A Proactive Network Management Scheme for Mid-split Deployment

A Technical Paper prepared for SCTE•ISBE by

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1. Introduction

Deployment of an expanding range of upstream split options for the return path in coax systems has many challenges. Among these challenges are old infrastructure components such as drop-amps and splitters, legacy customer premises equipment (CPE) and services sharing common or overlapping spectrum. This technical report presents a scheme that leverages remote feature control (RFC) and remote health monitor (RHM). These systems selectively enable enhanced return path high-speed internet service (HSI) for Cable Modems based on a quality of service (QoS) measurement from all CPE in the household. Specifically, current use cases will describe how DOCSIS© TLV84 is used to remotely enable mid and high-split. At the same time, downstream and upstream performance metrics, such as signal-to-noise (SNR), modulation error ratio (MER), and other metrics are remotely monitored from all CPE devices within the home and, in the case of high split and full duplex (FDX), within neighboring homes as well, to evaluate potential disruption of revenue generating services. Households are scored to determine whether they are capable of self-installation of enhanced HSI services. The advantage of this technique includes allowing: 1) scalable individualized and progressive HSI deployment with a remediation strategy focused only on customer networks where potential issues exist and 2) proactive and adaptive network operations in accordance to a varying environment thus minimizing trouble calls, truck rolls, and customer contact.

1.1. Benefits to Mid-split Deployment

DOCSIS has been a frequency-division duplex (FDD) access scheme, in that the upstream and downstream transmissions occupy different bands of the spectrum (Cablelabs, 2009) (Cablabs, 2017) (Cablelabs, 2019). Standard-split operates in the 5 – 42 MHz band for the upstream transmission and has been deployed in many operator networks. Standard split has served operators well, enabling them to provide their customers with up to 35 Mbps upstream capacity since the late 1990s.

CableLabs has provided multiple options for enhancing upstream capacity with multiple versions of DOCSIS. DOCSIS 3.0 introduced the 85 MHz upstream option and with it, the ability to increase upstream capacity via channel bonding. DOCSIS 3.1 required upper edges of the upstream band to include 85 MHz and 204 MHz, so named mid-split and high-split, respectively. DOCSIS©4.0 introduces full-duplex DOCSIS (FDX) that allows upstream and downstream transmissions to share the same spectrum band where the new upstream band edge requirement extends to 684 MHz (Cablelabs, 2020).

The mid-split scheme doubles the upstream bandwidth of the standard-split scheme, which immediately translates to an augmented capacity and increased quality of service. Since many operators limit their use of the standard split band to primarily the upper two-thirds of the band, the midsplit represents nearly a 3x increase in useable bandwidth. Usually, four 6.4 MHz SC-QAM upstream channels are configured in the 5 – 42 MHz regopm, providing 122 Mbps data rate with 64-QAM modulation. The mid-split scheme is able to add four more SC-QAM channels and offers a total upstream data rate of about 250 Mbps. Alternatively, it allows configurations of advanced OFDMA upstream channels. For instance, a 48 MHz wide OFDMA channel will enable a 500 Mbps upstream data rate with 2048-QAM modulation. With another bandwidth doubling offered by the high-split scheme, more than 1 Gbps of upstream data rate can be achieved.

With all of these options available to operators, it is likely that the upstream will evolve from standard split, to mid-split, to high-split, and beyond. The good news about this approach is that all of the lessons learned from incrementally increasing capacity with customer demand can be applied to the following evolutionary step. For example, the challenges for midsplit that are discussed in this paper will also be challenges for high split, and so on. Thus, solving these challenges now with new innovative approaches sets operators up for the future, with techniques and processes for deployments of even higher capacity upstream.

1.2. Challenges to Mid-split Deployment

The relatively limited upstream bandwidth of the standard-split has been satisfactorily serving customer needs of internet access, from web surfing to video streaming. Interactivity-intense applications, including gaming, video sharing and teleconferencing have become increasingly popular, especially since the COVID-19 pandemic and work-from-home have become a new normal for many customer households, resulting in higher demand for new upstream bandwidth. This trend has accelerated changing the DOCSIS network to the mid- or high-split.

Deployment of the mid-split involves re-allocation of the spectrum used by many existing services. For example, video services on standard EIA channels 2 to 6 with carrier frequencies 57 – 87 MHz will need to be moved to make space for mid-split upstream channels. The cable plant also needs upgrades of the diplexers used in active devices, including nodes, line extenders, trunk amplifiers, and even in-home drop amplifiers. These products must support specifications for mid-split between the forward and return bands. The above requirements are challenges in and of themselves. However, the thorniest problem is in the customer premise, where a mid-split capable gateway and legacy standard-split set-top boxes (STBs) need to seamlessly coexist. The former may cause interference to the latter due to adjacent channel interference (ACI) susceptibility.

Standard-split customer premise equipment (SS-CPE) includes video set-top boxes (STBs), pre-DOCSIS 3.0 cable modems (CMs) and DOCSIS 3.0 CMs with fixed standard-split diplex filters. Mid-split CPE (MS-CPE) are usually designed with software-selectable diplex filters which can switch between the standard-split and mid-split modes. Within a customer premise, CPE devices are usually connected to the cable feed off of a splitter -- which, without sufficient port-to-port isolation, will allow the MS-CPE's upstream transmission to interfere with the SS-CPE. The "mid-band" part of the upstream signals from the MS-CPE leak through the splitter into the downstream receiver of the SS-CPE, unfiltered. Even though spectrum re-allocations are implemented, such that the SS-CPE are not expecting any services in the mid-band, thus its tuners are not tuned to any frequencies in that band, the leaked signals unfortunately raise the noise floor at the radio frequency (RF) mixers and degrade the receiving SNR for all downstream services. The consequences will be increased receiving errors and deteriorating service quality. Adjacent channel interference (ACI) susceptibility is a term commonly used for this type of indirect interference scenario.

It may appear straightforward to solve this SS-CPE and MS-CPE coexistence problem by simply replacing the splitters with ones with higher isolation specifications. This solution may turn out to be prohibitively expensive, as it may not be an easy customer self-installation procedure, i.e. truck-rolls may needed, especially in the cases where there are many home devices, or when drop amplifiers are used. It is also unnecessary to blindly replace the splitters in all customer premises, as only a small portion of them would likely have experience-impacting effects due to the interference.

When systems allow, increasing the downstream transmission power may also help mitigate this ACI problem. However, most cable operators will have already maxed out downstream RF output power for other reasons, for instance to achieve household-per-node efficiencies. Therefore, increasing node output power is not always practical, and usually requires a whole-plant calibration for stable operations.

Deployment of the mid-split at the headend, in the cable plant and at the customer premise should be a gradual procedure. A progressive and adaptive approach is one in which the mid-split mode is "turned on" at customer premises, individually, and based on their unique site conditions, which may be more efficient and beneficial from an operator's perspective. Modern IP-based CPEs are mostly capable of remote feature control (RFC) and remote health monitoring (RHM). Enabling protocols such as SNMP and TR-069 will allow network operators to selectively turn on certain services, based on viability, and continuously monitor the quality of services, so as to proactively adjust operation modes and class of services.

This paper presents a scheme for mid-split deployment, which focuses on the SS-CPE and MS-CPE coexistence problem. Applying a number of existing RFC and RHM technologies, this procedure includes a proactive on-line evaluation of network conditions and service quality, thus is able to isolate sites suffering the coexistence interference without requiring an installer to be on-site. The procedure subsequently supports a progressive mid-split turn-on in a home-individualized, and, most importantly, cost-effective manner.

The rest of the paper is organized as follows: Section 2 and 3 will describe in detail the SS-CPE and MS-CPE coexistence problem and the proposed procedure of online detection of it. Section 4 will present data from a field trial and other similar use case scenarios.

2. Problem Statement – Coexistence of Mid-split and Standard-split CPE

To better appreciate the problem, refer to Figure 1 for an illustration of a typical configuration in a customer premise with coexisting MS-CPE and SS-CPE. The MS-CPE and SS-CPE share the cable feed through a splitter. The MS-CPE's upstream operates in the 5-85 MHz band, while the SS-CPE's diplexer cuts off 54 MHz and above for downstream traffic. With imperfect isolation of the splitter's output ports, the MS-CPE's upstream signal may leak into the SS-CPE's downstream RF front end. Even when careful spectrum arrangement avoids the 54-85 MHz band being used by any services for the SS-CPE, the leaked signal from the MS-CPE upstream may result in increased noise floors at the SS-CPE's demodulator, which consequently causes the SNR to deteriorate, bit error rate/modulation error ratio (BER/MER) to degrade, and ultimately service quality to be impaired.

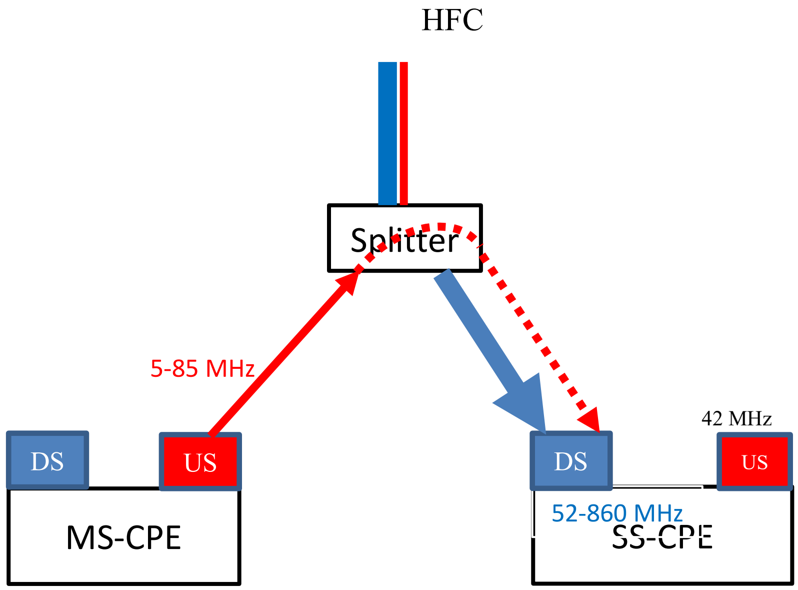

Figure 1 - Coexistence MS-CM and Pre-DOCSIS CPE

A simple estimate of a dominant noise floor increment could be as follows: The maximum transmission power of a 6.4 MHz DOCSIS 3.x SC-QAM upstream is 51 dBmV per 5.12 MHz; note that the maximum modulation bandwidth is 5.12 MHz. Assume the splitter port-to-port isolation is of a typical value of 30 dB. Then, the mid-band upstream signals from the MS-CPE will generate 51 - 30 = 21 dBmV per 5.12 MHz interference at the SS-CPE's downstream receiver. If the downstream bandwidth is of nominal value 800 MHz, the interference will add a noise of level $21 - 10\log_{10}\left(\frac{800}{5.12}\right) \approx -1.9$ dBmV per MHz. For a 6 MHz QAM channel, the increment of the noise power at the tuner would be $-2 + 10\log_{10}6 \approx 5.8$ dBmV.

Assume that the SS-CPE requires a minimum of 30 dB receiving SNR for satisfactory quality of services; also assume the cable plant is calibrated such that the CPE receiving SNR is of mean 40 dB and variance 3^2. With these conservative parameters, one could expect that about 10% of the SS-CPE population will suffer impairment to quality of services due to the 5.8 dBmV SNR degradation.

The interference to SS-CPE may not necessarily come from the MS-CPE's upstream transmissions directly. Even when there are no upstream channels configured within the mid-band of 42 – 85 MHz, the spurious emission of the existing upstream transmissions in the band of 5 – 42 MHz may still fall in the mid-band and then leak to the receiver of the SS-CPE, in the form of interference.

To target the root cause of the described problem, a simple solution may be to replace the splitter with one of higher port-to-port isolation specifications. For example, if a splitter of 40 dB port-to-port isolation is used, in the above calculation, the SNR degradation will become practically negligible. However, replacing splitters in customer premises may not easily be a self-installation procedure. Complex on-site work by technicians may be needed when the splitters are in hard-to-reach places. The solution will become prohibitively expensive if it has to be executed for every customer premise. It is also very inefficient based on the estimated percentage of the affected population.

3. A Proposed Method

An efficient solution should be proactive and individualistic. Proactivity means that the RF and network performance at the customer premises should be measured on site and in real time. Individualism means that the mid-split mode should be turned on or off for each customer premise individually, based on its unique RF and network conditions. The proposed method employs RHM and RFC technology to decide the mid-split readiness per customer premise and make a progressive deployment.

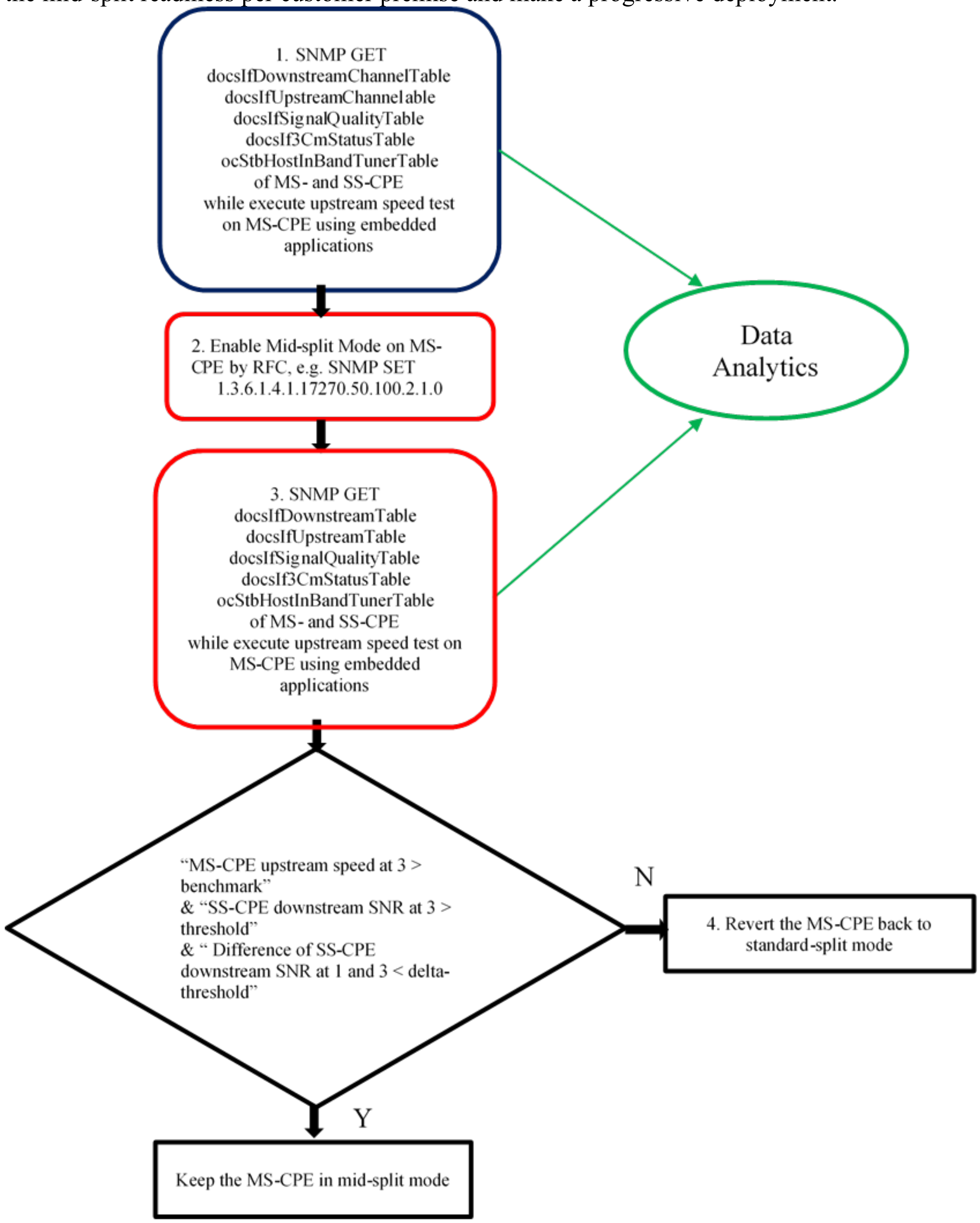

Figure 2 depicts an abstracted procedure of the proposed method. The first step is using SNMP to get the upstream and downstream metrics for the MS-CPE and SS-CPE, particularly under controlled upstream traffic that have been triggered using a speed test application. The data obtained at this step serves as a baseline for evaluating the improvements and impacts of a mid-split spectral allocation. The second step is turning on mid-spit mode on the MS-CPE. This can also be achieved through SNMP, by setting the MIB object 1.3.6.1.4.1.17270.50.100.2.1.0. Then the third step is to repeat the first. Finally, by comparing the data from the third and the first steps, operators can determine the mid-split readiness of the studied customer premises. If all criteria are met, the site can stay in mid-split mode; otherwise, it could be reverted back to standard-split mode.

The speed test part of the procedure serves two purposes: It provides a direct measure of the performance merits of the bandwidth augmentation brought about by the mid-split. It also facilitates the evaluation of impairments to SS-CPE by MS-CPE as an emulated interference.

The above procedure applies to each customer premises. The data from a large number of customer premises, correlated with MAC domains and other geographic information, can offer an inference of the network readiness for mid-splits at a larger scale. Potential issues in network components, such as standard split drop amplifiers blocking midsplit upstream transmissions, could be isolated.

Note that the above procedure exemplifies a usage of some standard RHM technology, such as the DOCSIS and OpenCable MIBs (Cables, 2020) (Cablelabs, 2013). Other technologies, such as TR-069 (Broadband Forum, 2018), are equally applicable, if corresponding data models are supported by the CPE. The speed test application is generally proprietary, which, nevertheless, is widely embedded in CPE firmware. Attention must be paid on running speed tests in that they may affect customer experience; therefore, the data collection steps are better performed during scheduled maintenance windows.

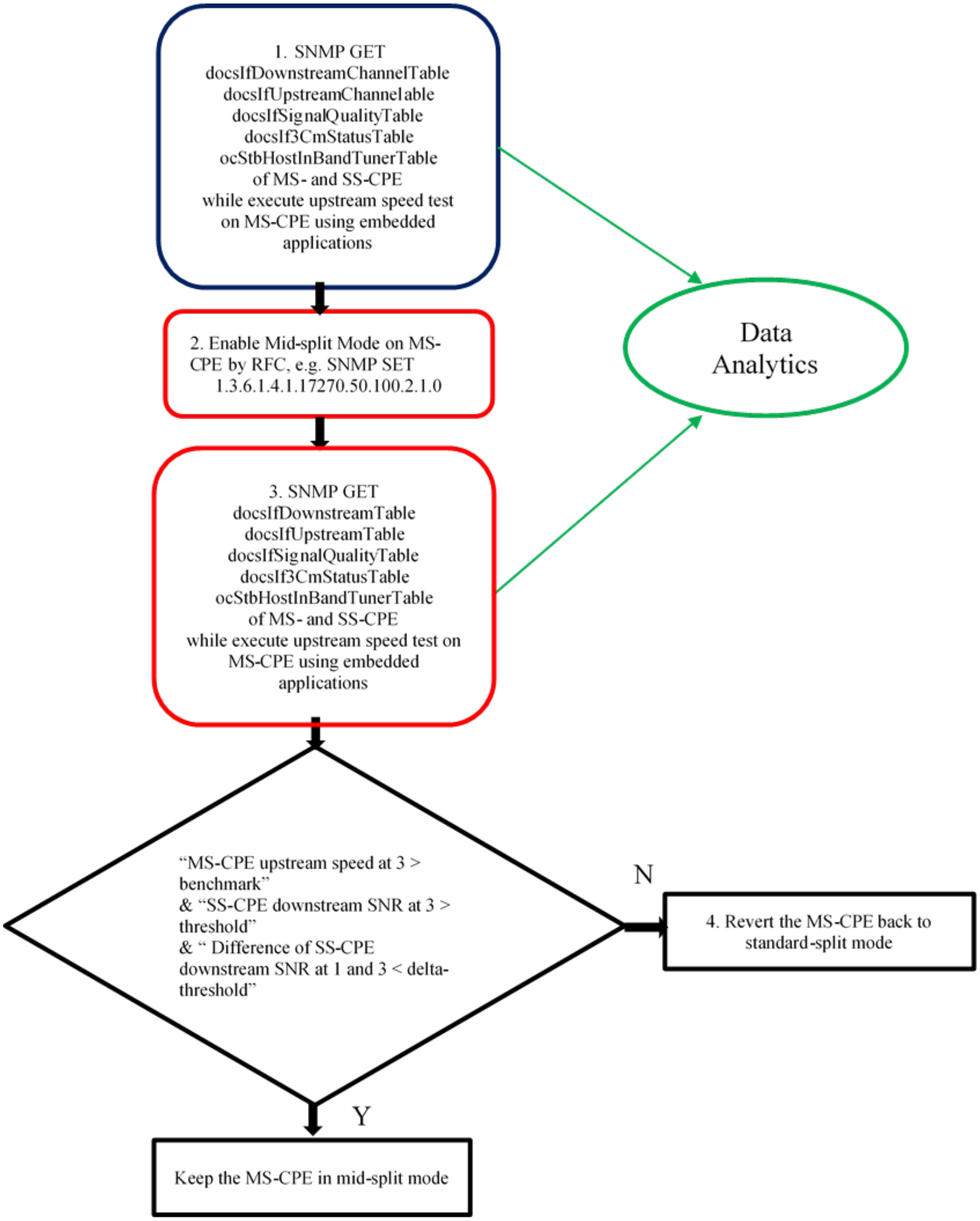

Figure 2 - RFC and RHM Procedure for Mid-Split Deployment

4. Case Studies

This section presents several trial cases of the application of the proposed proactive network management method in mid-split deployment at various levels.

4.1. Upstream Trial

This was a full-fledge mid-split deployment trial. The RHM had focused on noise level increases in the downstream band in the coexisting scenario. The docsIfSigQTable MIBs of the SS-CPE were specifically used as a sampling of the downstream spectrum at the 8 – 24 downstream frequency points. It was predetermined that if the MS-CPE would fall into a partial-service mode (indicating standard split drop amplifier issues), or the SS-CPE downstream SNR would drop below some threshold level (indicating splitter isolation or ACI susceptibility issue), then the customer premises would be failed for the mid-band mode.

Sixty-three customer premises were selected for the trial. Automated RHM and RFC activities take about 30 minutes. The trial results are shown in Table 1.

Table 1 - Results of the Eight Upstream Trial

Results	Automated Testing
Pass (SIK)	65% (41 subs)
Fail (Drop Amp)	29% (18 subs)
Fail (Isolation)	6% (4 subs)

4.2. Mid-split Spurious Emission Impairments to Video STB SC-QAM

The objective of this trial was not to add upstream channels in the 42 – 85 MHz band, but only to enable mid-split mode on the MS-CPE in standard split plant. Its purpose was to evaluate the interference resulting from spurious emissions of the MS-CPE to the coexisting SS-CPE. Note that even the MS-CPE's transmission in the 5-42 MHz band may generate spurs in 42-85 MHz band, which leak to the SS-CPE's receiver. Therefore, the method described in the previous section is readily applicable.

The MS-CPE involved in the trial were DOCSIS 3.1 cable modems, and the coexisting SS-CPE were set-top boxes. The metrics of interest in this trial were primarily the quality impairments of QAM videos on EIA channels 2-6. The MIB ocStbHostInBandTunerSNRValue had been specifically used for RHM. To make the SS-CPE tune to the designed channel between 2-6, a proprietary remote tune application was also used.

Twenty-one geographically-dispersed customer premises were selected. Automated RHM and RFC activities took about 45 minutes. Twenty premises showed no SNR degradation, and one suffered about a 2 dB SNR drop. Sample data of passed premises and failures are presented in Table 2.

Table 2 - Sample RHM Data

MS-CPE US frequency/Tx Power in stdsplit mode	36500000	45.5	30100000	45.8	23700000	45.8	17300000	45											
	57000000				63000000				69000000				81000000						
SS-CPE1 Tuner SNR (std-split/mid-split/mid-split with traffic)	41.9	41.8	41.8		41.9	41.9	41.8		41.9	42	41.9		41.5	41.5	41.5				
SS-CPE2 Tuner SNR (std-split/mid-split/mid-split with traffic)	43.1	43.2	43		43.1	43.2	43.1		42.9	43.2	43.2		42.5	42.5	42.5				
SS-CPE3 Tuner SNR (std-split/mid-split/mid-split with traffic)	43.2	43.2	40.4		43.2	43.2	43.2		43.2	43.2	43.1		43.2	43.2	43.2				
MS-CPE US frequency/Tx Power in stdsplit mode	30100000	43.3	17300000	44	23700000	43.3	36500000	43.5											
	57000000				63000000				69000000				79000000				8.5E+07		
SS-CPE1 Tuner SNR (std-split/mid-split/mid-split with traffic)	40.5	40.3	38.4		null	null	null		41.9	41.9	40.5		42.5	42.5	40.8		42.5	42.5	42.5
SS-CPE2 Tuner SNR (std-split/mid-split/mid-split with traffic)	38.2	38.1	36.7		39.1	39	37.4		39.8	39.8	38.4		40.1	40.1	39.6		40.1	40.1	39.9

This implies that future CPE deployments could continue to use a switchable diplexer, but using mid and high-split switchable CPE instead of low and mid split switchable variations. This technology re-use not only minimizes the variations in future CPE products, but also maintains high levels of return on investment in CPE to enable service growth, as customers progress from 100 Mbps to 1 Gbps upstream services.

4.3. 5th-Upstream Trial (In Progress)

The 5th-upstream is a 3.2 MHz wide channel with center frequency at 41.3. MHz; so, part of its spectrum is above 42 MHz. The purpose of this configuration is to increase the upstream bandwidth of the SS-CPE as well as the MS-CPE. The theory of such an operation lies in that, the transient band of the SS-CPE's diplex, combined with adaptive equalizer, may provide a sufficient 3.2 MHz wide frequency-flat channel. The RHM focus is on the partial service status, as well as spurious emissions to the 57 – 87 MHz band as discussed in the previous use cases.

The authors believe the above use case scenarios represent the tip of the iceberg when it comes to using online tools for solving a variety of challenges associated with enhancing upstream capacity. There will likely be multiple opportunities to reuse the tools discussed above to solve new, but similar, challenges associated with high split and FDX.

5. Conclusion

This paper illustrated a proactive and adaptive network management scheme which employs RHM and RFC to allow for progressive and individualistic deployment of a wider upstream signal path to mid-split frequency allocations, as it relates to the customer premises. The scheme is generic, such that various RHM and RFC technologies can plug-and-play. Besides automatic mid-split enablement on a per-home basis, the scheme also affords data analytics for network service quality.

The cases presented in this paper are for mid-split deployment. The proposed methods are equally applicable to high-split scenarios. As the high-split scheme is deployed in the vCMTS/R-PHY architecture and with OFDMA upstream channels, additional RHM tools may be needed and be available for the proactive network management tasks.

Abbreviations

ACI	adjacent channel interference
AP	access point
BER/MER	bit error rate / modulation error rate
bps	bits per second
CM	cable modem
CMTS	sable modem termination system
CPE	customer premises equipment
DOCSIS	Data-Over-Cable Service Interface Specifications
EIA	Electronic Industries Association
dBmV	decibels relative to one millivolt
FDD	frequency division duplex
FDX	full duplex
FEC	forward error correction
HFC	hybrid fiber-coax
HD	high definition
HSI	high-speed internet
Hz	Hertz
IP	internet protocol
ISBE	International Society of Broadband Experts
MER	modulation error ratio
MIB	management information base
MS-CPE	mid-split customer premises equipment
OFDM	orthogonal frequency-division multiplexing
OFDMA	orthogonal frequency-division multiple access
QAM	quadrature amplitude modulation
QoS	quality of service
RF	radio frequency
RFC	remote feature control
RHM	remote health monitor
SCTE	Society of Cable Telecommunications Engineers
SC-QAM	single channel quadrature amplitude modulation
SIK	self-install kit
SNMP	simple network management protocol
SNR	signal-to-noise ratio
SS-CPE	standard-split customer premise equipment
STB	set-top box
TLV	type-length-value
TR-069	technical report, 069 specification
vCMTS	virtual cable modem termination system

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