Smart Amplifiers – Are They Worth It?

A Technical Paper prepared for SCTE by

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1. Introduction

As the newest generation of the Data over Cable Service Interface Specification (DOCSIS) ecosystem takes shape, multiple system operators (MSOs) are contemplating upgrading their hybrid fibre coax (HFC) networks. Whether an operator chooses the full duplex (FDX) or frequency division duplex (FDD) variant of DOCSIS 4.0, all amplifiers in the network will need to be replaced by newer versions. Historically, amplifiers were simple devices set up during install and only revisited during routine maintenance or troubleshooting. However, there is an opportunity to enhance the functionality of these devices with the aim of decreasing the total cost of ownership (TCO) of the HFC network and to reduce the incidence and duration of customer impacting outages. This paper will present a fresh perspective on smart amplifier functionality and evaluate the potential benefits of deployment.

2. Background

2.1. Hybrid Fibre Coax Networks

In HFC networks, signals are combined in a hub site and transmitted over fibre optic cable to an optical node in the field. An analog optical node performs an optical to radio frequency (RF) transition and sends signals onto coax cables. Coax cable design follows a tree-and-branch topology, which was developed prior to the introduction of fibre optics when the function of the network was to distribute analog television channels [1]. Signals propagate through a cascade of amplifiers separated by coax cable and passives such that the gain of the amplifiers cancels out the loss of the cable and passives. This high-level topology is shown in Figure 1.

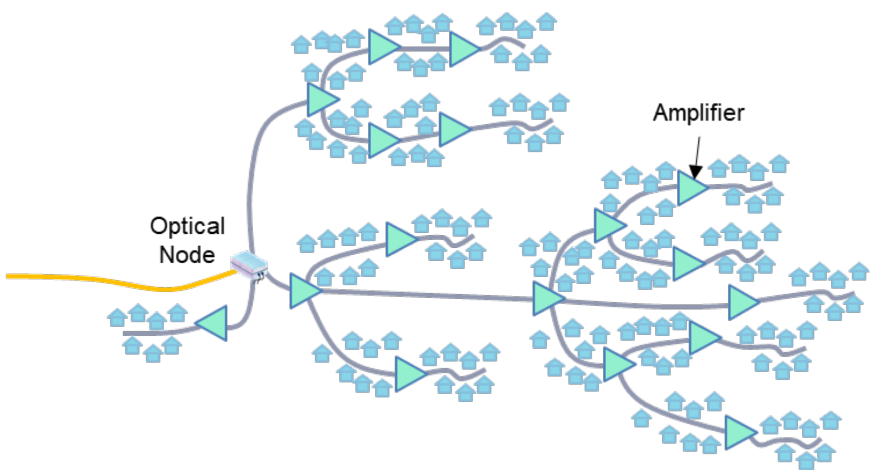

Figure 1 – Hybrid Fibre Coax Topology

HFC networks are designed to deliver signals to customer premises equipment (CPE) roughly at equal power across frequency to optimize signal quality. A complicating factor is that coax cable and passive devices have higher loss at higher frequencies. To correct for this effect, amplifier outputs are tilted so that signals at higher frequencies have higher output power than signals at lower frequencies.

2.2. Amplifier Functionality

Coaxial cable attenuation increases with the square root of frequency, as shown for CommScope QR540 cable in Figure 2.

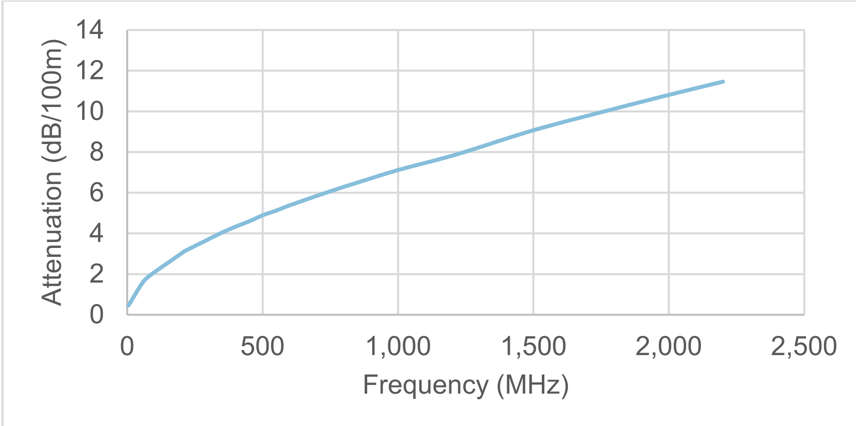

Figure 2 – Cable Attenuation with Frequency – CommScope QR540 [2]

Similarly, passives such as taps, splitters, and couplers have higher insertion loss at higher frequencies, as shown in Figure 3 for an ATX GigaXtend XST-24-20 model tap.

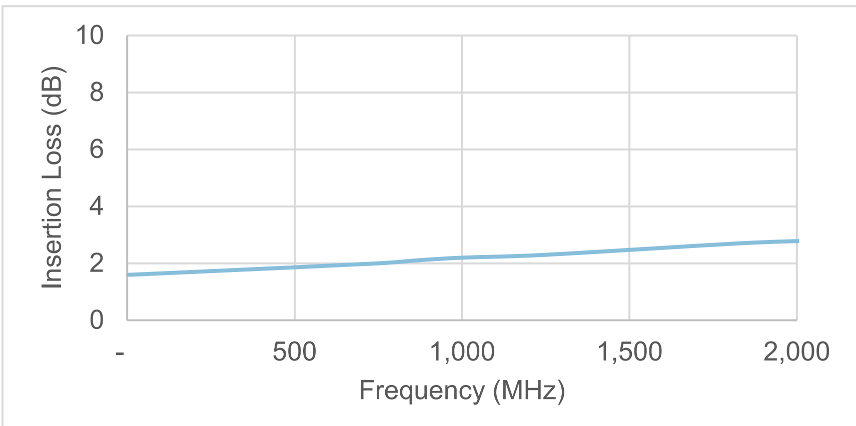

Figure 3 – Insertion Loss with Frequency – ATX GigaXtend XST-24-20 [3]

To optimize signal quality while compensating for frequency specific losses, amplifiers accept an input signal, condition it to be as flat across frequency as possible, amplify the signal, and then tilt the output. This allows a signal to be transmitted through a cascade of amplifiers and ultimately to homes with optimal quality. HFC networks are generally designed so that each amplifier has the same output levels, signified by the power level in the lowest and highest downstream channels. For instance, RF output levels can be 35/49 dBmV at 54/1000 MHz, as shown in Figure 4.

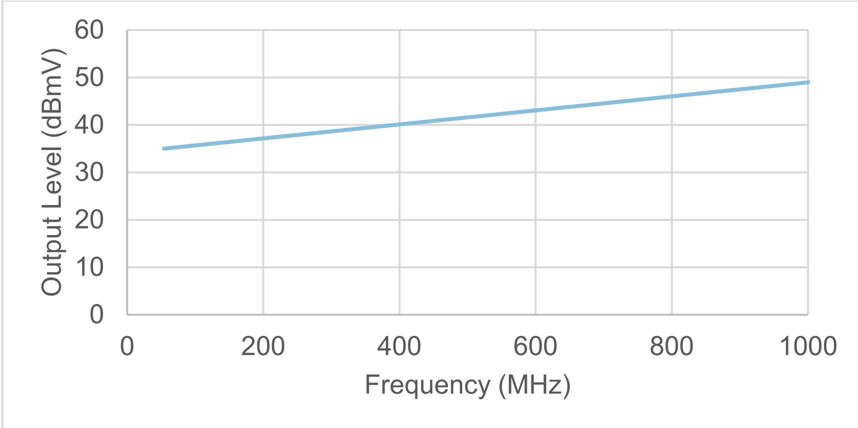

Figure 4 – Amplifier Output Levels

Amplifier signals are designed to stay within an optimal range of power level, such that they are not too close to the noise floor on the low end, or in danger of distortion at the high end. When designed and implemented correctly, signals can pass through a long cascade of amplifiers with little degradation in performance. Figure 5 shows the power level of a signal over frequency as it passes through a cascade of amplifiers and a tap to the customer premises.

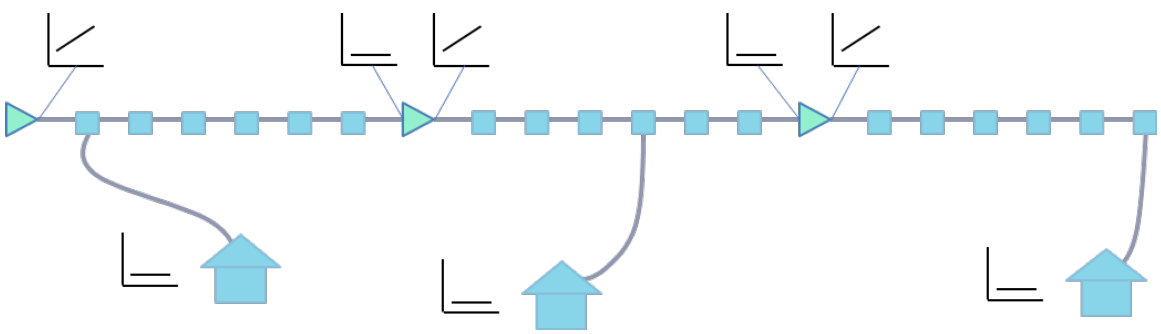

Figure 5 – Amplifier Cascade

2.3. Amplifier Block Diagram

Signals pass through many discrete steps inside an amplifier. A simplified amplifier block diagram is shown in Figure 6.

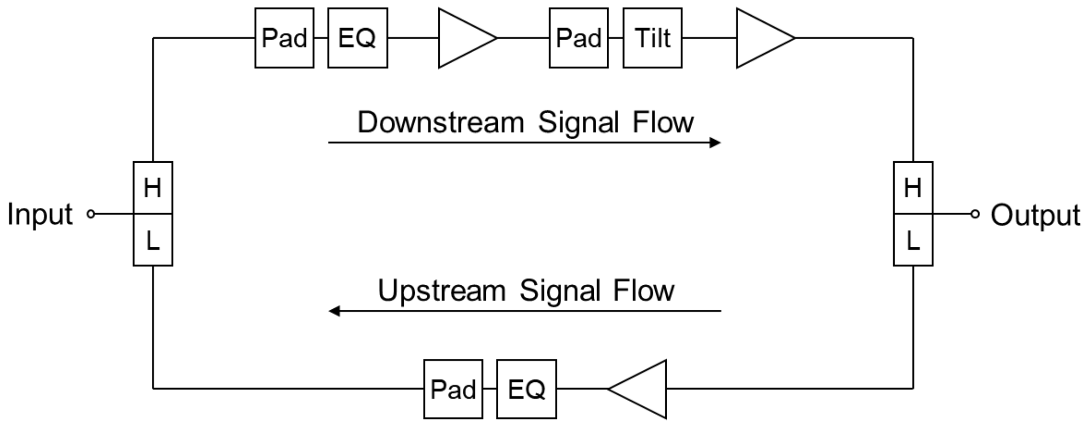

Figure 6 – Simplified Amplifier Block Diagram

Starting from the left, a downstream signal enters the amplifier and is directed along the top path by a diplex filter, signified as a box with an H (high frequency) and L (low frequency). An equalizer removes any frequency tilt remaining in the signal after traversing the cable and passives in the previous network segment, and an attenuator or pad ensures the signal level is in the optimal range for the preamplifier gain stage. Interstage attenuation controls the output level, while slope control sets the output tilt. The signal then goes through an additional diplex filter to be reunited with the upstream signal and exits the amplifier.

In the upstream, the signal flow is simpler, as losses at low frequency are smaller, allowing for a single gain stage. Starting from the right, an upstream signal enters the amplifier and is directed to the upstream gain stage, after which the signal is equalized, attenuated, and reunited with the downstream signal. Attenuation and equalization are generally accomplished using plug-in components such as attenuators and equalizers, which can be varied to achieve the desired levels.

An additional function not shown in Figure 6 is temperature compensation, commonly included in amplifiers as the attenuation of components such as cable increase with higher temperatures. Without temperature compensation, amplifiers that are set up on a hot day may amplify signals beyond specified levels on a cold day, and amplifiers set up on a cold day may not amplify signals enough as the temperature rises. Signal level changes due to temperature swings are more significant in the downstream because the attenuation is greater. Downstream temperature compensation systems use a feedback control loop, which attempts to keep a specific portion of the signal at a specified power level. If the level drops the system increases the gain, and if the level increases the system lowers the gain. In the upstream, a thermal attenuator can provide some compensation without the need for a control loop.

Amplifiers have historically been relatively simple devices that are set up during HFC network construction and only visited during routine maintenance or troubleshooting. However, smart enhancement can provide opportunities for greater network reliability and improve the customer experience. Now that amplifier functionality has been examined, smart enhancement will be discussed in following section.

3. Smart Amplifiers

Many amplifiers come with smart features that aim to improve the functionality of these devices. But what exactly is a smart amplifier, and what benefits do they bring to operators?

3.1. What Constitutes a Smart Amplifier?

The term smart amplifier is often used in two main contexts. The first is smart functionality that is local to the device, such as electronically selectable attenuation and equalization settings. It is expected that all 1.8 GHz amplifiers will have these features. The second is the ability to remotely communicate with the amplifier. This paper briefly discusses the first context but focuses on the second, as communications capability is expected to be optional, and MSOs will have to choose whether to make this investment.

3.2. Smart Setup

As mentioned earlier, amplifiers have generally used discrete plug-in components to vary settings such as attenuation and equalization. This requires HFC technicians to carry a stock of these components for setup and maintenance. In addition to added expense, this creates potential logistical issues. It is possible for a technician to *not* have the correct value component and be forced to use the closest value in their possession, resulting in a non-optimal setup. Plug-in components are a possible source of failure, as are their connections to the amplifier board. Even small failure rates of these components can cause an operational headache, and intermittent failures can be especially difficult to troubleshoot. For example, an attenuator that fails at high temperature may be tracked to an amplifier, only to have the problem cease when the amplifier is opened and the internal heat dissipated. Additionally, the mechanical joint between the component and the amplifier board can create unexpected problems when an incomplete connection is made. Wiggling or reseating the component may fix the problem, but a technician may end up discarding the component and installing a new one, fearing the problem will return.

An amplifier can be designed so that some or all configurable features are electronically selectable, either through a wired or wireless connection to a hand-held device. There are benefits to this type of system beyond avoiding issues with plug-in components. A greater range of potential settings and a larger number of incremental steps can be designed, allowing for a more precise setup. Additionally, authorization to make changes to amplifier setup can be more easily controlled, either by access to the required hardware or through restricted access via software.

3.3. Communication

While amplifiers with electronically configurable components can be referred to as smart amplifiers, a fundamental capability for this category of amplifier is the ability to communicate. Communication can be achieved either through a proprietary signaling protocol that uses upstream and downstream frequencies separate from end-user signals, or in-band through DOCSIS. There are pros and cons to both methods. Proprietary systems can use inexpensive transponders, especially if the quantity of data sent back and forth is small, but they require exclusive use of some amount of spectrum. DOCSIS communication can be more costly but has the benefit of sharing spectrum with other services, meaning that bandwidth is only used when amplifiers are sending or receiving data. In both scenarios, communication enables monitoring and control of smart amplifiers, however it adds both additional cost and complexity.

3.4. Monitoring

There are many different data points that can be monitored in a smart amplifier. These include:

- Configuration settings
- Power status
- Lid status (open/shut)

- Input/Output RF levels
- Diplex filter frequencies
- Temperature compensation

Input and output RF level monitoring requires additional hardware to evaluate signal strength. This can be done at specific frequencies or across the band with spectrum analysis functionality.

3.5. Control

It is possible to implement different levels of control in a smart amplifier. The simplest is remote setup via electronically configurable components. Combined with the ability to monitor input and output levels, a standard network setup can be achieved by a technician in an operations center, rather than sending a field technician to perform the work locally. More complex systems that control diplex frequency based on an evaluation of traffic requirements can also be designed.

DOCSIS 4.0 specifications allow for several diplex frequencies between 204 and 684 MHz [4]. A diplex frequency at 204 MHz would accommodate more downstream and less upstream traffic, while a diplex frequency at 684 MHz would accommodate more upstream and less downstream traffic. The ability to remotely change the diplex frequency would enable each node to be optimized for its traffic demand. For example, a node with many business customers might have a more symmetric traffic pattern when compared to a residential node. In the latter case, a diplex frequency of 300 MHz might be optimal, while in the former case, 684 MHz would likely best match the traffic pattern. Upstream and downstream spectrum allocation and associated ratios for each diplex frequency is found in Table 1.

Table 1 – DS to US Ratio of Different Diplex Splits

US Diplex Frequency (MHz)	US Spectrum (MHz)	DS Spectrum (MHz)	DS/US Spectrum Ratio
204	199	1536	7.7
300	295	1422	4.8
396	391	1302	3.3
492	487	1188	2.4
684	679	960	1.4

This table assumes worst-case downstream lower band edges and uses spectrum, not capacity, in calculating downstream to upstream ratio. Since upstream modulation rates tend to be lower than downstream modulation rates, the downstream to upstream capacity ratio would be slightly higher.

3.6. Automation

Electronically configurable attenuation and equalization, along with monitored signal levels, would allow for automated setup in smart amplifiers. This setup could be achieved locally at the amplifier through an application or push-button functionality. This would require logic to be implemented locally to the amplifier or in a hand-held device. Alternatively, if the device has communication capabilities, this logic could exist in a back-office system where the device is automatically configured to a predefined state when communication is first established after install.

4. Operational Considerations

While additional levels of intelligence in amplifiers can be beneficial, it is important to recognize that this intelligence will also change the operational model for setup, maintenance, and troubleshooting of amplifiers, with the goal of lowering lifecycle cost.

4.1. Amplifier Operations

In the absence of smart amplifier communication, all activities concerning those amplifiers require a technician to be physically present at the device. Adding smart features changes the way that HFC networks are set up and maintained.

4.1.1. Initial Setup

During the setup of new HFC networks, each amplifier is installed and configured by field technicians in the order of its position in the cascade. This is because the configuration of all amplifiers upstream will impact signal levels downstream. Consequently, amplifier setup happens sequentially, and a single technician may start at the first amplifier and physically move down the cascade, installing and setting up each device. However, if the amplifier is capable of remote configuration and signal level monitoring, amplifier setup can be completed by staff in an operations center. This would allow field technicians to install the amplifiers in the most efficient manner and configuration to happen remotely, without the requirement of being present at each device.

4.1.2. Maintenance

Routine maintenance of amplifiers is accomplished through sweep programs, where a group of technicians visit each amplifier in a node and confirm that signal levels are appropriate. Signal levels may change over time owing to different causes such as equipment aging, temperature swings, and deliberate changes that solve localized problems but create others. For example, a technician may increase signal level at a drop by raising the output signal level at the preceding amplifier, solving the immediate problem but potentially causing issues further downstream in the cascade.

Sweep programs are time-consuming as technicians must drive to each amplifier location, access the amplifier, open it up, connect it to a field meter and confirm whether setup is appropriate, and make any changes necessary. In the case of aerial plant, a bucket truck is required to access devices, whereas in underground plant, vaults and pedestals need to be accessed. Access can also be restricted in some extenuating circumstances, such as where amplifiers in buildings require special access, or when underground infrastructure is flooded. In the worst cases, access can require days or weeks of advance notice and fees to be paid. In addition, HFC spectrum has expanded and overlapped with mobile spectrum, creating another source of interference—through both mobile signals to the HFC network and HFC signals to the mobile network—and opening amplifier housings during a sweep program can exacerbate this issue. The extent to which MSOs utilize a sweep program can vary significantly, with some enacting rules about how often an amplifier is visited over time by a sweep program, while others may avoid them completely.

If a smart amplifier can monitor RF levels and be configured remotely, then a sweep program would be unnecessary or performed from the operations center, removing the requirements for field travel and amplifier access, ultimately creating operational efficiencies. However, the extent to which this eliminates effort depends on how a sweep is implemented at the operator level.

4.1.3. Troubleshooting

Amplifiers are potential points of failure as well as locations to subdivide the network during troubleshooting. Troubleshooting downstream issues can be achieved by working back from where the issue is reported. For example, if a modem is not receiving sufficient signal strength, a technician may visit the tap. If levels are poor at the tap, the technician will move upstream to the amplifier. If the amplifier has poor output levels, the technician can continue upstream through the amplifier cascade, ultimately to the node or hub site, to find the source of the problem. In the downstream, modem statistics can also be used to localize an issue. If there is only one modem suffering from low signal level, the problem is likely in-home or at the drop. If many modems are experiencing the issue, the common point of failure can be determined by an operations center, and technicians dispatched directly to the problem.

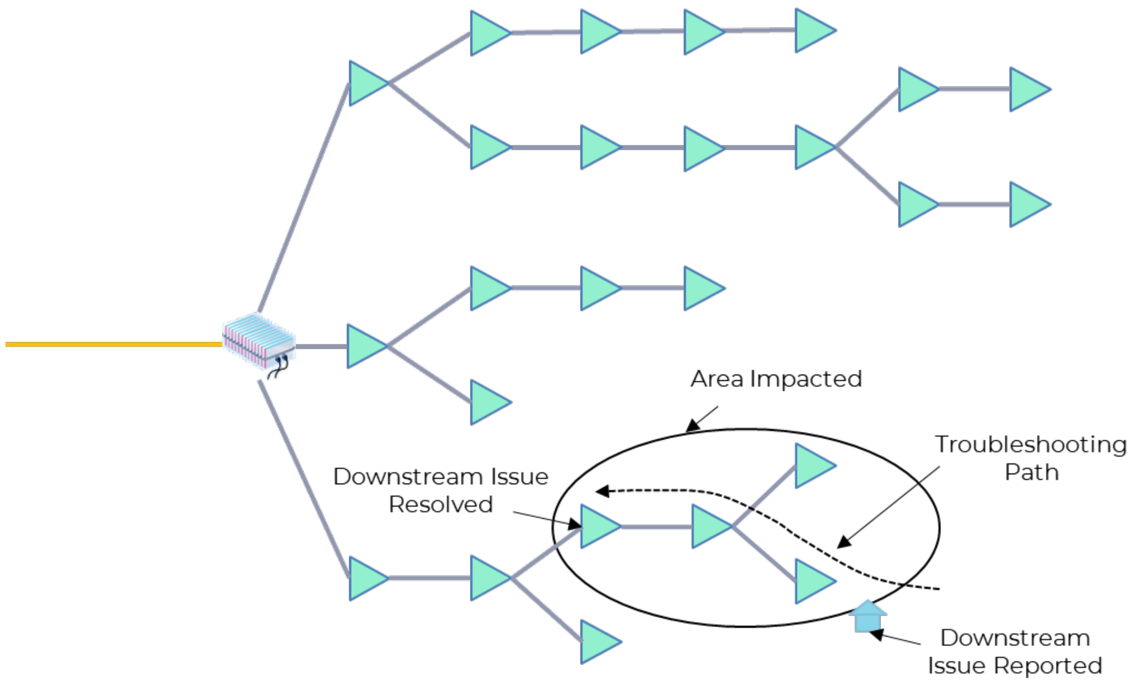

Figure 7 – Downstream Troubleshooting

Troubleshooting noise in the upstream cannot be accomplished by correlating modem statistics, as all upstream signals terminate at the same location in the hub site or at the node in distributed access architecture (DAA). In this case, technicians use a brute-force technique, working out from the node and looking at each output leg for noise. The noise is followed until it no longer presents, at which point it is determined that the noise is entering the network between that location and the last place it was observed.

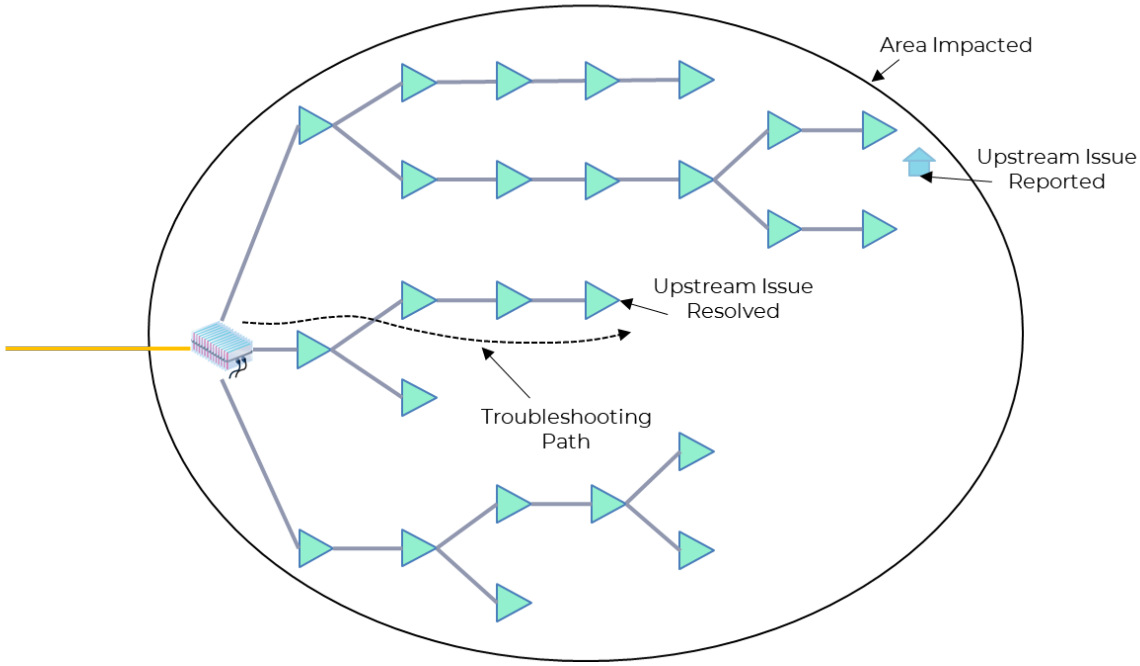

Figure 8 – Upstream Troubleshooting

Chasing intermittent noise can be difficult, time-consuming, and frustrating. It is not uncommon for a technician to be dispatched to troubleshoot upstream noise, only to have it disappear. The noise may return shortly after the technician has moved on to other activities, or it may not return for days, weeks, or at all.

The ability of smart amplifiers to aid in finding noise remotely is very useful. A remote system makes use of a spectrum analyzer in the hub site as well as the ability to temporarily increase the attenuation on each leg of a multiple-port amplifier one-by-one. If the noise presenting at the spectrum analyzer decreases when a specific amplifier leg is attenuated, it can be deduced that the noise is coming from that leg. This uses the same brute-force method used by field technicians, but eliminates the time required to drive to each location. It also allows a technician in the operations center to quickly address the issue when it is present in the case of intermittency.

To support the ability to remotely chase upstream noise, operators could also choose to only place modems or transponders in multiple-output amplifiers where noise would be entering the device from a single leg. The extent to which this strategy would work depends on how often the HFC network makes use of passive splitters instead of multiple-output amplifiers to split the network. Even in the case of splitter use, putting a modem or transponder in the first single-output amplifier downstream of a splitter leg would allow full functionality of a noise chasing system, but this could create logistical challenges as it can be difficult to ensure that the transponder or modem is put into the correct amplifiers.

4.2. Shaw Statistics

To estimate the amount of effort that could be eliminated with the implementation of smart amplifiers, it is important to have good statistics on technicians' activities. Ticketing systems for field technicians are used to assign work but are often not designed for statistical analysis. For example, drop-down boxes with a subset of potential problem categories and solutions often do not allow the flexibility to properly describe their activities, while free-form entries will vary in description from person to person and are difficult to analyze. Despite these issues, this data remains the best source of intelligence on how technicians use their time and where smart amplifiers can be most impactful.

Field technicians are often grouped by the function they provide, or by the area of the network they focus on. Some possible delineations include in-home, service, maintenance, construction, and plant. This section will only focus on troubleshooting activities and will exclude installs and disconnects.

Service calls are generated when a customer calls in with an issue that cannot be resolved over the phone. Customer service representatives create a ticket, enter a brief description of the issue from the customer's point of view, and include details from tools they have access to. The top 10 keywords are shown in Figure 9 as a percentage of use in ticket creation.

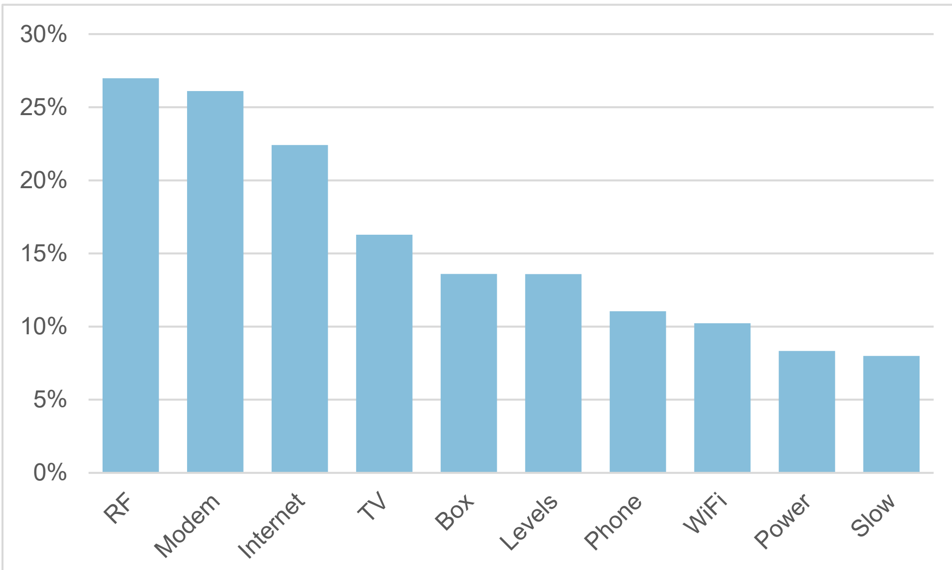

Figure 9 – Keyword Occurrence in Ticket Creation

Keyword analysis can give a high-level view of the issues that customers are experiencing but is inherently problematic as these words can be used in many contexts. As an example, the keyword "RF" can exist in the description "Poor RF Signal Levels" and "RF Signal Levels OK". Despite this, it can be observed that a common description from a customer perspective is the behaviour of the hardware or service. Descriptions such as "Modem won't turn on" or "Internet down" are common. Tickets are then assigned to field technicians who will investigate the issue at the customer premises. After investigating and resolving the issue, the ticket is closed, and an additional description is included in completion notes. The top 10 keywords used in ticket completion notes are shown in Figure 10.

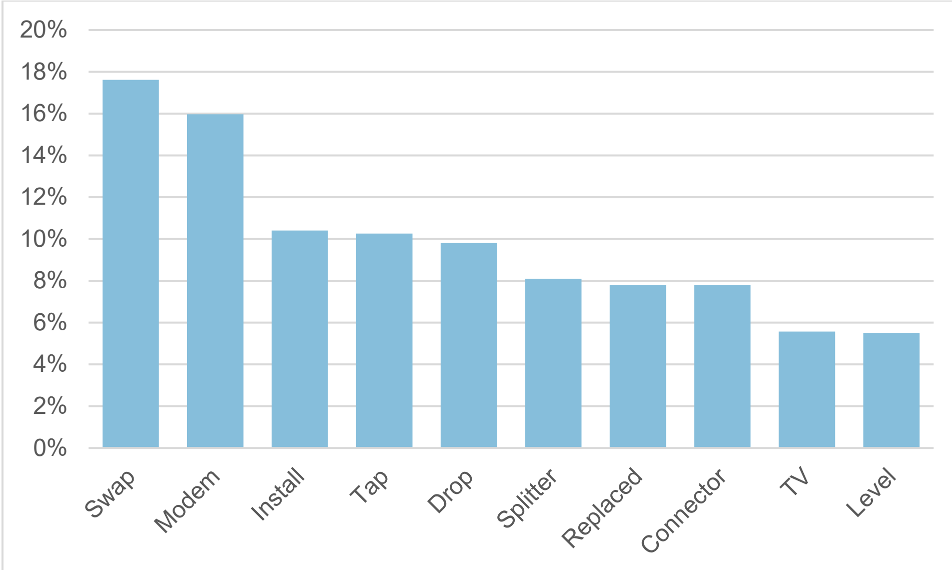

Figure 10 – Keyword Occurrence in Ticket Completion

The ticket completion notes provide insight into what the solution to the issue was. From the use of the keywords “swap”, “install”, and “replaced”, it can be inferred that changing out CPE is the most common solution to customer issues. The keywords “splitter” and “connector” are likely indicators of issues within the in-home wiring. The use of “tap” and “drop” point to issues outside of the home. Service or in-home technicians generally do not troubleshoot beyond the tap, so if an issue is traced to a cause beyond the tap, a ticket is opened for a maintenance or outside plant (OSP) technician to continue troubleshooting.

Outside plant tickets can also be created by the operations center when alarms occur or when customer issues are correlated to a single source. The number of in-home tickets is much larger than the number of outside plant tickets, as shown in Figure 11.

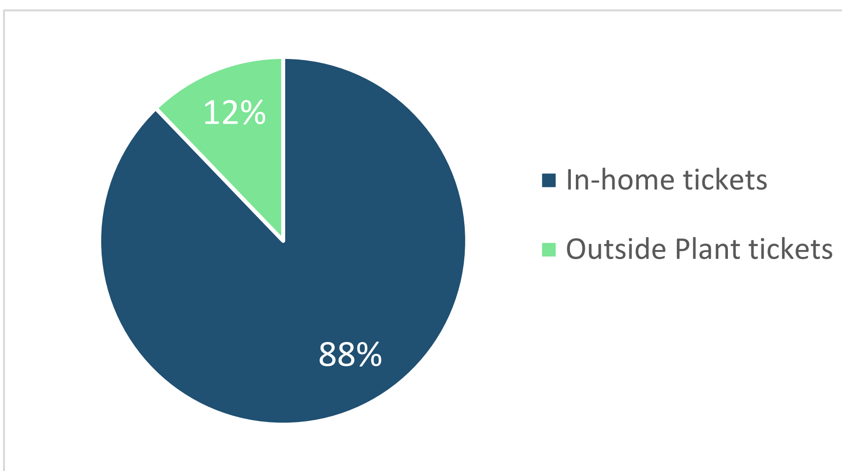

Figure 11 – In-Home vs Outside Plant Tickets

This figure represents the absolute number of tickets, and not time spent or cost incurred. In general, outside plant tickets take longer to resolve than in-home tickets and are more costly.

Outside plant referrals can be organized in a hierarchy using categorization data to estimate the number of tickets where work could be aided by smart amplifiers. Figure 12 shows the categories in the hierarchy pertinent to the discussion.

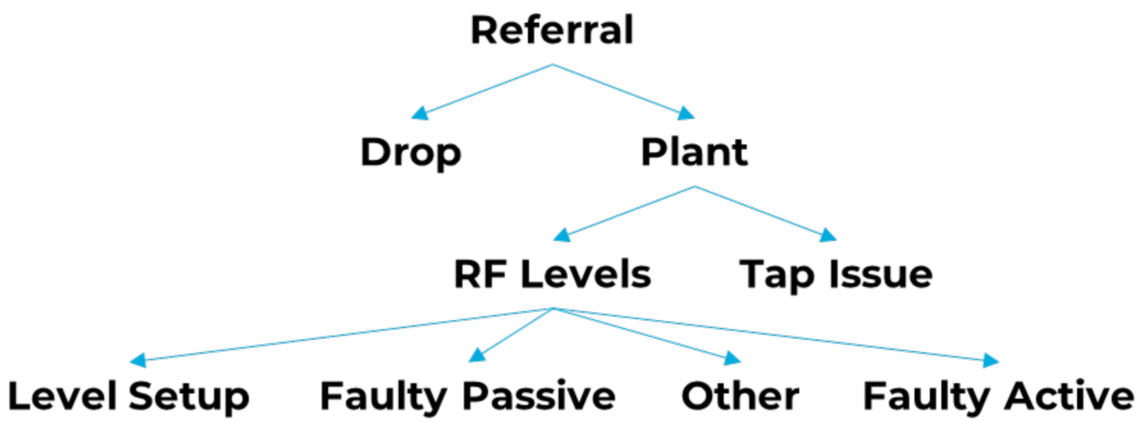

Figure 12 – Outside Plant Referral Hierarchy

One-third of plant referrals are for drop replacements while two-thirds involve issues at the tap or further into the network. Figure 13 is a Sankey diagram that visualizes the many-to-many relationship between categorizations within outside plant tickets.

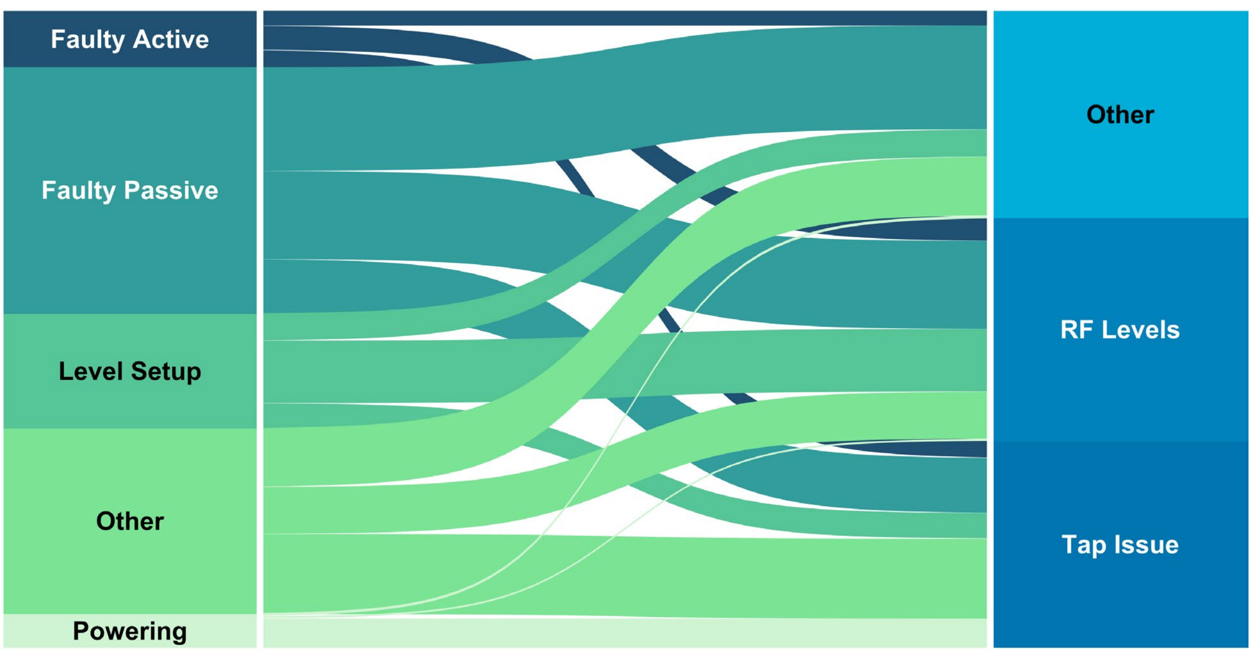

Figure 13 – Outside Plant Referral Tickets

The "Other" category above includes issues such as fibre-to-the-home (FTTH) tickets, logistical requests (e.g., for installing a larger pedestal), requests from the planning department, and no fault found scenarios.

While there are many different causes of plant issues, the majority will require checking RF levels at multiple locations. Smart amplifiers could be of help in this case, both by allowing remote RF level observation to find problems and for RF levels to be changed remotely. The degree to which a smart amplifier system would aid in solving the problem depends on where the specific issue is found. In the case of a damaged tap, the solution ultimately requires the tap to be changed out by a technician, but a smart amplifier system could localize the problem to a specific plant segment, saving troubleshooting time. Systems that correlate modem levels can also be used to determine the location of the problem, potentially to a greater degree owing to the larger number of modems.

A plant incident ticket hierarchy is shown in Figure 14. Only categories pertinent to upstream noise are shown.

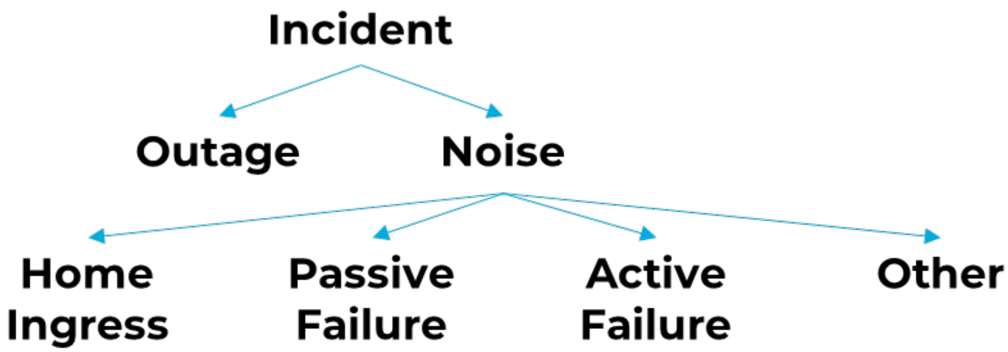

Figure 14 – Outside Plant Incident Hierarchy

Approximately one-third of incident tickets are for downstream outages while two-thirds are for upstream noise, which can be caused by a variety of different issues. Much of the ingress from homes is caused by telco noise, which is created when customers are connected to the HFC network and using their in-home coax wiring to pass signals using HFC upstream frequencies. The solution is to disconnect their drops at the tap, reconnecting them only if they become HFC customers in the future. Noise also enters the HFC network through weaknesses such as loose connectors and damaged cables. Again, a Sankey diagram can be used to see the many-to-many relationship between incident ticket categorizations in Figure 15.

Figure 15 – Outside Plant Incident Tickets

As noted earlier, the clearest benefit of a smart amplifier system is in chasing upstream noise, as this cannot be achieved through correlating modem levels or any other systems due to the noise funneling effect. Noise tickets are estimated to be approximately 3% of all tickets involving HFC in-home and outside plant troubleshooting. While this is a small number, it must be stated that noise chasing is among the most challenging and time-consuming activities that field technicians deal with.

4.3. Potential Value of Smart Amplifiers

Smart amplifiers can provide benefits by reducing required components such as attenuators and equalizers, saving time for field technicians, and reducing outage times for customers. The scale of the potential opportunity has changed over time owing to multiple factors that will be discussed below.

4.3.1. Node Size Reduction

The process of increasing capacity per home passed by building fibre deeper into the HFC network has reduced node sizes, both in terms of homes passed and the number of amplifiers. This has the effect of reducing the failure domain, increasing the uptime for all customers, and reducing the physical scope of troubleshooting. A node that has 1,000 homes passed and 100 amplifiers inherently has more potential sources of failure and is more difficult to troubleshoot than a node with 250 homes passed and fifteen amplifiers. Node sizes have decreased substantially in the past decades and will continue to do so going forward in response to increased traffic demands.

4.3.2. Proactive Network Maintenance

Proactive network maintenance (PNM) programs use performance statistics from modems to detect and fix HFC network problems before they cause customer impacting events [5]. Upstream equalizer settings can be correlated to find and fix impedance mismatches caused by weaknesses like cracked cables and loose connectors. A properly executed PNM program can ensure that the HFC network is in good shape, reducing issues in the network and direct impacts to customers.

4.3.3. Full Band Capture

Modems with full band capture (FBC) provide remote access to spectrum analyzer functionality. This allows for remote troubleshooting of several potential issues. Downstream troubleshooting, as described in 4.1.3, can be accomplished by using modems instead of taking readings at amplifiers.

4.3.4. Gateway Architecture

Legacy in-home wiring can consist of several splitters connecting a number of video, data, and phone CPE. In place of this arrangement, many operators are moving to a gateway architecture, where a single DOCSIS gateway connects to the HFC network and all services are accessed from this device. These two scenarios are shown in Figure 16.

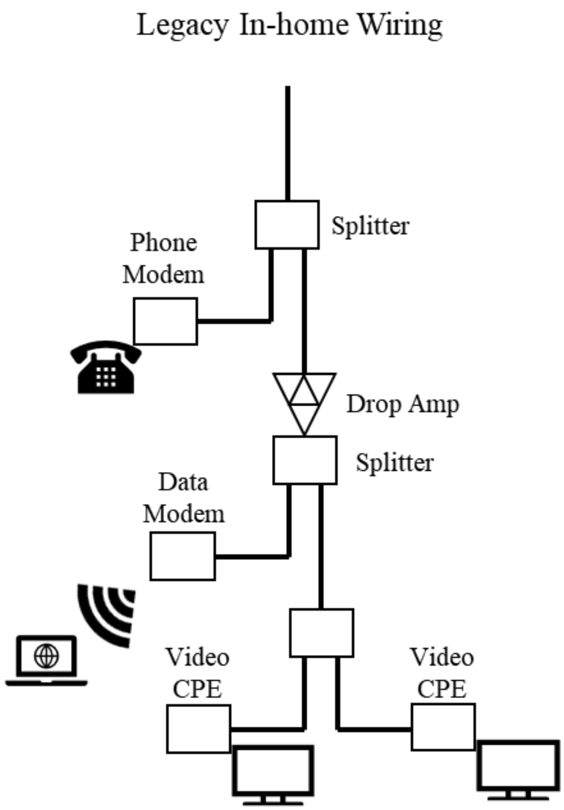

Figure 16 – In-home Networks

Moving to a gateway architecture has two main benefits. The first is that the signal level required to support a single CPE per home is lesser when compared with legacy architectures that involve splitting and will therefore suffer additional loss. This puts less pressure on the HFC network to provide sufficient signal level to support multiple boxes and reduces the need for drop amplifiers, which can amplify upstream noise in addition to desired signals. Secondly, a smaller number of endpoints reduces the potential for noise to enter the HFC network.

Smart amplifiers would have been more useful in years past when HFC networks were larger and more difficult to troubleshoot. Their value may have increased, however, due to the shift to work-from-home and hybrid-work situations driven by the COVID-19 pandemic, which has made customers less tolerant of unplanned outages.

5. Smart Amplifier Systems

Smart amplifiers that are remotely monitored and controlled require software to facilitate operation. There is potentially a large amount of data to be polled from amplifiers, and the number of amplifiers in an HFC network is large, requiring any system to be designed for usability. As of today, there are no industry standards, which means that systems are proprietary and only cover certain amplifier models. HFC networks tend to have amplifiers from multiple manufacturers for either historic reasons or in order to maintain multiple suppliers from a strategic sourcing perspective. The Society of Cable Telecommunication Engineers (SCTE) Smart Amplifier project, which launched last year, aims to create standards that the industry can use to develop smart amplifiers for DOCSIS 4.0.

5.1. Operational Shift

While smart amplifiers can reduce the workload for field technicians, it will create more work for technicians in operations centers. Amplifier setup and maintenance, and HFC technical work in general, has a large craft component and field technicians will often learn best practices over time with senior staff. This body of knowledge needs to be transferred to operations centers, as the ability to change the configuration of amplifiers in the field remotely should not be accessible to the uninitiated.

5.2. Maintenance

Making amplifiers smart adds new maintenance requirements and potential failure modes. Modems or transponders can go offline, requiring a technician to visit the amplifier to reset them. Power supply monitoring modems often suffer from this issue, but when they go offline the network continues to function. Because there is no direct customer impact to these types of modems going offline, it can be a low priority send a technician to bring them back online. This leaves operational teams with an incomplete picture of the health of the network. There is a significantly greater number of amplifiers than power supplies in the network, and as such the problem has the potential to be a magnitude larger, underscoring the need for smart amplifier components to be extremely reliable.

5.3. Additional Powering Requirement

The addition of a transponder or DOCSIS modem to each amplifier will create incremental powering requirements that will both increase operational costs due to the increased power usage and drive the need for additional power supplies. While this requirement is small in the overall context of powering the HFC network, it adds to other demands expected over the next few years. Additional power demands are expected to come from the transition to DAA, the use of small cells powered and backhauled using the HFC network and moving to 1.8 GHz. In addition to the added power requirement, a DOCSIS modem or transponder will add more heat that needs to be dissipated in an amplifier housing—something that may be challenging with 1.8 GHz amplifiers.

6. Strategic Value

HFC maintenance programs are often difficult to justify on financial arguments alone, especially as metrics such as “truck rolls avoided” are theoretical and subject to many different factors. Smart amplifiers also have strategic value that is not necessarily reflected in a financial analysis.

6.1. Smart Amplifiers in the Path to DOCSIS 4.0

Increasingly, HFC networks are competing against FTTH networks. In Canada, telcos have built out FTTH networks to most of their homes passed, and in the United States, telcos are not far behind. Current HFC networks can compete with gigabit passive optical network (GPON) downstream speeds, and high-split HFC networks can enable upstream speeds competitive with GPON. To compete with Ten Gigabit Symmetric Passive Optical Network (XGS-PON), HFC networks will have to be upgraded to DOCSIS 4.0, which enables 10 Gbps downstream and 6 Gbps upstream [6].

As customers look beyond speed when selecting a service provider, features such as latency and reliability become more important. While DOCSIS 4.0 will come with improvements in these areas, smart amplifiers have the potential to further improve HFC networks by reducing the incidence and duration of outages, making the overall network more reliable.

7. Financial Analysis

A financial analysis can be undertaken using data from ticketing systems and assuming high-level costs for smart amplifiers and field technicians' activities. This analysis should be considered directional as there are many uncertainties using both ticketing data and high-level cost assumptions.

7.1. Costs Avoided

The activity that is most affected by the introduction of smart amplifiers is upstream noise chasing. Smart amplifiers would allow noise to be located to a specific section of plant, at which point a field technician could be dispatched much closer to the source of ingress than would be the case otherwise. It can be assumed that 75% of upstream troubleshooting effort is eliminated by smart amplifiers, and a sensitivity analysis can be performed to gauge how that assumption impacts the net present value (NPV). While there is the potential to eliminate downstream troubleshooting efforts and prevent outside plant issues from causing needless in-home service calls, most of this functionality is available through PNM or similar modem performance analysis tools. Because of this, the assumption is made that smart amplifiers would not eliminate any effort for in-home or downstream issues. The estimated percentages for each category of activity are shown in Table 2.

Table 2 – Cost Avoidance Assumptions

Category	Percent Avoided
In-home	0%
OSP – DS Issues	0%
OSP – US Noise	75%

Assuming $300 for outside plant activities and $100 for in-home activities, the costs potentially avoided on a per-home passed, per-year basis is calculated as $0.75.

7.2. Smart Amplifier Costs

If an incremental cost of $50 per smart amplifier is assumed and there are 20 homes passed per amplifier, this leads to a figure of $2.50 per home passed. Yearly costs of a smart amplifier system in terms of maintenance and licensing are more difficult to estimate as they will vary with operator and solution. A cost of $0.50 per home passed per year with no capital start-up costs is assumed. An operator could alternatively develop a system in-house, in which case the yearly operational costs would be lower but the start-up costs would be potentially higher.

7.3. Net Present Value and Sensitivity Analysis

With the assumed costs and savings spread over a ten-year amplifier lifespan, the NPV of a smart amplifier system comes in at approximately $0. This means that for a positive NPV, either the costs must be lower than assumed, or the benefits be greater. A simple sensitivity analysis shows how the NPV is impacted by a change in the input variables.

7.3.1. Costs Avoided

Assuming other inputs remain the same, Figure 17 shows how the NPV is impacted by the costs avoided per home passed.

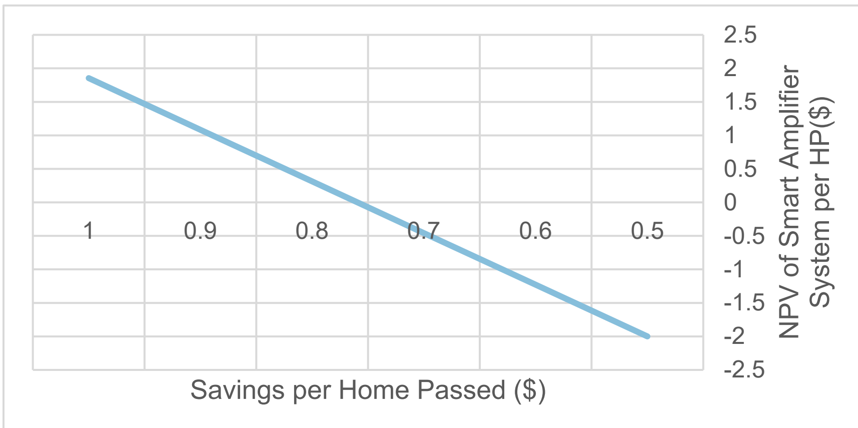

Figure 17 – Costs Avoided Sensitivity

A savings of $0.75 per home passed per year is a conservative estimate, which does not consider cost savings due to foregoing a sweep program, or due to the ability to remotely troubleshoot amplifiers that are difficult to access locally.

7.3.2. Maintenance Costs

Yearly maintenance costs, which include software licensing fees and costs related to system upkeep, would have to be higher than $0.50 per home passed per year before the system NPV would be negative, as shown in Figure 18.

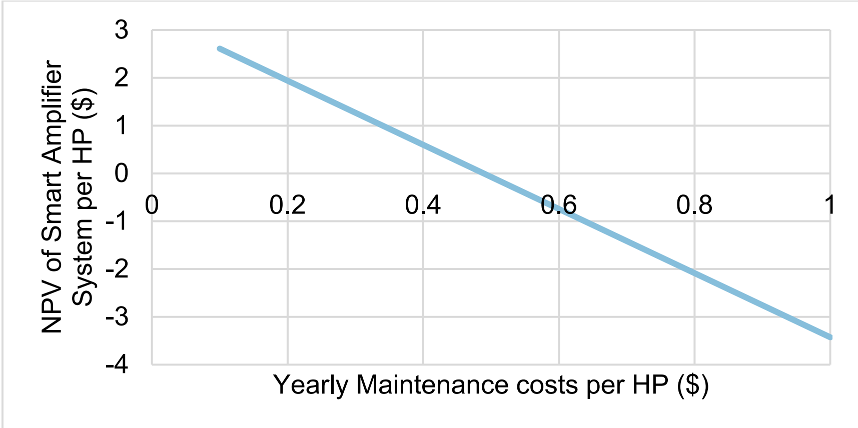

Figure 18 – Maintenance Cost Sensitivity

Maintenance costs are where companies offering smart amplifier back-office systems recoup their investment in development. Any systems that are over-engineered may risk becoming uneconomic and therefore unappealing to MSOs. Operators with in-house development capacity may be able to design and build their own systems once smart amplifier standards become available.

7.3.3. Incremental Amplifier Cost

The incremental cost of a smart amplifier would have to increase to over $50 per amplifier to turn the NPV negative.

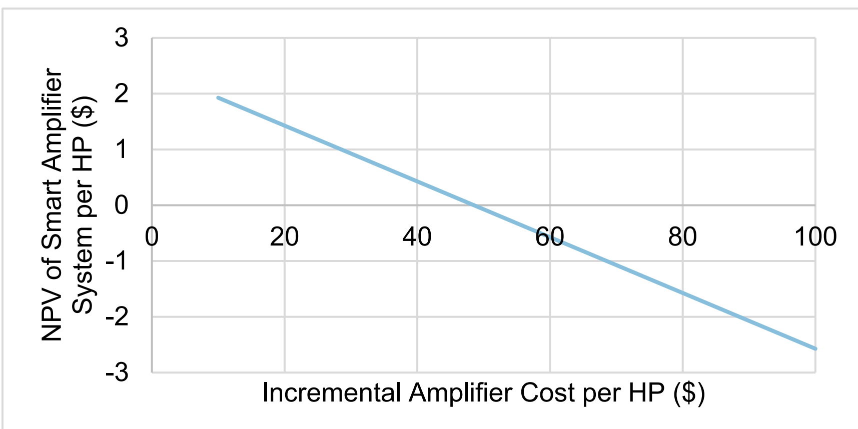

Figure 19 – Incremental Amplifier Cost Sensitivity

An effort has been made to use conservative costs and savings in this high-level financial analysis. The directional conclusion is that the value of a smart amplifier system under the assumptions used above is neutral, and a smart amplifier system would have to be carefully designed and properly executed to ensure a return on investment.

7.4. Context

It has been reported by Jeff Baumgartner at Light Reading that the costs to upgrade to DOCSIS 4.0 may reach $250-$400 per home passed [7]. The NPV of smart amplifiers should be thought of in this context, and whether the ultimate NPV is slightly positive or slightly negative, it represents a very small fraction of expected HFC network expenditure.

8. Conclusion

Smart amplifiers can reduce HFC network TCO and increase reliability by lowering the number of network outages and reducing the time required to troubleshoot issues. While PNM systems can provide this functionality in the downstream using modem-level data, locating the source of upstream noise is more challenging. This represents the greatest value for smart amplifiers. Analyzing data from operational ticketing systems can help in estimating the scope of potential savings. Using this analysis, a simple financial model shows that costs saved by reducing upstream troubleshooting effort pays for the investment in smart amplifiers. This must be taken in the context of DOCSIS 4.0 deployments, which will allow MSOs to compete against FTTH competitors. Any smart amplifier development should be designed carefully to avoid delaying equipment availability and made optional to allow MSOs to choose whether to make the investment.

Abbreviations

CPE	customer premises equipment
DAA	distributed access architecture
dB	decibel
dBmV	decibels relative to a millivolt
DOCSIS	Data Over Cable Service Interface Specification
FBC	full band capture
FDD	frequency division duplex
FDX	full duplex
FTTH	fibre-to-the-home
GHz	gigahertz
GPON	gigabit passive optical network
HFC	hybrid fibre coax
HP	home passed
MHz	megahertz
MSO	multiple system operator
NPV	net present value
OSP	outside plant
PNM	proactive network maintenance
RF	radio frequency
SCTE	Society of Cable Telecommunication Engineers
TCO	total cost of ownership
XGS-PON	ten gigabit symmetric PON

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