Smart Amplifier Ingress Noise Localization

Leveraging PNM UTSC, Available Headroom Calculations, Network Topology, and Smart Amplifier Ingress Switch

A technical paper prepared for presentation at SCTE TechExpo24

James Medlock
Founder & CEO
Akleza, Inc.
jmedlock@akleza.com

Robin Lavoie
Fellow, Network Architecture & Strategy
Cogeco Communications
robin.lavoie@cogeco.com

Bernie Cadieux
General Manager
Electroline Equipment Inc.
b.cadieux@electroline.com

Frédérick Plante
Vice President, Operations & Engineering
Electroline Equipment Inc.
Frederick.Plante@electroline.com

Table of Contents

Title **Page Number**

List of Figures

Title **Page Number**

1. Introduction

Locating return path noise sources in a hybrid fiber coax (HFC) plant continues to be a challenge for cable operators. Traditional techniques that utilize various methods to segment the return path in the hopes of identifying the leg contributing to the noise can be both time consuming and have a negative impact on subscribers due to network disruptions.

Society of Cable Telecommunications Engineers (SCTE) 279 [1] defines a standard for a new smart amplifier and SCTE 283 [2] defines an associated information model that provides monitoring and control functions. One feature defined in the standards is an upstream ingress switch. This is typically a three-state switch on each upstream input port, allowing the port to be configured as "on" (no extra attenuation), "off" (large attenuation added), or "-x dB" (specified attenuation added). By leveraging this feature, a remote application can temporarily adjust the attenuation of an upstream port while monitoring the return signal to determine if there is any change to observed ingress. By systematically traversing the network, it is possible to isolate the source of ingress to a specific amplifier leg.

The concept of an upstream ingress switch adjusting attenuation is not new to the industry and more commonly has been referred to as a "wink" switch. While in North America wink switches are not commonly deployed, there are some operators in Canada and Europe that have deployed wink switch functionality through standalone devices installed in the HFC network, or as add-on devices integrated into legacy amplifiers. These environments provide examples of how an end-to-end solution can operate once smart amplifiers are deployed and the function is more widely available. Additionally, some remote physical layer devices (RPDs) also support temporary ingress attenuation on each return port, providing yet another isolation point.

In this paper we will discuss leveraging the integration of proactive network maintenance (PNM) upstream triggered spectrum capture (UTSC), automated impairment detection, HFC plant topology data, and ingress switching to localize ingress noise events. We will discuss the challenges of implementing such a solution when considering intermittent and short-lived noise bursts, HFC plant topology discoveries, and the impact on cable modems related to available transmit headroom. Finally, we will look at the status of each component required to implement an end-to-end solution and any alternative solutions available using existing equipment.

2. Return Path Noise Impact and Challenge

Operating coaxial cable networks requires diligent maintenance on many fronts. The most challenging network problems are upstream ingress noise impairments. Intermittent issues can take weeks to resolve, as a technician would drive hours to reach a node where upstream ingress has been detected. Often they may start their investigation only to have the problem disappear. Indirect troubleshooting looking at downstream metrics is possible, for example by analyzing radio frequency (RF) level variation, looking at PNM anomalies such as frequency modulation (FM) ingress and long-term evolution (LTE) interference, or fixing leaks detected by leakage monitors. While solving these downstream issues will fix many upstream issues, it will not fix all of them.

The typical upstream ingress noise impairment investigation method requires opening the network at many amplifiers and passives, potentially disrupting customer services. Remotely addressable wink switches reduce the initial investigation time that could take weeks when intermittent impairments are present, to minutes with minimal impact to customer services. With the availability of wink switches, the maintenance process involves using a system to manually or automatically measure upstream ingress. Next add attenuation in the return path at a specific wink switch, and measure and compare upstream ingress metrics. Then proceed to the next wink switch in the amplifier topology until the segment between two amplifiers having ingress has been identified. The technicians will then troubleshoot the network segment the traditional way. Wink switches are a huge time saver with far lower impact on customer services than alternative methods.

One operator, Cogeco Communications, deployed addressable wink switch technology more than 20 years ago throughout its Canadian Québec networks. This technology is being used daily, saving huge investigation time and provides a validation of the importance of including the functionality in the next generation of smart amplifiers. Communication with the wink switches uses a hybrid management sub-layer (HMS) Physical (PHY) Layer with an media access control (MAC) layer. A controller provides an interface between applications and wink switches, allowing the switching of attenuation on an upstream leg. This architecture is similar to the controller and transponder architecture being defined for smart amplifiers.

Using this technology, major impairments detected during the night can be mitigated by adding attenuation to affected network segments until the next morning. Intermittent impairments can be remotely identified before they disappear. In areas of the Cogeco network where this technology has been deployed, the overall internal node quality index is four times better than areas where the technology is not deployed.

As will be discussed later in this document, understanding of the wink switch location within the network topology is vital to effectively use the technology. Including this functionality directly within a smart amplifier will help, however there still must be an understanding of how each port, and wink switch function is related to the network topology.

3. Ingress Localization Process Today

3.1. HFC Operation and Reverse Funneling

The HFC downstream network consists of a single transmitter and many receivers, cable modems, set top boxes, etc. Figure 1 shows a simple network where the purple lines indicate the downstream broadcast signals.

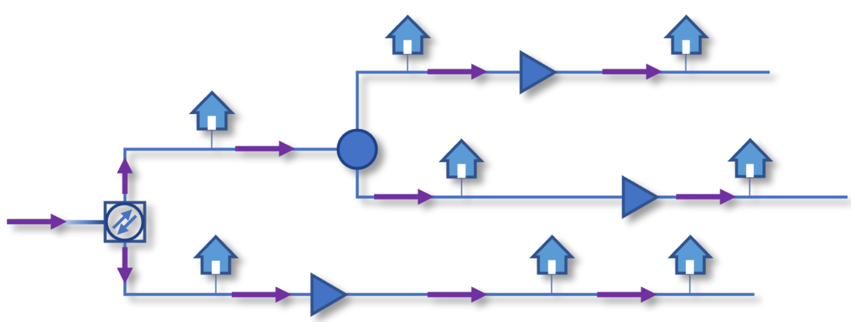

Figure 1 - Downstream Broadcast

On the upstream side however, there are many transmitters, Data-Over-Cable Service Interface Specification (DOCSIS®) devices, and one receiver, a cable modem termination system (CMTS) or RPD port. Upstream data transmissions are scheduled and therefore bursty in nature. Figure 2 illustrates upstream transmissions with each set of arrows representing the data from an individual device.

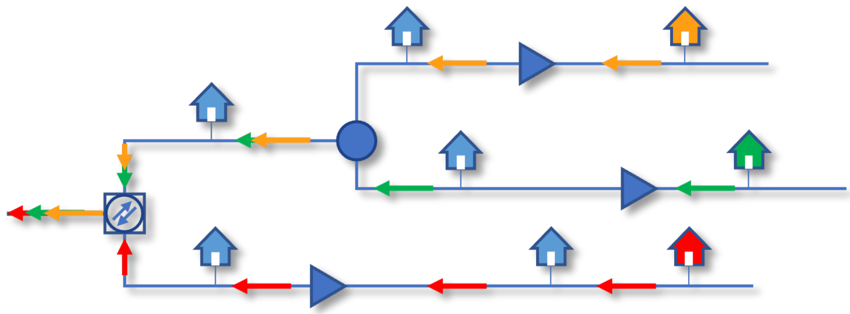

Figure 2 - Upstream Transmission

When an impairment in the network occurs that affects part of the downstream spectrum, such as a suckout caused by an impedance mismatch or a grounding issue at an amplifier or tap, only the devices downstream from that point are impacted. In Figure 3 the impairment indicated by the yellow lightning bolt would only impact the modem shown in red, or downstream from the location of the fault. By comparing the full band capture data from each of the modems it is possible to locate the area of the fault. Working upstream from where the fault is detected in the spectrum data, find the closest device which no longer shows the fault. The impairment must be between these two points on the network, the last one showing the fault, and the one not showing the fault.

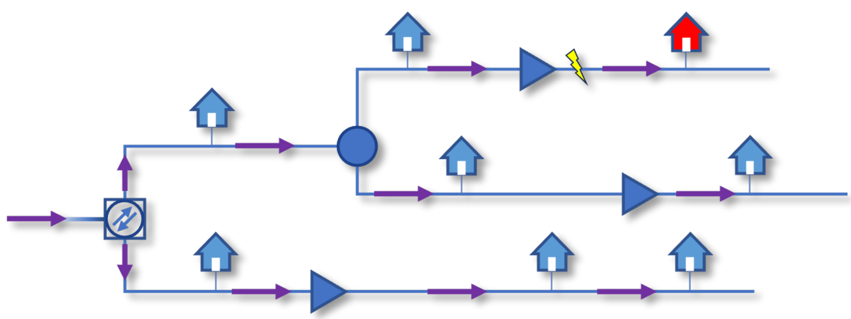

Figure 3 - Downstream Impairment

An upstream fault allowing unintended signals such as narrow band or impulse/burst noise to enter the network is not as simple to locate, however. Additionally, an impairment and resulting ingress noise in one part of the network can impact all upstream transmissions across the entire node. In Figure 4 the yellow lightning bolt indicates an upstream fault such as a crack in a cable that is allowing external power supply noise to enter the network. This interference noise is transmitted upstream along with any other intended signals such as burst transmissions from modems. As this noise source is not scheduled or controlled by the CMTS it can appear at any time and any frequency. If this is present when a modem is also trying to transmit, then the modems' data may be corrupted causing an increase in correctable and failed codeword counters. Additionally, the signal-to-noise ratio (SNR) for the overlapping channel will be reduced given the increased noise floor. This upstream impairment scenario is often referred to as reverse funneling, i.e. ingress noise coming from anywhere in the network is funneled together in the upstream.

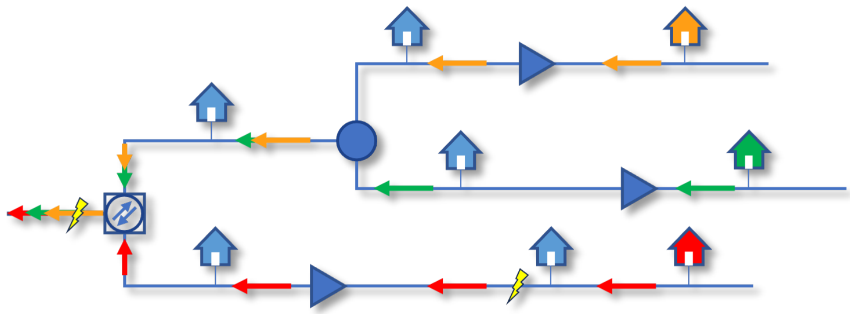

Figure 4 - Upstream Impairment

3.2. Upstream Impairment Localization

As described in the previous section, the upstream reverse funnel means that locating the source of ingress noise has several challenges. Unlike with downstream impairments where data can be collected from each DOCSIS device and a demarcation point identified where the problem exists and doesn't, data from each DOCSIS device does not generally help to locate upstream impairments. Note that some DOCSIS 3.1 modems support a feature called upstream data analysis (UDA) which allows these modems to capture their upstream transmission and may be able to detect nearby ingress. While UDA capable modems are not common in many operator networks, more detail on the types of impairments they can help isolate, and how they can be used to assist in locating upstream ingress noise can be found in [9].

When ingress noise is detected in a node, whether it's observed on a spectrum analyzer, in a return path monitoring tool, or indicated by upstream channel performance metrics such as SNR and forward error correction (FEC) statistics, the traditional and current mechanism to locate the source of the problem is to use a "divide and conquer" method. Looking at the node as a tree and branch network a technician would traverse the network, and at each junction point effectively disconnect a branch or leg and see if the ingress noise disappears. This may be achieved by removing a pad in an active device or physically disconnecting a cable segment. Depending upon the monitoring equipment available to the technician in the field, they may be able to look at the return spectrum on a local device such as an application running on a tablet or a field meter. If this is not available, then the technician may also need to work with a headend technician that can monitor the impact of the change using equipment installed at that location. At each junction point the goal is to identify which leg the noise is coming in on, dividing the network and working down the identified leg. Once the final leg has been identified, the technician must now go tap to tap and effectively continue the same process either by disconnecting drops or using a low impedance probe to allow local monitoring of the return path and/or introduce attenuation on the return path. If the ingress noise drops, then the problem is downstream, and the process should move to the next tap.

Not only is this process time consuming given that the technician must physically drive across the node area, stopping and testing at each active, but each test may also disrupt service to several customers. For customers on the affected leg, these disruptions will be repeated as the technician works their way through the network trying to locate the source of the ingress. For intermittent issues the technician must also wait long enough to determine if the ingress has in fact gone away. Depending upon how often bursts are seen, this potentially increases the time subscriber service is disrupted. Lastly, the act of performing these tests - opening amplifiers, connecting test probes, removing and replacing attenuator pads, may temporarily "fix" the problem only for it to return at some future time.

4. Streamlining The Process

As described in the previous section, tracking down impairments that allow ingress noise interference into the network is still a manual and time-consuming process. There are, however, several capabilities already deployed in operator networks, or coming with future network and tool upgrades, that will allow this process to become simpler and more streamlined. There are also some requirements on back-office systems that should not be overlooked.

While it is nice to believe that some new piece of equipment, or tool, is going to solve every problem, in reality, most problems require integrating data and functions from several different sources. Hunting the source of ingress noise interference is no different. While there are many benefits associated with the deployment of new smart amplifiers as we will discuss, they are only part of the solution.

To be able to identify, characterize, and localize ingress problems in a more streamlined way, the following functions are required:

- Upstream channel performance metric collection and alarming
- Upstream spectrum capture supporting both legacy and distributed access architecture (DAA) nodes
- Impairment detection to identify possible ingress events
- Physical and logical plant topology data
    - Active device topology discovery
- Cable modem channel metrics and location
- Smart amplifier and/or third-party ingress switch/wink functionality

5. Upstream Channel Metrics

One of the first indications of an ingress noise impairment that is impacting node performance is an alarm or trigger generated by a system monitoring DOCSIS channel performance metrics, SNR as well as FEC correctable and uncorrectable errors. Ingress noise occurring in frequencies used by upstream single-carrier quadrature amplitude modulation (SC-QAM) and orthogonal frequency division multiple access (OFDMA) channels, will reduce the SNR for the channel, or receive modulation error ratio (RxMER) per modulation profile and subcarrier for an OFDMA channel, and cause an increase in the number of correctable or uncorrectable errors depending upon the power level of the ingress noise.

SNR and FEC counters should be collected periodically for each upstream channel and evaluated against acceptable thresholds. Each channels' metrics should be considered independently, as ingress noise can impact just a single channel. DOCSIS modems that bond multiple upstream channels can compensate by utilizing other channels. They will however be operating in a partial mode with a lower available capacity.

6. Upstream Triggered Spectrum Capture

UTSC is a CMTS feature that can be used by operators for network operations monitoring, maintenance, and troubleshooting. UTSC allows return path spectrum to be captured at either an RF upstream port on a CMTS line card or an upstream port on an RPD. The captured spectrum data is transmitted to a PNM server for display, data analysis, and can be used to identify problems such as ingress noise interference.

UTSC is a fast Fourier transform (FFT) based spectrum capture function implemented by the DOCSIS burst receiver where the input signal is sampled in the time domain, digitized, and transformed into the frequency domain. This type of spectrum capture is particularly suited to real-time analysis and monitoring without the need for dedicated capture hardware.

The DOCSIS 3.1 Converged Cable Access Platform (CCAP) Operations Support System Interface Specification [3] outlines several configurable triggers that control when spectrum capture is initiated and includes free running, idle service identifier (SID), cable modem MAC address, mini-slot count, SID, quiet probe symbol, burst interval usage code (IUC), timestamp, and active probe symbol. As of today, free running mode is the only universally available mechanism supported across CMTS implementations. Other triggers may be available, but implementation differs across CMTS vendors.

Figure 5 shows an example display from a UTSC based return path monitoring tool. While the data returned is only live spectrum amplitude, an application can augment this display by computing additional metrics such as max hold, min hold, average, and live max (a max hold that decays over a configurable period). The example highlights different elements of the return spectrum including typical return SC-QAM and OFDMA channels, and an area of ingress interference. It is also possible for a UTSC application to collect additional performance metrics for each of the channels including SNR, total codewords transmitted, corrected codewords, and failed codewords. Each of these metrics allows the user to better understand the impact of the ingress interference and how it may be affecting SNR and FEC counters.

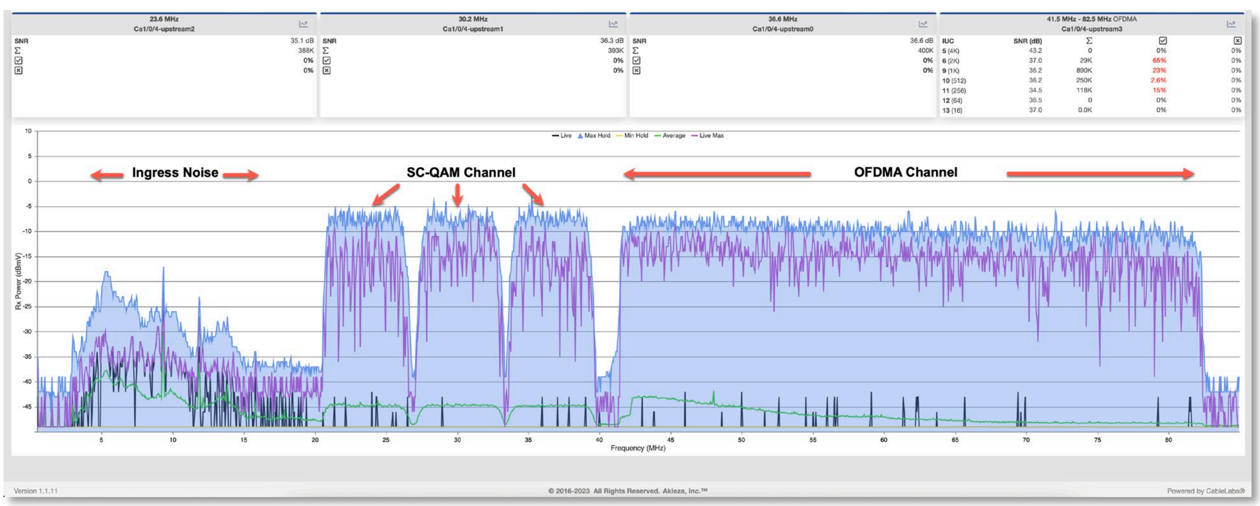

Figure 5 - Return Spectrum as Captured by UTSC

Figure 6 shows another UTSC example where burst ingress interference can be seen primarily impacting the 2 to 16 MHz part of the spectrum. As this overlaps the lowest configured channel the channel metrics also highlight a problem, reporting an SNR of 29.2 dB and higher than expected correctable and failed codewords. The spectrogram or waterfall chart in the bottom portion of the display highlights the bursty nature of the ingress and the extent of each burst. While relatively constant background noise can be seen in this lower part of the spectrum, large intermittent bursts are indicated by the bright colored areas in the chart. This view also shows the frequency of these bursts by providing a historical view over a short period of time.

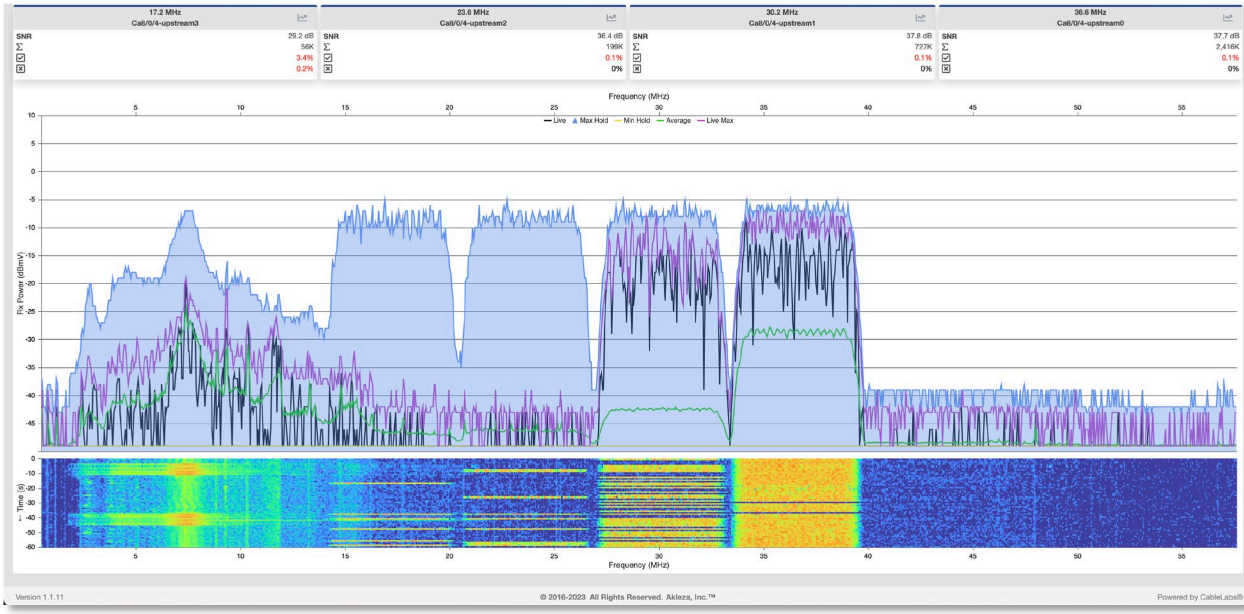

Figure 6 - Example UTSC Display Showing Ingress Noise

In addition to providing a common platform for collecting return spectrum data across CMTS and RPD ports, UTSC spectrum data can be used as a basis for impairment detection.

Spectrum capture functionality was first introduced in the cable modem with the addition of the PNM full band capture feature as described in the DOCSIS Best Practices and Guidelines PNM Best Practices: HFC Networks (DOCSIS 3.0) [7] document. SCTE 280 2022 [6] discussed how this spectrum data can be used to identify different types of impairments in the downstream spectrum and typical causes of each. Spectrum capture for the upstream is described in section 6.4 of the PNM Current Methods and Practices in HFC Networks (DOCSIS 3.1) [4] document. Similarly to SCTE 280 2022 for the downstream spectrum, Network Operations Subcommittee (NOS) OP 209 [7] discusses various impairments visible in upstream spectrum data and their typical causes.

Given the bursty nature of transmissions in the upstream, spectral impairment detection is more challenging. However, some common impairment signatures are present that can be detected. With the addition of the UTSC idle SID trigger, impairments under the carrier that are masked by modem burst transmissions become visible, although currently this capability is limited due to CMTS vendor implementations.

Figure 7 highlights some of the impairments that might be visible and that can be automatically detected using the UTSC data.

While each of the impairments can be disruptive to service, intermittent impulse/burst noise often causes severe impact to upstream channels while being difficult to locate given its intermittent nature.

Narrowband signals such as Citizens Band (CB), Ham, Short Wave, and FM broadcasts have a relatively narrow bandwidth and while not as impactful on an upstream channel, do provide an indication of a shielding integrity issue in the cable plant. Historically some technicians have used short bursts of CB radio broadcast to help locate such impairments.

While common mode disturbance (CMD) is generated by the power supply circuitry in active devices, one common occurrence is characterized by a noise hump around 23 MHz and associated with certain older models of modem. When detected, a review of the installed cable modem models within the node may provide a possible list of candidate problem modems and their location.

Optical beat interference (OBI) is an upstream impairment affecting fiber to the home deployments, especially radio frequency over glass (RFoG) architectures. This can occur when multiple modems transmit simultaneously. While a CMTS may be configured so only one modem transmits at a time, it is possible for the optical network unit (ONU) at the customer premises to transmit independently of the CMTS scheduler. For example, this has been observed when a subscriber disconnects service, but the ONU remains attached and powered on. Local electrical pickup or ingress on the ONU can cause the device to transmit independently.

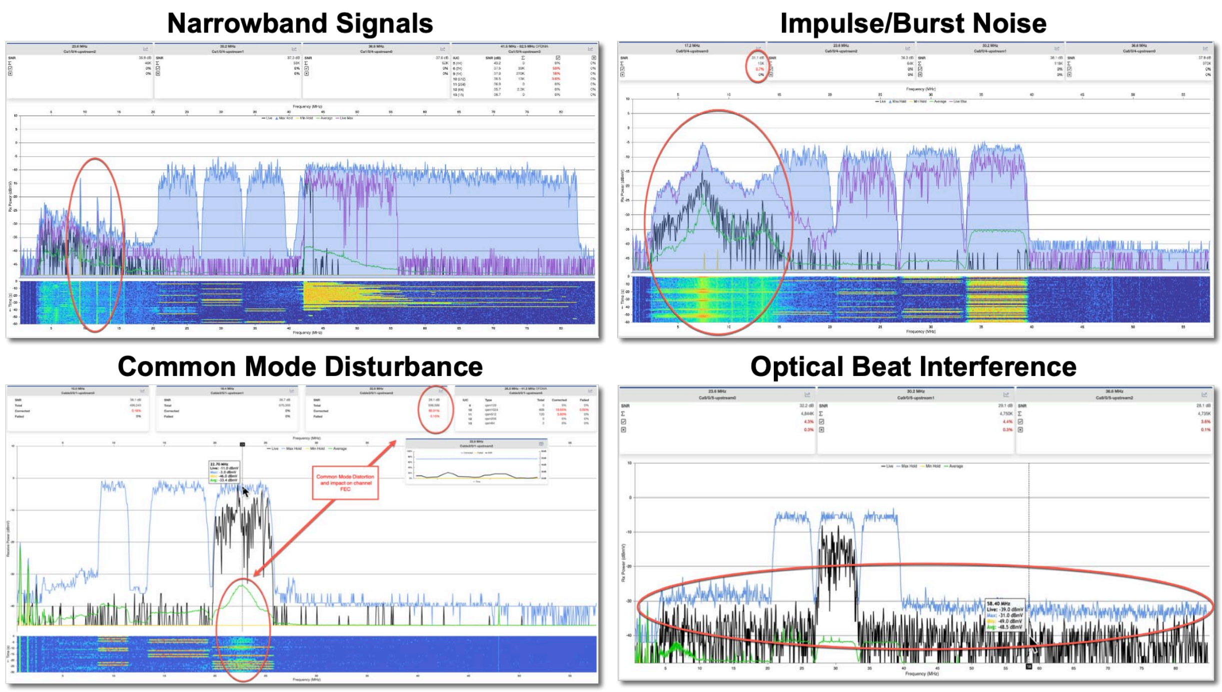

Figure 7 - Upstream Spectrum Impairments

NOS OP 209 discusses several other impairments and their characteristics as well as provides background information about the two-way operation of the cable network, the various active and passive components found within the network, and the different measurement and troubleshooting tools and metrics available.

7. Active Device Topolology

To be able to effectively locate ingress problems, technicians must understand the plant topology within the node they are investigating. As described in section 3.2 Upstream Impairment Localization, locating the area of ingress noise requires a divide and conquer method. To facilitate this localization, an understanding of amplifier and directional coupler location is required. Also needed is topology information describing how these devices are interconnected, port X on device A connects to port Y on device B, etc.

Figure 8 illustrates an example node showing modems and their status from a PNM tool along with an overlay of the physical cable plant topology from a graphical information system (GIS) database. This “as built" or "as is" map is typically maintained by an operators' engineering group to facility maintenance, management, and planning operations. While a GIS provides information about the physical location, type, and configuration of active and passive devices, on its own it does not provide information to allow a technician or software system to traverse the network performing divide and conquer tests. This requires logical topology data that contains the elements of the network as a tree with nodes[1] and branches.

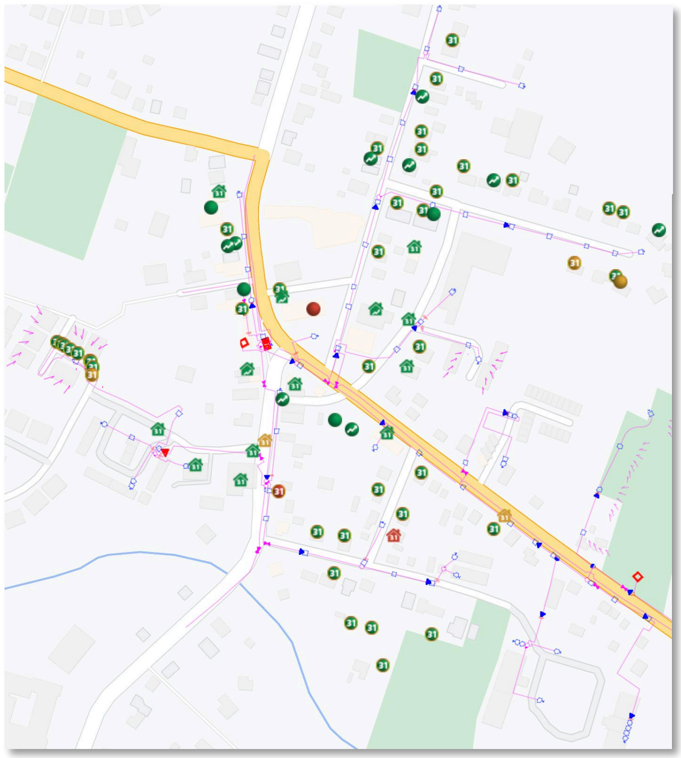

Figure 8 - Node GIS Topology

Figure 9 shows this same example node displayed as a logical topology. For clarity, each of the tree nodes is shown using standard graphic symbols for cable systems [10]. In software this is referred to as an n-ary or generic tree that is a collection of nodes where each node is a data structure that consists of records and a list of references to its child nodes (duplicate references are not allowed). The tree can be traversed top to bottom using a depth first or breadth first search.

To find the leg that is responsible for the ingress noise, a breadth first search, starting at the root node which in this case is the fiber node, will be used. At each level of the tree, each leg that supports testing is tested to determine if ingress noise can be observed. When found, the search follows that leg to the next lower level until the bottom of the tree is reached. This determines the area of the network that the ingress noise is coming from. As described, this is like the logical process a technician should perform in the field, although given their geographical location the technician may bypass this strict traversal and not test every junction point if there is other information that might suggest the location. While this might work in some cases, it can also increase the time to locate the problem, as it is more of a random search approach.

[1] In this context a node refers to a point of convergence within a hierarchical tree, not the physical device in the network referred to as the node, or fiber node.

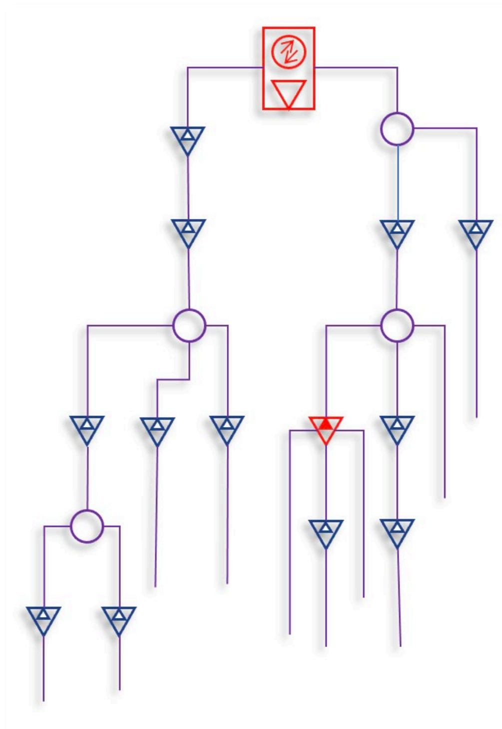

Figure 9 - Node Logical Topology

8. Cable Modem Transmit Power Available Headroom

Cable modem upstream transmitters are designed to handle a range of net attenuation between each modem and the CMTS or RPD burst receiver. Net attenuation is the combination of all upstream active device gains and cable and passive device loss in the upstream signal path.

Cable modem transmit headroom refers to the margin between the actual signal power transmitted by the modem and the maximum allowable transmit power level, P_{max}. It indicates how much room there is for the modem to increase its' transmit power to maintain a reliable connection. Expanding the upstream operating bandwidth and adding more channels impact the cable modem upstream transmit power as the modems' available transmit power spectral density (PSD) is reduced as the power is spread over a wider RF bandwidth. Hranac et al. [8] discusses the issues around modem transmit power headroom and how this must be managed as network changes are deployed.

Also, when adding attenuation to an upstream path using a smart amplifier ingress switch or standalone wink switch function, available transmit headroom must be considered. The addition of 6 dB of attenuation to help identify the location of ingress noise might have the unintended consequence of forcing modems into partial service mode if there is not enough transmit headroom for them to adjust to the increase in net attenuation between their location and the upstream burst receiver. At the very least, a transmitting cable modem may take on bit errors, even if the additional attenuation period is too short of a duration to cause re-ranging.

The modem transmit power available headroom can be calculated from the channel transmit power data collected for each cable modem in a node. Hranac el al. [8] further details the required calculations based on the collected data. By understanding the minimum and maximum available transmit headroom across the node, an understanding of the possible impact of adding attenuation can be evaluated.

While in most sub and mid split network node environments today 6 dB of additional attenuation does not typically present a problem, high split upgrades and the associated addition of secondary or wider OFDMA channels may increase the likelihood of approaching the maximum transmit power level. It should be noted however, that even 6 dB of attenuation may impact individual channels, causing the modem to enter partial mode during the ingress noise testing activity. Any network operations center (NOC) alarming process should be notified ahead of time about the potential for modems going into partial mode, reducing the OFDMA modulation profile being used, or even going offline for a short period of time.

9. Smart Amplifier

The SCTE smart amplifier defined in SCTE 279, offers significant advancements over traditional amplifiers, including automated gain control, remote management, self-optimization, power efficiency, advanced noise reduction, support for expanded frequency spectrum up to 1.8 GHz, and improved durability. These features make it a more reliable, efficient, and an adaptable choice for contemporary cable and broadband networks, ensuring high-quality signal transmission and easier maintenance.

9.1. Ingress Switch

An important function of the smart amplifiers' management features is an upstream ingress switch. This is typically a three-state switch on each upstream input port that is user selectable to assist in ingress localization efforts. The three states for the upstream RF path are "On" (no extra attenuation added), "Off" (a very high amount of attenuation added), or "-x dB" (where either a fixed or a user selected amount of additional attenuation is added).

In most implementations of ingress switch functionality available today, 6 dB of added attenuation is commonly used rather than a configurable amount.

The upstream ingress switch function as defined in SCTE 279 is described as a "should" requirement meaning that a smart amplifier vendor does not have to implement it. Support for this functionality is encouraged however and should be on operators feature requirement list when selecting a smart amplifier vendor.

Figure 10 shows an extract of the configuration section of the information model for a smart amplifier defined in SCTE 283. An information model represents the structure, semantics, and constraints of information and provides an abstract framework for organizing and defining how information is to be used, stored, and managed. The highlighted section shows the UsIngressSwitchCfg which represents the control and configuration elements related to the ingress switch function.

Based on current CableLabs practices, information models are converted to yet another next generation (YANG) data models that are designed to model configuration and state data manipulated by network management protocols such as Network Configuration Protocol (NETCONF). While modern management protocols such as NETCONF or Representational State Transfer Configuration Protocol

(RESTCONF) are encouraged, it is expected that a simple network management protocol (SNMP) management information base (MIB) will be developed to support configuration via an SNMP interface.

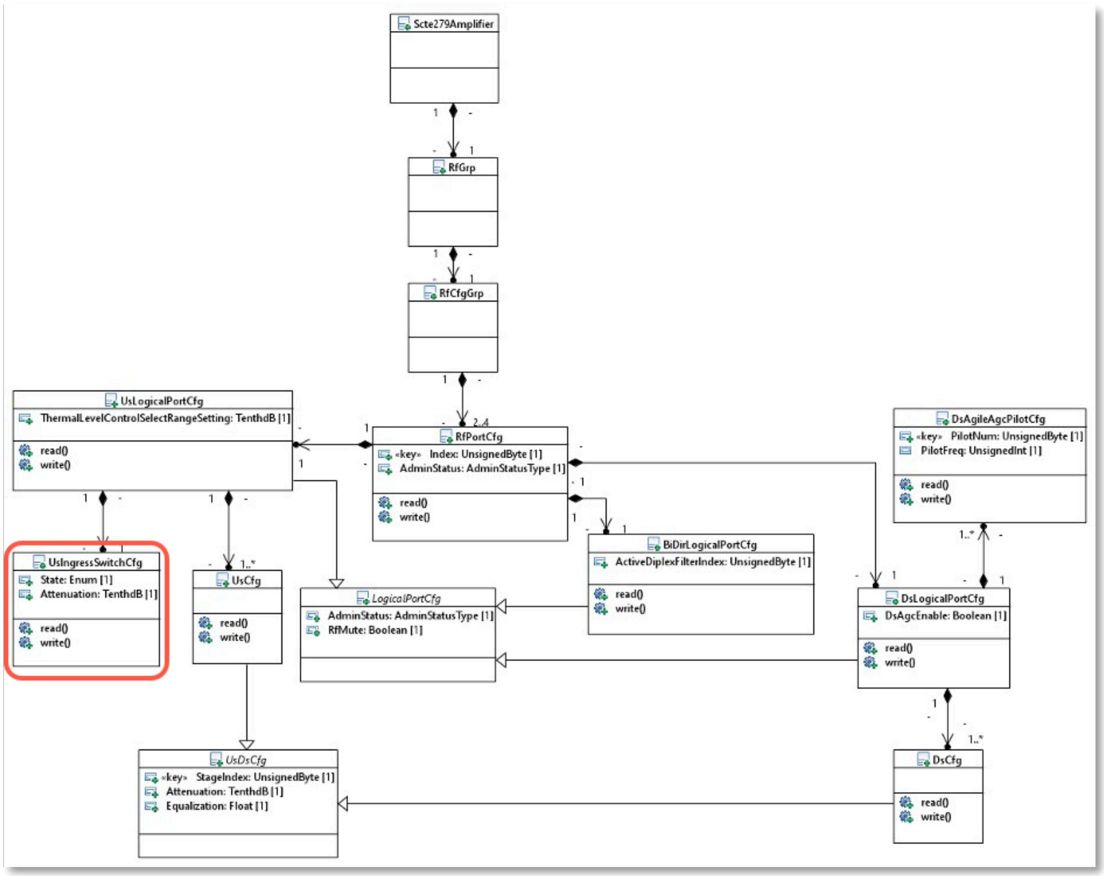

Figure 10 - Smart Amplifier RF Configuration Information Model

Figure 11 shows a proposed YANG model for the UsIngressSwitchCfg based on the SCTE 283 information model.

```
container us-ingress-switch {
    description
        "This object controls the upstream ingress switch
        configuration. An upstream ingress switch is typically
        a three-state switch on each upstream input port that
        is user selectable to assist in ingress localization
        efforts.";
    list us-ingress-switch-cfg {
        key "port-index";
        min-elements 1;
        description
            "This object configures upstream port.";

        leaf state {
            type enumeration {
                enum ON {
                    value 1;
                    description
                        "It indicates no extra attenuation added";
                }
                enum OFF {
                    value 2;
                    description
                        "It indicates a very high amount of attenuation
                        added";
                }
                enum ATTENUATED {
                    value 3;
                    description
                        "It indicates either a fixed or a user
                        selected amount of additional attenuation
                        is added";
                }
            }
            default ON;
            description
                "This object controls the configuration of the
                upstream ingress switch.";
        }
        leaf attenuation {
            type uint16;
            units "tenthdB";
            default 0;
            description
                "As indicated in RfCapabilities, UsLogicalPortCapabilities,
                then a selectable amount of attenuation is available.";
        }
    }
}
```

Figure 11 - US Ingress Switch YANG Model

The configuration and operation of the feature is quite simple. For a desired upstream port, the port state is set to the value defined in Figure 11 as either ON, operating normally, OFF, a high amount of attenuation added, or ATTENUATED, a fixed (typically 6 dB) or user defined amount of attenuation is added. If supported, the user defined attenuation amount can be configured. Several smart Amplifier vendors have already implemented this feature and provide their own proprietary Representational State Transfer (REST) or SNMP based configuration interfaces. As SCTE and CableLabs complete their development of the information and data models, it is expected that these vendor implementations will transition to the defined standard.

Figure 12 shows an equivalent SNMP model (MIB objects) converted from the YANG model. Note that development of the final YANG and SNMP MIB data models has not been completed by CableLabs at the time of writing and the models shown are examples of what these might look like given the current information model definition. Once completed, the final models should be available from SCTE and/or CableLabs.

```
usIngressSwitchCfgTable OBJECT-TYPE
  SYNTAX      SEQUENCE OF UsIngressSwitchCfgEntry
  MAX-ACCESS  not-accessible
  STATUS      current
  DESCRIPTION "This table configures upstream ports."
  ::= { usIngressSwitchCfg 1 }

usIngressSwitchCfgEntry OBJECT-TYPE
  SYNTAX      UsIngressSwitchCfgEntry
  MAX-ACCESS  not-accessible
  STATUS      current
  DESCRIPTION "An entry in the upstream ingress switch configuration table."
  INDEX  {
            portIndex
         }
  ::= { usIngressSwitchCfgTable 1 }

UsIngressSwitchCfgEntry ::=
  SEQUENCE {
     portIndex                Unsigned32,
     ingressSwitchState       INTEGER,
     ingressSwitchAttenuation Unsigned32
}

portIndex OBJECT-TYPE
  SYNTAX      Unsigned32
  MAX-ACCESS  read-only
  STATUS      current
  DESCRIPTION "The port index for the upstream ingress switch configuration."
  ::= { usIngressSwitchCfgEntry 1 }

ingressSwitchState OBJECT-TYPE
  SYNTAX      INTEGER {
                  on(1),
                  off(2),
                  attenuated(3)
              }
  MAX-ACCESS  read-write
  STATUS      current
  DESCRIPTION
      "This object controls the configuration of the upstream ingress switch.
      on(1) indicates no extra attenuation added,
      off(2) indicates a very high amount of attenuation added,
      attenuated(3) indicates either a fixed or a user selected amount of additional
      attenuation is added."
  ::= { usIngressSwitchCfgEntry 2 }

ingressSwitchAttenuation OBJECT-TYPE
  SYNTAX      Unsigned32 (0..65535)
  UNITS       "tenthdB"
  MAX-ACCESS  read-write
  STATUS      current
  DESCRIPTION
      "As indicated in RfCapabilities, UsLogicalPortCapabilities,
      then a selectable amount of attenuation is available."
  ::= { usIngressSwitchCfgEntry 3 }
```

Figure 12 - US Ingress Switch SNMP Model

9.2. Smart Amplifier Transponder

SCTE 283 defines the information model, but it does not define the communication method. Operators provided requirements around functionality, power, security, and for many most importantly, cost. This led to discussion and work within the SCTE NOS WG4 – HFC Management working group to define a narrowband transponder that could be used to communicate with a smart amplifier. Several smart amplifier vendors have presented proposals based on various technologies such as hybrid management sub-layer (HMS), Long Range Wide Area Network (LoRaWAN), Power Line Communication (G3-PLC), or using an embedded DOCSIS cable modem, although this last option does not seem to support the power and cost requirements that operators are looking for. As each of the other proposed communication methods does not allow direct communication with each transponder, a controller is used to act as the gateway or proxy between an application and a smart amplifier via its transponder. It is expected that the implementation of the SCTE 283 information model will therefore be built into the controller. This allows vendors to implement their own low-level communication while providing a standard northbound SCTE 283 interface.

This architecture does require some changes to the information and associated data models to accommodate for the fact that requests to the controller need to target specific smart amplifiers using some unique address or index. Specification updates and model develop is a work in progress within SCTE NOS WG4 and CableLabs.

9.3. Cable Modem Topology Discovery

While the primary motivation of defining the ingress switch functionality in the smart amplifier was to assist in identifying the area of ingress noise, the functionality can also be used to help identify network legs that modems are physically attached to, and group these into common upstream paths. Cable operator plant maps typically provide GIS information for the active and passive devices such as amplifiers, directional couplers, taps, etc. Data specific to individual modems or subscriber locations and which tap they connect into the network via, is often not something available. Cheng et al. [11] describes one approach that is being researched by CableLabs that uses artificial intelligence (AI) and machine learning (ML) techniques to analyze DOCSIS metrics, including upstream timing offsets and attempts to automatically generate a network topology. While promising, there are challenges in both collecting the data given different equipment vendor implementations, as well as accuracy of some of the data.

An alternative approach that allows us to identify the network legs that modems are attached to is by using the smart amplifier ingress switch function and monitoring the upstream transmit power from the modems. As the ingress switch attenuation is enabled, the modems will increase their transmit power and this change can be detected by looking at the before and after values.

Using this technique, it is possible to determine the amplifier legs that modems are connected to, but it does not enable detection of the specific tap attachment. In Figure 13 for example, it is possible to distinguish the group of the modems shown in red and purple versus those shown in yellow and green. Within the group shown in yellow and green however, it is not possible to identify which output of the directional coupler each modem is attached to. Even with these limitations however, this level of topology information is useful when chasing other problems such as amplifier configurations, active and passive device grounding faults, micro-reflections, etc. Fault localization using PNM data and tools uses the comparison of "signatures", such as pre-equalization coefficients, downstream spectrum impairments, Orthogonal Frequency Division Multiplexing (OFDM) RxMER per subcarrier degradations, between modems to isolate faults. A problem indicated by one modem in a home but not another indicates an in-home issue. A problem indicated by a modem for one subscriber but not another subscriber on the same tap indicates a drop or in-home issue. A problem common to several subscribers on a leg indicates a cable or active problem. To accurately compare results, it is therefore important to understand how modems connect onto the network and their relationship. While two neighboring, or closely neighboring modems may not show the same problem, as each side of a street may be fed from a different distribution leg. In this case direct comparison is only relevant to the modems on one side of the street.

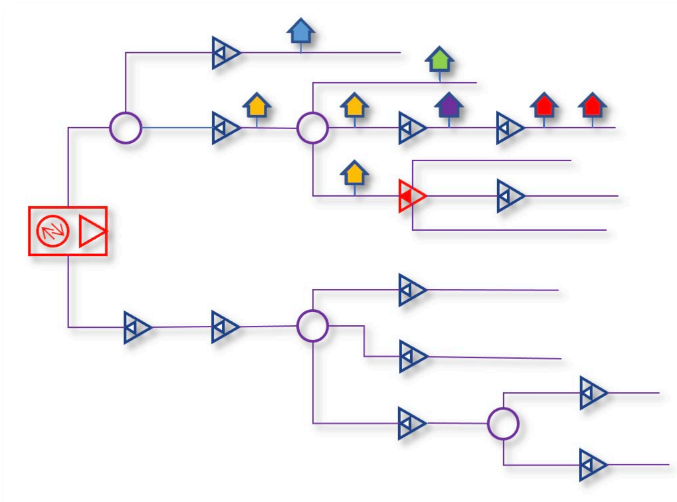

Figure 13- Cable Modem Topology Discovery

10. Automated Solution

With the deployment of smart amplifiers supporting ingress switch functionality, or for networks where legacy wink switches are already deployed, the ingress noise impairment detection and localization process has the potential to be simplified and made more efficient. This, along with the other monitoring features and data allows the development of a more automated system to detect ingress noise.

Channel performance metrics and PNM UTSC data allows us to automatically detect nodes that are experiencing ingress noise impairments. Importantly, this data allows us to prioritize impairments that are having a direct impact on channel performance and therefore subscriber service. While ingress noise in vacant parts of the return spectrum that are not overlapping active upstream channels is an indication of a cable plant shielding problem that should be fixed, it can be of a lower priority as it is not directly impacting subscriber service.

GIS and logical plant topology data allow a system to traverse the network tree in a systematic breadth first search method, performing tests on each leg.

Collection of cable modem transmit power levels and channel configuration data allows a system to determine what, if any, areas of the network might be impacted by adding upstream attenuation and if such a test can be safely performed without potentially impacting customer service.

Ingress or wink switch test points in the network allows a system to automatically add attenuation on each network leg while monitoring PNM UTSC data and channel performance metrics to determine if the change has any effect on the detected ingress noise. This process is continued down each network leg until the last identifiable leg that ingress noise is visible on is determined. With this information it is then possible to dispatch a technician close to the area of the impairment.

With the technician on-site and around the impairment, PNM UTSC data and displays allow the technician to verify that changes have successfully fixed the cause of the ingress noise impairment. Continued monitoring of channel performance metrics and PNM UTSC data over a repair cool-down period ensures that the fault was correctly repaired and not just temporarily masked or not visible because the noise source wasn't transmitting.

11. Conclusion

Identifying, finding, and fixing upstream noise faults has been, and continues to be a time consuming and costly maintenance activity for cable operators. This has been a problem since the introduction of the two-way cable system given the reverse funnel affect where ingress noise signals anywhere in the network can disrupt and impact the upstream transmission for any modem.

Locating ingress involves segmenting the network while monitoring the upstream using a divide and conquer method. This has required technicians to drive across the node, effectively disconnecting legs of the network and watching to see if the ingress disappears. This may also require a headend technician to be available at the same time depending upon what return path monitoring equipment is available.

Deployment of the next generation smart amplifier, or legacy wink switches into the network adds the capability to remotely, and temporarily, modify the upstream attenuation so that a monitoring system can detect if the change has impacted ingress noise and therefore identify the area of the impairment.

Early implementations of smart amplifiers are already available, and within SCTE the information and data models are being developed to provide a standard way to communicate and control this functionality.

While the ingress switch function is important to support the development of an automated solution, on its own this does not magically provide a solution. As was discussed, impairment detection, understanding of GIS and logical network topology, and available cable modem transmit headroom are equally important and required when developing a solution. Luckily these various software systems are available today in many networks often driven by other requirements such as monitoring return spectrum as DAA is deployed.

Leveraging existing wink switch functions and implementing a standard-to-vendor specific interface “shim” allows the development of an automated solution today while smart amplifier technology is rolled out.

Ingress noise is not going away, and in fact as networks increase their upstream spectrum moving to high split, more potential noise sources move into the upstream. Having a more efficient and automated way to detect and locate these impairments is going to continue to be a large part of cable operators’ maintenance activities, but with the introduction of the smart amplifier ingress switch feature there will be new tools available to help. As a result, the cable operator will see a faster mean time to repair and savings in operations and maintenance costs.

Abbreviations

AI/ML	artificial intelligence/machine learning
ANSI	American National Standards Institute
A-TDMA	advanced time division multiple access
CB	Citizens Band [radio]
CCAP	converged cable access platform
CM	cable modem
CMD	common mode disturbance
CMTS	cable modem termination system
CPE	customer premises equipment
dB	decibel
dBmV	decibel millivolt
DAA	distributed access architecture
DOCSIS	Data-Over-Cable Service Interface Specifications
FBC	full band capture
FEC	forward error correction
FFT	fast Fourier transform
FM	frequency modulation
GHz	gigahertz
GIS	graphical information system
HFC	hybrid fiber/coax
Hz	hertz
HMS	hybrid management sub-layer
IUC	interval usage code
kHz	kilohertz
LTE	long-term evolution
MAC	media access control
MDU	multiple dwelling unit
MER	modulation error ratio
MHz	megahertz
MIB	management information base
NETCONF	network configuration protocol
NOC	network operations center
NPR	noise power ratio
OBI	optical beat interference
OFDM	orthogonal frequency division multiplexing
OFDMA	orthogonal frequency division multiple access
ONU	optical network unit
PHY	physical layer
PLC	power line communication
PNM	proactive network maintenance
PSD	power spectral density
REST	representational state transfer
RESTCONF	representational state transfer configuration protocol
RF	radio frequency
RFoG	radio frequency over glass

RNG-RSP	ranging response
RPD	remote PHY device
RxMER	receive modulation error ratio
SC-QAM	single carrier quadrature amplitude modulation
SCTE	Society of Cable Telecommunications Engineers
SID	service identifier
SNMP	simple network management protocol
SNR	signal-to-noise ratio
TCP	total composite power
TCS	transmit channel set
TDMA	time division multiple access
UDA	upstream data analysis
UTSC	upstream triggered spectrum capture
YANG	yet another next generation

Bibliography & References

[1] SCTE 279 2022, 1.8 GHz Broadband Radio Frequency Hardline Amplifiers for Cable Systems
[2] SCTE 283 2023, Information Model for Smart Broadband Amplifiers
[3] Data-Over-Cable Service Interface Specifications DOCSIS® 3.1 CCAP™ Operations Support System Interface Specification CM-SP-CCAP-OSSIv3.1 (Cable Television Laboratories)
[4] PNM Current Methods and Practices in HFC Networks (DOCSIS® 3.1) CM-GL-PNM-3.1 (Cable Television Laboratories)
[5] DOCSIS® Best Practices and Guidelines PNM Best Practices: HFC Networks (DOCSIS® 3.0) CM-GL-PNMP (Cable Television Laboratories)
[6] SCTE 280 2022, Understanding and Troubleshooting Cable RF Spectrum
[7] NOS OP 209[2], Understanding and Troubleshooting Cable Upstream RF Spectrum
[8] Cable Modem Transmit Headroom Resiliency Management (2023), A Technical Paper prepared for SCTE by Ron Hranac, Roger Fish, Tom Kolze, Satish Mudugere, Alexander Podarevsky, Jason Rupe, Foad Towfiq, Sheldon Webster, Larry Wolcott, Lei Zhou
[9] PNM Upstream Data Analysis (2023), A Technical Paper prepared for SCTE by Larry Wolcott, Rob Gonsalves, Jonathan Leech
[10] ANSI/SCTE 87 2017, Graphic Symbols for Cable System
[11] Exploring Programmatically Generated HFC Plant Topology (2023), A Technical Paper prepared for SCTE by Lin Cheng, L. Alberto Campos, Justin Riggert, Larry Wolcott

[2] At the time of writing, NOS OP 209 is going through the final approval and ballot process within SCTE. Once approved, the document number will be updated, and the document made publicly available.