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Leakage Detection in a High-Split World

Industry Progress Toward a Viable Solution

A Technical Paper prepared for SCTE by

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1. Introduction

System leakage monitoring and detection in a Low-Split and Mid-Split world involves detecting leakage of transmissions originating from a CMTS, CCAP, R-MACPHY node and R-PHY node. Legacy methods for accomplishing this have been in place for many years and are well-understood.

In Low and Mid-Split scenarios, the aeronautical band from 108 MHz to 137 MHz lies within the downstream spectral band. With DOCSIS® 3.1 High-Split and DOCSIS 4.0 Ultra-High Split, the aeronautical band will fall within the upstream spectral band. As a result, system leakage monitoring and detection in High-Split and Ultra-High Split scenarios involves detecting leakage of transmissions that originate from a cable modem (CM). This requires a completely new way of approaching the problem.

The cable industry has made significant recent progress analyzing the alternatives available to solve the High-Split and Ultra-High Split leakage detection problem, specifying the necessary support in industry standards, and validating in laboratory and controlled outdoor environments. This paper discusses the progress that has been made on the most promising of these alternatives which has now become part of the DOCSIS 3.1 specifications.

2. Basic Concepts of the Chosen Solution

A paper from Comcast and Arcom Digital [4] described the problem well and offered four possible solutions. It suggested that the most viable of these alternatives is one where the CM is granted opportunities to transmit OFDMA Upstream Data Profile (OUDP) test bursts under the control of the CMTS, CCAP, or R-MACPHY node (hereafter referred to simply as "CMTS"), in an operator-specified leakage detection test spectral region in or near the aeronautical band. Figure 1 illustrates an example of such a leakage detection test region that is placed between 138.1 MHz and 139.7 MHz in an OFDMA channel that spans 108 MHz to 204 MHz.

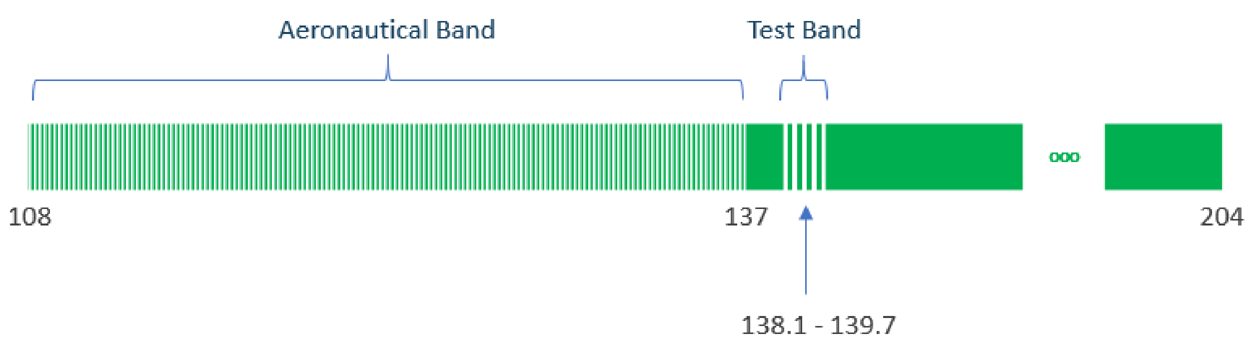

Figure 1 – Example Leakage Detection Test Region

DOCSIS 3.1 CMs are required to support transmission of OUDP test bursts on all OFDMA channels, as specified in [2]. An OUDP test burst has a specific MAC header and payload data format. It is transmitted by the CM using the modulation order and Pilot Pattern configured in a burst profile definition for the minislots granted to the CM for the test burst.

The CMTS is configured to make OUDP test burst grants covering the operator-configured leakage detection test spectral region. Field detectors tune to this spectral region and detect egress of the OUDP burst signal from the cable network by looking for the specific known Pilot Patterns from these test burst transmissions made within the region by CMs. The Pilot Patterns that are easiest to detect and

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correspondingly provide the greatest detector sensitivity are those which are most densely populated with pilots. The two densest Pilot Patterns are illustrated in the [1] excerpts in Figure 2 and Figure 3. Pilot Pattern 4 is recommended for 2K FFT leakage detection test bursts. Pilot Pattern 11 is best for 4K FFT leakage detection test bursts.

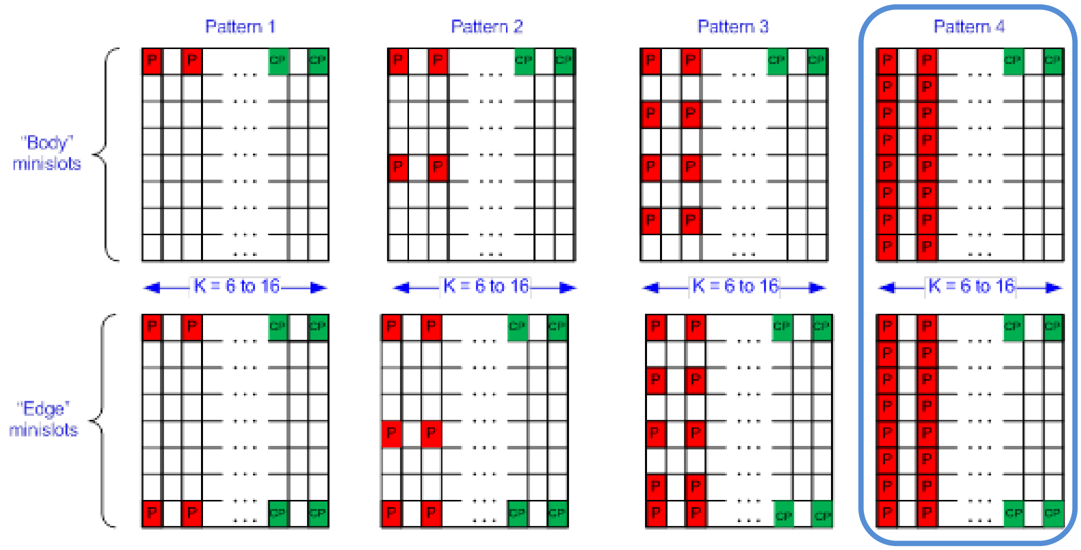

Figure 2 – Recommended 2K FFT Pilot Pattern for Leakage Detection Bursts

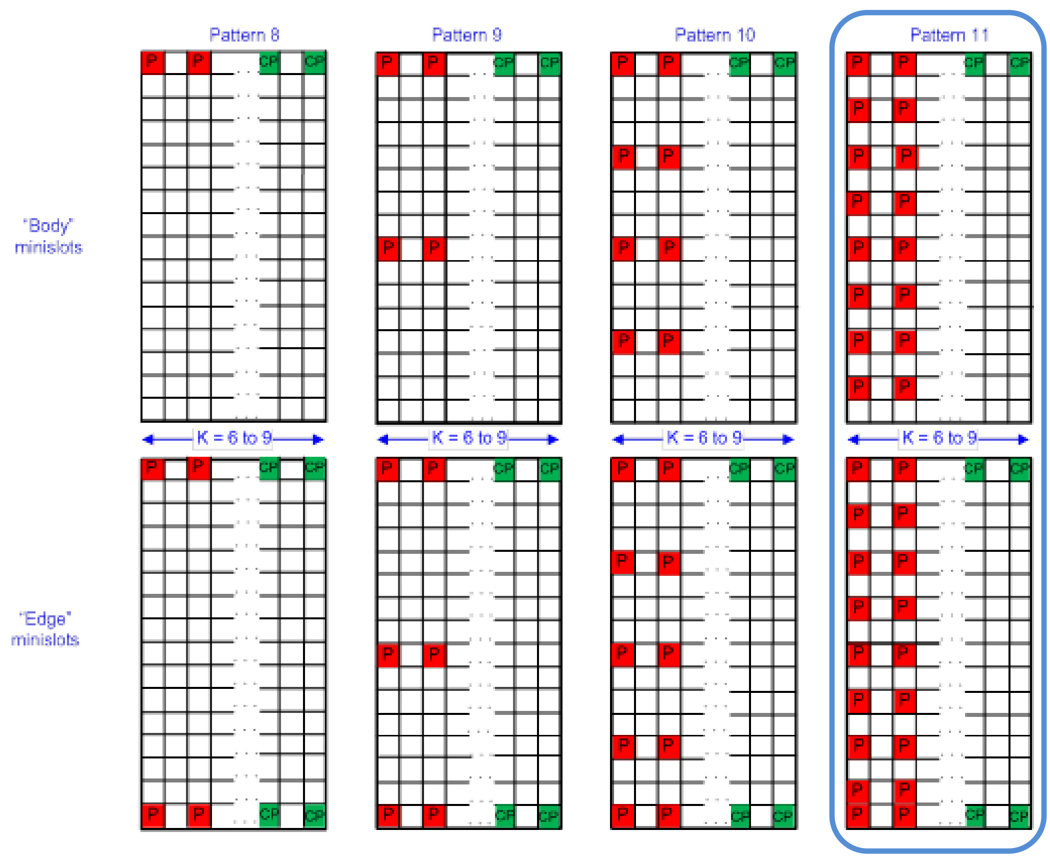

Figure 3 – Recommended 4K FFT Pilot Pattern for Leakage Detection Bursts

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A user interface, Command Line Interface (CLI) and/or Application Programming Interface (API), is enabled at the CMTS to define the scope of leakage detection tests and to control scheduling of OUDP test bursts within the specified scope. For example, a CLI would specify which CM(s) to test, the frequency range of test region to use for grants, OUDP test burst duration, etc. An information model representing the configurable attributes for such a user interface has been specified in [3].

The user interface also supports reporting metrics that verify test performance. In a perfect world there will be no leakage detected. Without test metrics, there is no way for the operator to be certain that grants were made to CMs and that granted CMs responded with test burst transmissions. For this reason, a complete solution provides leakage detection test metrics per tested CM.

3. Leveraging the Solution

3.1. Leakage Detection Testing Use Cases

The DOCSIS 3.1 specifications support testing of a single CLI/API-specified CM, a CLI/API-specified ordered list of CMs, a CMTS-determined ordered list of CMs based on a CLI/API-specified upstream scheduling domain (e.g., OFDMA channel ID, MAC Domain), or CMTS-determined ordered lists of CMs created for every upstream scheduling domain in a CLI/API-specified scope, such as an entire CMTS or a specific R-PHY or R-MACPHY node.

The variety of use cases supported allows the operator to perform leakage testing according to their desired implementation. This facilitates lab testing of CMs for support of OUDP test burst capabilities and field detectors and applications for performance in various leakage scenarios. It enables both targeted (e.g., per CM, per upstream scheduling domain, per node) and sweep-based (e.g., per CMTS) testing and provides an opportunity to combine use cases to support maximum automation and intelligence in the leak identification process.

As one possible use case, consider a scenario with a theoretical Flexible MAC Architecture (FMA) MAC Manager which provides management functionality for three R-MACPHY nodes that are deployed in the same geographic area. Each of these R-MACPHY nodes has two Upstream Service Groups (i.e., upstream scheduling domains). A single leakage detection test session is configured at the MAC Manager to cover all three of these R-MACPHY nodes. All of the upstream scheduling domains in all of these R-MACPHY nodes will then simultaneously have leakage detection test sessions running. Each leakage detection test session automatically includes all DOCSIS 3.1 CMs which are currently using the specific OFDMA channel that is undergoing testing. This widespread sweep coverage approach, illustrated in Figure 4, is most suitable for operators that just want to set up leakage testing and leave it. It would also be appropriate at times when aeronautical flyovers are being performed for leakage detection. Leakage would be detected by field detectors encountering leaked signals from OUDP test bursts. Leakage can be isolated manually by monitoring detector strength-of-signal and detector proximity to the leak.

Automation can be introduced via field detectors equipped with GPS and associated leakage applications. Field detectors would transmit their current GPS locations to the application, and the application would communicate with the MAC Manager via an API to schedule testing, for example, only in those nodes which currently have field detectors operating in proximity to the node. Scheduling would need to be refreshed every few minutes to account for vehicle movement, but the process is easily automated. Since vehicles equipped with leakage detection equipment are only in a small percentage of nodes at any one time, this process could decrease the cumulative bandwidth required for leakage detection, allowing the test region to be scheduled for normal data transmission when there is no leakage detection occurring on the nodes where service vehicles are not nearby.

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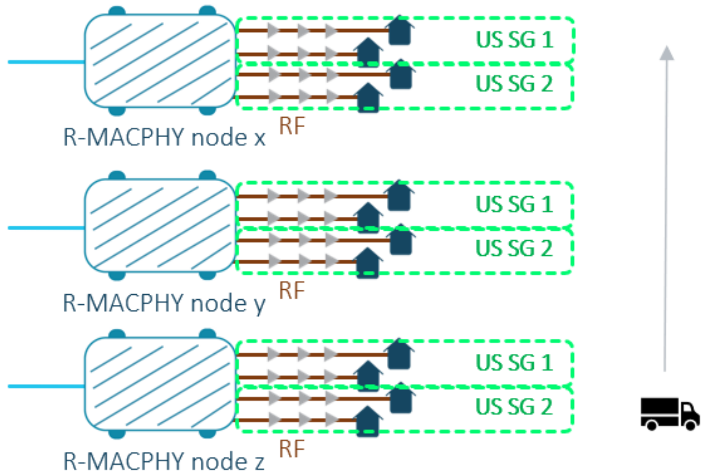

Figure 4 – Example FMA Leakage Detection "Sweep" Test

An alternative use case might be to configure test sessions using an ordered list of CMs. The list of CMs on-line and available to test could be provided by the MAC Manager to the leakage application using an API. The API then would instruct the MAC Manager as to the desired test burst sequence and the desired scheduler control parameters. Since CMs are generating OUDP bursts in a known order and the characteristics of the bursts are known, it is possible using intelligent detection algorithms to determine exactly which CM in the sequence was bursting when leakage was detected. This type of targeted leakage testing is illustrated in Figure 5.

The leakage application could then query a database that associates the MAC address of the CM causing leakage to the physical address of the leak such that repair can be scheduled. This could happen without the field technician leaving the vehicle. As such, utilizing ordered lists can potentially result in significant time savings in the last step leak identification process. The ordered list technique can also be useful in remotely determining whether the leak source is in the hardline (where multiple CMs could be detected as the leakage source) or the drop (where only one CM could be resolved as the leakage source).

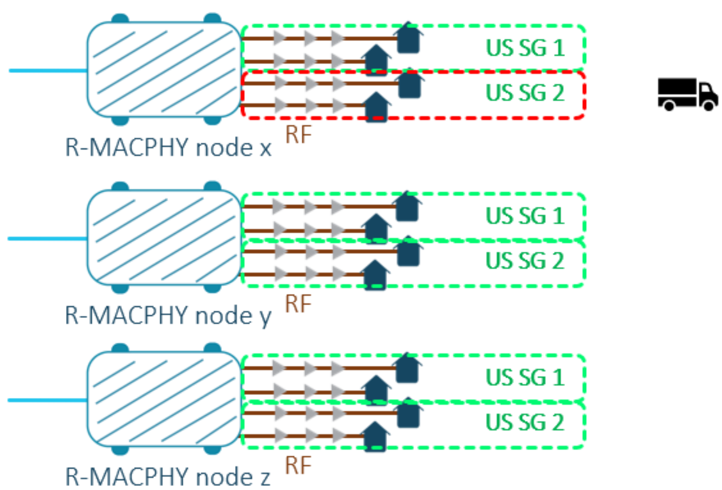

Figure 5 – Example FMA Leakage Detection Targeted Test

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A similar process using an ordered list containing only one or a few CMs could also be used as technique to confirm that the CM whose transmissions are suspected to be source of the leak is in fact the exact source. In Figure 6, a single CM in an Upstream Service Group is specifically tested for leakage.

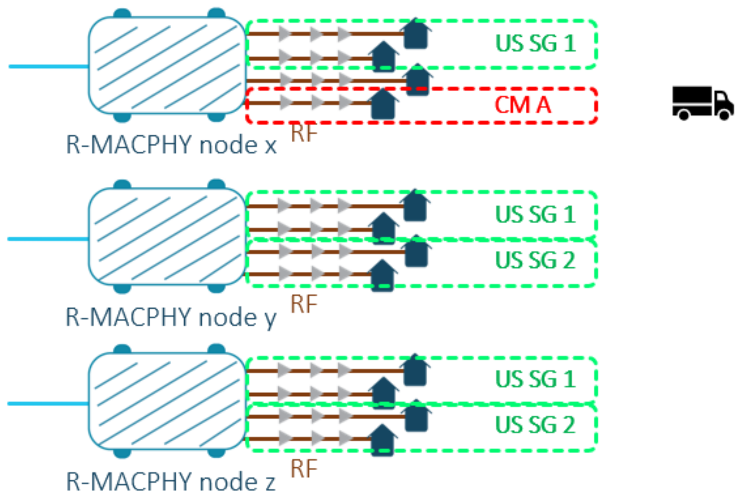

Figure 6 – Example FMA Leakage Detection CM Specific Test

3.2. Configuration of OFDMA Channels for Leakage Detection Testing

Operators are responsible for configuring their OFDMA channels to maximize data throughput. They are also responsible for OFDMA channel configuration aspects to enable leakage detection in High-Split and Ultra- High Split band plans. A leakage detection test region needs to be defined where OUDP test burst grants can be made to CMs by the CMTS. This test region can be in or near the aeronautical band, which lies between 108 MHz and 137 MHz. Ideally the test region is just above the aeronautical band so that leakage testing does not actually result in leakage into the aeronautical band.

A modulation profile, or Interval Usage Code (IUC), needs to be configured for leakage detection OUDP test burst granting into the test region. This profile must cover the minislots which fully span the leakage detection test region frequencies. The profile should also specify the densest Pilot Pattern available on the OFDMA channel for use in the test burst. As previously mentioned, Pilot Pattern 4 is recommended when the channel uses a 2K FFT and Pilot Pattern 11 is recommended when the channel uses a 4K FFT.

Since a DOCSIS 3.1 CM is only required to support two IUCs per OFDMA channel, it is recommended that the OUDP test burst configuration within the test region be assigned to IUC 13, which is generally the most robust profile. Another IUC can be defined to cover optimal data transmissions by the CM when the test region is not being used for leakage detection testing.

3.3. Configuration of Leakage Detection Testing Sessions

[3] specifies the configuration necessary for supporting a variety of leakage detection testing use cases. It defines a generalized information model that can be used for CLI-based or API-based implementations. The information model can be supported with CableLabs® standardized YANG code. A protocol for the API has not yet been specified by CableLabs®. Obvious alternatives are available such as NETCONF, which is a standard OSSI protocol, and gRPC/gNMI, which is becoming commonly used in Streaming Telemetry applications and in several FMA interfaces.

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The configurable parameters provided by the information model are:

- Test region start and end frequencies
- Test scope:
  - Single CM MAC address or
  - Ordered list of CM MAC addresses in a single upstream scheduling domain or
  - Interface name of upstream scheduling domain (OFDMA channel ID, MAC Domain) or
  - Specific R-PHY or R-MACPHY node or
  - Full CMTS/CCAP/MAC Manager scope
- Scheduler control parameters:
  - Duration of test burst per CM, in number of frames
  - Duration of gap between CMs in a list, in number of frames
  - Duration of gap between cycles through a list of CMs, in number of frames
  - Scheduled start time of test (i.e., time of day; not precision timing)
  - Scheduled stop time of test (i.e., time of day; not precision timing)
  - Explicit immediate test enable/disable

Leakage detection tests are configured as independently controllable test sessions that focus on lists of CMs within a single upstream scheduling domain. Each session is identified by a session ID. When a leakage detection test session is created for CMTS, CCAP or MAC Manager scope, a master session ID is created as a control envelope for the independently controllable constituent test sessions in scope, each of which receives its own session ID.

3.4. Execution of Leakage Detection Tests

During a leakage detection test session, the CMTS upstream scheduler cycles through each list of CMs repeatedly and independently. Note that the single CM use case is a degenerate case of a list of CMs with only one CM in it. The rules followed by the CMTS upstream scheduler per configured test session are as follows:

- Grant OUDP test burst opportunities to each CM in the list over the entire test region spectrum and for the number of frames configured by burst duration
- Do not grant to multiple CMs in a given list in the same OFDMA frame
- Provide a gap between CM grants if one has been configured (intra-CM gap)
- Provide a gap between cycles through the list if one has been configured (inter-cycle gap)
- When a cycle through a list completes, including the intra-CM and inter-cycle gaps, start a new cycle through the list and continue this process until the test completes.

Intra-CM and inter-cycle gaps provide flexibility to support different scenarios. In one case it may be that the amount of time required to get through a full cycle is quite low and available time remains to transmit data. Gaps can provide the opportunity to do so. In addition, Probes need to be transmitted periodically by CMs as part of regular maintenance activities. Probes cover the entire spectrum of an OFDMA channel and cannot be scheduled if there is constant transmission of OUDP test bursts in the channel. As another example there several Proactive Network Maintenance (PNM) capabilities such as Active and Quiet Probe and Upstream Triggered Spectrum Capture where the entire OFDMA channel may be needed for other purposes for a specific period. Gaps in the leakage detection burst grant cycle can be leveraged for these activities as well.

Figure 7 illustrates a theoretical example of a 16 minislot OFDMA channel with a four minislot leakage test region. In practice the OFDMA channel will be much wider and there would be more data minislots relative to the test region. The test region in this example is being scheduled for four frames each to three CMs in the upstream scheduling domain. There is no intra-CM gap and there is a four frame inter-cycle

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gap where the inter-cycle gap is being used for Probe transmissions and for data transmission. The CMTS scheduler inserted a P-MAP for the Probes and left the first two frames of MAP #3 for data transmission.

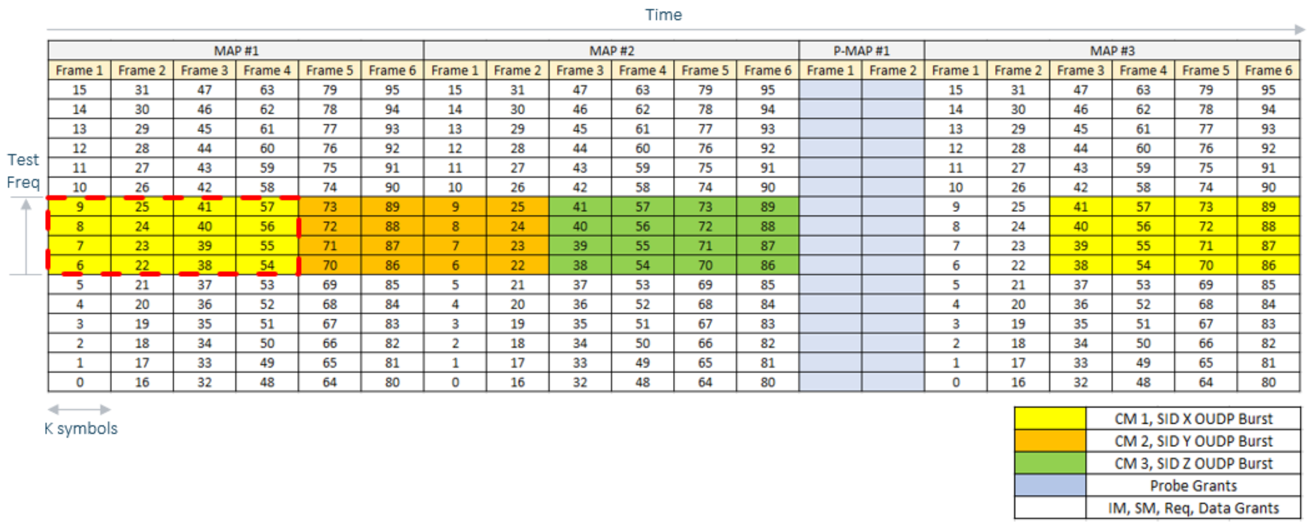

Figure 7 – Example Scheduler View with Leakage Detection Test Region

It should be noted that there are some differences in upstream scheduler processing rules for CLI/API-specified versus CMTS-determined lists of CMs. In CLI/API-specified list cases the cycle is not disrupted when CMs are not available to transmit (e.g., are offline). The unavailable CM is simply skipped in the cycle and its position is not granted at all. This preserves the timing of the cycle, which can be used algorithmically to determine when leakage is detected what CM was transmitting.

For CMTS-determined lists, the order of CMs is preserved but empty spots do not need to be maintained when a CM becomes unavailable. Conversely, if a CM becomes available during a test it can be inserted into the list by the CMTS. It is not expected that automatic determination of which CM transmission led to leakage is possible in this case. It is more likely that a manual detector strength-of-signal and proximity approach is used, or that the GPS location of the field detector at the time leakage is detected will be noted, and that further isolation will be required.

3.5. Leakage Detection Testing Metrics

In a perfect world there will be no leakage detected. Without test metrics, there is no way for the operator to be certain that grants were made to CMs and that granted CMs responded with test burst transmissions. For this purpose, the CableLabs specifications include metrics to count the number of OUDP test bursts granted per CM for leakage detection as well as the number of bytes received at the CMTS from the CM for these grants. There is also a “no burst received metric” available as an alternative to the bytes received metric. These metrics are shown in Table 1.

In combination with existing leakage detection verification mechanisms used for downstream leakage detection (e.g., service vehicle mileage and plant coverage records), these metrics can and will be used by operators in their reports to authorities, such as the FCC and CRTC, to prove the effectiveness and accuracy of their leakage testing operations.

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Table 1 – Leakage Detection Test Metrics

Attribute Name	Units	Description
NumBurstsGranted	Grants	Count of grants made to a CM's OUDP Test SID during a leakage detection test session
NumBurstsNotReceived	Bursts	Count of bursts not received for bursts that were granted during a leakage detection test session
NumTestBytesReceived	Bytes	Count of bytes received for grants made to CM's OUDP Test SID during a leakage detection test session

3.6. Feature Interactions with Leakage Detection Testing

There are several feature interactions to consider with leakage detection testing. As previously mentioned, Probes need to be scheduled periodically for ranging-related functions such as determining CM transmit pre-equalizer coefficients, and for taking RxMER measurements. Probes consume minislots over the entire OFDMA channel and therefore cannot be granted when OUDP test bursts are taking place in the leakage detection test region of the channel at the same time. For this the CMTS implementation must either interrupt the leakage detection test session or make use of intra-CM and/or inter-cycle gaps. The decision is implementation specific. However, interrupting sessions where a CLI/API specifies the list of CMs to test can disrupt automatic determination of CMs causing leakage and is therefore not the best choice in such a scenario.

Similarly, the Active and Quiet Probe Proactive Network Maintenance (PNM) test relies on Probe grants to take measurements of underlying noise in an OFDMA channel at the CMTS. The same considerations as mentioned above apply to this PNM test.

OUDP test bursts were originally created to gather information on FEC performance or count CRC errors for a particular modulation profile. OUDP test bursts used for this purpose are generally to assign profiles to a CM for data transmission, which is typically done early in the lifetime of a CM's registration with the CMTS. In the same fashion as the Probe discussion, these bursts can either interrupt existing leakage detection tests or can be made to fit within intra-CM and/or inter-cycle gaps.

The DOCSIS specifications support a battery back-up mode for appropriately equipped CMs to transition into when they lose AC power. In battery back-up mode, CM functionality is taken down to a minimal viable subset of its full functionality to preserve battery life but at the same time keep the CM operational. It is implementation specific as to what the CMTS does in this case. On one hand, exempting the CM from leakage detection tests can save battery. On the other hand, if the CM transmissions are causing leakage it would be good to learn that.

Finally, DOCSIS Light Sleep and Energy Management Modes are supported in the specifications, even though not largely deployed. Having CMs that are otherwise idle transmitting OUDP test bursts as part of leakage detection testing clearly interacts with the CM's ability to sleep and conserve power. Once again, it is implementation specific how these features interact.

NOTE: Standards work on High-Split and Ultra-High Split leakage detection will continue as operators determine their strategies for deployment and field operations in the presence of these new capabilities.

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4. Testing the Leakage Detection Solution

Significant progress has been made in demonstrating the viability of the OUDP test burst approach for leakage detection. Recently, successful radiated leakage detection was accomplished from an OUDP burst signal transmitted by a DOCSIS 3.1 CM. The test was significant and a milestone because the CM which generated the OUDP test burst was directed to do so by an R-MACPHY node using standard DOCSIS MAC Management signaling. This test was a natural progression from previous testing of the OUDP approach which was accomplished using test equipment which generated the OUDP test burst, or by using a diagnostic CMs instructed to burst directly via serial control.

4.1. Test Setup

The test setup is as shown in Figure 8. Using the R-MACPHY node's MAC Manager CLI, the OFDMA channel and test session configurations were input into the R-MACPHY node. The node then instructed the CM via DOCSIS MAC Management messages to generate OUDP test bursts according to the specified test session configuration. The coax output of the CM was connected to a reversed two-way splitter with one leg connected to node via the access network and the other leg connected to a transmit antenna to create a leaked RF signal over the air. The RF signal leakage was received by the field detector antenna – which measured the OUDP leakage signal level. The detector was configured and tested first in a lab and then vehicle mounted for drive-out testing.

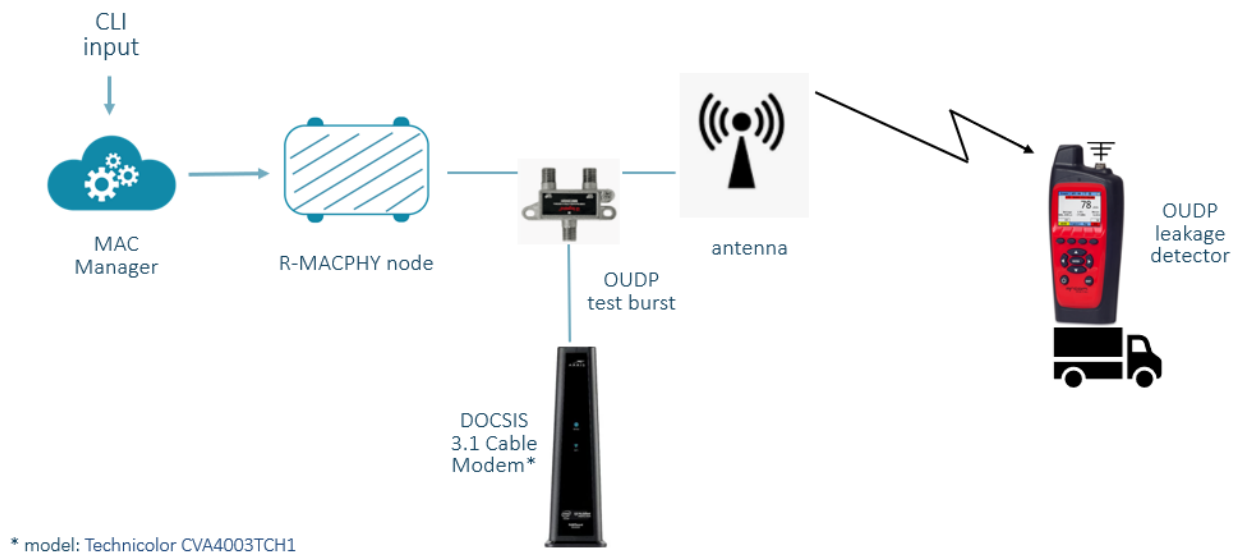

Figure 8 – Test Setup

4.2. Test Environment Configurations

In practice OFDMA channel and leakage detection test region configurations are an operational decision made by individual cable operators. We expect that common practice will be to define a narrow band test region of approximately 1.6 MHz located just above the aeronautical band in the OFDMA channel. Burst descriptors must be defined such that the desired burst characteristics will be used by the CMs when transmitting OUDP test bursts in the test region. These burst characteristics impact field detector sensitivity so must be chosen carefully. Field detectors must also be configured to match the test region frequencies and the expected OUDP burst characteristics used by CMs in the test region.

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The OFDMA channel parameters of interest when configuring the OFDMA channel where the leakage detection test region resides are illustrated in Figure 9. Of these, the key variables are the size of the test region and Pilot Pattern configured in the burst descriptors defining the region, and number of symbols per frame and Cyclic Prefix of the OFDMA channel. It is desirable to use the least amount of spectrum needed for the test region. Our recommendation is to keep the test region to four minislots, or 1.6 MHz. The recommended Pilot Patterns for optimal field detector sensitivity are Pilot Pattern 4 for the 2K FFT and Pilot Pattern 11 for the 4K FFT. The number of symbols per frame needs to be balanced between optimal data throughput on the channel and field meter sensitivity. Fewer symbols per frame is better for field meter sensitivity. More symbols per frame may be better for data throughput. Cyclic Prefix length impacts the symbol duration and CMTS burst receiver accuracy. We show the values which are optimal for field detector sensitivity.

Parameter	2K FFT	4K FFT	Comments
Channel Start Frequency	108.50	108.50	Frequency of first active subcarrier in OFDMA channel (subcarrier# 74 | 148)
Channel Width	95	95	Range of active subcarriers within OFDMA channel (max 95 MHz)
Subcarrier Spacing (kHz)	50	25	
Symbols per Frame (K)	6	6	Range: 6-18 (2K FFT), 6-9 (4K FFT)
Cyclic Prefix	512	512	Value: 96, 128, 160, 192, 224, 256, 288, 320, 384, 512, 640
Pilot Pattern in Test Region	4	11	Configure in the Burst Descriptor for Test Region minislots (use IUC 13)
Test Region Start Frequency	138.10	138.10	Preferred frequency of first subcarrier of Test Region
Test Region Stop Frequency	139.70	139.70	Stop - Start should = multiple of 400 kHz (recommend 1.6 MHz, or 4 minislots)

Figure 9 – OFDMA Channel Configuration Key Parameters

Given an OFDMA channel with a configured leakage detection test region, the next step is to define the desired leakage detection test session configuration. When performing leakage detection testing on groups of CMs in a scheduling domain it is necessary to provide adequate burst durations per CM to achieve the desired field detector accuracy. It is also desired to use the minimum burst duration to enable a shorter overall time to cycle through the group of CMs. This is done to ensure that leaks can be detected by field detectors at vehicle speeds. The configurations shown in Figure 10 were selected such that sensitivity of the detection is sufficient to meet FCC signal leakage requirements when the CM is granted a minimal burst duration such that each CM within an Upstream Service Group can burst at least once every half second, as required for a robust confirmation of detection.

The CableLabs specification also specifies configuration for a gap between CM transmissions and between cycles through groups of CMs. These gaps are left to allow for data transmission when the number of CMs is low, and to allow for maintenance activities such as Probe transmissions.

Parameter	2K FFT	4K FFT	Comments
Burst Duration per CM (Frames)	8	4	
Gap Between Cable Modems (Frames)	0	0	
Gap Between Cycles Through List (Frames)	8	8	Leave for Probe processing; each CM gets a full symbol in Probe frames

Figure 10 – Leakage Detection Session Parameters

The OFDMA channel configuration and leakage detection test session configuration needs to be aligned with field detector configuration. Field detector configuration is vendor specific. Details of that are not provided here.

For the leakage detection test described in this paper we tested with a single CM which was granted a continuous stream of OUDP test burst opportunities by an R-MACPHY node. The OFDMA channel was from 108 MHz to 204 MHz with active subcarriers between 108.50 MHz and 203.50 MHz and 50 kHz

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subcarrier spacing. The channel was configured with 18 symbols per frame, which was designed to test the worst sensitivity at the field meter. Cyclic Prefix was 512.

The test region was defined with burst descriptors to cover 135.025 MHz to 136.825 MHz. Pilot Pattern 4 was configured.

The spectrum of the OUDP test burst generated by the CM under test is shown in Figure 11.

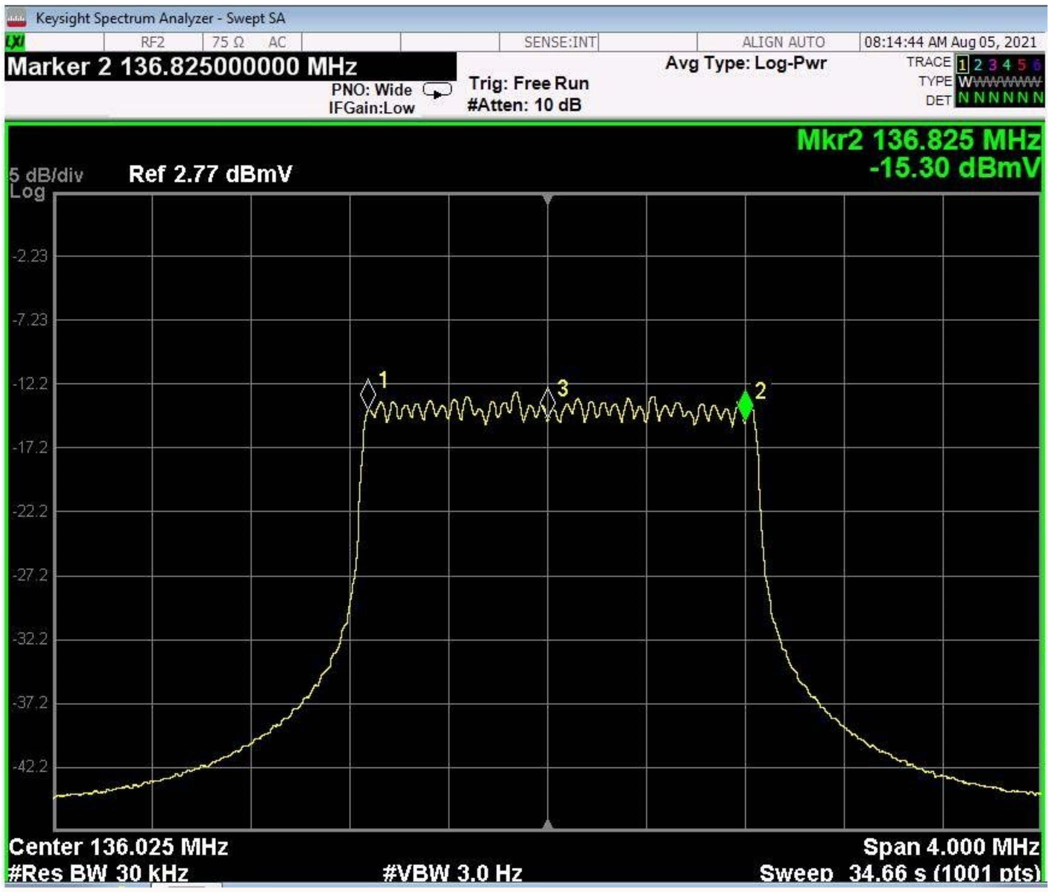

Figure 11 – Leakage Detection OUDP Test Burst Spectrum

After initial hard wired conducted tests were performed in the lab to confirm configuration alignment between the OFDMA channel, test region and field detector, a simple drive-out test was performed. A leak was generated outside of the building using an antenna tuned to the 136 MHz detection frequency. The antenna was connected to the CM output via a reversed two-way splitter as shown in the test setup. A vehicle was outfitted with a corresponding 136 MHz receive antenna, a GPS antenna, and an OUDP leakage detector. No leakage signal was detected until the OUDP burst command was entered into the R-MACPHY node's MAC Manager CLI. Once the CM began to burst, signal leakage was continuously detected, as illustrated in Figure 12.

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Figure 12 – Leakage Detection in a Stationary Vehicle

The vehicle was then used to perform a short drive-out in the parking lot around the building, which is indicated in the bread-crumb trail on Figure 13. Each red dot shows a detection point in the one second leakage detection measurement interval. The test session was quite successful, and there was no trouble in detecting the OUDP test bursts. Since the transmitted signal level was a relatively large, leakage was recorded along the entire drive route. Detected signal leakage levels on the far side of the building were as expected, less than as compared to detection points in closer proximity to the leakage source.

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Order/leak: Unassigned | Tech ID: All
PSID: All | Hub: All | Node: All
Level >=: 20 | Number: 50 | Sort by: Level Down
Loaded leaks: **3**. Total in database: **3** | Leak # Search

Leak ID	Leak level, [µV/m]	Address	PSID	HUB	Node / device	Details	Manage	Ordered date
1	1000/-/-	185 Ainsley Drive, Syracuse, NY 13210	00000	OUDP Test Hub No.1	Not available	Info	Manage	
2	794/-/22	unnamed road, Duluth, GA 30097	00000	OUDP Test Hub No.2	Not available	Info	Manage	

Figure 13 – Leakage Detection in a Moving Vehicle

Future testing will be expanded to include multiple CMs in a group, along with the capabilities and use cases as described in this document. This type of testing will be enabled as vendors implement the functionality described in [3], and as operator plans for operationalizing leakage detection in their High-Split deployments become clear.

5. Conclusion

The OUDP test burst approach for detecting CM initiated signal leakage in DOCSIS 3.1 High-Split and DOCSIS 4.0 Ultra-High Split continues to look quite promising and viable. Excellent progress has been made with support of the OUDP test burst approach being specified in the [3] standard, which provides great flexibility to the operator community by enabling a variety of use cases such that the signal leakage process can be aligned with individual operator goals.

Significant progress has also been made with recent successful tests which prove that DOCSIS 3.1 CMs under the control of an R-MACPHY node can be instructed to and can in fact generate OUDP test bursts, and that the corresponding OUDP test burst (leakage signal) is able to be detected by an OUDP leakage detector installed in a vehicle while performing a drive-out.

As these advances morph into viable operations strategies the primary blocking factor for High-Split deployments in North America will be removed and operators will have at their fingertips the ability to offer 1 Gbps upstream services.

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Abbreviations

AC	Alternating current
API	Application Programming Interface
CCAP	Converged Cable Access Platform
CLI	command line interface
CM	Cable Modem
CMTS	Cable Modem Termination System
CRC	cyclic redundancy check
CRTC	Canadian Radio-television and Telecommunications Commission
DOCSIS	data over cable service interface specification
FCC	Federal Communications Commission
FEC	forward error correction
FFT	Fast Fourier Transform
FMA	Flexible MAC Architecture
Gbps	Gigabits per second
gNMI	gRPC Network Management Protocol
gRPC	gRPC Remote Procedure Call
GPS	Global Positioning System
IUC	Interval Usage Code
kHz	kilohertz
MHz	Megahertz
MAC	Media Access Control
NETCONF	Network Configuration Protocol
OFDMA	orthogonal frequency-division multiple access
OUDP	OFDMA Upstream Data Profile
PHY	Physical layer
PNM	Proactive Network Maintenance
P-MAP	Probe MAP
RF	Radio Frequency
RxMER	Receive Modulation Error Ratio
SCTE	Society of Cable Telecommunications Engineers
SID	service identifier
YANG	Yet Another Next Generation

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