the DAA node and customer homes. As we continue to build out our DAA network, deployments now include RPDs in typical "N+X" (X = number of RF amplifiers) using Mid-Split amplifiers swapped into existing amplifier locations to minimize plant rework. The entire DAA footprint is Mid-Split ready, and the process of activating the Mid-Split spectrum has begun, configured using both DOCSIS 3.0 SC-QAM channels and DOCSIS 3.1 OFDMA channels up to 85 MHz.

One of the advantages of using the vCMTS and DAA is the ability to perform extensive monitoring of the network and easily build custom tools and dashboards. These dashboards are critical during deployment to ensure we have visibility into the devices and network as the spectrum and upstream OFDMA are being activated.

We look at these aspects in more detail below.

6.1. Mid-Split Activation

Activating the Mid-Split spectrum is a multi-stage effort including planning, construction, spectrum activation, in-home health assessment, remediation and monitoring. Through June 2022, Comcast has over 30,000 DAA nodes built and activate, and the Mid-Split migration process has begun. The engineering effort, testing and planning for deployment is paying off and the monitoring tools and dashboards developed have been invaluable.

Spectrum activation consists of two stages:

1) Updating the system to use the OFDMA spectrum. This includes pushing an updated configuration to the RPD which has a 5 channel bonding group (4 SC-QAM channels + one OFDMA channel to 85 MHz). Figure 12 is illustrative of this configuration.

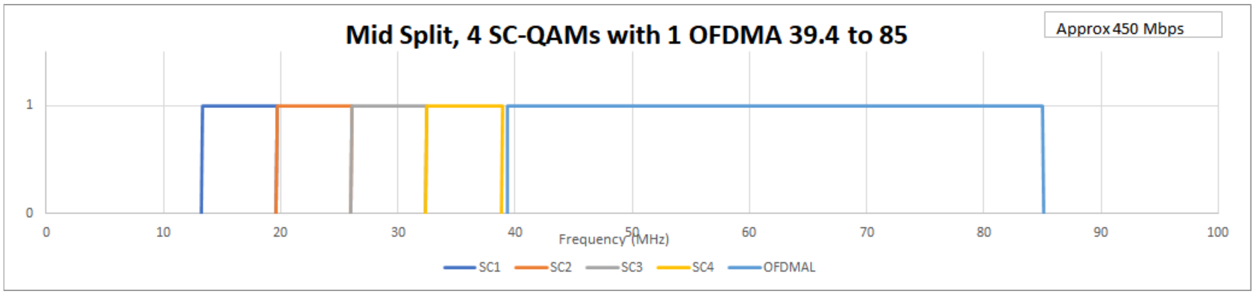

Figure 12 – Mid-Split Channel Configuration of 4x SC-QAM + OFDMA

2) Running iHAT

a) Measures video interference on accounts with STB boxes and moves devices which are determined to have video interference to the standard 4 SC-QAM channel bonding group via Dynamic Bonding Change request.
b) Moves devices which have OFDMA blocked and cannot use the OFDMA channel back to the 4 channel bonding group using Dynamic Bonding Change request.
c) Steering the devices which cannot use OFDMA to the 4 channel SC-QAM bonding group prevents these from showing as in "partial" state in the monitoring tools.

During the spectrum activation and iHAT process, devices are monitored to ensure they are online and using the appropriate channel bonding group based on the device capability and iHAT analysis.

Upon initial spectrum activation, devices which have the spectrum between 42 and 85 MHz impaired will not bond to the Mid-Split OFDMA channel. These devices will initially show as upstream partial until iHAT is run. Once iHAT is run, these will be moved to the 4-channel bonding group and show as fully online.

As of June 2022, Comcast has over 35,000 DOCSIS 3.1 devices activated with Mid-Split and OFDMA across approximately 1,800 RPDs. The rate of activation will accelerate in the 2nd half of 2022 and through 2023 as new products enabled by Mid-Split are brought to market.

6.2. New Tools and Automation

Achieving the scale noted above would not be possible without monitoring dashboards. One of the main dashboards used during activation is the iHAT dashboard. This dashboard monitors the progress of checking for OFDMA partials and testing for video interference. In-home video interference, which caused by adjacent channel interference, is measured by having the cable modem send out a 1.6 MHz wide OUDP burst. This burst is sent out at the same spectral density as the OFMDA channel. The level of interference from this burst is measured at the adjacent STB in the home. If this burst exceeds a pre-determined threshold vs the downstream QAM signals at the STB, the cable modem is steered back to the 4 SC-QAM 4 channel bonding via DBC and will not use the OFDMA. This account is noted for remediation to be able to activate the OFDMA spectrum.

iHAT also checks the OFDMA channel and if it is registered and bonded. If the OFDMA channel is bonded and the account passes the video interference on the accounts with STBs, the CM remains in the 5 channel bonding group with OFDMA active.
If the OFDMA channel is not registered and bonded, iHAT steers the CM to the 4 SC-QAM bonding group via DBC. This removes the status of partial and shows the device online. The account is targeted for remediation to determine why the OFDMA channel is not bonded.
The iHAT dashboard can look at the entire network, specific PPODs, and specific RPDs to see the number of devices with OFDMA blocked and video interference. Figure 13 is a sample of the iHAT dashboard after spectrum activation for a single PPOD which includes 154 RPDs.
This Dashboard shows the following:

- <u>RPD Count</u>: This is the total number of RPDs tested for the specific PPOD and timeframe selected.
- <u>Total number of tests</u>: This is the total number of tests performed which include testing for OFDMA Blocked, Video Interference
- <u>Pass</u>: Number of devices which can connect to the OFDMA channel and which pass the video interference test
- <u>OFDMA Blocked</u>: Number of devices which cannot connect to the OFDMA channel. This is caused by standard split in-home drop amps, or other in-home or plant issues affecting the Mid-Split OFDMA spectrum
- <u>Video Interference</u>: Number of devices which STB boxes on the same account, which connect to OFDMA, but where the OUDP burst received at the STB box is higher than the downstream QAM by the pre-determined threshold

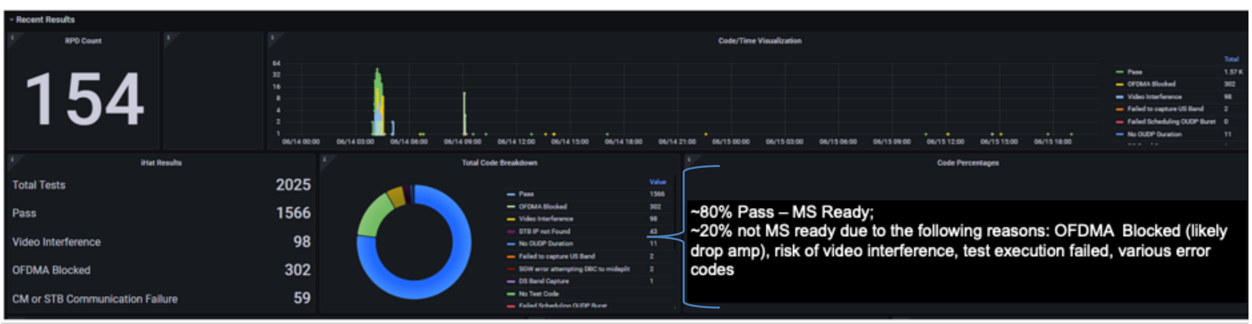

Figure 13 – Test Sample of an iHAT Dashboard

Additional tools and dashboards have been built to monitor the OFDMA health across the network. The dashboard in Figure 14 shows the OFDMA health for a specific PPOD. This dashboard can show the performance of critical OFDMA physical layer parameters of the whole network or down to a specific RPD.

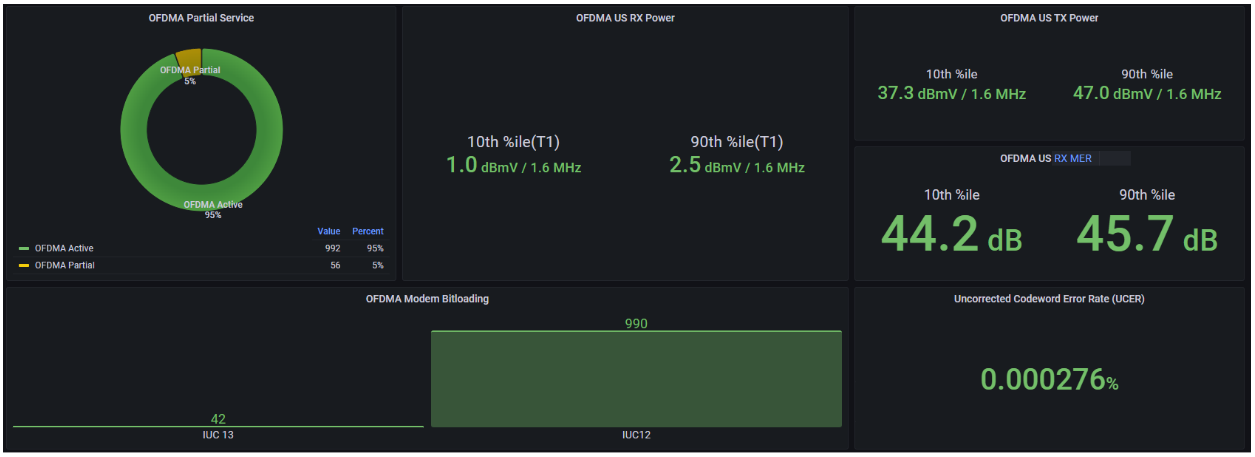

Figure 14 – OFDMA Health Statistics

The dashboard in **Figure 15** shows the state of OFDMA cable modems and the percentage of OFDMA partials in a PPOD and the overall change in OFDMA partial count before and after running iHAT. Partial count is reduced significantly post iHAT.

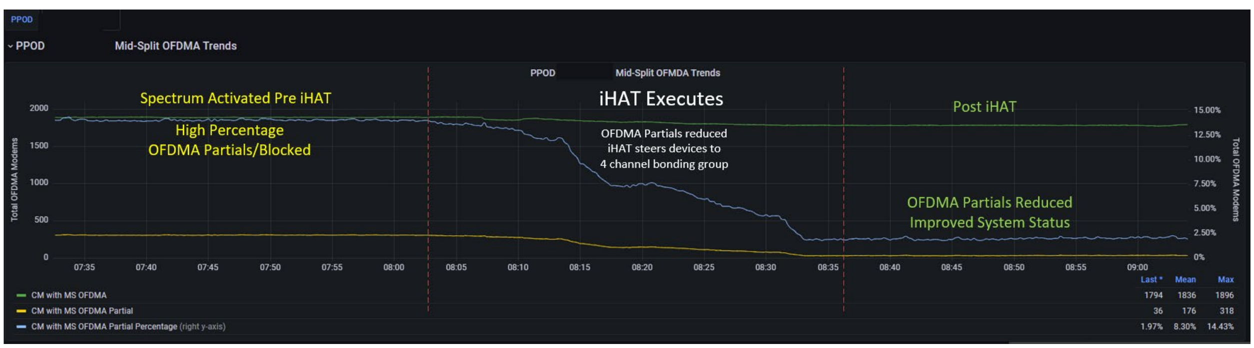

Figure 15 – iHAT Execution Statistics

Standard existing tools are also used when activating the OFDMA spectrum. Yeti, which is an upstream spectrum analysis tool, has been updated to support Mid-Split can be used to verify the health of the upstream OFDMA spectrum. Figure 16shows the upstream spectrum with the full 5-channel bonding group including OFDMA. In the Figure 17, the Yeti capture shows the 4 SC-QAM channels prior to adding OFDMA. Noise can be seen in the OFDMA band at 44-60 MHz and at 83 MHz. This is off air ingress from channels 2,3 and 5 which will have some effect on the total upstream capacity, but with PMA will be minimized.

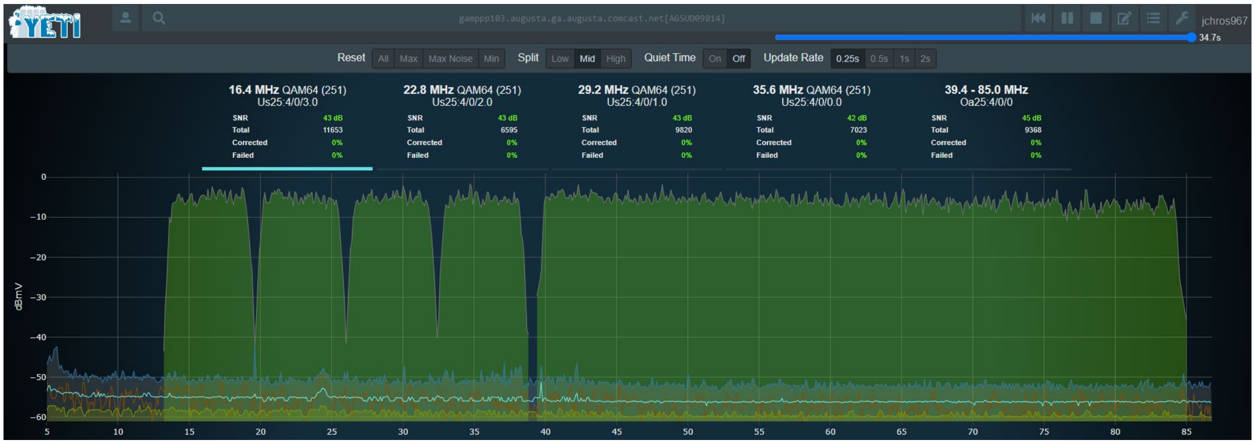

Figure 16 – Mid-Split Full Channel Configuration of SC-QAM + OFDMA

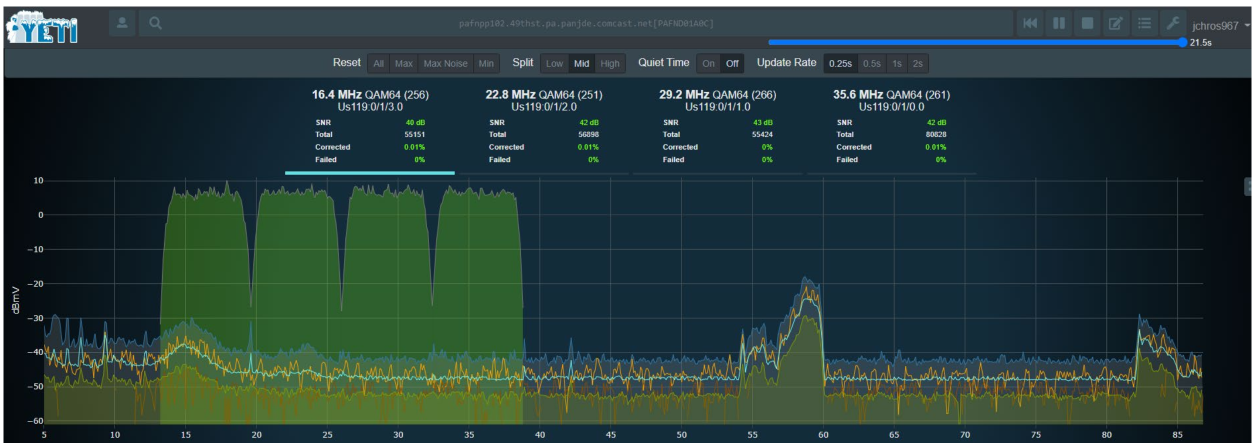

Figure 17 – Mid-Split Upstream Spectrum Capture Prior to Adding OFDMA

Numerous other tools and dashboards are available for scale deployment of mid-split and the ones above provide a look into the detail needed for this deployment.

Among the most important of these is the capacity impact of Mid-Split. Referring to Figure 16, a standard 4x SC-QAM plus an OFDMA channel from 39.4 MHz to 85 MHz offers a bonded total capacity of approximately 450 Mbps, with some variation around that depending mostly upon network fidelity variables. Of course, only the DOCSIS 3.1 devices can avail themselves to this bonded capacity. The DOCSIS 3.0 devices have their traffic contained completely within the SC-QAM allocation.

While only, roughly, doubling the upstream spectrum, we can calculate that the mid-split spectrum powered by DOCSIS 3.1 increases capacity > 4X compared to the standard 4-channel SC-QAM low-split upstream allocation. During the COVID outbreak, where an urgent need for capacity was felt everywhere and DOCSIS 3.1 had not yet been enabled (and still is not in the low-split spectrum), Comcast deployed 6 SC-QAM upstream channels to relieve congestion. This 6-channel capability represents effectively the “maximum” D3.0 only capacity in a low-split system by which to compare the Mid-Split allocation with the OFDMA augmentation.

Because of the interplay of device penetrations, capacity available to devices classes, and the variations of the network's ability to support QAM profiles, Comcast made an investment in capacity analytics to quantify how the introduction of OFDMA would impact network capacity in order to make good business decisions around device upgrades, network upgrades, and regional priorities.
For a complete analysis of the capacity impacts of Mid-Split with OFDMA, the reader is referred to [1].

6.3. Implications to Traffic Growth, Plant Upgrades, and Service Speeds

Mid-Split expansion takes the available upstream bandwidth from 37 MHz to a limit of 80 MHz. It was defined in DOCSIS 3.0, with the upper limit selected in part to fall just below the FM radio band in the US, while preserving the important downstream video out-of-band (OOB) signals widely used by legacy QAM set-top boxes (STBs). In recent history, it has been the upstream bandwidth limitation in the face of continued traffic growth that drove network upgrade activity.

The average per-user peak-busy-hour (pbh) upstream is still in the hundreds of kbps range – 400-500 kbps going into 2022. The downstream, by contrast, is about 10x that or more. As a general rule, the upstream payload has on average grown more slowly than downstream, although it has tended to more volatility year-over-year as different “killer apps” arose such as peer-to-peer file sharing (i.e. Napster) and home security video cameras. However, where DS was racing ahead at 50% per year for many years, driven by streaming video most recently, upstream averaged 20-30% - and less or flat in some years. An additional bonus of Mid-Split is that this new upstream spectrum is typically cleaner. As a result, when combined with use of much more spectrally efficient DOCSIS 3.1 OFDMA, the Mid-Split impact on network lifespan is extremely powerful. Roughly twice the total upstream spectrum converts to 3-4 times the available capacity.

Figure 18 shows the time runway generated by three options – node split, node split plus upgrade to Mid-Split, and finally N+0 with Mid-Split. While N+0, with smaller service group size, offers the longest runway of the three, an N+x migration tied to a node split is also a very effective way to extend HFC lifespan to nearly 7 years.

A key benefit of N+x with spectrum migration is its ability to add capacity quickly when compared to N+0. When the Covid-19 traffic spike eliminated months of CAGR lifespan, N+x upgrades brought more US bandwidth to the network quickly to reset the lifespan timeline. With a year of capacity growth runway erased by the pandemic – perhaps it flattens as the effect recedes and a new normal established – alternatives such as drop-in HFC upgrades that are both fast and effective make a sensible augmentation step.

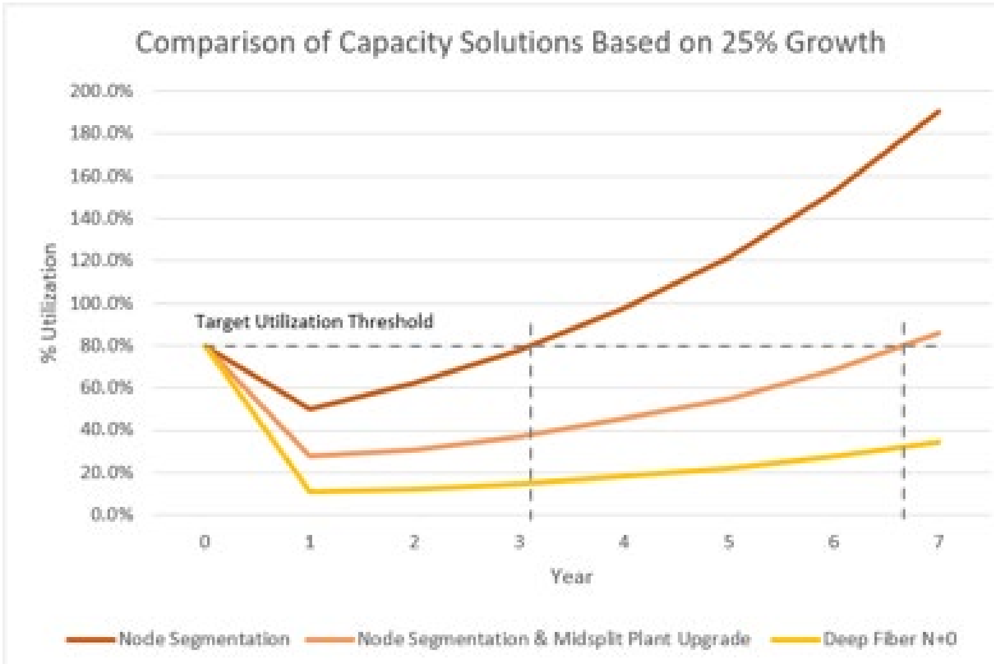

Figure 18 – Mid-Split Upstream Spectrum Capture Prior to Adding OFDMA

The 7 years of lifespan offers a comfortable window of time to assess HSD trends (is CAGR changing), technology availability options (i.e. DOCSIS 4.0, R-OLT FTTH), and assess emerging applications and the speed, utilization, latency, and jitter requirements that they entail and adjust accordingly if necessary.

Lastly, while the "big story" for upgrading to Mid-Split is been its ability to deliver a long-term life span for the HFC plant without a major compromise of downstream bandwidth, there are significant upstream service speed opportunities as well. The Low-Split upstream payload data capacity using D3.0 SC-QAM with 64-QAM carriers is about 100 Mbps, and residential upstream service speeds limited to 35-50 Mbps today.

By contrast, the available capacity for a DOCSIS 3.1 CM in a Mid-Split network using the configuration shown previously in Figure 16, and as noted on the figure and observed in the prior section, is about 450 Mbps. This will enable upstream speeds of 100 Mbps, 200 Mbps, and up to 300 Mbps – under an empirical set of guidelines for penetration, utilization, service group size, etc. The field trial activity previously described validated speeds in scale up to 200 Mbps in preparation for market launches of these speeds in the future.

As DOCSIS 3.1 device penetration continues to increase, the DOCSIS 3.0 QAM carriers can be exchanged for more bandwidth efficient DOCSIS 3.1 OFDMA, which will make this bandwidth approximately 60-80% more efficient on average, resulting in the 450 Mbps of capacity increasing to over 600 Mbps if fully converted to DOCSIS 3.1, which would take practical speeds up to at least 400 Mbps.

So, the Mid-Split upgrade represents a strategy that addresses both effective capacity growth management and higher speed product offerings for residential and business customers.

7. Conclusion

Consumer usage trends continue to fluctuate as new applications and societal shifts take place. The year 2020, inclusive of the global pandemic, accelerated and altered some of the usage trends. Many companies sent employees to work from home at the onset of the pandemic while some schools went completely virtual. Online gaming has become less of a leisure hobby and adopted by many professional teams inspiring a young generation of one day having the opportunity to participate and potentially create and monetize for themselves . One thing is clear, all usage, including upstream, is likely to continue increasing. As we enter the last quarter of 2022 one would be hard pressed to believe we will ever see ourselves in a pre-pandemic state of usage trends. If anything, we should accept what we know today as the new normal and tactically plan to continue bolstering and augmenting our networks.

Mid-Split scratches the surface for the potential of our networks, but it is a realization of what was once only a vision not many years ago. We've built the tools, processes, training, technology and end-to-end systems to develop, launch, scale, support, and maintain a DOCSIS 3.1 OFDMA Mid-Split activate network, and Comcast and our customers are reaping the rewards of this effort through a healthier, smarter, more capable network that provides a better, high availability Internet experience for our customers with higher upstream speeds to deliver on these emerging trends and application

Looking ahead, the advent of High-Split and DOCSIS 4.0 FDX present their own new challenges that, much like Mid-Split, appear daunting at the outset. However, much like we've done in the past, we will use the collective wisdom of the industry to take on these new challenges. The learnings we have gained and will continue to gain building out DAA Mid-Split will make the path that much easier for the generations to follow.

Abbreviations

ACI	Adjacent Channel Interference
AGC	Automatic Gain Control
BAU	Buisness as Usual
BG	Bonding Group
CACIR	Carrier-to-Adjacent Channel Interference Ratio
CAGR	Compounded Annual Growth Rate
CDF	Cumulative Distribution function
DAA	Distributed Access Architecture
DBC	Dynamic Bonding Change
DSG	DOCSIS Settop Gateway
FDD	Frequency Division Duplex
FDX	Full Duplex
FTTH	Fiber-to-the-Home

HHP	Households Passes
iHAT	in-Home Assessment Test
LoQ	Line-of-Questioning
MER	Modulation Error Ratio
MTA	Media Terminal Adaptor
MUSL	Mid-Split Spectrum Upstream Launch
NI	Neighbor Interference
OFDMA	Orthogonal Frequency Division Multiple Access
OOB	Out-of-Band
OUDP	OFDMA Upstream Data Profile
OSP	Outside Plant
OTA	Over-the-Air
PHT	Performance Health Test
QAM	Quadrature Amplitude Modulation
SNR	Signal-to-Noise Ratio
STBs	Settop Boxes
TaFDM	Time and Frequency Division Multiplexing
TCP	Total Composite Power

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