Tackling Upstream Ingress and CPD Issues in High-Split Cable Networks

Challenges and Solutions

A Technical Paper prepared for SCTE by

Claus Lassen
Senior Architect, HFC Networks
Norlys
clalas@norlys.dk

Steve Condra
Senior Director, Product Management
Teleste Intercept, SCTE Member
440 Forsgate Drive, Cranbury, NJ 08512
+16786418099
steven.condra@telesteintercept.com

Arttu Purmonen
Vice President, System Marketing
Teleste Corporation
Telestenkatu 1, Kaarina, 20660
+358405562942
arttu.purmonen@teleste.com

Pekka Hilke, Teleste Corporation

Niko Suo-Heikki, Teleste Corporation

Henri Aittomaa, Teleste Corporation

Table of Contents

List of Figures

List of Tables

1. Introduction

The cable industry plans to leverage Data Over Cable Service Interface Specification (DOCSIS) 4.0 technology over hybrid fiber-coaxial (HFC) networks to meet the demands of future bandwidth-intensive applications. While it remains uncertain which new split frequencies cable operators will deploy in their networks, there is consensus that the upstream frequency band will expand (Ciarla, 2023; Segura, 2022). However, this extended upstream introduces new challenges. Among these challenges, upstream ingress (Ciarla, 2023; Hranac et al., 2022; Segura, 2022; Topazi, 2022), and common path distortion (CPD) stand out as significant issues (Heiler et al., 2022). While these problems have long been recognized, it is crucial for cable operators to continually evolve their strategies for managing them, particularly during the transition to high-split networks and the deployment of distributed access architecture (DAA) (Segura, 2022).

Insights from various articles clearly show that addressing upstream ingress and CPD requires proactive measures, such as the deployment of proactive network maintenance (PNM) technology, which plays a crucial role in detecting and resolving these issues (Ciarla, 2023; Hranac et al., 2022; Volpe, 2019; Walsh, 2020; Wolcott, 2019). In response to the evolving landscape of cable networks, cable operators are striving to optimize workforce efficiency, improve subscriber experiences, and ensure reliable network performance through the adoption of innovative technologies and proactive maintenance practices (Volpe, 2019; Wolcott, 2019).

Norlys, a leading Danish cable multiple-system operator (MSO), has been at the forefront, pioneering large-scale high-split upgrades across its entire cable network infrastructure while concurrently rolling out DAA in Denmark. This case study elucidates the upstream challenges Norlys encountered and the solutions they employed. We then extrapolate these learnings to a North American context. This comprehensive approach is aimed at helping North American cable operators maintain high network uptime for the benefit of their subscribers and preempt issues before they negatively impact the customer experience.

In the context of cable networks, a 'high-split' configuration refers to the utilization of frequencies below 204 MHz for the upstream (return path) and frequencies above 258 MHz for the downstream (forward path). This shift in frequency allocation presents both new challenges and opportunities for cable operators. Moreover, the adoption of DAA, which involves implementing remote PHY devices (RPDs) or remote MAC PHY devices (RMDs) in place of traditional fiber nodes, further transforms the network infrastructure.

This paper is structured as follows: first, we define and categorize ingress and CPD; second, we delve into Norlys' experiences and the problems caused by ingress and CPD; third, drawing on the Norlys' case study, we establish foundational premises to frame the subsequent discussion in a North American context; fourth, we examine the requirements for tackling upstream ingress and CPD issues in North American high-split cable networks. We conclude by outlining the limitations of the paper and discussing future developments that could assist cable operators in managing ingress and CPD in their networks more efficiently.

2. Definitions and Categories of Ingress and Common Path Distortion

In high-split cable networks, upstream ingress is a critical concern, and it refers to the unwanted intrusion of external signals within the 5 to 204 MHz range of the upstream frequency spectrum (Ciarla, 2023; Hranac et al., 2022; Segura, 2022; Topazi, 2022). This interference, originating from a range of sources including both human-made and natural factors, poses significant challenges for cable operators striving to maintain signal integrity and ensure optimal network performance. As highlighted in the articles, upstream ingress is a persistent issue that can lead to interference and disruptions in the cable network. Operators confront the challenge of identifying and mitigating the sources of ingress to maintain signal quality and prevent service degradation. Furthermore, CPD complicates these challenges in cable networks, arising from the non-linear behavior of specific network components, particularly oxidized connectors (Heiler et al., 2022).

Table 1 - Classification of Ingress and CPD

Signal	Subcategory	Bandwidth	Origin
Ingress	Short-Term Ingress	Narrowband	Network
			Customer premises
		Wideband	Network
			Customer premises
	Long-Term Ingress	Narrowband	Network
			Customer premises
		Wideband	Network
			Customer premises
CPD	Short-Term CPD	Wideband	Network
	Long-Term CPD	Wideband	Network

2.1. Subcategories of Upstream Ingress

Short-Term Ingress: In our paper, short-term ingress refers to interference that lasts less than the period required to locate its exact source using traditional methods, such as truck rolls. These methods involve a field technician visiting locations that house RF amplifiers or fiber nodes and using measurement devices to determine where ingress enters the network or where CPD is created. As the field technician can only make educated guesses about these locations, they usually have to visit several sites before pinpointing the exact source. The duration of these visits, or 'truck rolls,' varies, so there is no exact time limit; however, short-term ingress typically lasts from one hour to several hours.

Long-Term Ingress: In this paper, long-term ingress refers to interference that persists long enough to be located using traditional methods, typically lasting from hours to days. By defining short-term and long-term ingress in this way, we indicate that traditional methods cannot locate short-term ingress, as by definition, once located, it becomes a long-term issue. Our rationale for this choice will become clear in later chapters.

Both short-term and long-term ingress can be further categorized based on their bandwidth. Narrowband ingress refers to interference with a bandwidth of less than 1 MHz, while wideband ingress implies interference with a bandwidth exceeding 1 MHz. The 1 MHz limit is a pragmatic choice, as broader signals are more likely to disrupt more than just one single-carrier quadrature amplitude modulation (SC-QAM) upstream channel. Typical sources of narrowband ingress include broadcast radio, analog television channels, amateur radio, public safety networks, and baby monitors. Conversely, common sources of wideband ingress can include electrical motors, power switching devices, lightning, and digital equipment, which can generate strong electromagnetic fields. We also classify ingress based on its entry point into the cable network. Here, the term "customer premises" refers to individual residential houses or apartments, while "network" refers to all other locations within the cable television network.

2.2. Common Path Distortion

CPD is caused by non-linearities within the network, frequently due to oxidized connectors (Heiler et al., 2022). This distortion manifests as wideband noise in the return spectrum, adversely affecting network performance. Importantly, CPD mainly stems from parts of the network susceptible to oxidation and corrosion. When high downstream signal levels pass through these damaged network parts, performance is compromised. Contact points prone to CPD are affected by vibrations, changes in humidity, and temperature variations, all of which can influence network integrity. Consequently, both short-term and long-term CPD can be present in a cable network, but it very seldom originates from individual customer premises.

3. Norlys' Experiences

Our paper primarily concentrates on the emergence and resolution of ingress and CPD issues in high-split cable networks. Consequently, our discussion of Norlys' network upgrade will be concise. Our focus will rather be on a detailed examination of the ingress and CPD issues that Norlys encountered following the completion of their high-split rollout.

3.1. The High-Split Roll-Out

In 2016, Norlys operated cable networks using frequencies up to 65 MHz for upstream and up to 860 MHz for downstream. Although Norlys could have increased upstream capacity by further segmenting the network and upgrading to the 85 MHz return path, these methods were deemed to offer only modest improvements. The intense competition among fixed broadband providers, the increasing prevalence of full fiber-to-the-home (FTTH) installations, and a fully deployed downstream spectrum collectively influenced the decision to transition to a high-split (204 MHz/1.2 GHz) cable network. To achieve high spectral efficiency, Norlys decided to combine the high-split with DAA roll-outs. The existing network cables, power supplies, and documentation were primarily in good condition. However, to ensure all upgrade prerequisites were met, Norlys opted to run a few pilot projects before proceeding with the full roll-out. The main roll-out process spanned four years and was completed in 2021.

Following the roll-out, Norlys now operates a modern cable network, composed of 204 MHz / 1.2 GHz intelligent RF amplifiers, 1.2 GHz passives, DOCSIS 3.1 RPDs, and a DOCSIS 3.1 converged cable access platform (CCAP). The network is managed via the CCAP core, PNM, and a network management system (NMS). The NMS and PNM are both accessible, remotely and locally, to field technicians tasked with resolving ingress and CPD issues. Nearly all amplifier cascades have fewer than five amplifiers (N+5), and the majority of cable modems are DOCSIS 3.1 compliant. However, only customers requiring high upstream capacity orthogonal frequency-division multiple access (OFDMA) have had new wall outlet installations. Most customers still have the traditional (65 MHz / 85 MHz) European-style wall outlet with a separate FM radio port, even though FM radio is no longer available in the network, as frequencies below 204 MHz are allocated for upstream use. Figure 1 presents the essential network elements and management systems. FM radio signals are still partly present in the network as a form of ingress that enters the network via the traditional wall outlets.

PNM: The proactive network maintenance functionality, enabled by cable modems and CCAP cores, generates data to facilitate its operation (Volpe, 2019; Wolcott, 2019). PNM plays a crucial role in identifying and alerting network operators to the presence of interference, including both ingress and CPD. While PNM provides valuable insights into the general nature of problems caused by interference, it's important to note that it might not be sufficient for pinpointing the exact source of the interference. For instance, Norlys' experiences indicate that locations where micro-reflections occur may not necessarily align with the points where ingress enters the network or where CPD originates.

NMS: The network management system has the capability to collect and analyze data produced by the connected (intelligent) amplifiers. When combined with PNM data, it provides Norlys with tools to pinpoint the sources of ingress and CPD more precisely. The NMS has many additional functions beyond the scope of our article, but for the purpose of locating disturbance sources, it must be capable of adjusting forward and return path gain, attenuation, and signal level of amplifiers. The impact of these changes can be monitored using both the PNM and the NMS. Without connected amplifiers (Segura, 2021), the functionality of the NMS is significantly compromised.

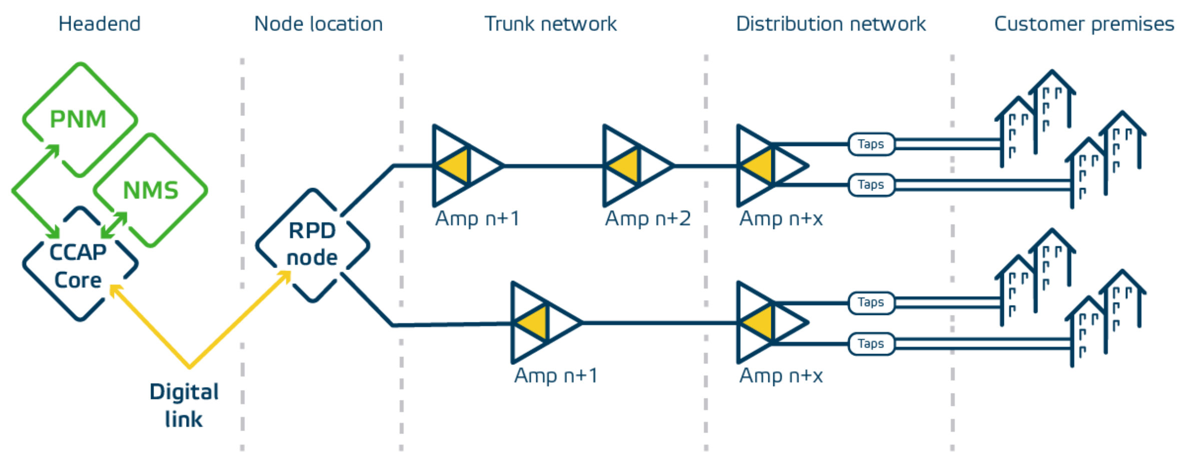

Figure 1 - Essential Network Elements

Intelligent, Connected, and Smart Amplifiers: The terms "intelligent amplifiers" and "smart amplifiers" are often used interchangeably (Segura, 2021). However, in this article, we delineate three distinct categories of amplifiers: "intelligent," "connected," and "smart." We classify them to discuss their unique features and their significance to North American cable operators. "Smart amplifiers" denote those equipped with automatic features, such as automatic level and slope control (ALSC) or return follows forward (RFF), which necessitate a microprocessor. "Connected amplifiers" represent a subset of smart amplifiers that can be remotely interfaced with the NMS, either unidirectionally or bidirectionally. Meanwhile, "intelligent amplifiers" describe a particular type of connected amplifiers fitted with full transponders that support upstream monitoring. As such, they are capable of upstream ingress/CPD analysis. Figure 2 showcases relationships between the three sets of categories. All amplifiers used by Norlys are classified as intelligent amplifiers. They operate in either trunk or distribution modes, with each mode demanding specific configuration templates. Norlys' amplifiers are equipped with DOCSIS 3.0-based transponders and a tuner, essential for enabling upstream measurements. These transponders connect to the NMS via the simple network management protocol (SNMP).

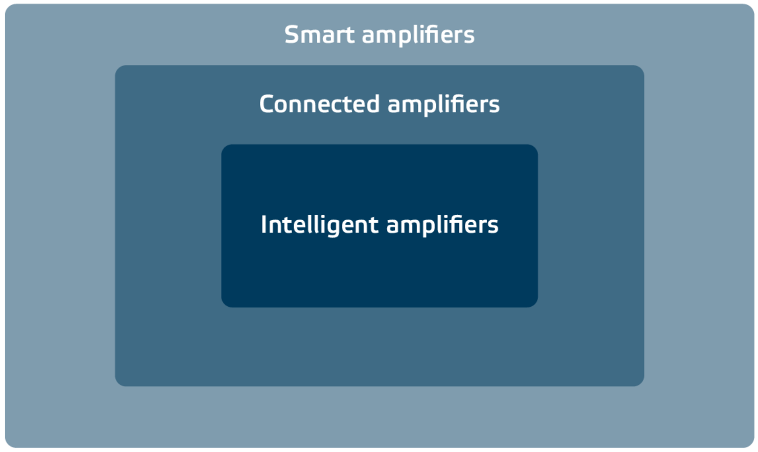

Figure 2 - Three amplifier categories

During the upgrade process, Norlys chose to maintain the levels of downstream signals. However, the upstream signal levels were typically reduced by 5 dB. This adjustment was made to establish a safety margin, ensuring that the cable modem's maximum transmit power wasn't exceeded when using the full upstream spectrum. Additionally, it aimed to mitigate distortion in amplifiers that could arise from increased upstream channel loads. It's important to highlight that this reduction in signal levels led to a decrease in the upstream carrier-to-noise ratio (CNR). To counteract this, Norlys shortened the amplifier cascades and minimized the size of amplifier clusters through segmentation—both measures aimed at reducing noise. Furthermore, the "analog" fiber originally placed between the headend and the optical nodes was substituted with "digital" fiber connecting the CCAP core and the RPDs.

3.2. Ingress and CPD Challenges Following the High-Split Roll-Out

Norlys has identified all previously mentioned categories of ingress and CPD within their network as discussed in Chapter 2. However, there has been a notable decrease in the occurrence of these issues, both during and especially after the completion of the roll-out. Along with a reduction in network issues, the process of resolving them has become more proactive. As a result, subscribers now enjoy higher quality service and experience reduced network downtime. It's critical, however, not to jump to conclusions regarding causality. The improved network quality isn't due to higher upstream frequencies, but to the introduction of new devices, tools, and tightened connectors. Therefore, even if the network had been upgraded while maintaining the old frequency split (65/85 MHz), the network quality would have improved if the same tools (NMS, Intelligent amplifiers, PNM) were utilized. Of course, a massive network upgrade to support the same frequencies doesn't make practical sense. Despite the upgrades, ingress and CPD remain persistent challenges in maintaining network performance. Figure 3 offers an illustrative representation of the likelihood of ingress and CPD occurrences within the network, emphasizing their significance. From the available data, it's clear that ingress is the predominant form of disturbance across three quadrants, and narrowband ingress originating from customer premises dominates. On the other hand, wideband distortion, which could be attributed to either ingress or CPD, primarily originates from the network itself. These findings underline the importance of addressing both ingress and CPD to ensure optimal network performance.

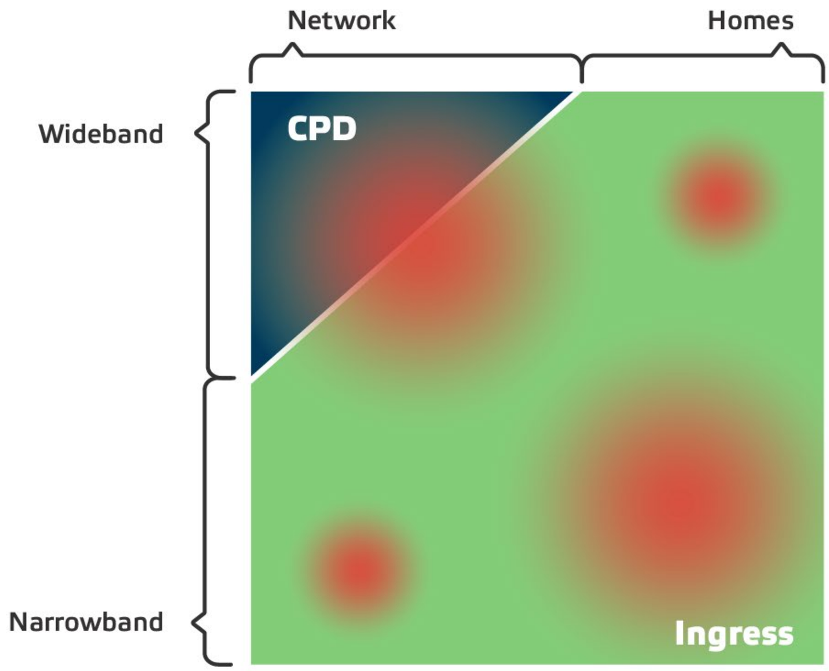

Figure 3 - Probability of Disturbances

3.3. Detecting, Finding, and Solving Ingress and CPD Issues after the High-Split Roll-Out

Instead of subscribers initiating complaints due to poor network quality, most ingress and CPD issues are first detected by the PNM, and occasionally by amplifiers capable of sending ingress alarms to the NMS. The process triggered by the PNM is illustrated in Figure 4. When the PNM sends an upstream interference alarm (1), it indicates the presence of either ingress or CPD. The PNM has access to data generated by the CCAP core, RPDs, and cable modems. This data encompasses, but is not limited to, upstream modulation error ratio (MER) per channel and per subcarrier, codeword error ratio (CER), and the upstream spectrum. Consequently, an initial understanding of whether the interference is related to ingress or CPD can be formed early on and confirmed in subsequent stages of the process.

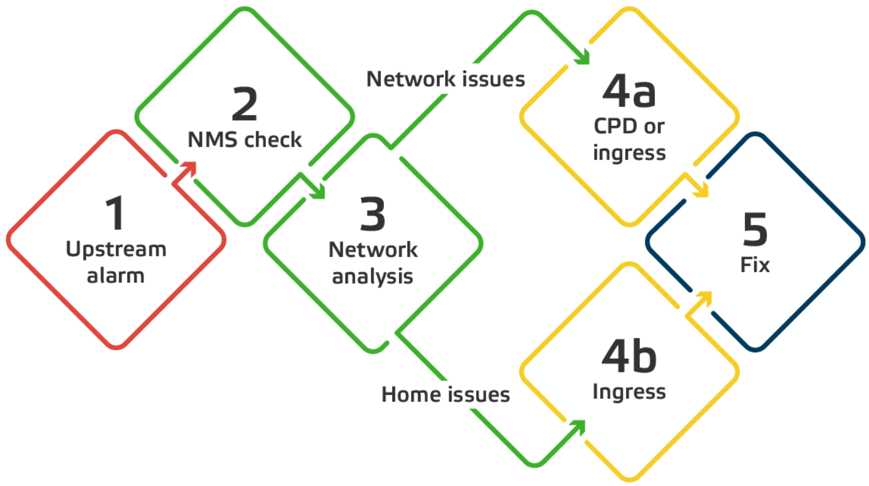

Figure 4 - Logical Flow of Ingress and CPD Detection

Next, the NMS is examined (2) to determine if it shows alarms from RF amplifiers below the specific RPD. In such cases, the NMS, rather than the PNM, can be utilized to analyze the amplifier upstream inputs more accurately, leveraging a remote connection facilitated by a transponder present in each amplifier. (3) The network is dissected amplifier by amplifier, following the amplifier cascade downwards towards the subscribers. This analysis is based on the 6 dB upstream attenuation that can be remotely toggled in every amplifier. While there are other possible levels of attenuation, Norlys has chosen 6 dB. If this attenuation diminishes the interference level, the interference is confirmed to be already present in the amplifier's upstream input, and the subsequent amplifier (N+2) is then examined. This investigation continues until the 6 dB upstream attenuation in the amplifier (N+X) does not affect the level of disturbance. In such an instance, it's known that the issue enters the network between amplifiers N+X and N+X-1. Even though the process involves multiple steps, it doesn't have to be time-consuming, as it can be expedited by the NMS.

When interference permeates the network between amplifiers, be it trunk or distribution, a further CPD analysis (4a) is conducted if the interference has a wideband nature. This analysis is executed using the NMS, which can remotely adjust the downstream level/gain of a specific amplifier, as CPD disrupting the upstream is induced by downstream distortion falling over upstream frequencies. Manipulating the downstream level/gain uncovers if the interference is a result of CPD. This information proves valuable for field technicians, as CPD tends to occur in connections close to the amplifier downstream outputs, where the downstream signal level is high, and the upstream signal is relatively low. Consequently, CPD directs field technicians to inspect connections near the amplifier.

Considering that the NMS operates on servers, it can be accessed by authorized personnel either at the headend or in the field. This allows a single individual to autonomously pinpoint and address network issues. If interference is detected below the last amplifier and it's not related to CPD, the PNM can be employed manually to inspect the parameters of the cable modems. If the last amplifier has multiple ports, the number of cable modems requiring examination can be further narrowed down. In such scenarios, the upstream inputs of the chosen amplifier can be attenuated individually. A 6 dB attenuation can reveal which drop line is the source of ingress. Typically, in these situations, the ingress originates from the subscriber's premises. Any information that reduces unnecessary customer premises visits—often necessitating separately scheduled appointments—is invaluable. Once the problematic customer premises are identified, the necessary repair can be carried out.

3.4. Short or Long-Term Interference and "Blind" PNM

Previously, short-term ingress and CPD were characterized as disturbances lasting shorter than the time needed to identify and rectify the exact source using traditional methods, such as truck rolls. In the context of these traditional methods, "short-term" could span several hours, during which subscribers might face network disruptions or reduced bandwidth. However, Norlys has adeptly reduced the average time to identify the origins of ingress and CPD by synchronizing the functions of the PNM system, NMS, and intelligent RF amplifiers. This proactive and integrated strategy has effectively redefined formerly "short-term-untraceable" issues as "long-term" – not because they last longer, but because they now endure sufficiently long for their sources to be identified and addressed by the faster method.

While rare, there may be instances where the PNM system has limited visibility, making it unable to access particular cable modems or groups thereof. This is more probable with software that hasn't fully matured in the cable modems. Though such issues commonly originate from the cable modems themselves, Norlys acknowledges that intense interference might cause a modem to disconnect. Regardless of the root cause of this "PNM blindness," RF amplifiers equipped with transponders, in conjunction with the NMS, offer a means for remote troubleshooting. In extreme scenarios, remotely deactivating a specific amplifier input can confine noise funneling problems to a particular subsegment below that input. This proactive approach ensures that the broader subscriber base remains shielded from disturbances related to such noise funneling challenges.

3.5. The Bridge to North American Context

Ulaga et al. (2021) underscored the paramount importance of foundational premises in delineating new concepts. These premises are assertions that pinpoint and expound on the core tenets of a phenomenon. In this article, we lay out the foundational premises drawing from key insights from Norlys' experiences. These will steer the conversation in the North American context in the ensuing chapter. Figure 5 depicts these foundational premises:

(1) With traditional methods, the cumulative time needed to address CPD & ingress-related challenges comprises both the time taken to fix the issue and the time to identify its origin. An elongated timeframe heightens the risk of subscribers encountering suboptimal service quality.
(2) By harnessing the PNM, bolstered by the monitoring capabilities of DOCSIS devices (CCAP core, RPD, cable modems), and integrating it with the NMS, which benefits from the monitoring and remote management functions of connected RF amplifiers, cable operators can achieve time efficiency in pinpointing CPD and ingress problems.
(3) This time conservation can be labeled as "proactive time." During this proactive time, the problem is present but has not yet garnered complaints from subscribers.
(4) An extended proactive time results in subscribers benefiting from an increased quality of service.
(5) While PNM provides invaluable insights into the network, it is not wholly adequate if the overarching ambition of network operators is to maximize both proactive time and the quality of service experienced by users.

The experiences of Norlys and the foundational premises prompt us to consider two key questions, which we will tackle in the subsequent chapter: (1) How applicable are Norlys' experiences in the North American context? and (2) How can we optimize 'proactive time' within North American networks?

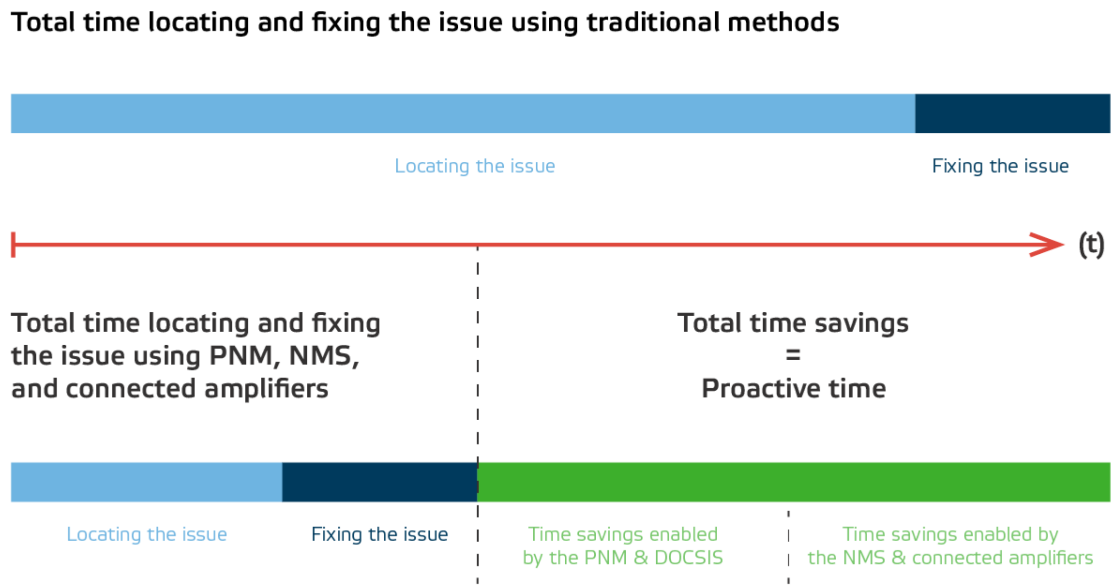

Figure 5 - Illustration of the Foundational Premises

4. Ingress and CPD in the North American Context

While the specific circumstances of Norlys in 2016 may not directly align with the current situation faced by North American operators, many of the issues they encountered are relevant and applicable. The high-split upgrade, combined with the deployment of DAA and the limitation of N+5 cascaded amplifiers behind RPDs, are common aspects in the North American context as well. With upcoming upgrade projects in North America, there is a growing focus on transitioning to a 204 MHz / 1.8 GHz cable network (also known as extended spectrum DOCSIS (ESD)). This presents operators with a unique opportunity to enhance their networks by leveraging the orchestration of PNM, NMS, and intelligent or connected 1.8 GHz amplifiers equipped with smart functionality. It's worth noting that the PNM Working Group has already published operational practices, guidelines, standards, and training content, demonstrating that the benefits of PNM are well-recognized and understood in the North American cable industry (Hranac et al., 2022; Volpe, 2019; Walsh, 2020; Wolcott, 2019). Thus, after discussing the extent to which Norlys' experiences are applicable in North America, we focus on expanding understanding of the cost versus synergistic benefits of NMS and intelligent/connected amplifiers, aiming to maximize proactive time.

4.1. Applicability of Norlys' Experiences to the North American Context

Norlys' coaxial cables are buried underground. This placement makes them less susceptible to environmental factors such as rain, wind, animals, ultraviolet radiation, and outdoor temperature fluctuations, all of which can potentially harm cables and their connectors. Also, amplifiers in North America are more exposed to these elements but temperature fluctuations are a significant issue in Europe too as street cabinets can heat excessively during summer. In some North American systems, moisture infiltrating the connectors might freeze, leading to damage. Hence, there's a higher likelihood of connectors in North American networks oxidizing. Damaged cables and connectors often result in ingress, while oxidized connectors are prone to causing CPD.

For Norlys, FM radio interference originating from customer premises is a predominant source of upstream ingress. In contrast, North American operators might find terrestrial very high frequency (VHF) television more problematic. Here, VHF can seep into the high-split upstream frequency band via homes or impaired outdoor cables and connectors. While various factors suggest North American cable networks could be more at risk from environmental changes, also the strategies to address these issues diverge slightly. For instance, while Europe's underground coaxial cables seldom suffer damage, when they do, mending them is especially tough due to restricted access. In Europe, addressing amplifier-related problems typically involves inspecting street cabinets. In North America, however, mending strand-mounted amplifiers demands specialized tools. Consequently, we foresee that repairs might prove more demanding in North American networks, emphasizing the value of tools that can pinpoint the location of faulty network components.

Customers of Norlys benefit from wall outlets that offer an additional layer of protection against ingress arising from in-home installations. In contrast, in North America, the use of a basic splitter can increase the risk of ingress, especially if the splitter is of subpar quality or has sustained damage. Despite warnings against subscribers tampering with splitters, cables, or attempting DIY installations, these issues continue. In extreme cases, a single individual's DIY attempt can jeopardize service quality for the entire node/RPD area. In summary, while North American operators might face challenges similar to those addressed by Norlys, the frequency and severity of such problems might vary. However, the difference in experiences between Norlys and its North American counterparts might not be more pronounced than the variations seen between operators in the southern and northern parts of North America.

4.2. How we can optimize 'proactive time' within North American networks

Norlys has enhanced its network quality by leveraging PNM, strengthened by the monitoring capabilities of DOCSIS devices. The information they provide is further integrated with the situational awareness of the NMS, which benefits from the monitoring and remote management functionalities of the intelligent RF (204 MHz / 1.2 GHz) amplifiers. While the North American cable industry has led the way in PNM and DOCSIS innovation, a significant challenge remains: How can new 1.8 GHz amplifiers be connected to the NMS? Without this connection, cable operators cannot achieve optimum proactive time, crucial for elevating network and service quality.

When Norlys started its upgrade in 2016, both DOCSIS 3.0 transponders and hybrid management sublayer (HMS) transponders were mainstream solutions. Norlys chose to adopt DOCSIS 3.0-based transponders equipped with integrated upstream analyzers. This choice was influenced by the simplicity and capabilities these transponders offered. For instance, the chosen RPDs did not require support for narrowband digital return (NDR) and narrowband digital forward (NDF). Additionally, there was no need for HMS-capable devices and management systems. The inclusion of an upstream analyzer in the transponders allowed Norlys to conduct more detailed upstream analyses, aiding them in a closer examination of ingress and CPD issues. However, as of this writing, DOCSIS 3.0 transponders are nearing the end of their lifecycle. The current HMS standard faces challenges, including limitations in the ultra-high split frequency range, the security of the supported SNMP version, IPv6 compatibility, and maximum packet/frame size. While delving into solutions for these challenges is beyond the scope of this article, we aim to provide technical insights for the North American cable industry. This industry must deliberate whether future transponders should be HMS or DOCSIS-based, or if both should and can remain available also in the future.

While Norlys employs intelligent amplifiers (refer to Figure 2 and respective definitions), many of the capabilities they offer would still be available even if future ESD amplifiers were connected. In such a scenario, the adjustments of amplifiers and their impact on upstream ingress and/or CPD would be monitored by RPDs, rather than other amplifiers higher up in the cascade. However, DOCSIS 3.1-based transponders present different advantages compared to their HMS-based counterparts. A deeper understanding of these advantages and disadvantages is rooted in their primary application and is further illustrated in Table 2. DOCSIS has been specifically designed to cater to subscribers seeking ultra high-speed broadband. DOCSIS cable modems are consumer devices powered by electricity within customer premises. While power consumption is a critical factor, it can be offset if the trade-off results in enhanced broadband speeds. In-home installations tend to be more forgiving than challenging outdoor environments. Consequently, the environmental standards that DOCSIS silicon vendors must meet are relatively "lenient" compared to those for outdoor conditions. While the older DOCSIS 3.0-based transponders were closely aligned with HMS-based transponders, the divide between DOCSIS and HMS is widening, when/if DOCSIS 3.1-based transponders come into play. This divergence, along with the gap it represents, will likely expand as newer DOCSIS generations emerge in the future.

The origins of HMS lie in the management of cable television network elements having high density and strict footprint requirements. HMS has been steered towards a communication method that, while low in bandwidth, is exceptionally robust. Although certain DOCSIS 3.1 upstream modulation alternatives also boast significant robustness, using them would not result in "in-band" communication. This means the same spectrum wouldn't be used for both telemetry and subscriber broadband applications. Additionally, the lifecycle of HMS is more focused on network management than on subscribers. As a result, a single HMS generation can span multiple DOCSIS generations. However, the move towards distributed access signals the need for the next version of HMS, which we refer to as HMSv2 in this paper. The specifics of SCTE 25-1 termination, whether it be (1) in the RPD software, (2) in the out-of-band (OOB) gateway device, or (3) realized through direct NDF/NDR-to-HMS conversion in the HMS gateway, still require the collective input of the cable industry to reach a consensus.

Table 2 – Transponder Alternatives

Technology	**DOCSIS 3.1-based**	**HMSv2-based**
Primary Application	Ultra high-speed broadband	Management of HFC devices
Standard/Specification	DOCSIS	Extended SCTE 25-1/2
DS Frequency Range	112…1218 MHz	258…650 MHz
US Frequency Range	5…204 MHz	5…204 MHz
Technical Advantages	• No need to use NDR/NDF • No separate spectrum needed for telemetry • No separate HMS gateway needed	• Low power consumption • Smaller footprint (board space) • Purpose-built robust modulation for telemetry
Technical Disadvantages	• Higher power consumption • Consumer technology that should be field hardened • Less robust RF modulation	• Needs SCTE 25-1 termination • Separate spectrum allocation needed for OOB • Current standard needs updates

5. Conclusion

Throughout this article, we have aimed to be transparent and informative, enabling readers to follow our reasoning. However, before concluding, we want to address some limitations of our article.

5.1. Limitations

In Chapter 2, we use a 1 MHz limit to differentiate between narrowband and wideband. We recognize this limit as somewhat arbitrary; it could be narrower (e.g., 0.5 MHz) or wider (e.g., 2 MHz). Nevertheless, we've applied this limit consistently throughout our article, allowing readers to judge if a different threshold would better suit them. This delineation also influences Figure 3. While the figure uses a fourfold table to depict wideband/narrowband and network/home disturbances, we're aware that some disturbances don't fit neatly into these categories. Rather than presenting these issues as binary, we view them as opposite ends of “spectrums”. To communicate this nuance, we've placed the x (Network, Homes) and y axis (Wideband, Narrowband) labels in the corners of Figure 3, instead of centralizing them.

Further clarification is needed for Figure 5, which portrays total time savings as a combination of those enabled by PNM/DOCSIS and by NMS/amplifiers. This illustration doesn't suggest the time savings from each are equivalent. In reality, PNM/DOCSIS may offer more time savings in some instances, while in others, the NMS in conjunction with connected amplifiers might be more beneficial.

One key limitation we'd like to clarify pertains to a potential misreading of section 4.2. This section might suggest that the need for amplifier transponders arises exclusively from ingress and CPD issues, and that the choice between DOCSIS and HMS-technologies is purely technical. However, addressing disturbances in the cable network is just one aspect of the broader value proposition of transponders. These transponders offer multiple functions not detailed in our article, such as (1) remote alarms, (2) full-band capture of the downstream spectrum, (3) remote amplifier hardware diagnostics, and (4) remote adjustments of RF alignments. Beyond these technical aspects, the cost difference between DOCSIS and HMS transponders will undoubtedly be a critical factor when producing the next generation of connected, or even intelligent, amplifiers at scale.

5.2. Concluding thoughts

Through an in-depth case study, coupled with extrapolated findings, our article provides valuable insights for North American cable operators aiming to maintain and even enhance network uptime by promptly addressing ingress and CPD issues. We believe North American operators have a unique opportunity in the upcoming years to elevate the capacity and quality of their networks, especially as high-split and DAA rollouts commence. Additionally, we introduce a categorization of amplifiers to delineate the similarities and differences among "intelligent amplifiers," “connected amplifiers,” and "smart amplifiers." Concurrently, we emphasize the critical nature of determining the connectivity solutions for future amplifiers. The cable industry may not be poised to back both alternatives, namely HMS and DOCSIS transponders.

Abbreviations

ALSC	automatic level and slope control
bps	bits per second
CCAP	converged cable access platform
CER	codeword error ratio
CNR	carrier-to-noise ratio
CPD	common path distortion
DAA	distributed access architecture
DOCSIS	data over cable service interface specification
ESD	extended spectrum DOCSIS
FTTH	fiber-to-the-home
HFC	hybrid fiber-coaxial
HMS	hybrid management sublayer
Hz	hertz
MAC	medium access control
MER	modulation error ratio
MSO	multiple-system operator
NDF	narrowband digital forward
NDR	narrowband digital return
NMS	network management system
OFDMA	orthogonal frequency-division multiple access
PNM	proactive network maintenance
QAM	quadrature amplitude modulation
RFF	return follows forward
RMD	remote MAC PHY device
RPD	remote PHY device
SCTE	Society of Cable Telecommunications Engineers
SC-QAM	single-carrier QAM
SNMP	simple network management protocol

Bibliography & References

Ciarla, R. (2023, Summer). Ingress Again? Making cable shielding effectiveness possible. Broadband Library

Heiler, G., Gadermaier, T., Haider, T., Hanbury, A., & Filzmoser, P. (2022). Identifying the root cause of cable network problems with machine learning. Springer Nature Code of Federal Regulations, Title 47, Part 76

Hranac, R., Rupe, J., Torbet, D., & Volpe, B. (2022, Fall). How Will Proactive Network Maintenance Change Under DOCSIS® 4.0? SCTE Standards Journal.

Segura, N. (2021, Winter). Intelligent Amplifiers for 1.8 GHz HFC Extended Spectrum — A Smart Idea. Broadband Library.

Topazi, C. (2022, Winter). OFDMA and Ingress, Some frequently asked questions (and a few answers). Broadband Library.

Ulaga, W., Kleinaltenkamp, M., Kashyap, V., & Eggert, A. (2021). Advancing marketing theory and practice: guidelines for crafting research propositions. AMS Review, 11(3–4), 395–406.

Volpe, B. (2019, Spring). What Can DOCSIS PNM Do For Me? Broadband Library

Walsh, J. (2020, Winter). Protecting Our Network Heroes, Keeping customers connected and technicians safe. Broadband Library.

Wolcott, L. (2019, Spring). PNM: State-of-The-Art and 2019 Roadmap. Broadband Library

