SCTE STANDARDS JOURNAL

VOLUME 3 NO. 1 February 2023

SCTE TECHNICAL JOURNAL

SCTE
a subsidiary of CableLabs®

SCTE STANDARDS JOURNAL

SCTE TECHNICAL JOURNAL

VOLUME 3, NUMBER 1

February 2023

Society of Cable Telecommunications Engineers, Inc.
140 Philips Road, Exton, PA 19341-1318

Table of Contents

Editorial Correspondence: If there are errors or omissions to the information provided in this journal, corrections may be sent to our editorial department. Address to: SCTE Journals, SCTE, 140 Philips Road, Exton, PA 19341-1318 or email journals@scte.org.

Submissions: If you have ideas or topics for future journal articles, please let us know. All submissions will be peer reviewed and published at the discretion of SCTE. Electronic submissions are preferred, and should be submitted to SCTE Journals ,journals@scte.org.

There was big news out of Philadelphia earlier this month but – alas! – it did not involve the Eagles and the Super Bowl.

This was the headline that jumped out at me: Comcast's news that it would be lighting up 10G in 10 million homes by the end of the February was a game-changer for our industry. By completing 10G's evolution from the drawing board to the home, Comcast has shown how our work – cable broadband technology – is keeping our industry ahead of the competition in delivering services that can improve how consumers live, work, play, and learn.

This edition of the SCTE Journal includes two papers that lean into the 10G future; both originally were presented at SCTE Cable-Tec Expo® 2022:

- "How will Proactive Network Maintenance Change Under DOCSIS® 4.0," a particularly timely piece by longtime industry technologist Ron Hranac, CableLabs' Jason Rupe, CommScope's Dan Torbet, and The Volpe Firm's Brady Volpe on the importance of developing new Proactive Network Maintenance (PNM) and service operations standards and solutions to ensure that DOCSIS 4.0 service reliability is met; and
- "A Roadmap for Cable Access Reliability," by CableLabs' Jason Rupe and Ron Hranac, that emphasizes the importance of CableLabs and SCTE leadership in the area of network reliability.

In addition, the Journal includes:

- "Sustainable Supply Chain Assessment for Cable Ops" by Villanova University's Mario Aleman, Mariah Bodine, Yen Leng Chong, and Queen Okon, and their advisor, Prof. Karl Schmidt.
- "An Analytical Framework for Solving Telecom for Wellness Challenges," by Duke Tech Solutions' Sudheer Dharanikota and Shaw Communications' Clarke Stevens.
- "Reflecting on Energy and Broadband Thoughts from Colorado 2022," a letter to the editor from SCTE's Derek DiGiacomo.

The SCTE Standards Program continues to spearhead the technical standards that are the foundation of our industry's success. On February 28 we will open the Call for Papers for SCTE Cable-Tec Expo® 2023 October 17-19 in Denver. We urge you to help us lead the way by participating in the standards process and by submitting abstracts to the Cable-Tec Expo Program Committee at https://expo.scte.org/call-for-papers/.

Thanks, as always, for your support of our industry.

SCTE STANDARDS JOURNAL

How Will Proactive Network Maintenance Change Under DOCSIS® 4.0?

A Technical Paper prepared for SCTE by

Ron Hranac,
rhranac@aol.com

Jason Rupe, Ph.D. CableLabs®

Dan Torbet, CommScope

Brady Volpe, The Volpe Firm

This paper was originally published in the proceedings of the SCTE Cable-Tec Expo® 2022 Fall Technical Forum. It is being reprinted here because it is particularly applicable to current projects in the SCTE Standards program, notably the creation by industry experts of standards and operational practices for Network and Service Reliability and DOCSIS 4.0 Tools and Readiness. For more information, see scte.org/standards.

Table of Contents

List of Figures

List of Tables

1. Introduction

DOCSIS® 4.0 specifications introduced two important changes beyond DOCSIS 3.1 specifications: extended spectrum, and full duplex transmission. As a result, the assumptions change around the interpretation of proactive network maintenance (PNM) data, how the PNM tests and queries may work, and the sensitivity of some frequencies to certain impairments. As such, PNM tools will likely evolve, and operator use of PNM will need to increase to assure service reliability is met.

This paper outlines expectations around how the network will change, and as a result how network operations may change. It can serve as the foundation for an industry project plan to develop network and service operations solutions to keep pace with new DOCSIS 4.0 technology.

2. PNM Overview

During SCTE's 2008 Cable-Tec Expo in Philadelphia, CableLabs' Alberto Campos, Eduardo Cardona, and Lakshmi Raman presented a paper titled "Pre-equalization Based Pro-Active Network Maintenance Methodology" [1]. The authors proposed using cable modem (CM) upstream transmitter adaptive pre-equalization coefficients to detect and localize plant impairments.

The basic idea involved (1) deriving complex frequency response signatures from pre-equalization coefficients, (2) looking for responses indicative of the presence of linear distortions,[1] and (3) overlaying CM location information from the cable company's customer database on a system topology display of some sort – for instance, digitized outside plant maps.

In 2009 CableLabs formed a PNM working group to implement the ideas presented in the Expo '08 paper. The output of the working group's efforts was a PNM best practices document published by CableLabs in 2010 (updated versions of the best practices document have since been published [2]), followed by a reference implementation.[2]

Using the CableLabs PNM best practices recommendations and sometimes also the PNM reference implementation, several cable operators and third parties were able to create software-based PNM applications. The PNM applications allowed operators to remotely identify and locate plant and drop impairments using data from CM upstream pre-equalization coefficients.

When the DOCSIS 3.1 specifications were created, a decision was made to incorporate provisions and "hooks" for PNM in those specs. PNM was revamped for DOCSIS 3.1 specifications from the ground up to provide downstream and upstream "test points" in the cable modem termination system (CMTS) and cable modem, allowing operators to characterize and troubleshoot hybrid fiber/coax (HFC) plant and subscriber drops; support remote proactive troubleshooting of plant faults; and improve reliability and maximize throughput in well-maintained plants. As shown in Figure 1, from [3], the cable network can be thought of as a device under test (DUT), and PNM measurements are virtual test equipment. For more information, see Section 9 of the DOCSIS 3.1 PHY Specification [3], which details PNM support and requirements.

[1] Linear distortions in cable networks include micro-reflections, amplitude ripple, and group delay distortion.
[2] SCTE's Network Operations Subcommittee Working Group 7 (NOS WG7), created in 2017, also handles PNM. The CableLabs and SCTE PNM working groups collaborate on the subject, and each group's efforts complement the other's.

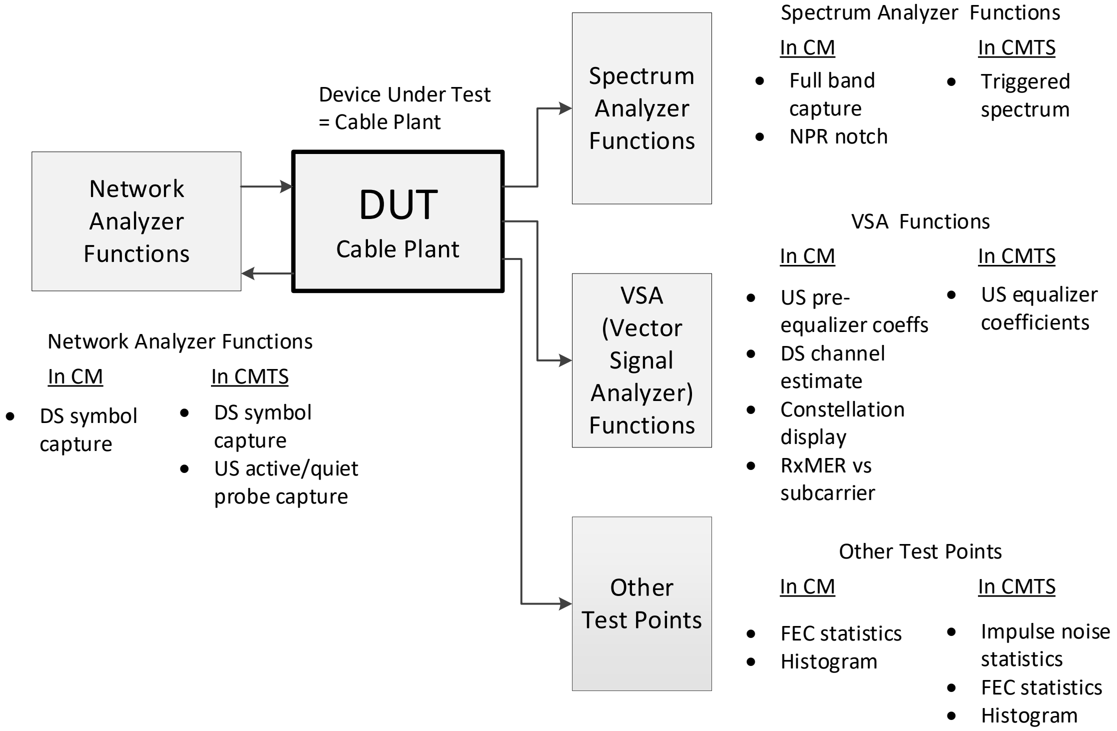


Figure 1 - DOCSIS 3.1 "test points" for an HFC network.

3. What is DOCSIS 4.0?

DOCSIS 4.0 specifications, released in 2019, are the latest in the DOCSIS family. The following description from the introduction in the DOCSIS 4.0 Physical Layer Specification [4] provides an overview:

> This generation of the DOCSIS specifications builds upon the previous generations of DOCSIS specifications (commonly referred to as the DOCSIS 3.1 and earlier specifications), leveraging the existing Media Access Control (MAC) and Physical (PHY) layers. It includes backward compatibility for the existing PHY layers in order to enable a seamless migration to the new technology. Further, the DOCSIS 4.0 specifications introduces Full Duplex (FDX) DOCSIS PHY layer technology as an expansion of the OFDM PHY layer introduced in the DOCSIS 3.1 PHY specification to increase upstream capacity without significant loss of downstream capacity versus DOCSIS 3.1. The DOCSIS 4.0 specification also builds upon DOCSIS 3.1 OFDM and OFDMA technology with an extended Frequency Division Duplex (FDD) DOCSIS alternative. DOCSIS 4.0 FDD supports legacy high split and also provides extended splits up to 684 MHz in an operational band plan which is referred to as Ultra-high Split (UHS). DOCSIS 4.0 FDD also introduces expansion of usable downstream spectrum up to 1794 MHz. Both the FDX and FDD DOCSIS 4.0 alternatives are based on OFDM PHY. Many sections refer to basic OFDM sublayer definitions described in [DOCSIS PHYv3.1].

Cable operators have for decades designed their networks to use sub-split band plans. A sub-split band plan is one that has most of the usable radio frequency (RF) bandwidth allocated to downstream signal transmission. A small portion near the lower end of the usable spectrum is allocated to upstream transmission. For example, a common sub-split band plan used in North America and elsewhere has the upstream operating from 5 megahertz (MHz) to 42 MHz, and the downstream operating from about 54 MHz to the highest downstream frequency limit (e.g., 750 MHz). In an effort to increase upstream capacity and data throughput, the industry has been migrating to mid-split and high-split band plans, with the former using 5 MHz to 85 MHz for upstream transmission, and the latter using 5 MHz to 204 MHz for upstream transmission. For more information on band splits and their history, see [5].

Introduced at the 2019 CES, the cable industry's 10G Platform [6], [7] will deliver speeds of 10 gigabits per second (Gbps) with improved reliability, security, and lower latency, using DOCSIS 3.1 and DOCSIS 4.0 technologies, passive optical networks (PON), coherent optics, dual channel Wi-Fi®,[3] and more.

In particular, the 10G Platform will take advantage of DOCSIS 4.0 technology's expanded spectrum usage – to 1794 MHz (aka 1.8 gigahertz, or GHz) or higher – and more efficient use of parts of the RF spectrum with FDX operation.

3.1. Frequency division duplexing

Originally called "extended spectrum DOCSIS" (ESD), the term frequency division duplexing (FDD) is used in the DOCSIS 4.0 specifications. The reason it's called FDD is because, just like DOCSIS 3.1 and earlier technology, downstream signals operate in one frequency range and upstream signals operate in a different frequency range. The DOCSIS 4.0 upstream RF spectrum can operate to as high as 684 MHz, and the downstream to as high as 1.8 GHz or more. Figure 2, from [4], shows the configurable FDD upstream allocated spectrum bandwidths.

[3] Wi-Fi® is a registered trademark of the Wi-Fi Alliance®. Wireless local area networks (WLANs) are commonly called Wi-Fi.

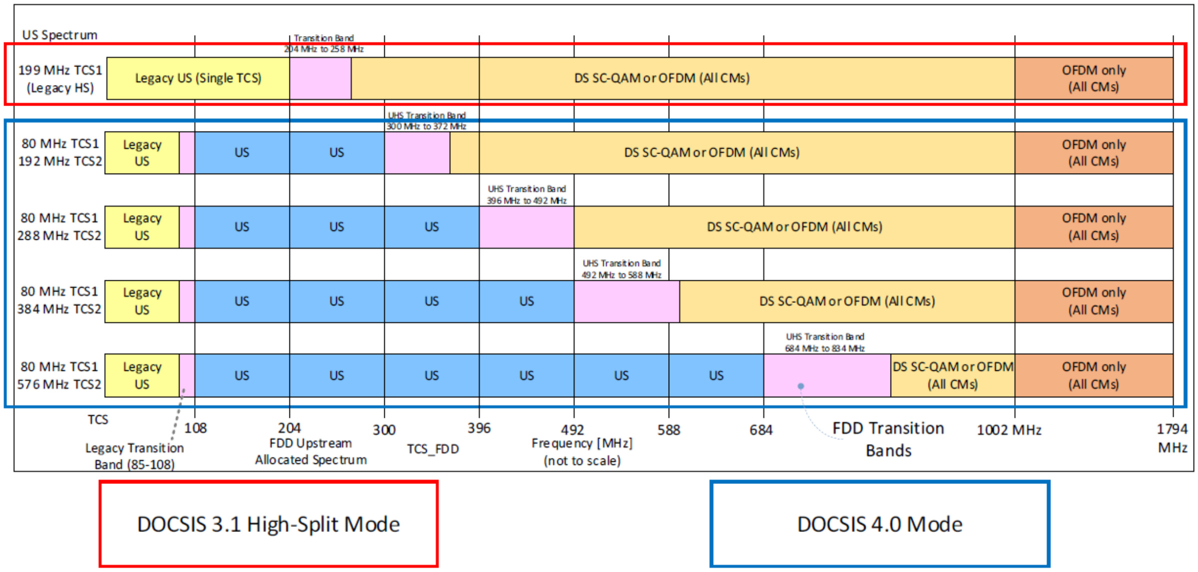


Figure 2. FDD frequency maps.

3.2. What is full duplex?

FDX – commonly known as "FDX DOCSIS" – was originally introduced as an annex in DOCSIS 3.1 specifications, and is now part of the DOCSIS 4.0 specifications. Through the magic of echo cancellation (EC) and other technologies, FDX allows the carriage of downstream and upstream signals on the same frequencies at the same time. The graphic in Figure 3, from [4], shows configurable FDX allocated spectrum bandwidths, including what is called FDX allocated spectrum. The latter comprises the frequency ranges where downstream and upstream signals can simultaneously occupy the same frequencies, allowing increased data speeds in both directions.

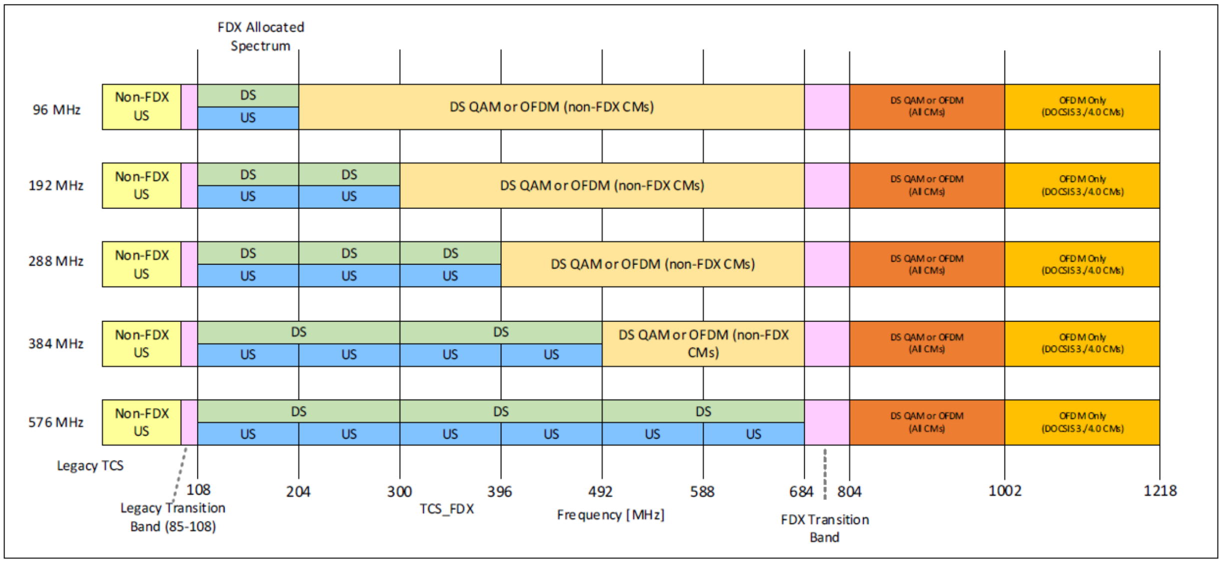


Figure 3. FDX frequency maps.

3.3. PNM in DOCSIS 4.0 networks

As mentioned previously, [3] includes a full section (section 9) covering PNM. "Section 9 PROACTIVE NETWORK MAINTENANCE" in [4] simply says "See [DOCSIS PHYv3.1] section 9."

While the PNM parameters in [3] are for the most part directly applicable to DOCSIS 4.0 technology deployments, there are some important differences and some new challenges. For example, full band capture (FBC) in cable modems will have to support a higher upper frequency limit in the downstream, to 1.8 GHz in FDD applications. Indeed, all of the downstream PNM parameters described in [3] and referenced in [4] will need to support operation to 1.8 GHz, and the upstream PNM parameters will need to accommodate operation in all of the supported frequency ranges to as high as 684 MHz.

Cable network operation on higher frequencies in both the upstream and downstream will be susceptible to new sources of ingress, as well as services with which signal leakage can interfere. Other challenges include such things as management of total power at active device outputs; isolation requirements for FDX; additional attenuation at higher frequencies; PNM test and query; and more. Developers and users of PNM tools and applications will need to understand these challenges, many of which are discussed in subsequent sections of this paper.

4. Plant Preparation and Transition path

The best proactive network maintenance is that which happens when the network is being prepared for DOCSIS 4.0 technology, well before an impairment occurs.

As networks are being upgraded, consider drop tests as well, to find potential leakage, poor drop performance, and potential sources for non-linear impairments. Passive intermodulation (PIM) distortion is anticipated to be worse in DOCSIS 4.0 networks with higher operating levels. Plant preparation is a convenient opportunity to find and remove any older distribution and drop passives that will not perform well at higher frequencies, find and remove bad or detrimental filters (including in-line equalizers), and find and remove any house amplifiers that will impact service. Degraded and poor performing drops may also have difficulty carrying signals at higher frequencies.

In-depth guidance on plant preparation is beyond the scope of this paper, but the authors acknowledge its importance for PNM. In particular, operators must address plant quality before upgrading to and deploying DOCSIS 4.0 technology.

The next section discusses some of the challenges related to managing impairments, and the potential impacts of those impairments on DOCSIS 4.0 technology deployments. Other potentially impacting topics, such as FDX-capable amplifiers and smart amplifiers, are also discussed.

5. Impairment Management and Other Challenges

5.1. Challenges in legacy plants

Figure 4 shows the results of end-to-end testing of a tapped feeder leg (active device output to last tap) using legacy components designed for a maximum downstream frequency of 1 GHz to perhaps 1.2 GHz. The coaxial cable has a standalone attenuation at 1 GHz of about 24 decibels (dB), typical of just under 1000 feet of 0.500 hardline coax. Looking at the S_{12} and S_{21} traces,[4] the combined insertion loss (cable plus passives) is about 45 dB at 1 GHz, typical of a span of feeder with taps and other passives. Of particular concern is the sharp frequency response rolloff starting at about 1.3 GHz in the S_{12} and S_{21} traces (circled in red in the figure), indicating that attenuation at higher frequencies is substantial. That rolloff is caused by the passives. The S_{11} trace, from which return loss can be derived, also indicates poor performance above about 1.3 GHz. From this example, operation above 1.3 GHz would be impossible using the legacy passives.

Cable operators contemplating operation to 1.8 GHz will need to evaluate their networks to determine to what extent upgrades or changes will be necessary to support higher downstream frequencies. PNM tools will need to support operation at the higher frequencies, too.

[4] The S_{11}, S_{12}, S_{21}, and S_{22} parameters in the figure are scattering parameters, or S-parameters. For more on S-parameters, see [13]

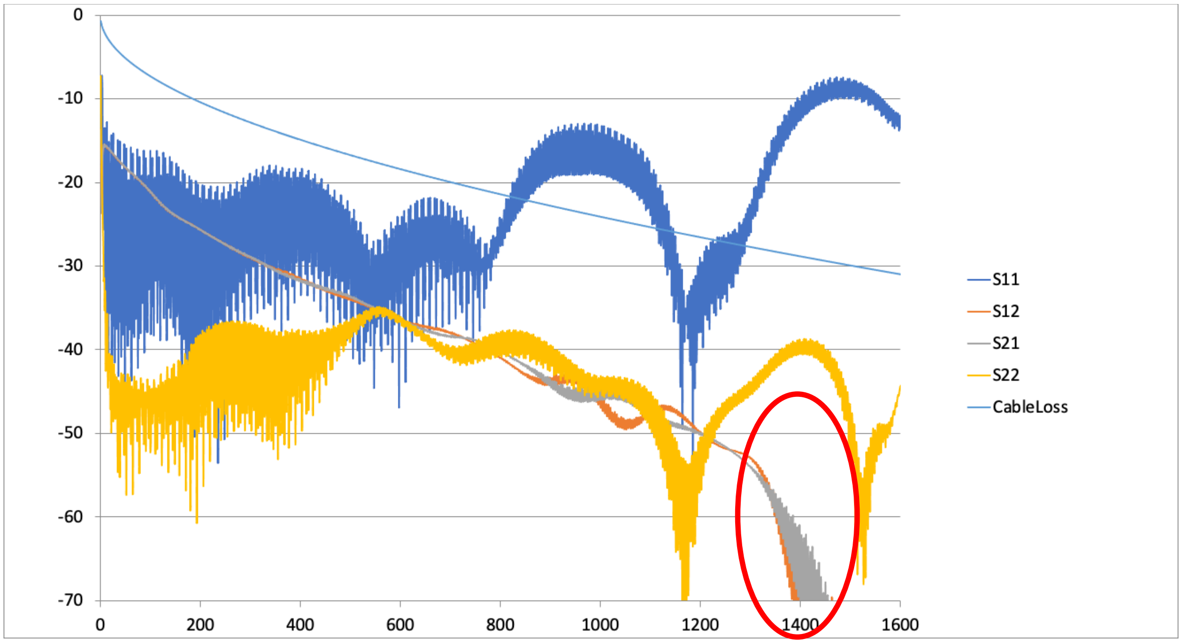


Figure 4: End-to-end test results for a legacy tapped feeder. Graphic courtesy of CableLabs.

5.2. Potential sources of ingress at higher frequencies

Cable operators are already familiar with sources of ingress and over-the-air signals affected by signal leakage in the 5 MHz to 1 GHz frequency range. Most operators have little or no experience with ingress and leakage at frequencies above 1 GHz, though. Figure 5, from [10], shows over-the-air frequency allocations in the United States from about 900 MHz to 1850 MHz (frequency allocations in other countries may be different). This frequency range includes the 902 MHz to 928 MHz industrial, scientific, and medical (ISM) band (shared with amateur radio); the 23 centimeters amateur radio band (1240 MHz to 1300 MHz); six aeronautical radio navigation bands (960 MHz to 1215 MHz, 1300 MHz to 1350 MHz, and four smaller bands from 1559 MHz to 1626.5 MHz); some long term evolution (LTE) bands; among others. GPS frequencies[5] are in the 1100 MHz to 1600 MHz frequency range, too. Signals on some of the aforementioned frequencies are potential sources of ingress interference to the cable network, and can be interfered with by signal leakage.

PNM's full band capture and receive modulation error ratio (RxMER) will continue to be valuable for identifying and helping to locate potential ingress, especially at the higher frequencies discussed here.

[5] Global Positioning System (GPS) frequency L1 is 1575.42 MHz (15.345 MHz bandwidth); L2 is 1227.6 MHz (11 MHz bandwidth); and L5 is 1176.45 MHz (12.5 MHz bandwidth). See https://www.nist.gov/pml/time-and-frequency-division/popular-links/time-frequency-z/time-and-frequency-z-g

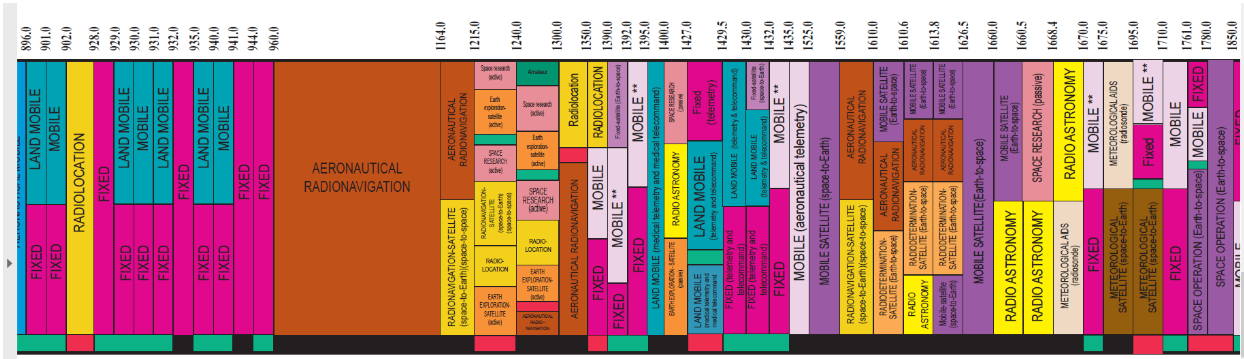


Figure 5. Over-the-air frequency allocations in the U.S. from about 900 MHz to 1.85 GHz.

5.3. Distribution and drop impairment impacts on FDD and FDX

A comprehensive list of plant and drop impairments and their impacts on FDD and FDX operation could easily be the basis for a standalone paper. The following are some of the more important considerations.

- Proper attenuation/insertion loss, frequency response, return loss, port-to-port isolation (where applicable), and other characteristics of network and drop actives, coaxial cable, passives, connectors, etc., across the full operating bandwidth are critical. Out of spec performance for any of the aforementioned could negatively affect FDD and FDX operation.
- Ingress in FDX bands causes errors in channel characterization, and the RF bandwidth of the spectrum affected by noise funneling can be larger in an FDX architecture than in others because of its wider upstream bandwidth. Noise funneling remains a problem because one source impacts all. That is, severe ingress from just one drop can significantly impair a node's upstream performance, regardless of the size of the node's service area or the number of homes passed – decreasing the size of the serving area does not necessarily decrease the noise problem. As well, drop ingress in an FDX band could impair downstream (in the drop) and upstream performance.
- Common path distortion (CPD), originating from inside customers' homes, might be increased by high transmit levels of FDX and FDD CMs.
- An FDX or FDD CM located on unconditioned house wiring, rather than the point of entry, could experience more problems on average. This outcome is due to additional complexity of the inside wiring, presence of drop passives and actives, the number of connectors, etc.

5.4. Managing total composite power

To overcome increased attenuation at higher frequencies in FDD networks, active device output power – including output total composite power (TCP) – will be higher. Figure 6, from [11], illustrates three examples of signal level-versus-frequency in an FDD network. PNM tools can be an important part of the management of active device signal levels and TCP. Section 30.14 and Appendix J of [11] include additional discussion about TCP.

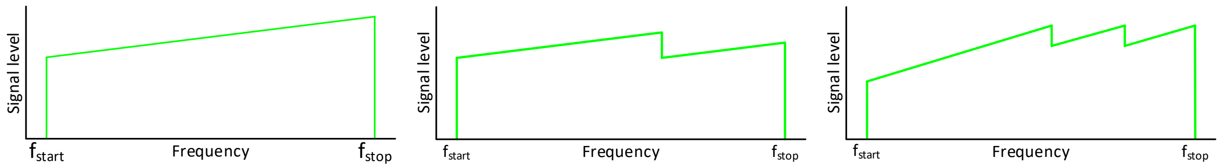


Figure 6. Examples of active device output signal level versus frequency in an FDD network.

5.5. OUDP leakage detection

While signal leakage detection is generally not part of a PNM toolset, ingress detection is, and the two are often related. That is, if leakage exists ingress usually does, too. In high-split and ultra-high-split band plans, the 108 MHz to 137 MHz aeronautical band overlaps part of the cable network's upstream spectrum. Leakage detection and measurement are more challenging, since a continuous downstream leakage test signal cannot easily be transmitted in or near aeronautical band frequencies. One promising method is to use OFDMA upstream data profile (OUDP) for leakage detection and monitoring. This approach is discussed in [12], and recent lab and field test results are encouraging.

5.6. Outside plant amplifiers and impacts on PNM

5.6.1. FDX amplification and PNM

RF amplifiers are an integral part of any HFC network. Their primary purpose is to amplify and condition RF signals so that they may propagate through subsequent spans of coaxial cable. Coaxial cable attenuates RF signals in a non-uniform manner (that is, cable attenuation is greater at higher frequencies than it is at lower frequencies), thus requiring the next RF amplifier to again amplify and condition the RF signals. Rinse and repeat. RF amplifiers and fiber nodes have one or more devices in them called a diplex filter. Two diplex filters are shown in **Error! Reference source not found.**(a) and a simulated transition band of the frequency response of a sub-split diplex filter is shown in **Error! Reference source not found.**(b). The purpose of the diplex filter is isolate the downstream from the upstream path in the active device, helping to prevent problems such as oscillation.

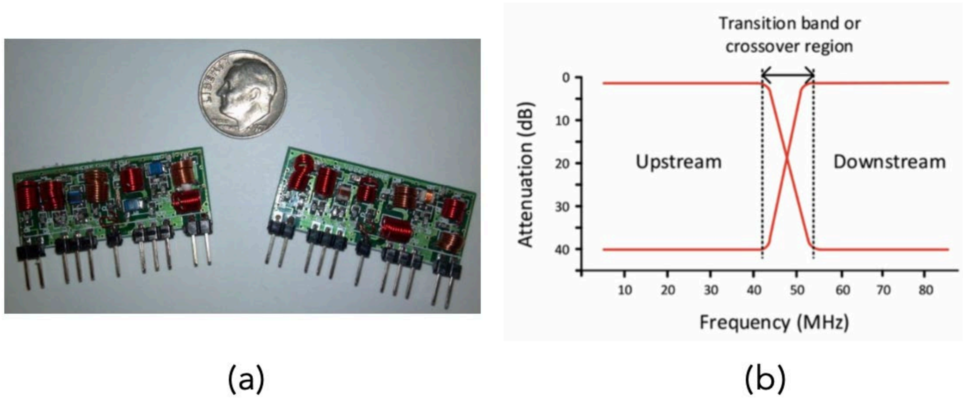


Figure 7: Example diplex filter (a), diplex filter transition band (b).

Diplex filters are not compatible with FDX operation. This is because upstream and downstream signals are present on some frequencies at the same time. The diplex filter prevents this from occurring, so FDX networks require one of two considerations:

- A network design with a fiber node and no active devices after the fiber node (aka Node + 0).
- A design with a fiber node and amplifiers capable of amplifying in both directions without diplex filters, or dedicated FDX-capable amplifiers with echo cancellation.

In the case of FDX amplification and PNM, a Node + 0 network in theory makes for a much simpler network to maintain and troubleshoot. Since it lacks any actives after the fiber node, one only need be concerned with the node (and perhaps power supply), the hardline coax, passive devices, and subscriber drops and their components. When considering troubleshooting using such things as correlation groups and echo cavities, the following are important:

- The number of subscribers available in a correlation group will typically be smaller due to smaller service groups.
- Echo cavities will always be formed between the fiber node and passive devices and/or damaged coax/connectors. Actives after the node will no longer play a role in echo cavities.
- The number of impairments in a given plant segment will decrease because the number of connectors, coax, etc. will be fewer.
- Node + 0 will not fix pre-existing distribution coax and drop issues. RF failure group sizes may be reduced, and some causes of failure eliminated, but the number of overall service issues may or may not be greatly reduced.

While the general maintenance requirements for a Node + 0 network are not substantially expected to go down, the overall performance is expected to improve. This is because RF downstream signals from the fiber node will be nearly equivalent to those in the headend from a quality perspective. Further, upstream signals from the CM will be received and demodulated at the fiber node, assuming a DAA deployment with digital fiber links.

PNM will be a key troubleshooting tool in an FDX deployment to monitor performance, impairments and EC performance. It is assumed that for FDX to be successful some amplification may be required in HFC networks. It will be essential for PNM to have visibility into FDX amplified networks, especially at the amplifier level. See the next section on smart amplifiers.

5.6.2. Smart amplifiers and FDD

FDD is very different than FDX in its requirements for diplex filters and amplification, but there is one commonality discussed this section: smart amplifiers.

FDD will still require diplex filters to separate the downstream from the upstream in actives and certain passives. However, diplex filters in an FDD environment will need to at a minimum be upgradable and ideally programmable (or remotely switchable). Similarly, the RF conditioning circuitry in RF amplifiers should also be programmable. Vendors are producing new amplifiers with diplex filters and conditioning circuitry which can be remotely configured or locally configured with a mobile app.

This leads into the concept of smart amplifiers. Smart amplifiers not only include the ability to eliminate legacy plug-in pads and equalizers, but they are also adding PNM functionally such as full band capture so that one can remotely see the output of the amplifier to configure its padding and conditioning. PNM can take advantage of FBC in the fiber nodes and amplifiers as yet another monitoring point in the field to identify and localize RF impairments. This is useful for both FDD and FDX deployments.

Because the FBC capability in smart amplifiers is built on CM technology, other PNM tests can use the CM in the amplifier. Now the amplifier can be used for all PNM tests supported by the CM chipset. Of particular importance is that this functionality operates over the extended upstream and downstream RF bandwidths.

6. DOCSIS 4.0 Technology

6.1. Triggered RxMER

As stated in [4], FDX modems can measure RxMER over all subcarriers at the same time. This measurement is triggered by events including time triggers, echo canceller training (ECT) probe triggers, and OUDP sounding triggers.

Time triggers could be the most useful for PNM because they are triggered at a specific time, and that time could be correlated to certain events by the CMTS or converged cable access platform (CCAP). For example, a CM can measure RxMER per subcarrier while a specific test downstream signal is sent, and while another upstream signal is sent by another CM. This could be used to find nonlinear impairments. Also, it could be used to synchronize data collection on multiple CMs at once, or to coordinate with a test device signal or measurement, or to time an external radio signal to potentially look for ingress sources, for example.

ECT RxMER probe triggers measure a modem's receive capabilities during worst case conditions, used for setting bit-loading after echo cancellation training. As such, it could be useful for PNM as an indication of the environment for transmission, and will provide a peek at the bit loading that the CM is capable of achieving.

OUDP sounding triggers allow measurement of the interference between CMs. With a measure and a sounding CM pair, the information could be very useful for PNM, particularly for fault localization. The information may even be useful to verify relative location information.

While these alternate forms of RxMER are described for the DOCSIS 4.0 protocol in both the PHY [4] and MULPI [8] specifications, the OSSI [9] specifications have not yet outlined how the data would be reported for fault management purposes.

6.2. Interference group information

The CMTS or CCAP determines a given FDX modem's participation in an interference group (IG) and transmission group (TG) after modems have performed sounding. This process helps the CMTS to identify which CMs interfere with other CMs on a given HFC plant segment. During sounding one CM is granted time to transmit and surrounding CMs are told to measure the per-subcarrier RxMER for the FDX sub-band being used for the sounding. Future enhancements in the OSSI specifications are planned to address the reporting of which CMs have been placed into specific IGs and TGs. Because CM membership in a given IG or TG is not operator-configured, the CMTS/CCAP is the source of truth for these associations.

Additionally, FDX manages the usage of a given FDX sub-band through the use of what is called a resource block (RB). It is possible to assign a given RB in a given TG as either static (always one direction, usually upstream) or dynamic (scheduled by the CMTS or CCAP, the block operates in both directions in a given sub-band for a specific TG). In the dynamic resource block assignment (RBA) scheduling, RBA switching can happen at an extremely fast rate which makes tracking and reporting of the RBA metrics challenging.

6.3. Echo cancellation in the node

To maintain increased capacity, and to meet 10G goals, greater reliance on echo cancellation is to be expected. When echo cancellers do not perform as needed, RF impairments may impact service.

FDX-capable nodes support simultaneous upstream and downstream communications over each FDX channel. FDX-compliant CMs will operate in FDD mode, where on any FDX channel or sub-band, the CM is either transmitting in the upstream or receiving in the downstream direction. To avoid the risk of co-channel interference (CCI) and adjacent channel interference (ACI) between CMs, the CMTS schedules transmissions and grants such that a CM does not transmit at the same time as other CMs that are susceptible to interference from the transmitting CM. CM to CM interference susceptibility is measured through a sounding process that is defined in the specification. Even with the CMTS determining interference groups, there is still a need to manage the impacts of upstream and downstream signals at the node. The FDX node has to employ echo cancellation methods to help remove the reflection of the downstream transmitted signals that are reflected back from components in the node and in the plant which impact the reception of upstream signaling. This echo cancellation can be done in both the analog and digital domains. In the analog domain, traditional techniques can be utilized that copy the DS carriers and then manipulate phase and magnitude and then apply that as a filter on the receiver path. EC conducted in the digital domain allows for near signal regeneration, depending on the node design. At the node, the DS signals are at their strongest so this method can be effective at cancelling out echoes in the FDX node itself.

From a PNM point of view, more work and definition need to be performed to determine how to measure and report echoes, and the signals after echo cancellation has been performed. As more FDX plant and nodes are deployed, these challenges will be met, and new management objects will be created which will aid in better performance of these plant segments.

A pre-EC RxMER measurement, possible at the node, could provide some information about the signal before EC, which may be partially informative toward gauging the EC effectiveness.

Generally, there are four approaches for providing this information, which could be useful for PNM and operations tools and applications:

- a measure in the specification that is based on what is described here;
- a measure in the specification that is based on some combination of US and DS RxMER and maybe more to describe some equivalent of the effort spent on echo cancellation and how much more could be corrected, without getting into manufacturer-specific intellectual property;
- a best practice based on one of these approaches, doing what is best to use external testing and available measures to provide equivalent information; and
- new requirements to collect and hold the information for future use.

A fiber node typically feeds up to four legs of coax. Management of the FDX spectrum and EC process in nodes with multiple legs can vary among vendors, with potentially different implementations. Actual capabilities and details are beyond the scope of this paper. However, from a PNM perspective there would be value if per-leg EC data were available.

The authors suggest that the DOCSIS specifications teams develop an engineering change to provide management objects that describe the limits and performance of ECs.

6.4. Echo cancellation in the CM

As with the node EC, a couple of parameters should be reported for the FDX CM EC. However, the FDX CM is a lower cost device and may not have the horsepower to provide all the measurements that a node could.

- EC is trained or not trained—In the OSSI and MULPI specifications, a trained EC is sufficiently converged. Reporting on the state of training is important for PNM. For instance, if the EC is not converged, reception of the channel(s) in the sub-band might not be usable, and knowing that the EC is not converged provides valuable information for troubleshooting why the channel/sub-band is not usable.
- Echo before and after cancellation—Operators need a way to express this so they can characterize the plant and find when and where changes happen in the network.
- Margin remaining before EC begins to have problems—Operators need a way to express this parameter. The specifications development organizations could suggest measurement and reporting methods.
- Any indication of why an EC cannot train or is on the margin—For example, if there is a particular echo that is too big, then data on that echo could be used to provide the echo's distance, which would allow an operator to troubleshoot. The industry will need to determine how that information would be communicated and what the data would look like.

7. Telemetry

With increased complexity and the expectation of new service-impacting failure modes being revealed in the network, new telemetry, and more frequent telemetry in some cases, will be needed. PNM fault management requires identification of faults from the telemetry, and then use cases for localizing the fault must follow. Fault identification requires a broad scope covering the entire network, with an initial granularity for the next step of fault management; fault localization requires several different groupings and finer resolution of telemetry. PNM fault management will require ways for operators to manage their operations and maintenance costs, so improvements in tools will follow the improvements in telemetry delivery.

PNM telemetry today consists of queries (polling data that are intermittently collected) and tests (requiring configuration to enable the data collection). In DOCSIS 3.0 networks, Simple Network Management Protocol (SNMP) was the primary method in use. The need for larger data sets occurred with DOCSIS 3.1 technology. Trivial File Transfer Protocol (TFTP) was introduced to enable more optimal data transfer than what is possible with SNMP. TFTP was adopted by CM vendors, but had limited adoption by CMTS vendors.

DOCSIS 4.0 technology brings new possibilities with telemetry from CMTS equipment. With R-PHY architectures, there are new tunneling protocols such as Layer 2 Tunneling Protocol (L2TP) pseudowires presenting a packet streaming protocol (PSP). DOCSIS 4.0 technology brings requirements for more data, more measurements, more often. SNMP will continue to increase our “technical debt” that limits the full capabilities of monitoring platforms. L2TP is one such protocol that is in use by CMTS vendors for transporting large amounts of data fast.

With R-MACPHY, YANG data models describe the methods for acquiring telemetry, delivered through TFTP, HTTP, and other means. Like L2TP, YANG models eliminate limitations with SNMP and bring data aggregation from DOCSIS devices into the 21st century. YANG models are an interesting discussion topic but are not a requirement for CMTS vendors to support, therefore, similar to TFTP it could be unlikely that CMTS vendors will adopt YANG models.

Vendors have developed proprietary solutions, based on protocols and techniques such as L2TP, CMTS SSH direct READ access, Kafka bus access, and more. Proprietary solutions have proven to be substantially more effective than SNMP and deliver critical data in near-real time. Examples of this are upstream spectrum analysis and OFDMA RxMER per subcarrier data. Vendor implementations of streaming telemetry using proprietary solutions enable upstream spectrum analysis which rival hardware-based spectrum analyzers in terms of trace update response time. Further, OFDMA RxMER data can be obtained on a fully loaded CMTS chassis every 15 minutes for every active CM connected to that CMTS. This can be done simultaneously while running other PNM tests. For cable operators considering upstream profile management application (PMA), this is a game changer. Those familiar with standard PNM tests know that running OFDMA RxMER typically prevents one from running any other PNM test, such as upstream triggered spectrum capture (UTSC).[6]

The advent of smart amplifiers will add a new telemetry opportunity. This paper previously discussed the FBC capability in smart amplifiers, but there is far more to it. DOCSIS 4.0 amplifiers are expected to run hotter, provide more gain, operate at higher frequencies, and contain sophisticated internal electronics. Having an on-board CM enables the ability to monitor the modem’s internal temperature sensor(s), voltages, and any other on-board sensor the vendor may choose to include. All this data gets communicated directly back to the CMTS and the monitoring system. Vendors could, for example, give access to mainline power supply monitoring, RF probing, and more. Each amplifier becomes another telemetry point in the network. How the telemetry is retrieved is again up to DOCSIS 4.0 specifications and vendor implementation. Ideally it will not use SNMP.

What does all this this mean? There are many solutions being tested on the open market for DOCSIS 4.0 data collection. Further, new solutions are being proposed by CableLabs. It will ultimately be up to the cable operator community to drive which technologies are adopted and implemented. This paper has identified the need that DOCSIS 4.0 technology has for PNM. However, it should be apparent to the reader that a gap exists. That gap is the lack of a clear path between how vendors and operators will align to a consistent PNM implementation and how PNM will function across multiple vendor platforms to meet the expectations of cable operators. It is recommended that operators understand this gap and align to address it.

---

[6] Rather than track per-modem OFDMA RxMER per subcarrier (and preclude the use of UTSC by field personnel), some operators monitor port average RxMER and other data at the upstream input to the CMTS/CCAP. If a problem is detected, then data from individual modems can be looked at more closely.

8. Test and Query

As discussed previously in this paper, DOCSIS 4.0 technology brings new opportunities and challenges from a PNM perspective. New test methods and data analytic queries must be created and optimized for new spectrum changes and new technologies, such as echo cancellation. As data speeds increase, bandwidths expand and complex technologies are introduced, PNM will be increasingly more important to ensure continued quality of experience (QoE) to subscribers. There is no doubt that subscribers will continue to be more dependent on high-speed data, and competition will continue to apply pressure to improve network quality.

8.1. Challenges and Opportunities with FDD

In FDD, the upstream band can extend to as high as 684 MHz. In DOCSIS 3.1 technology, the highest upstream frequency is 204 MHz. Higher frequencies mean much more data to aggregate and store in databases from cable modems and CMTSs. Further, large data sets require significantly more CPU (or GPU) processing power from an analytics standpoint when identifying impairments. Today, most modems and CMTSs still rely on SNMP to retrieve data from them. While SNMP has been a great protocol for the cable industry for more than a decade, it is a very slow and outdated protocol. Fortunately, CableLabs specifications are moving towards other methods of obtaining large data sets, such as TFTP and streaming telemetry. It is critical that adoption of these methods by vendors occurs quickly.

The downstream spectrum in FDD will also be increasing from 1.2 GHz to 1.8 GHz with visions of one day supporting up to 3 GHz (or higher!). As in the upstream, this will require cable modems to support FBC up to the highest frequency supported in the network. Currently, DOCSIS 3.1 modems support FBC up to 1.2 GHz while DOCSIS 3.0 modems only support FBC up to 1 GHz. One can see the disparity of a 1.8 GHz network supporting a mixture of DOCSIS 3.0, 3.1 and 4.0 cable modems. As DOCSIS 4.0 modems are initially deployed, one will have limited visibility to impairments in the RF spectrum above 1.2 GHz, assuming significant deployment of DOCSIS 3.1 modems. It is expected that many passive devices, and subscriber drop cables and components, will have various impairments above 1.2 GHz because the 1.2 GHz to 1.8 GHz spectrum has never been widely tested. It may sound trivial when speaking in terms of “GHz,” but this is 600 MHz of largely untested spectrum that PNM will be essential in analyzing and testing. DOCSIS 4.0 modems with FBC capabilities up to 1.8 GHz are essential. Further, a method of quickly obtaining the FBC spectrum from 5 MHz (or lower) to 1.8 GHz will be critical.

Upstream spectrum analysis is a “meat and potatoes” feature of any PNM application. Technicians rely on it every day to identify and resolve return path ingress and other impairments. The state-of-the-art return path upstream spectrum analysis relies on a CableLabs-based specified measurement called UTSC. UTSC enables compatibility across vendors and platforms whether it is integrated CCAP (iCCAP) or distributed access architecture CCAP (dCCAP). CCAP vendors and PNM vendors will need to ensure their platforms support upstream spectrum analysis up to the highest frequencies supported in FDD. Further, vendors must be able to support fast refresh speeds on upstream spectrum analysis over a much wider bandwidth in order to capture transient noise events, many of which may occur at higher frequencies not previously seen. The current state of DOCSIS 3.1 UTSC across the vendor space is non-optimal in that each CCAP vendor has partial adoption of the CableLabs UTSC specification. This state creates challenges for adoption by cable operators, and a lack of feature sets with some vendors means that not all tests are supported. It will be important that vendors fully adopt

UTSC in DOCSIS 4.0 networks so that operators are able to troubleshoot more complex problems as frequency expansion will certainly bring unanticipated complexities.

8.2. Challenges and Opportunities with FDX

Like its counterpart FDD, FDX has similar upstream and downstream frequency expansion challenges for PNM. However, FDX adds more technical hurdles which PNM will be critical to help solve. For instance, downstream FBC at the CM may contain upstream and downstream transmissions within the same interference group in the FDX band (108 MHz to 684 MHz). Visualization and troubleshooting of simultaneous upstream and downstream will lead to new challenges for both vendors and technicians.

Having visibility into the level of EC and reserve EC capacity will be essential. As previously discussed, the CMTS and CM have EC functionality. The authors believe that it will be possible to determine some amount of impairment between the CMTS and the CM by utilizing the information provided by the EC operation in the CM and FDX node.

In general, PNM tests for FDX will be more challenging overall than FDD. A general summary of this can be seen later in Table 1.

8.3. DOCSIS 4.0 Impact on Standard PNM Tests

As defined in the DOCSIS 3.1 and 4.0 specifications, there exists a standard set of PNM test and query features designed to enable cable operators and vendors to obtain optimal troubleshooting data from the CMTS and CMs. Those specifications are designed in order to establish consistent inter-operability among vendors of CMTS, CM and PNM software. This section provides a brief description of each PNM test followed by table that summarizes the gaps for full support of DOCSIS 4.0 FDD and FDX.

DS Symbol Capture (CM and CCAP)

Description:

- The DsOfdmSymbolCapture object provides partial functionality of a network analyzer to analyze the response of the cable plant. A symbol is generated at the CCAP and also captured at the CM, and then the results compared.

DsOfdmNoisePowerRatio (CCAP/Spectrum)

Description:

- The purpose of downstream NPR measurement is to view the noise, interference and intermodulation products underlying a portion of the OFDM signal. As an out-of-service test, the CCAP can define an exclusion band of zero-valued subcarriers which forms a spectral notch in the downstream OFDM signal for all profiles of a given downstream channel. The CM provides its normal spectral capture measurements per [PHYv3.1], or symbol capture per [PHYv3.1], which permit analysis of the notch depth. A possible use case is to observe LTE interference occurring within an OFDM band; another is to observe intermodulation products resulting from signal-level alignment issues. Since the introduction and removal of a notch affects all profiles, causing possible link downtime, this feature is intended for infrequent maintenance.

DS CM Spectrum Analysis Full Band Capture

Description:

- This test allows for the full band capture of the DS RF spectrum that the modem is configured to use.

CmDsOfdmChanEstimateCoef

Description:

- The purpose of this table is for the CM to report its estimate of the downstream channel response. The reciprocals of the channel response coefficients are typically used by the CM as its frequency-domain downstream equalizer coefficients. The channel estimate consists of a single complex value per subcarrier. The channel response coefficients are expressed as 16-bit two's complement numbers using 2.13 nibble format. The CM samples are scaled such that the average power of the samples is approximately 1, in order to avoid excessive clipping and quantization noise.
- Summary metrics (slope, ripple, and mean) are defined in order to avoid having to send all coefficients on every query. The summary metrics are calculated when the corresponding MIB is queried. A Coefficient filename and trigger are provided to obtain the channel coefficients.
- The CM will report these metrics for each OFDM channel it has been assigned.

CmDsConstDispMeas

Description:

- The downstream constellation display provides received QAM constellation points for display. Equalized soft decisions (I and Q) at the slicer input are collected over time, possibly with subsampling to reduce complexity, and made available for analysis. This measurement is intended for data subcarriers only. Up to 8192 per OFDM channel samples are provided for each query; additional queries can be made to further fill in the plot.

ModulationOrderOffset

Description:

- This attribute specifies an offset from the lowest order modulation for the data subcarriers in any of the profiles in the downstream channel. If the lowest order modulation order that the CM was receiving was 1024-QAM and the ModulationOrderOffset was zero, then the CM would capture the soft decision samples for all of the subcarriers which were using 1024-QAM. If the ModulationOrderOffset was 1, then the CM would capture the soft decision samples for all of the subcarriers using the next highest modulation order in use for the profiles in the downstream channel.

CmDsOfdmRxMer

Description:

- Provides measurements of the RxMER for each subcarrier.

CmDsOfdmMerMargin

Description:

- Provide an estimate of the MER margin available on the downstream data channel with respect to a modulation profile. The profile may be a profile that the modem has already been assigned or a candidate profile. This measurement is similar to the MER Margin reported in the OPT-RSP Message [MULPIv4.0].

CmDsOfdmFecSummary

Description:

- The purpose of this item is to provide a series of codeword error rate measurements on a per profile basis over a set period of time.

CmDsHist

Description:

- The purpose of the downstream histogram is to provide a measurement of nonlinear effects in the channel such as amplifier compression and laser clipping. For example, laser clipping causes one tail of the histogram to be truncated and replaced with a spike. The CM captures the histogram of time domain samples at the wideband front end of the receiver (full downstream).

Upstream Histogram

Description:

- The upstream histogram provides a measurement of nonlinear effects in the channel such as amplifier compression and laser clipping. For example, laser clipping causes one tail of the histogram to be truncated and replaced with a spike. When the upstream histogram enable attribute is set to 'true', the CCAP will begin capturing the histogram of time domain samples at the wideband front end of the receiver (full upstream band). The histogram is two-sided; that is, it encompasses values from far-negative to far-positive values of the samples. The histogram will have a minimum of 255 or 256 equally spaced bins. These bins typically correspond to the 8 MSBs of the wideband analog-to-digital converter (ADC) for the case of 255 or 256 bins. The histogram dwell count, a 32-bit unsigned integer, is the number of samples observed while counting hits for a given bin and may have the same value for all bins. The histogram hit count, a 32-bit unsigned integer, is the number of samples falling in a given bin. The CCAP will report the dwell count per bin and the hit count per bin. When enabled, the CCAP will compute a histogram with a dwell of at least 10 million samples at each bin in 30 seconds or less. The CCAP will continue accumulating histogram samples until it is restarted, disabled or times out. If the highest dwell count approaches its 32-bit overflow value, the CCAP will save the current set of histogram values and reset the histogram, so that in a steady-state condition a complete measurement is always available.

US Impulse Noise

Description:

- The UsImpulseNoise object provides statistics of burst/impulse noise occurring in a selected narrow band. A bandpass filter is positioned in an unoccupied upstream band. A threshold is set, energy exceeding the threshold triggers the measurement of an event, and energy falling below the threshold ends the event. An optional feature allows the threshold to be set to zero, in which case the average power in the band will be measured. The measurement is time-stamped using the DOCSIS 3.0 field of the 64-bit extended timestamp (bits 9-40, where bit 0 is the LSB), which provides a resolution of 98 ns and a range of 7 minutes.

- The CCAP provides the capability to capture the following statistics in a selected band up to 5.12 MHz wide:
  - Timestamp of event
  - Duration of event
  - Average power of event
- The CCAP provides a time history buffer of up to 1024 events. In steady state operation, a ring buffer provides the measurements of the last 1024 events that occurred while the measurement was enabled.

Us OFDMA Active and Quiet Probe

Description:

- The purpose of upstream capture is to measure plant response and view the underlying noise floor, by capturing at least one OFDMA symbol during a scheduled active or quiet probe. An active probe provides the partial functionality of a network analyzer, because the input is known, and the output is captured. This permits full characterization of the linear and nonlinear response of the upstream cable plant. A quiet probe provides an opportunity to view the underlying noise and ingress while no traffic is being transmitted in the OFDMA band being measured.
- When enabled to perform the capture, the CCAP selects a specified transmitting CM, or quiet period when no CMs are transmitting, for the capture. The CCAP sets up the capture as described in [MULPIv3.1], selecting either an active SID corresponding to the specified MAC address or the idle SID, and defining an active or quiet probe. The active probe symbol for this capture normally includes all non-excluded subcarriers across the upstream OFDMA channel, with pre-equalization on or off as specified in the MIB. The quiet probe symbol normally includes all subcarriers, that is, during the quiet probe time there are no transmissions in the given upstream OFDMA channel. For the quiet probe, the CCAP captures samples of at least one full OFDMA symbol including the guard interval. The CCAP begins the capture with the first symbol of the specified probe. The sample rate is the FFT sample rate (102.4 megasamples per second).

Us OFDMA MER per Subcarrier

Description:

- This item provides measurements of the upstream RxMER for each subcarrier. The CCAP measures the RxMER using an upstream probe, which is not subject to symbol errors as data subcarriers would be. The probes used for RxMER measurement are typically distinct from the probes used for pre-equalization adjustment. For the purposes of this measurement, RxMER is defined as the ratio of the average power of the ideal QAM constellation to the average error-vector power. The error vector is the difference between the equalized received probe value and the known correct probe value. If some subcarriers (such as exclusion bands) cannot be measured by the CCAP, the CCAP indicates that condition in the measurement data for those subcarriers.

Us Triggered Spectrum Capture

Description:

- Capture of upstream spectrum through a number of triggering means including free run, time stamp value, mini-slot number, MAC-SID, idle SID, symbol, event trigger, and IUC.
- Note that reliable US triggered spectrum capture is a top priority for PNM in general, as this has not yet been implemented following the specifications.

8.3.1. Summarizing the gaps

With a high-level understanding of each of the PNM test queries, Table 1 provides an overview of the needed support in DOCSIS 4.0 tools for FDD and FDX as of the writing of this paper. As can be seen in Table 1, it is expected that PNM testing on FDD channels will be less impacted than PNM testing on FDX channels due to the intrinsic complexities of FDX. In general, when PNM tests are run on a channel configured in the FDX band, to perform downstream PMN tests like DS Symbol Capture and NoisePowerRatio, the RBA for the sub-band must be set in the downstream direction, and upstream PNM tests will need the sub-band to be configured in the upstream direction while the test is performed. Cable operators deploying FDD or FDX will experience new challenges. Having proper tools, especially proper PNM tools, will enable cable operators to be better positioned to effectively and quickly troubleshoot complex problems in their HFC networks.

Table 1. Impact of FDD and FDX on DOCSIS 4.0 PNM tests

DOCSIS PNM Test	FDD Impact	FDX Impact
DS Symbol Capture (CM and CCAP)	None	RBA configured for DS, Testing required – investigation required
DsOfdmNoisePowerRatio (CCAP/Spectrum)	None	RBA for sub-band used on target DS – investigation required
Spectrum Analysis Full Band Capture	More bins, more data	Dual direction, more bins, more data, more complexity, filters in modems may differ by vendor – investigation required
CmDsOfdmChanEstimateCoef	None	Only possible when RBA for TG is set in DS direction, other dependencies involved
CmDsConstDispMeas	None	Uncertain. There may be an ability to capture I and Q values in two directions – investigation required

ModulationOrderOffset	None	None expected
CmDsOfdmRxMer	None	None Expected
CmDsOfdmMerMargin	None	None Expected
CmDsOfdmFecSummary	None	Test runs for several minutes which may be impacted based on RBA scheduling – investigation required
CmDsHist	None	Undetermined what happens with this test when in FDX operation – investigation required
Upstream Histogram	None	Uncertain how to measure the FDX band from 108 MHz to 684 MHz and how to account for any co-channel interference and echo cancellation
Us Impulse Noise	None	Recommend that this test does not apply to the FDX band
Us OFDMA Active and Quiet Probe	None	Multiple issues to address such as configuring all RBAs for the TG and configuring active probes – investigation required
Us OFDMA Rx Power	None	None expected
Us OFDMA RxMER per Subcarrier	None	If other transmission groups are operating in a DS direction, the RxMER values for the tested OFDMA channel could be lower – investigation required
Us Triggered Spectrum Capture	Wider spectrum, more bins, more data	Wider spectrum, more bins, more data, in addition, for SID filtering all TGs and channels must be sync'd to same TG to get a valid measurement

8.3.2. What is required?

As shown in Table 1, several PNM tests are impacted when FDX has been configured for operation. The most obvious impact is seen in the FDX allocated spectrum and the need for the test to be performed when the specific sub band that the channel is configured to use is set in the correct direction. As more FDX segments are brought into service over the next 12 to 24 months, these issues will be overcome and the specific impacts, and their workarounds, will be better understood through additional testing and use. FDX also has the concept of sounding, and the usage of that data for PNM related activities has yet to be explored fully and will be studied once enough DOCSIS 4.0 FDX modems and nodes are deployed.

FDD, in contrast, does not have as significant of an impact to the PNM testing because these channels are all in place today; the issue here is that there are more of them and a greater frequency span to cover for tests including FBC in the modem.

Another class of products will be employed for DOCSIS 4.0 deployments: smart amplifiers. These updated components in the plant will be more bi-directional and have capabilities for sampling and some PNM testing as well, which will allow the operator to have another valuable testing point in the network for measurement and troubleshooting analysis.

There will be challenges that will be met during this period. Some of the challenges are outlined as follows, and are expected to serve as the foundation of an industry project plan to resolve these challenges:

- Vendors of PNM tools must adapt some of the testing to accommodate the FDD and FDX impacts and the implementation of smart amplifiers that are added to the plant.
- Cable company operations and back-office teams dealing with the increased amount of data coming from devices in the field.
- Scheduling of testing for FDX channels.
- Compliance of FDD- and FDX-capable CMTSs and CMs with the DOCSIS 4.0 specifications
- Interoperability among vendors' products (CMTSs, nodes, CMs, etc.) with both FDD and FDX
- Clearly defined FDD and FDX PNM test and query specifications from the standards and specifications development organizations
- Adoption of FDD and FDX PNM test and query DOCSIS specifications by vendors
- Standards and specifications development groups exploring further the usage of FDX sounding data for PNM testing; the addition of test capabilities in smart amplifiers and other plant equipment is an area ripe for study and requirements creation that will likely see more activity as more FDX plant and modems become available.

In order to address the challenges identified above and develop the proposed industry project plan, the following groups will need to collaborate as has historically been done in specifications development:

- Chipset vendors
- CMTS vendors
- CM vendors
- PNM tool vendors
- Standards and specifications development organizations
- Cable operators

Input and collaboration from all parties are essential for bridging the gaps identified in this document.

9. Conclusions

The past several years have seen significant progress in the use of equipment and PNM tests. This has provided a new level of capability for cable operators to offer more services at higher data rates to more subscribers. As the industry looks to the near future with DOCSIS 4.0 technology and FDX and FDD updates to the plant, these well-known tests will continue to provide significant insight into the health and operation of our cable networks. Operators can rest a little easier knowing that the same applications and methods being used today can be extended, with modifications, into the DOCSIS 4.0 networks that will soon be deployed. While there are still areas for continued innovation and standards work, the authors feel optimistic that the groundwork that has already been implemented will continue to provide operators with actionable data that can help to keep our networks healthy.

However, there is an opportunity for improvement. Many PNM tests were defined in the DOCSIS 3.1 specifications and implemented by equipment vendors. Some of those tests have been invaluable, such as downstream RxMER per subcarrier. However, other tests, such as UTSC giving insight into return path noise and upstream RxMER per subcarrier have been inadequately adopted by vendors. In preparation for deployment of DOCSIS 4.0 technology, this paper has identified gaps in PNM which are needed to support DOCSIS 4.0 deployments. While specifications can include recommendations, it is up to the cable operator community to decide if PNM test functionality, such as return path monitoring (e.g., UTSC) and extended frequency FBC are valuable tools or not. It is incumbent on cable operators to hold discussions with vendors and determine the priorities. Should enhancing PNM be a priority or not? This is a question cable operators must determine and communicate to their vendor partners.

10. Abbreviations and Definitions

10.1. Abbreviations

ADC	analog-to-digital converter
CCAP	converged cable access platform
CCI	co-channel interference
CM	cable modem
CMTS	cable modem termination system
CPD	common path distortion
CPU	central processing unit
DAA	distributed access architecture
dCCAP	distributed CCAP
DOCSIS	Data-Over-Cable Service Interface Specifications
DS	downstream
DUT	device under test
EC	echo canceller
ECT	echo canceller training
ESD	extended spectrum DOCSIS
FBC	full band capture
FDD	frequency division duplexing
FDX	full duplex [DOCSIS]
FEC	forward error correction

FFT	fast Fourier transform
Gbps	gigabits per second
GHz	gigahertz
GPS	Global Positioning System
GPU	graphics processing unit
HFC	hybrid fiber/coax
HTTP	Hypertext Transfer Protocol
I	in-phase
iCCAP	integrated CCAP
IG	interference group
ISM	industrial, scientific, and medical
IUC	interval usage code
L2TP	Layer 2 Tunneling Protocol
LSB	least significant bit
LTE	long term evolution
MAC	media access control
MER	modulation error ratio
MHz	megahertz
MIB	management information base
MULPI	MAC and upper layer protocols interface
NPR	noise power ratio
ns	nanosecond
OFDM	orthogonal frequency division multiplexing
OFDMA	orthogonal frequency division multiple access
OSSI	operation(s) support system interface
OUDP	OFDMA upstream data profile
PHY	physical layer
PIM	passive intermodulation
PNM	proactive network maintenance
PMA	profile management application
PON	passive optical network
Q	quadrature
QAM	quadrature amplitude modulation
QoE	quality of experience
RB	resource block
RBA	resource block assignment
RF	radio frequency
R-PHY	remote PHY
R-MACPHY	remote MAC PHY
RxMER	receive modulation error ratio
SCTE	Society of Cable Telecommunications Engineers
SID	service identifier
SNMP	Simple Network Management Protocol
SSH	secure shell
TCP	total composite power
TFTP	Trivial File Transfer Protocol

TG	transmission group
US	upstream
UTSC	upstream triggered spectrum capture
WLAN	wireless local area network
YANG	yet another next generation

11. Bibliography and References

[1] Campos, A., E. Cardona, L. Raman, “Pre-equalization Based Pro-Active Network Maintenance Methodology.” Proceedings of SCTE Cable-Tec Expo, Philadelphia, PA, 2008.

[2] *PNM Best Practices: HFC Networks (DOCSIS 3.0)*, Cable Television Laboratories. https://www.cablelabs.com/specifications/proactive-network-maintenance-using-pre-equalization

[3] Data-Over-Cable Service Interface Specifications DOCSIS® 3.1 Physical Layer Specification CM-SP-PHYv3.1-I19-211110, Cable Television Laboratories. https://www.cablelabs.com/

[4] Data-Over-Cable Service Interface Specifications DOCSIS® 4.0 Physical Layer Specification, CM-SP-PHYv4.0-I02-200429, Cable Television Laboratories. https://www.cablelabs.com/

[5] Hranac, R., “Understanding Band Splits in Two-Way Networks,” *Broadband Library*, Spring 2020, https://broadbandlibrary.com/understanding-band-splits-in-two-way-networks/

[6] https://www.10gplatform.com/

[7] https://www.cablelabs.com/10g

[8] Data-Over-Cable Service Interface Specifications DOCSIS® 4.0 MAC and Upper Layer Protocols Interface Specification CM-SP-MULPIv4.0-I05-220328, Cable Television Laboratories. https://www.cablelabs.com/

[9] Data-Over-Cable Service Interface Specifications DOCSIS® 4.0 CCAP™ Operations Support System Interface Specification CM-SP-CCAP-OSSIv4.0-I07-220629, Cable Television Laboratories. https://www.cablelabs.com/

[10] U.S. DEPARTMENT OF COMMERCE, National Telecommunications and Information Administration, Office of Spectrum Management “United States Frequency Allocations: The Radio Spectrum” frequency allocation chart. https://www.ntia.doc.gov/page/2011/united-states-frequency-allocation-chart

[11] SCTE 270 2021 Mathematics of Cable

[12] Chrostowski, J. et al, “Leakage in a High Split World: Detecting and Measuring Upstream Leakage Levels in a One Gpbs Symmetrical High Split Hybrid Fiber Coax Network.” Proceedings of SCTE Cable-Tec Expo 2020. https://www.nctatechnicalpapers.com/Paper/2020/2020-leakage-in-a-high-split-world

[13] Hranac, R., "A Quick Look at S-Parameters," *Broadband Library*, Winter 2019, https://broadbandlibrary.com/a-quick-look-at-s-parameters/

SCTE STANDARDS JOURNAL

SCTE a subsidiary of CableLabs®

A Roadmap for Cable Access Reliability

A Technical Paper prepared for SCTE by

Jason Rupe, Principal Architect, CableLabs, SCTE Member
858 Coal Creek Circle
Louisville, CO 80027
j.rupe@cablelabs.com
303-661-3332

Ron Hranac
rhranac@aol.com

This paper was originally published in the proceedings of the SCTE Cable-Tec Expo® 2022 Fall Technical Forum. It is being reprinted here because it is particularly applicable to current projects in the SCTE Standards program, notably the creation by industry experts of standards and operational practices for Network and Service Reliability and DOCSIS 4.0 Tools and Readiness. For more information, see scte.org/standards.

Table of Contents

List of Figures

1. Introduction

As the speed of access networks increases and become less of a bottleneck to providing quality service, customers turn their concerns toward reliability. But they refer to service reliability, not network reliability. Still, network reliability is a key component of a reliable service. So, what is a cable operator to do?

As the cable industry turns more attention toward reliability, we have the opportunity to lead. The reliability engineering discipline is many decades old, and has a lot of tools, knowledge, and practices that we can start from, along with our own cable industry history of successful reliability engineering. Now, service usage is different, expectations are higher, networks are built and services are provided in new and different ways, and the technology we use today is rapidly evolving. The way we assure reliability has to be different too.

This paper provides a roadmap for addressing network and service reliability for the cable industry. Instead of a complete answer, it is a roadmap for the work ahead. There are many routes to take depending on where and how far the service provider wants or needs to go. CableLabs® and the Society of Cable Telecommunications Engineers (SCTE) can provide the van pool for part of the journey, and there will be vendors at the rest stops to help, but the journey is for the operators to take.[1]

2. Goals for cable network and service reliability

In support of our industry's 10G Platform goals, operators have a lot of well-informed tasks to accomplish. Categorically, some of these tasks include:

- Assure service reliability primarily, which requires network and system reliability, availability, maintainability, and appropriate resiliency and survivability. But it also requires reliable processes, procedures, management, and more.
- Build a foundation of understanding, linking customer experience to system and network events, so operations, design, and upgrades all provide the best service possible.
- Design reliable network and service solutions, with degrees of freedom to manage service reliability, that are also reliable in executability, obtainability, etc.
- Select reliable, repairable solutions and components for given deployments.
- Create and maintain fault management that is reliable, inexpensive, and maintainable. That includes proactive network maintenance (PNM), which identifies and can be used to fix faults before customers are impacted.
- Develop operations tools that are inexpensive, reliable, understandable, and useful for proactive and reactive maintenance.
- Build intelligence to enable micro-financial decisions for preventive maintenance, technology replacement, resiliency, operations planning, etc.

2.1. Measure to Manage

Service and network reliability require well defined measures of performance that can enable management for effective results. This requires well understood service performance measures, network performance measures, and operations performance measures. When a customer experiences any service friction, that should be reflected in a key performance indicator. Aligning the measures to the customer

[1] Get it? A Roadmap for Cable Access Reliability (CAR). Did you expect a General Path Solution (GPS)?

experience is most important. It is not acceptable to answer a customer complaint with an "everything looks fine" because that suggests either you are blind to an important aspect of service, your measurements are insufficient, or your customer is wrong. The latter option is not a helpful assumption. The other two tell you improvement in your operations is needed. High levels of "no trouble found" point to the need for improvement as much as repeat trouble tickets do.

Doing all of this well requires knowledge of the failure modes, effects on networks and service, and criticality of the failure modes. A useful tool for capturing and referencing this knowledge is a failure modes, effects and criticality analysis (FMECA). Considering fault management in networks and complex systems, faults should be included with failures.

To obtain and maintain this knowledge, effective collection of components and failure modes is required. This enables analysts to determine useful corporate knowledge including what manufacturer or lot of components are not performing to specifications, what parts are wearing out, which failure modes must be addressed quickly to defend service, etc.

The most convenient example with direct application to our cable industry happens to be in this year's Cable-Tec Expo. See [2] for this year's Fall Technical Forum paper on applying FMECA to cable faults. Also see the Appendix of this paper for an example with explanation. This work is based on expert knowledge and is generalized for hybrid fiber/coax (HFC) networks.

But operator specific knowledge is necessary to support reliable services, so that problems specific to certain plant designs, aging or degradation, or even poorly performing components (hardware or software) can be found and addressed.

To use our cable industry's strength of sharing knowledge and energy toward common goals, we could develop standard methods for coding repair tickets to capture failure mode and component details so operators can fully benefit from this knowledge, and apply it to assure service. But the implementation and use of the result will still be operator specific.

The industry could also benefit by standardizing how service and network reliability are measured. Fortunately, we're well on our way in an effort through the CableLabs PNM Working Group, which is sharing the output with several SCTE Working Groups, too.

But the work is just beginning, and the industry can benefit much by continuing the effort further. We should work to specify standard ways for measuring service and network reliability including

- the measurement definitions,
- how they relate to service and network reliability,
- how to track statistics and interpret them, and
- how to set control limits, perhaps setting specification limits, too.

See the Appendix for a starting framework that could serve as the foundation. But it is only a start. As you will see in the rest of this paper, we need equivalent, supportive measurements from all aspects of network operations to fully support service reliability.

2.2. Setting Service Level Agreements

Based on existing service performance information, service level agreements (SLAs) for high end customers can be set with confidence, and even rebates can be offered at net profit. When new technology is involved, models of the resulting performance may be needed, and appropriate SLAs should be set based on the network providing the service. Fortunately, simple mathematical models are often sufficient for setting and designing services for SLAs.

SLAs should be based on customer use cases but translated to service and network measures of performance. Define the service missions and translate the measurements defined to the customer use cases. For example, consider the use case of watching a movie through video streaming, including pausing a few times, requiring several functions to work when needed for the duration; what is the resulting experience, and how does it vary by customer or network condition or resource utilization?

The SLAs must be set rationally, so that they are achievable, and demonstrable. Achievability can be validated through a model, and the model fed with field data when available. Demonstrability can be achieved through data collection and translation to the customer experience. The translation again can be achieved through a use case model. For example, the movie use case just mentioned requires high availability from the network and supporting systems, and reliable performance of the network and functions for the duration of the use. If the network availability is 99.99% (equally 0.9999), and the probability of successfully delivering the movie and needed functions for the two-hour duration is 0.99999, then the overall probability of success for that mission is approximately $0.9999 * 0.99999 = 0.99989$. If a user has this use case once a week, then the probability of not experiencing a failed attempt to watch a movie in a year is approximately $0.99989^{52} = 0.9943$; there is a good chance (0.0057) that quite a few customers (more than two in a thousand) will not be able to watch a movie at least once a year, even with these seemingly high reliability and availability targets!

2.3. Service Assurance

Low friction, high reliability service is delivered through reliable networks and systems supported by reliable, efficient operations. From a network perspective, reactive, proactive, and predictive maintenance all play a role, along with fault management.

- *Reactive*: Fast restoration first then repair, prioritized by severity of impact.
- *Proactive*: Timely repair, cost efficient, prioritized by severity and opportunity, afforded due to resiliency, with no restoration needed. Also, proactive maintenance can be thought of as fault management, as it is a mechanism to manage faults before they become failures that must be reactively addressed.
- *Predictive*: Planned maintenance to address degradation before service is impacted in any way. Predictive maintenance occurs before a fault impacts network or service performance, so it can happen ahead of proactive maintenance. For example, detecting a trend in early degradation of a particular component type can lead an operator to predictively replace those components based on useful life prediction. Prognostics and Health Management is an emerging field of research which addresses this need. But predictive maintenance can also follow from proactive maintenance, such as when additional damage is observed in the proactive repair, leading to further maintenance planning. Well planned maintenance can minimize operations costs.

Standard methods for coding repair tickets to capture failure mode and component details for service and network assurance, as mentioned previously, would help operators gain full benefit from that knowledge for superior service assurance.

Note that reliable operations can play a most important role when customer facing, because operations usually faces the customer in response to service friction. The first touch point for a customer when they experience friction is usually the call center; today that is supplemented with a software application. Behind these touch points resides all the network operations tools and back-office systems, all of which are a part of the service provided, and must reliably reduce friction for that customer. A poor experience is a failure in service, so must be addressed through rapid reactive repair. Likewise, service can be proactively and predictively repaired, too, through early detection of risk (security, privacy, fault, and failure), and continuous improvement of systems and processes.

See Figure 1 for a depiction of the various types of repair cycles which complement and assure effective operations. Note that predictive management of services includes planning and engineering, including information technology (IT), functions that engineer reliability into the solutions that deliver service, as well as predictive maintenance to replace failed systems well before they have a chance to degrade other parts or impact network functions, far ahead of impacting service. But if you wait or don't detect the problems that become faults and failures, then you can still stay ahead of service impact through proactive management, which includes fault management and PNM, plus other forms of proactivity. But if you wait further, service is impacted because the faults and failures are felt by the customer through their service experience. Reactive management requires fast, and often expensive, restoration and repair; but sometimes the repair is not as fast as everyone wants because other resources, processes and systems are reactively taxed. Spare parts supply chains may extend the restoration and repair time, as might technician availability. When service is impacted, severity should determine the restoration priorities, and repair to follow that. Note that, with proactive and predictive maintenance, restoration is not necessary. Reactive repair requires more work, higher stress, higher cost, and results in less customer happiness.

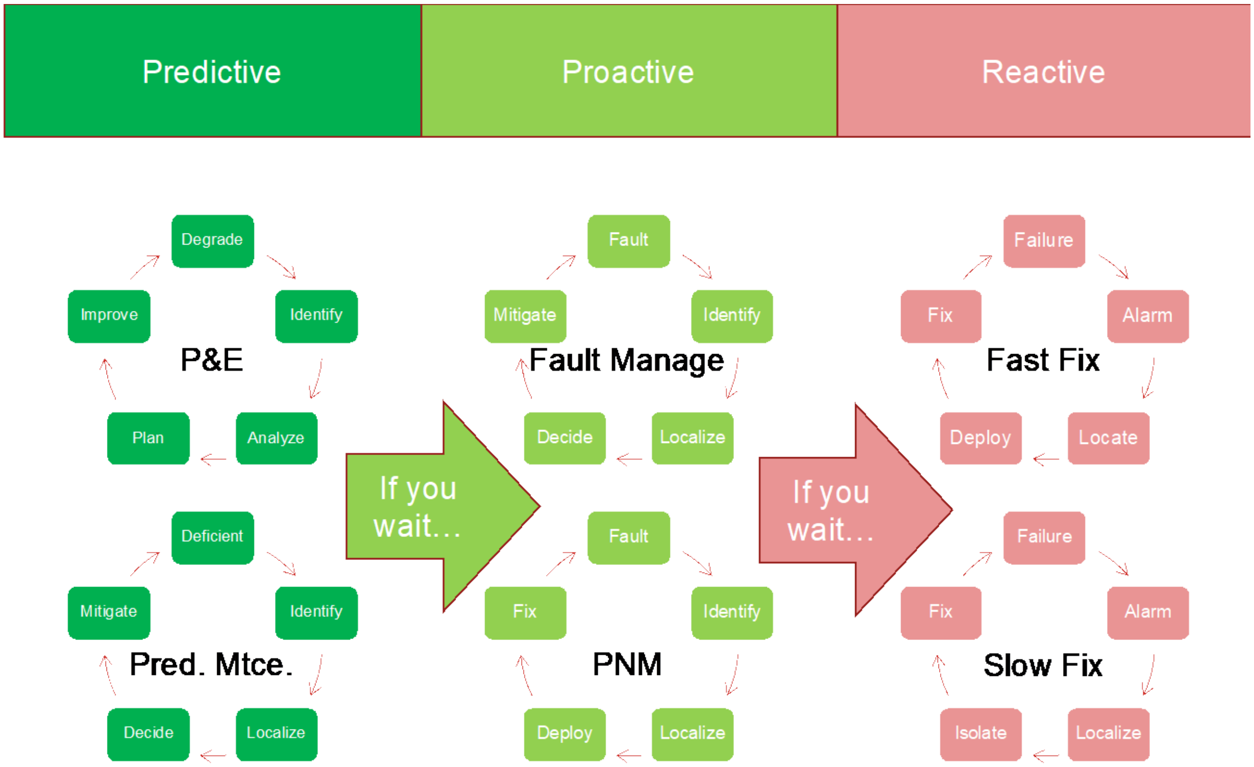


Figure 1 – Various types of repair cycles coexist in operations.

2.4. Fault Management

Knowing how a network can fail, the faults that lead to failures, and how those faults and failures are revealed in network performance can let an operator automate fault management and operate using PNM. Identifying the faults that impact service and where they come from is an important first step. How they relate to failures is important, too. An important goal in fault management is to automate as much of the fault identification, localization, and isolation as possible. And to do so reliably, which includes low false positive and very low false negative occurrences.

Based on event frequency, effect on service, and ability to test or monitor, set the policy based on established goals. Faults that are automatically mitigated can be ignored by repair technicians, but may need to be monitored by systems if they are indicators of other problems. Faults that require intervention can be handled with the appropriate repair cycle. Efficient fault management, like repair, requires an effective way to translate telemetry into action, such as the ProOps framework available from CableLabs [3], [4], [5] which provides a framework to observe (collect telemetry and information), orient (add context, assess the information, and potentially collect more information to assess), decide (translate information into faults and failures, then identify and localize faults and failures), and act (take appropriate action based on the assessment and information, with consideration of resources, priorities, schedules, etc.).

2.5. Repair and Supply Chain Optimization

With a strong handle on the priorities and planning for maintenance, operators can optimize their repair operations in many ways. Planning repairs on a longer schedule allows optimization of the travel time and distance required with maintenance, avoids unproductive technician time, and minimizes outage impact on service.

In addition, spare parts can be optimized to reduce held inventory and assure spare parts are on hand when and where needed to never adversely impact service, and never require expensive expedited shipping of parts. Critical parts necessary to correct critical failures should be readily available. Well-designed spare parts inventories can be created with lowest cost and appropriate spare parts availability. There are many applicable mathematical models available that can help operators set optimal inventory levels and policies for given targets of delivery time and probability of shortage.

2.6. Removing Degraded or Poor Quality Components

Technicians who deal with the plant all day know that some components wear out sooner than others, and some have specific faults in their design or manufacture that results in failure modes that emerge earlier or uniquely to these components. Sometimes environment has a strong influence on the early emergence of these failure modes. Temperature cycling, humidity, exposure to water, and even dry climates can impact network components differently. But even in controlled environments, poorly designed, selected, or built components can exhibit early failures which need to be addressed predictively. Early warnings from a few components can foretell the emergence of failures in the rest. As a result, tracking failure events by component type, manufacturer, age, location, and other factors can allow the operator to predict early issues and address them with predictive maintenance programs, instead of waiting for one-by-one replacement at failure. It is far cheaper to replace soon-to-fail components while doing other maintenance, to save on truck rolls and unproductive time. If such a program is required earlier than expected, a vendor management issue may need to follow, including perhaps warranty assisted replacement.

2.7. Vendor and Contract Management

Once an operator sets their goals for service, and can articulate how the network and its components translate to meeting those goals, they can align their contracts toward the goals, and even manage vendors to meet their contribution to the goals.

Component and system testing assures functionality, which reduces friction in the user experience. Testing for design and features is well established in our industry. Testing for basic features and functionality is a necessary foundation. Testing for capabilities necessary to provide specific services and features is important, too. Because long duration testing of hardware-software integrated systems is not feasible in most cases, it is important to test software well, life test hardware, and design-in system health monitoring and management capabilities for what can't be assured otherwise. Measuring early and useful life performance of components and system parts allows prediction of problems and validation of vendor performance.

2.8. Network Design

Networks should be built with performance goals in mind, and that performance should include reliability concerns as well. Doing this requires modeling of network behavior, including protection and restoration and resiliency mechanisms, for hardware, software, systems, and even people.

Network architecture will dictate allocations of service and network reliability to provide a given level of service, based on the measurements specified. How much friction-degradation and/or downtime can be allowed at, say, an optical backbone link as compared to the cable modem termination system (CMTS), cable modem (CM), or access network? Operators who are targeting service and network reliability will be collecting information and modeling to assure good decisions get made at the point of system and network design. This purposeful design enables management of network sections and knowing where to focus resources for network and service health.

Network operational cost-benefit modeling is an important component of this ability. Start with a framework for modeling the needed tradeoffs and making decisions around improvements.

This work can apply to operations design. Should a technician be sent to fix a proactive problem today, or should we wait a week in case there are more issues that can be solved with the same truck roll? If we are not sure whether a particular fault is caused by a failure mode in the home or in the yard, which technician type should be sent to keep costs lowest, and have the best chance of fixing the problem the first time?

This work can apply to decisions about the customer, too. For example, it may be worth modeling the impact of an uninterruptable power supply (UPS) in the home, or conduct a cost-benefit analysis of providing long term evolution (LTE) backup in the gateway.

But most obviously, architecture choice applies to the network decisions too. Should the operator consider media access control (MAC) manager redundancy architectures, or is a single hardware solution good enough if software and/or state are maintained redundantly? Should nodes be daisy chained in a particular deployment scenario, or is an optical ring truly necessary for the level of service we need to provide?

All these decisions need to be made with data and analysis considered, not just a gut feel, or a first-cost-driven approach. For some examples which come from our own world and are simple to use, see [6], [7].

2.9. Technology Tradeoffs and Lifecycle Management

Operators and vendors both need to benchmark the performance and reliability of existing deployed technology. This allows us all to set goals for future technology based on needed improvements or stability of reliability, availability, maintainability, survivability, and performance. Operators can model the comparison in deployed areas against the goals set by the company, and then enforce the component performance to assure goals are met as the new technology is deployed. Some high-level steps to follow:

- Benchmark existing technology
- Set goals for architectures as deployed
- Set goals and requirements for components
- Deploy and measure performance

Network components wear out. Replacing versus repairing is a decision that should consider costs, useful life, and impact to service.

At some point, an entire system or network may need to be replaced, because it has been used to the end of its useful life. This limit happens when the network or system can no longer meets its intended function in a reasonable way, or the requirements of the system or network have shifted so it can no longer meet the current set of necessary use cases.[2] See [8] for an appropriate model and treatment of the problem. Planning for wear out is important for budgeting, operations planning, supply chain management, and more.

3. History is Our Foundation

The cable access network community has given attention to reliability for decades, with considerable success. Aside from the various papers mentioned in the previous section, there are several other noteworthy works worth mention, study, and utilization.

In the late 1980s the cable industry began upgrading its networks from all-coax tree-and-branch to what is today known as HFC. Around the same time, the industry became interested in network reliability. Operators, equipment vendors, and others worked together to determine just how reliable cable networks really were and what it would take to improve their reliability. Of particular interest was whether cable networks could meet the old Bellcore “four nines” availability spec. More on that in a moment.

The topic of network reliability and availability is introduced in the context of cable networks in [10]. In chapter 20 of that book, the topics of benchmarking, definitions, calculations, redundancy, and network analysis are all discussed.

In 1992, CableLabs and several cable operators organized an Outage Reduction Task Force to “address the issues that stem from cable system outages.” The task force studied and reported on key topics relating to reliability in the cable industry [11]. CableLabs published “Outage Reduction” as a summary of the task force’s work, with chapters covering seven major topics in a large three-ring binder:

[2] Arguably, DOCSIS technology was born out of the need to meet the new set of use cases that the current network technology could not; but the network could be augmented to allow it to meet the new use cases, reusing coax.

- Customer expectations, detection, and tracking
- Reliability modeling of cable TV systems
- Plant powering in cable TV systems
- Outside plant and headend protection
- Service restoration
- Cable TV system power supplies
- Power grid interconnection optimization

"Outage Reduction" was accompanied by a computer diskette with a Lotus 1-2-3 based reliability model. In addition to the published document and reliability model, CableLabs conducted half-day training workshops for member companies on the subject matter in the document's first four chapters.[3] Among the many recommendations in "Outage Reduction" was a critical threshold of no more than two outages in a three-month period (0.6 outages per month per subscriber) be a target for operators to achieve and maintain.

While the aforementioned guidance was considered suitable at the time for an entertainment model, any movement to telephony and data services required a higher performance threshold – hence the interest in the Bellcore four nines (99.99%) Standard Application Grade availability spec [12]. That parameter translates to no more than 53 minutes of outage time per year. Studies and analyses in the 1990s confirmed that cable networks could meet four nines, assuming certain network architecture design criteria, device and component cascade limits, backup power and redundancy, and so forth.

While much has changed since the cable industry's earlier work in reliability and availability, some of the methods and knowledge collected form a useful foundation for today. Now that we are in a DOCSIS access network world, some of that work should be revisited.

Alberto Campos [13] in 2011 presented a paper that laid another foundation for evaluating the quality of experience (QoE). He tied performance metrics that impact QoE to the events that operators experience in the network, and the reliability of several of these features. He identified a large number of factors that contribute to the customer experience, and highlighted the importance of key elements by proposing a service availability metric. This proposed approach gathered in one place the many factors that influence service reliability and quality, plus it provided a convenient way to pull it all together into a single quantity for management. With some updating, a useful standard or operational practice could be created; with additional tailoring, operators can have a strong foundation of measurements to manage with.

Thankfully, SCTE has a new working group on Network and Service Reliability which should be the right place to tackle the new challenges, building on the foundations noted in this paper, and the papers and resources referenced by these works.

4. Conclusions

If you are an operator, you probably have been thinking while reading this paper that you already are doing all these things. You may have even participated in some of the noted foundational work. But there are at least two questions each of us should ask:

[3] The first four chapters of "Outage Reduction" were also published in the December 1992 through March 1993 issues of *Communications Technology* magazine.

- Are we designing and executing these activities toward improved service and reliable networks and services? and
- Are we maintaining our reliability management and knowledge with changes to service, customer demand, technology changes, competition, and factors outside our control?

Operations survive by being cost focused. But that focus should be a long-term focus. And when it is, designing your operations and services toward appropriate reliability goals is your friend, and serves as the lenses for you to keep your eye on that long-term focus of managing cost as well as revenue and the drivers of both.

Once you can answer the two previous questions, you are ready to join us at SCTE's Network Operations Subcommittee Working Group 8 (NOS WG8): the Network and Service Reliability working group. See you there!

5. Appendix

5.1. Failure Modes, Effects, and Criticality

FMECA is a proven methodology for analyzing a system, process, or network for ways it can fail, determining the effects of failure, and assessing the criticality of each failure modes. The applications of this method are broad, but generally allow for appropriate design of technology to meet the requirements. An existing deployed solution is often a source of information when conducting an FMECA, either for augmenting the existing solution with improved operations, telemetry, fault management, etc.; or for designing the next generation solution for optimal performance.

A sub-team from the PNM Working Group at CableLabs has been working for many months on an FMECA that focuses on physical layer failures from the headend out to the customer, the access network. A sample of that is provided in Figure 2.

FMECA — Layer 1 = PHY first, make the layer cake later

System	Subsystem	Component	Failure Mode	Sub-effect	Network Eff	Service Effect	Probability	Detection method
Cable Access								
	Back office	DHCP server						
		PIP Timer						DS Spectrum Analysis
		TFTP Server						
		Config Server						
		Config files						
		TFTP proxy						
	Headend or Hub	CMTS		x				
		Headend Combiner	Adjacent Channel Power Alignment	x				
			incorrect filters, attenuators, etc.					
			failed slope control - in line eq failed					
			bad solder joints					
			misconnected					
			Cross talk - isolation					
		Headend Combiner - connector	bent					
			mis-thread					
			loose	x				
			corroded					
			crimp, poor fittings					
			mechanical failure					
			wrong type, model, poor fit					
			open	x	x	x	high	hard failure, loss connection, localize by impact range & customer call
			EMC - poor connection quality					
			weatherproofing failure or missing					
			incorrect stinger length					
		Headend Combiner - Amp	bent					
			mis-thread					
			loose	x				
			corroded					
			crimp, poor fittings					
			mechanical failure					
			wrong type, model, poor fit					
			open	x	x	x	high	hard failure, loss connection, localize by impact range & customer call
			EMC - poor connection quality					
			weatherproofing failure or missing					
		Optoelectronics						
		Local TV						
		Satellite	Source problem (satellite, uplink, programmer, etc.)					

Figure 2 – A sample of the draft FMECA currently being built.

In the figure, see hardline, connector, and part of the adapter failure modes; these components are part of the outside plant subsystem of the cable access system. Component and subsystem effects are described under the sub-effect heading, where we include several degradation causes and detectable impairment types. Under the heading of network effect, we indicate the effect each failure mode can have on the network from accelerating degradation, through signal impedance and capacity loss, to network separation. The service impact is indicated under service effect, and depicted in greater detail in Figure 3.

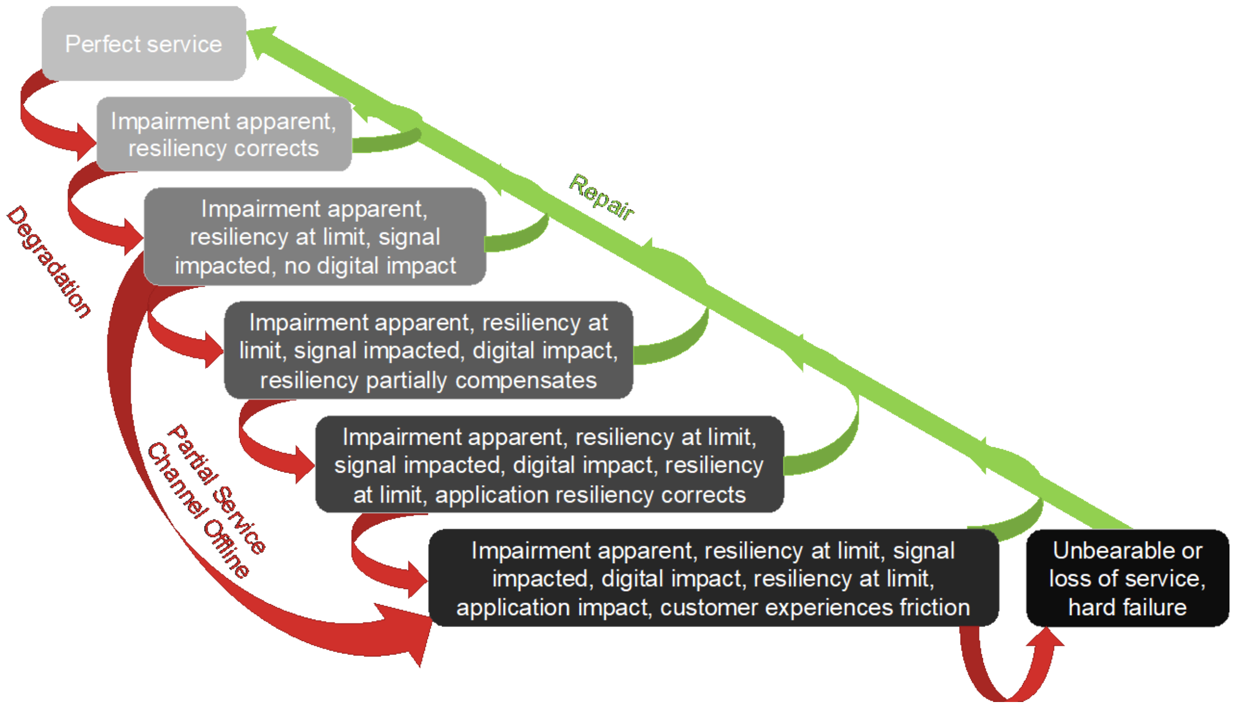


Figure 3 – A depiction of how network performance states relate, from perfect function to untolerable or failed service.

The FMECA here is focused on the physical network as it supports the mission of customer service. But some failure modes can be detected early, and some may accelerate degradation which eventually impacts service.

Because some of the failure modes can have no immediate effect on service, the FMECA documents some effects that impact the network and its components as well. PNM has identified and cataloged several signal impairments that when not too severe do not impact service, but can impact network RF bandwidth or at least foretell of future service issues.

As this work continues, we should be able to show how the repair actions relate to the failure modes, and thereby find new opportunities for improving fault management (identification, localization, and removal) in the access network.

5.2. Service Reliability

5.2.1. Reliability of a service is availability

Reliability is the probability that a system or component is working at a future time when needed. Replace component or system with product, and the intent is close but not accurate.

A service can experience downtime or degradation, but is repairable. Reliability is a non-increasing function which does not describe a repairable thing like a service. What we really want to consider then is availability, which is the probability of a service being in a functional state at some future time. And usually that future time is not defined, so we usually mean a long-term steady state of the system.

Put another way, managing service reliability requires an availability measure of the service.

5.2.2. Reliability of a service is really performance

But a service is a complicated mix of use cases and capabilities, any one or more of which could be available at different times. The service is not a single thing necessarily, and depending on how a customer wants to use it, may or may not work as intended. And if not as intended, is there value in it working in an alternate way or a degraded way? Think in terms of an email that does not go through right away, or a streaming video that takes a few seconds to buffer; does the customer notice or care, or not?

To address this issue, the concept of performability was developed many decades ago. It is a functional convolution of the performance probability distribution function with the value achieved at each performance level possible. While complicated, it does deliver a single measure of performance.

Put another way, service availability actually needs to be a performance measure of the service that includes each possible degraded performance level including complete failure, and the utility that a customer gets from the given performance level. Network reliability and performance both contribute to service availability, but they do not represent it.

5.2.3. Customers are a mystery

Note, however, that each customer is different, and the impact to their perception of performance levels varies by their situation, tolerance, emotions, and the value they put on aspects of the service. A CEO trying to close an important deal might value video conferencing much more than a student doing homework. Further, tolerance for a degraded condition might depend on the person's tolerance to previous outages, expectations of the overall quality of service, and other factors.

Put another way, the impact of service performance on individuals is highly variable and complex. The utility they get, and their overall tolerance of the experience being poor, are not easy to quantify. All an operator can do is provide the best level of service they can for the use cases known, at the price point customers are willing to pay for it.

5.2.4. Service performance

Because simple is an important goal when developing measurement systems, and recognizing that all services are a three-legged stool of cost, performance, and reliability, with cost being understood by the customer, our measure should be centered around performance and reliability, which as just described is really the aspects of performance that are delivered in each available state.

In other words, we can quantify the probability of the service delivering given levels of performance, which is what we can manage. We can seek to understand the customer, what they care about, what they are willing to pay for, and how they see competitive options. But first we must measure what we are providing in terms of service: the performance of that service as a probability space, not just an average, not an average and standard deviation, but as a probability function.

5.2.5. Measuring service performance

The task here is to identify the features of a service that describe the utility of the service to a customer. If latency is not important to, say, a webpage load, then latency measures are less important. But if the service is also being used for video conferences or video games, then latency matters, and a solid latency measurement is important to service reliability.

Examining the use cases and types of service we offer in our industry, a few basic performance measures are obvious.

1. *Goodput* – bits per second, throughput of the useful service-delivering bits on the network, assuming digital data delivery (not analog video, for example).
2. *Latency* – how long it takes to deliver each bit of data.
3. *Jitter* – packet delay variation, or how stable is the latency, and to a certain extent the goodput of the service.
4. *Packet Loss* – data that does not reach its destination.
5. *Availability State* – what is the state of performance of the service in terms of its capability?

Note that, at a packet or bit level, packet loss may be a considered measurement for either availability or as a factor for goodput or latency.

While necessary for measuring service reliability, these measures are not sufficiently described yet, and are not the end of the task for providing service.

Each performance measure statistic must be based on sufficiently detailed measurements to assure sufficient resolution of the differences in service performance levels, and measure all aspects of the performance measure. For example, measuring performance once a day at the same time every day is neither sufficient resolution nor unbiased. Measuring from the CM to the node is not an end-to-end measurement so does not represent the service experience. For understanding service reliability in sufficient depth, service providers have to design the measurement system thoughtfully, to meet their goals of continuous improvement and maintain a focus on service assurance.

But also knowing there is a problem is only the beginning; it takes more information to know the cause, locate it, and remove it from impacting service. That is the work of network operations, or network reliability, which is a key part of service assurance.

5.3. A proposed measurement framework for cable

Each service should have requirements in terms of required goodput, latency, jitter, packet loss for performance, and availability, if at all possible. Lacking a complete set of requirements, it is still incumbent on the provider to measure the service delivered. This section proposes a service availability measure based on telemetry that can be collected from the cable network.

Many of the measurements suggested here are a part of the proposed FCC 22.7, which was announced in late January of 2022. That proposal makes addressing this issue an urgent one, but also supports much of what is addressed in this document, the first draft of which formed in late 2021, with this version acknowledging what is known about the FCC proposal.

First, we need to consider several aspects of the service from a measurement feature point of view. Then we can treat each measurement in that framework.

5.3.1. Features

Several features of service reliability measurements were suggested earlier.

- Use of the measures – Depending on the various uses of the measure, the remaining features must be sufficient to address all needs.
- Bias in the measures – Because service usage varies by time of day, day of week, etc., any point measurement must be taken over a sufficiently large amount of time, with sufficient frequency, and of a sufficient sample size of the traffic to be measured.
- Resolution of the measures – The frequency of sampling must be sufficient to provide proper resolution. For example, an estimate of availability found by sampling daily will not provide good resolution for a highly available service for quite some time.
- Service level – The applications should provide the estimates when and where possible. But that is not always possible. So, service specific measures of performance at the end devices are close and sufficient for many uses. And because the operators do not manage the applications in many cases, but only the service classes as defined in DOCSIS, we should rely on these service classes first, and augment with application specific measurements when possible.
- Actual or surrogate – In some cases, we use special measurement packets to estimate actual service performance. But this method is known to be highly inaccurate and relies on a translation model that is not ideal. It is best to avoid this approach, and favor measurements on the actual traffic.

Each of these features need to be applied to each measurement. The measurements in the set are complimentary, so a complete set is needed.

5.3.2. Goodput

Throughput in terms of end user useful data is goodput. If a goodput measurement is not possible, then a throughput measurement by service type is a useful approximation because goodput can be estimated from this throughput by modeling for overhead.

When the data rate needed exceeds the capacity of the link, interface, or other component, packet queueing and congestion happen, unless discard is the only option. When the purchased data rate is not supported in the grants given by the CMTS to the CM, then applications experience latency. These understandings lead to secondary measurements for throughput.

In many cases, this measurement is used to guard against network congestion. In the access network, a simple network utilization may be sufficient. But when considering that there are customers who may be impacted by impairments and low signal-to-noise ratio (SNR), or high performing customers who also are high bandwidth users, individual CM-level throughput is important to estimate.

Recommendation: One measurement of network utilization, one measurement of bandwidth requests made and granted requests by CM, and one measurement of utilization by profile by CM. All separate for upstream and downstream.

5.3.3. Latency

DOCSIS has defined a latency measurement to support low latency DOCSIS (LLD). This measurement is taken at the CM supporting DOCSIS measurement, which is a subset of the actual experience, but a useful one nonetheless. Using this measurement for all service traffic is an excellent starting point.

Recommendation: Use the LLD latency measurement already defined for DOCSIS, and apply it to all service classes. Report by CM and service class. Augment with application-level sampling of packet delay when possible.

5.3.4. Jitter

Jitter, or packet delay variation, is the variation in the arrival of data. Some applications handle this factor through buffering, but not all applications can be made insensitive to jitter. A measurement of jitter for service types sensitive to it would be important to define. Jitter is strictly defined already, but there are alternatives that we could develop that would meet the needs for our industry.

The time between the arrival of packets would provide useful data for estimating a jitter-like measurement. A mechanism that provides the packet delay variation directly is useful if it is well defined, testable, and validate-able.

Recommendation: Use packet-level jitter measurements already defined in specifications. Augment with application-level sampling when possible.

5.3.5. Packet Loss

While packet loss is not permanent in reliable transmission protocols, thus would be reflected in terms of latency and jitter and goodput at the application layers, it is included here as it is a proposed measure in FCC 22.7.

Applications that rely on unreliable transmission protocols will not experience packet retransmission, so packet loss is an important problem and should be measured.

Applications that are latency-impacted may discard packets that are late, resulting in the same impact as packet loss. Therefore, some application consideration is important for packet loss measurement.

Forward error correction (FEC) statistics are included in DOCSIS and would be an important supportive measurement to include here, and for a DOCSIS reporting point of view would surely be more than sufficient as a measurement which can generate appropriate statistics.

However, we may need to report FEC statistics by service class or application to provide a useful measure of service reliability-availability.

Recommendation: Rely first on FEC statistics, particularly uncorrectable codeword errors. Each of these represents lost packets or data which require either application layer or protocol layer retransmission or re-requests. For reliable protocols, measure discarded packets and retransmissions. For unreliable protocols, measure lost packets. Augment with application-level sampling of packet loss when possible.

5.3.6. Availability

The overall availability of the network is an obvious, important component of service reliability. Network availability should consider cases where the user wants to use the service, but it is not available. Estimates can be obtained through polling logs from the CM, or polling state from the CMTS, or through ping-response approaches, or likely a combination.

Timeout statistics would be a useful contributor here, but there are known issues with timeouts being inaccurate as estimates of availability due to various contributing factors. However, it may serve as a surrogate measure that could be translated into an availability estimate through a translation model, or as a contributor toward an estimate that incorporates logs and other traffic data.

Recommendation: Provide timeout statistics, augmented with logs from the CMTS and CM to estimate network availability. More detailed assessment is needed to develop the models here. Augment with application-level or device specific sampling when possible.

Overall recommendation: Measure or estimate the service experience; when insufficient, drill down toward the cause, and address the fault.

6. Abbreviations and Definitions

6.1. Abbreviations

CEO	chief executive officer
CM	cable modem
CMTS	cable modem termination system
DOCSIS	Data-Over-Cable Service Interface Specifications
FCC	Federal Communications Commission
FEC	forward error correction
FMECA	failure mode, effect, and criticality analysis
HFC	hybrid fiber/coax
IT	information technology
LLD	low latency DOCSIS
LTE	long term evolution
MAC	media access control
NOS WG8	[SCTE] Network Operations Subcommittee Working Group 8
PNM	proactive network maintenance
QoE	quality of experience
SCTE	Society of Cable Telecommunications Engineers
SLA	service level agreement
SNR	signal-to-noise ratio
UPS	uninterruptable power supply

6.2. Definitions

There are many sources for finding definitions of reliability and the many related terms. A few simple ones are offered here, and hopefully explain away some of the sources of confusion. Unfortunately, some of these terms have use in marketing, engineering, and non-technical contexts with different meanings. Even in an engineering use, there are often assumptions being made that make it difficult to know just what is being defined and under what context. As we apply a little focus on these definitions for our specific purpose, consider that these definitions also are the desirable properties of networks and services.

- *Reliability* as a word by itself is ambiguous, context dependent, and can mean a lot of different things depending on the situation. Consider first the perspective of the user of the word, and the context they use it under.
    - Customer – Whatever it is, it must work as I want it when I want it, without repair action on my part, so that the system is invisible to me when I use the service – this is service or use case reliability.
    - Provider – Sometimes a service provider uses this word to mean availability, suggest a lower repair rate, infer fewer customer calls, or other operational costs – this is operations reliability, or network reliability [1].
    - Academic – A more precise definition of reliability is the probability that something functions as intended up to time $t>T$ given it works at time $T=0$. This is the reliability at time t. Note the reliability function is a decreasing function over time. Note also this says nothing about networks and services, which are repairable.

Availability is better suited for repairable items, though reliability is still relevant.

- *Availability* is the long-term percentage of time that a repairable system works. In other words, availability is the ratio of time that a service, device, or network is available for use over the total time, usually expressed as a percentage of the total time. Equally, it can be expressed as the probability that a repairable system works at some far future time. As such, availability considers the uptime, downtime, and repair time issues of the system or network as a whole. It can't tell you whether failures are frequent or infrequent, or repairs are lengthy or fast, but tells you the proportion of time that something can be counted on to work.
- *Maintainability* is the ease with which something can be maintained. Often this feature is determined by maintenance time estimates, sometimes through time and motion studies. Maintainability can include repair, but does include planned maintenance.
- *Repairability* refers to how easily and quickly a component or system can be repaired, or the property of being repairable. This term focuses on repair instead of planned maintenance, though the distinction is not always clear.
- *Survivability* is the ability of a system or network to operate under attack, and provide service in the presence of failures. Parts can fail, but the system or network still functions and provides service.
- *Resiliency* refers to failure recovery and fault tolerance, and the ability to provide service under degradation, over a broad range of demands. Degradation exists, but service functions.

Note that survivability and resiliency are related, but different in that the former refers to surviving a partial failure such as a lost link in a mesh network, while the latter refers to functioning under degradation such as ingress interference in a DOCSIS® network.

- *Performability* is the convolution of the performance function and the probability function of the system. It's a complicated concept, but let's think of it like this: 90% of the time, my bike works great; but 9.9% of the time, the tires are low and it is hard to pedal the bike; and the rest of the time, the bike is in the shop. If I consider that the bike with low tires performs at 50% while the fully functional bike is performing at 100%, in this simple example, the performability overall is $(0.9 * 1) + (0.099 * 0.5) + (0.001 * 0.0) = 0.9495$, which is less than 95%, even though availability is 99.9%. Think of performability as a state probability weighted performance measurement. Then realize that the probability function of the possible states, translated to the probability function of the possible performance levels, is a better measure of the experience than simple availability. If you replace the performance states with a continuous performance function, the concept still works though the math gets more complicated. But keep in mind that a single number representing performability is not as useful as the full function representing probability of performance.

Referring to the customer's definition of reliability, see that all these factors contribute to a user's perception of service or use case reliability. The unreliability of a service can be impacted by a number of performance measures as they relate to the usage or use cases associated with the service. Users are all unique, but they reveal their preferences through their product choices and willingness to pay for features; this information translates well to their perception of service friction[4] and thus reliability.

7. Bibliography and References

[1] R. Hranac, "Service Availability," Communications Technology, December 2007. Available at https://scte-cms-resource-storage.s3.amazonaws.com/07-12-01%20service%20availibilty.pdf

[2] M. Spaulding, L. Wolcott, J. Rupe, "Improving Operational Intelligence for Maintaining Cable Networks," SCTE Expo 2022.

[3] J. Zhu, K. Sundaresan, J. Rupe, "Proactive Network Maintenance using Fast, Accurate Anomaly Localization and Classification on 1-D Data Series," 2020 IEEE International Conference on Prognostics and Health Management (ICPHM), 2020.

[4] J. Rupe, J. Zhu, "Kickstarting Proactive Network Maintenance with the Proactive Operations Platform and Example Application," SCTE Expo 2019.

[5] J. Rupe, J. Zhu, "Comparison of RxMER Per Subcarier, Bit Loading, and Impairment Driven versus Meaurement Variability," SCTE Expo 2020.

[6] J. Rupe, "A General-Purpose Operations Cost Model to Support Proactive Network Maintenance," SCTE Expo 2019.

[7] N. Foroughi, J. Rupe, "Distributed Gain Architecture: Increased Performance, Decreased Power Draw," SCTE Expo 2020.

[8] J. Rupe, "Optimal Maintenance Modeling on Finite Time with Technology Replacement and Changing Repair Costs," Annual Reliability and Maintainability Symposium (RAMS), 2000.

[4] The concept of service friction in this context is new; we use it here to represent any impedance a customer experiences from using a service as intended in the desired manner.

[9] M. Spaulding, L. Wolcott, J. Rupe, “Improving Operational Intelligence for Maintaining Cable Networks,” SCTE Expo 2022.

[10] W. Ciciora, J Farmer, D Large, M. Adams, “Modern Cable Television Technology: video, voice, and data communications,” Elsevier, 1999, 2004.

[11] Outage Reduction Task Force, “Outage Reduction,” CableLabs Technical Report 1992.

[12] Telcordia Technologies Generic Requirements, “Reliability and Quality Measurements for Telecommunications Systems (RQMS-Wireline),” GR-929-CORE, 2002.

[13] A. Campos, “Holistic Approach to Evaluating Quality of Experience,” SCTE Cable-Tec Expo 2011.

SCTE STANDARDS JOURNAL

An Analytical Framework for Solving Telecom for Wellness Challenges

A Technical Paper prepared for SCTE by

Sudheer Dharanikota, Managing Director,
Duke Tech Solutions, Inc., SCTE Member
111 Fieldbrook Ct.
Cary, NC 27519
sudheer@duketechsolutions.com
+1-919-961-6175

Clarke Stevens, Principal Architect, Emerging Technologies,
Shaw Communications Inc., SCTE Member
1801 N. Broadway, Suite 501
Denver, CO 80202
clarke.stevens@sjrb.ca
720-723-2316

Table of Contents

Title **Page Number**

List of Figures

Title **Page Number**

1. Executive Summary

Telecom for Wellness (T4W) is a multibillion industry in its nascent stages. SCTE is working with the Healthcare Information and Management Systems Society (HIMSS) and several cable operators to prepare their infrastructures, including their analytical platforms, in readiness for T4W challenges and opportunities. These use cases can range in complexity from an individual who would like to stay safe and independent in their home for as long as they can (also known as aging in place, or AIP) to home-as-a-hospital (HAH). At last year's SCTE Cable-Tec Expo [1], we discussed the different metadata required for addressing focused problems and creating an end-to-end architecture to resolve them. In this paper, we extend these concepts to elaborate on how cable operators can create a suitable analytical framework for solving many T4W problems.

In this paper we will:

- Define the different classes of T4W challenges.
- Identify how operators can leverage their existing data monitoring points to collect relevant parameters.
- Analyze how operators can solve different T4W challenges with data they are already collecting:
    - Using the historical and current information collected from the devices;
    - Using metadata extracted from diverse sources;
    - Specifying different algorithms for specific classes of challenges; and
    - Keeping in mind the differentiators that we can create for cable operators.
- Discuss different data protection and privacy mechanisms operators need to deploy for T4W.
- Discuss the significant privacy issues associated with personal health information.

We intend to expand this framework to create standards and/or operational practices for T4W solutions within SCTE. Privacy as used in this paper refers to the Health Insurance Portability and Accountability Act of 1996 (HIPAA), a federal law that requires creation of national standards to protect sensitive patient health information from being disclosed without the patient's consent or knowledge. See https://www.cdc.gov/phlp/publications/topic/hipaa.html.

2. Introduction

The wellness industry is going through a major transformation to modernize infrastructure [2], reduce cost, and increase the quality of care. In a series of articles, we have suggested how the telecom industry can assist the wellness industry (Refer to [3], [4], [5], [6], [7], [8], [9]). We call this inter-industry collaboration telecom for wellness (T4W). Even though the T4W opportunity is not limited to these two major intersection points ([2]), we focus on aging in place and telehealth use cases to illustrate our thoughts on the end-to-end T4W architecture in [10]. Refer to [11] for six different opportunities that a telecom operator can address through the T4W analytics covered in this paper. The SCTE Data Standards Subcommittee (DSS), of which the authors are members, is actively working on T4W solutions for the AIP and telehealth areas in Working Groups 3 [12] and 4 [13].

	Aging in Place	Telehealth
Users	Older adults (65+), caregivers	Individuals, providers
Stakeholders	Family members, care givers, doctors, service personnel etc.	All family members, providers, (payors)
Needs	Communicating, monitoring, service, support, integration	Communicating, monitoring, integrating with provider systems
Challenges	Ease of use, provider network integration, problem solving	Ease of use, device and EMR integration, remote monitoring,
Telecom opportunity	End to end solution, managed services, provider integration	End to end solution, managed services, provider integration

Figure 1 - T4W opportunity and challenges summary

References [3] and [4] provide a quick summary of T4W opportunities and challenges from AIP and telehealth points of view. Here we generically use telehealth to encompass both remote non-clinical services as well as telemedicine which refers to all kinds of medical, diagnostic, and treatment-related services (typically by doctors. Many of the needs, challenges, and telecom opportunities of both markets are similar (refer to the SCTE working group analysis at [12], [13]). Some of the high-level use cases that need to be supported for these two markets include:

A. Providing basic communication between users and providers/caregivers;
B. Providing seamless communication between users and stakeholders (refer to Figure 1);
C. Monitoring users' health metrics, mobility, fall detection, etc.;
D. Analyzing the data collected from users and properly notifying stakeholders;
E. Assisting T4W service provider's claims by documenting their process accountability; and
F. Offering managed services to effect installations, product support, and other services to improve adoption and retain customers.

Many of these use cases — ranging from AIP, independent living, and HAH use cases (the extreme ends of the T4W) – are discussed further in [11] with consideration of the opportunities for the cable operators.

In the next sections, we summarize the T4W architectural needs, provide an end-to-end framework, discuss individual components, and start discussing the **T4W analytical framework** concept.

2.1. End-to-end high-level T4W architecture

Figure 2 provides a high-level end-to-end architecture proposed a market analysis [2] based on different T4W market opportunities. The framework is further elaborated in [10].

To understand the end-to-end T4W architecture, we first need to understand the users, service providers, and the other stakeholders using the architectural framework to evaluate the analytical components proposed in this paper. We will also use AIP and telehealth use cases (as provided in section 2) to do this.

1. <u>In-home healthcare/wellness aware gateway</u>: For use cases A, B, and C, a gateway needs to be present in the T4W home. This gateway, as shown in Figure 2, acts as an integration point for monitoring ~~the~~ sensor devices (e.g., motion sensors, remote patient monitoring equipment) and integrating with the interactive services endpoints (such as unified communication services). This sensor network gateway (SNG) can be a standalone device or integrated with other vendor equipment such as the set-top box or residential gateway.

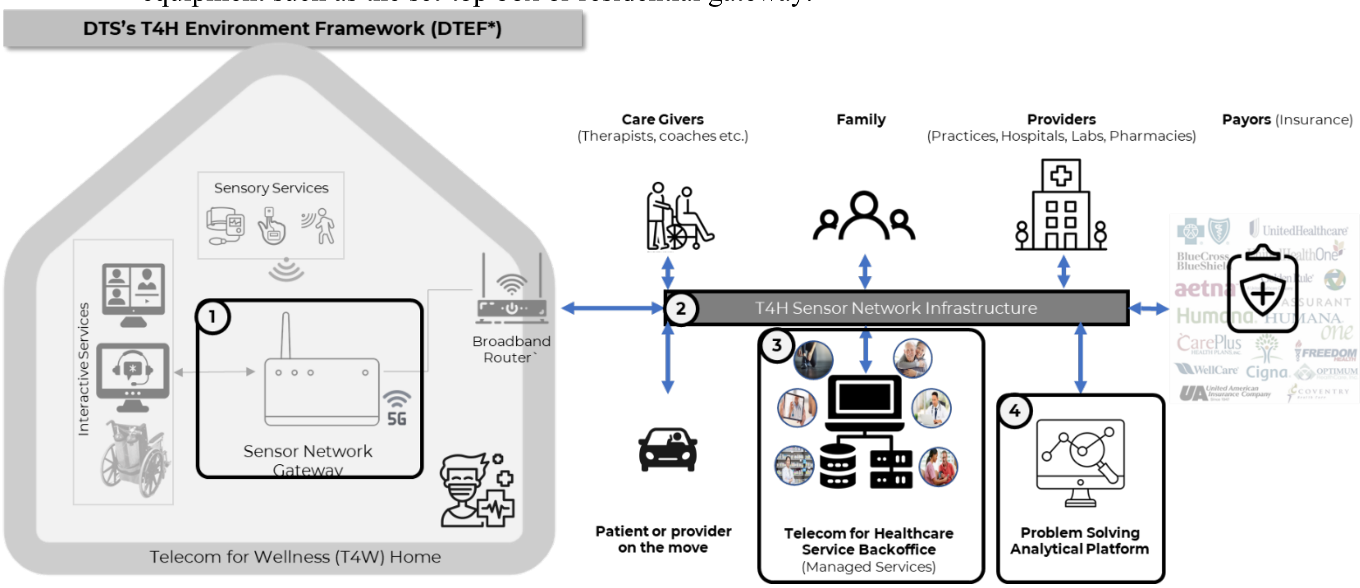


Figure 2 - DTS's Telecom for Wellness Environment Framework (DTEF) Based Components

2. <u>T4W-aware network infrastructure</u>: Again, for the use cases A, B, and C, T4W requires connections between users, providers, and other stakeholders. This requires not only reusing the existing telecom infrastructure but also needs to meet reliability, security, and privacy requirements specified by the T4W architecture. The communications infrastructure will have to meet the needs of the sensor network traffic, unified communications traffic, and notifications to the different stakeholders. To differentiate (or to keep the focus on) the T4W needs, we call this the T4W sensor network infrastructure.
3. <u>T4W-aware service back office</u>: The cable operators have all the required infrastructure for managing end-to-end services. As mentioned in use case F, it is essential to turn the fragmented, gadget-oriented point solutions into an end-to-end professionally managed service. This can be best accomplished by telecom operators who have access to such infrastructure and have been managing communications infrastructure for 90+% of the households in the US. We call such infrastructure T4W service backoffice.
4. <u>T4W aware problem-solving analytical platform</u>: Finally, as mentioned in use cases D and E, this infrastructure attempts to solve the challenges stakeholders are facing. These challenges and related algorithms may be unique to the healthcare/wellness industry, but the overall platform can leverage the highly secure and reliable infrastructure that Telecom operators use today. We call this repurposed analytical platform the **T4W problem solving analytical platform**.

In the following sections, we summarize the T4W problem-solving analytical platform framework from both metadata and telemetry and gap analysis points of view. These were originally presented in [1].

2.2. Metadata and telemetry details

There are multiple locations, as shown in Figure 4, where the T4W-related metadata and telemetry information can be gathered ([1]). These data collection points include:

- **In-home device interface:** This interface is used to monitor the in-home T4W sensors and interactive devices. The quality of experience (QoE) [14] metadata can be monitored from this data collection point.
- **In-home network interface:** The upstream interface of the sensor network gateway can be used for aggregated in-home information such as broadband connectivity-related data and per session-related monitoring.
- **T4W sensor network interface:** The reliability and availability metrics can be monitored from the T4W sensor network infrastructure.
- **T4W service back-office interface:** This interface provides the overall service level QoE metrics, aggregate service level information, Quality of care analysis metrics, governance metrics, etc.
- **T4W analytical interface:** This interface provides the responsiveness, accuracy, and success rates of the problem-solving analytical infrastructure.

The information collected from the above interface must be securely collected and must follow HIPAA privacy compliance [15]. This will be further elaborated in this document.

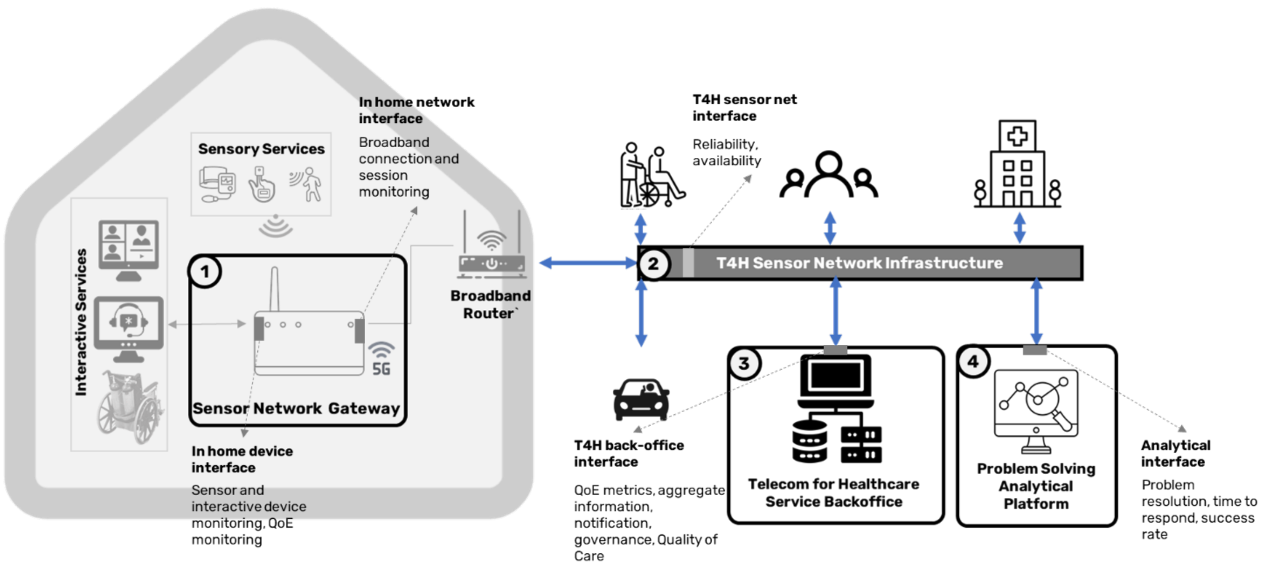


Figure 3 - Different Monitoring Points in Telecom for Healthcare Architecture

2.3. Interaction of metadata with the analytics framework

The topic of data collection [1] is not complete without understanding the context of how the data would be used. In [10], we explain the end-to-end T4W architecture including the analytical platform, as shown in Figure 4. Various categories of data are stored and used in the problem-solving analytical platform. The analytical platform provides the interface to different metrics and assists in providing timely notifications to the stakeholders. These analytical functions as represented in Figure 4 can either be centralized or distributed inside/close to the home for availability purposes.

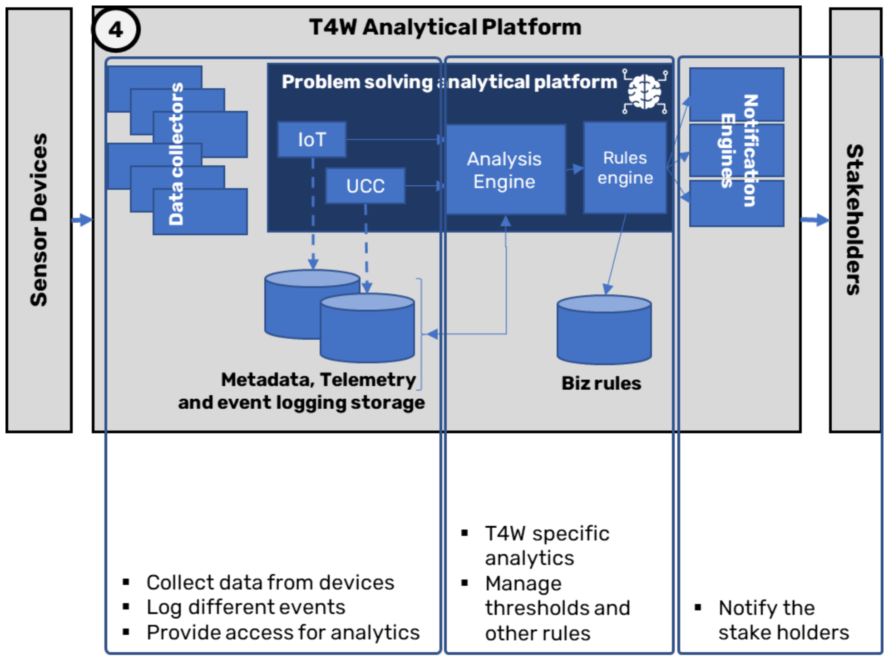


Figure 4 - Using Metadata to Solve T4H Analytical Problems

As presented in Figure 5, many of the analytical components relevant to the T4W solutions are already developed for the current cable operator solutions, as explained in [1], [10]. As described in the comments section, these solutions need to be extended for the T4W requirements. Also note that the performance of the platform, which is currently tuned for the network device level needs to be scaled to per-stream level information gathering. The current telecom solution data security and privacy constructs must be validated against the needs of T4W. Although the responsiveness of the current solutions is good for telecom needs, using this platform for the time-critical and highly

Component*	Status in MSO	Comments
Data collectors	Existing for IoT and other service info.	Need to repurpose for T4W data
Analysis engine	Existing for IoT engines	Need additional development for T4W
Rules engine	Potentially new function	Need solutioning
Notification engines	Existing with service assurance tools	Need to extend to T4W
Data privacy	Existing for PII	Need to extend to PHI**
Performance	**Status in MSO**	**Comments**
Scalability	Device level alarms	Need to extend to per sub per stream
Security	SNMPv3 based	Need to validate if this is enough
Privacy	PII after collection	Need to validate if we need to anonymize at the collection points
Reliability	Reliable communication	No additional changes in our opinion
Responsiveness	Good for current use	Crucial for the success

(*) Green bands represent lower complexity in adopting
Yellow bands represent higher complexity in adopting
(**) PHI – Patient Health Information

Figure 5 - Gaps in the end-to-end Analytical Platform

responsive T4W solutions calls for a fresh look at the data architectures. Further analysis of these architectural constructs will be conducted in the SCTE working groups [12][13].

In the rest of the paper, we will bring the analytical architectural components, metadata capabilities, and available infrastructure with the help of different classes of T4W challenges.

3. Classes of AIP and telehealth challenges and examples

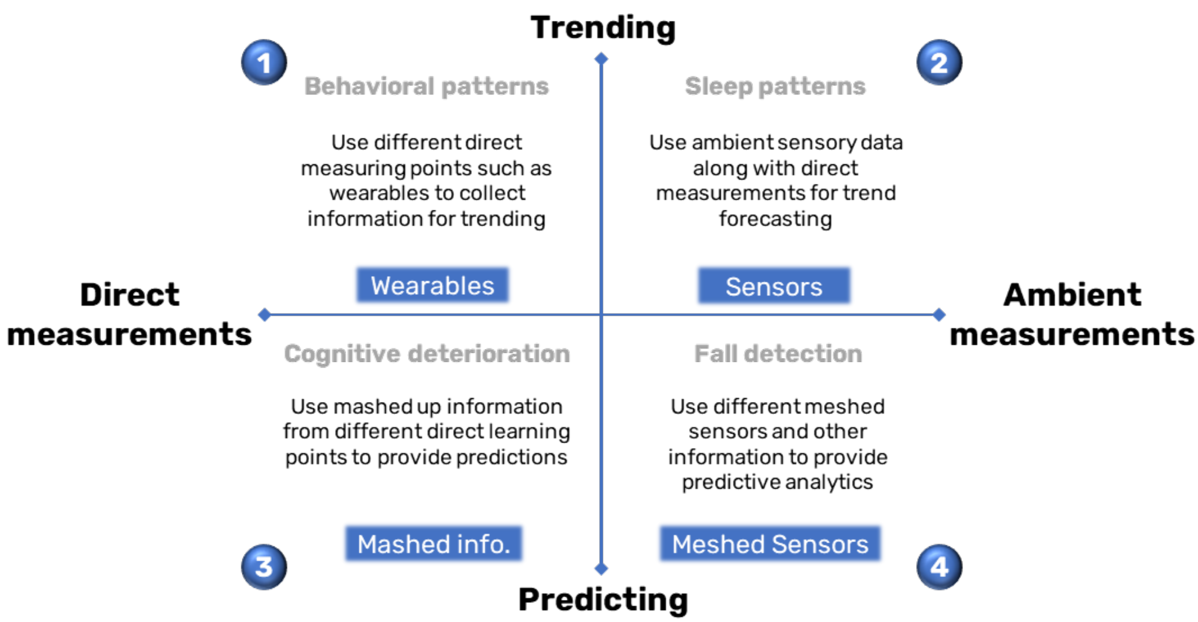
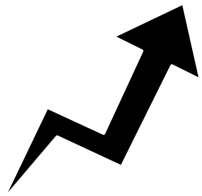


Figure 6 - Different Classes of T4W Analytical Problems and their Dimensions of Analysis

The T4W challenges can be analyzed in the dimensions of the complexity of measurements and the type of analysis, as shown in Figure 6. The data measurements can be from direct access to the devices (such as wearables) to the implied knowledge gained by the ambient sensors. The type of analysis can range from basic trend forecasting to complex predictive analytics. These four classes of problems are shown in the figure with examples.

3.1. Direct trending

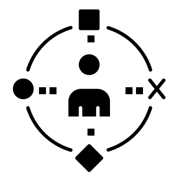


Definition: Make recommendations or send notifications based on ~~the~~ directly measured information trended over a period.

Sources of information and examples: Most of the wellness applications collect data from different devices to perform the basic trend analysis. The data collected here could be the measurements from the wellness monitoring devices such as wearables to hospital-provided monitoring devices in a HAH setting.

Monitoring and reporting: Monitoring can be by automatic collection of data from the applications on the wellness devices or manually initiated collection at regular intervals. This information is retained on the devices or on their corresponding application or by trending software used for the analysis. Much of this data is stored for a designated period such as weeks or months for trend analysis and may be backed up for future reference. This data management infrastructure can monitor the trends and its impacts by assigning thresholds for different conditions. When these thresholds are crossed the application can send a notification to the stakeholders about the user, thus providing value added services in the wellness ecosystem.

3.2. Ambient trending

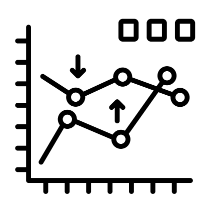


Definition: Make recommendations or send notifications to stakeholders based on directly measured and ambiently monitored information to provide relevant trends.

Sources of information and examples: These are the applications where multiple sources of information are correlated to determine a trend. The sources of information could be from the devices that are monitoring certain aspects of the user (with consent). For example, a user being monitored for sleep apnea through breath rate, blood oxygen levels, and heart rate analysis is a potential application. Other mundane applications can be passively monitored: timely consumption of medication, time taken to do certain tasks, gait, glucose levels, blood pressure, cardiac arrhythmia, asthma, body weight, oximetry, etc.

Monitoring and reporting: Most of the data here is monitored from sensory devices such as recording devices, contact monitoring devices, activity monitoring devices, etc. As before this information is retained on the devices or their corresponding application or by trending software for ~~the~~ analysis. This data may be stored for a designated period such as weeks or months for the trend analysis and may be copied for future reference or backed up for retention. Here in addition to trend analysis, algorithms need to do correlation between different events and variance from expected behavior. When these correlations identify discrepancy, the application can send a notification to stakeholders about the user, thus enabling value added services in the wellness ecosystem. One important aspect of such ambient information gathering is the user may decide to have selective / restricted information communicated to different stakeholders. The applications and infrastructure should respect these restrictions and work with the available data.

3.3. Direct predictions

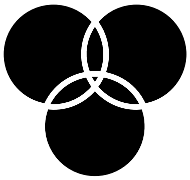


Definition: Make recommendations or send notifications to ~~the~~ stakeholders based on directly measured and algorithmically assessed information to provide predictions.

Sources of information and examples: These are ~~the~~ applications where multiple direct sources of information are correlated to make a prediction. In this class of applications, the data collected and derived is used to go beyond creating a basic trend to make a prediction on the future possibilities. The sources of information could be from devices that are monitoring (with consent) certain aspects of the user to correlate for the potential challenges. For example, a user being monitored for cognitive decline through activity monitoring, trending, and correlation from different data sources. Other applications can be monitoring eating patterns, exercise patterns, etc. to support the individual's wellness goals.

Monitoring and reporting: The monitoring, storage, and privacy needs are the same as in ambient trending application. The complexity is in the data being collected, and the algorithms used to solve different challenges.

3.4. Ambient predictions



Definition: Make recommendations or send notifications to stakeholders based on ~~the~~ directly measured, ambiently monitored and algorithmically assessed information to provide predictions.

Sources of information and examples: These are the applications where multiple directly attached and other sensory device information sources are correlated to make a prediction in near-real time. In this class of applications, the data collected and derived is used to go beyond creating a basic long-term prediction, providing a quick lifesaving recommendation. The sources of information could be from the devices that are silently monitoring certain aspects of the user to correlate for potential challenges. For example, an elderly user could be monitored for fall detection based on the ambient sensory information from different sensory sources with real-time analytics closer to the individual. Note that the proper training of the algorithms and validation process steps should be included into this class of applications to avoid false positives.

Monitoring and reporting: The monitoring, storage, and privacy are the same as in direct prediction application. The complexity is in the data being collected, the algorithms used to solve different challenges, and the swiftness of making the recommendations. This near real-time response requires the analysis being done in the device, in the home, or near the user.

3.5. Integrating with the existing in-home devices

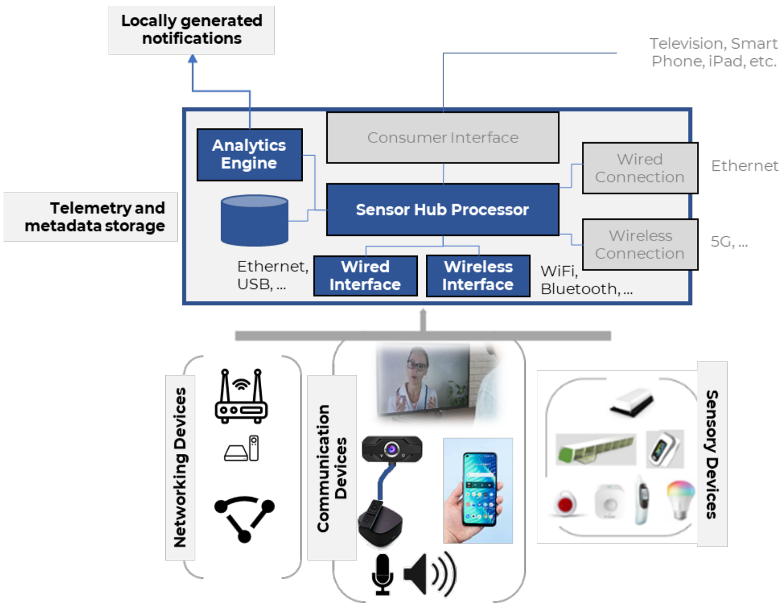


Figure 7 - SNG for Supporting T4W Analytical Framework

In Figure 3 we introduced the concept of the SNG which is used at home for T4W support and elaborated it at SCTE CableTec Expo 2022 [17]. A high-level diagram of the SNG and its relevance to the T4W analytical framework is shown in Figure 7. The SNG is the glue between the in-home T4W devices and the analytical problems they are solving for the users. This has interfaces to different networking devices (such as routers, set top boxes, meshed networking devices, etc.), to the communication devices (such as audio, video, cellular, etc.), and to the sensory devices (such as medical monitoring, motion detection, etc.). As highlighted in the figure, the interfaces to the in-home devices (to extract the relevant information), the storage (to host an applicable amount of data for analytics), and the analytics engine that is part of the processor (to solve important local analysis and provide notifications) are the important components for the T4W analytical framework.

Table 1: Characteristics of different T4W analytical challenges

Analytical challenge	Local Intelligence	Local Analytics	Local Storage
Direct Trending	Not required	Off-line	Not required
Ambient Trending	Good to have	Mostly off-line	Required
Direct Prediction	May be required	Mostly off-line	Required
Ambient Prediction	Required	Near real-time	Required

Table 1 above summarizes the importance of the SNG components in solving the four categories of the challenges to address T4W services.

4. Dos and don’ts of T4W information management

The T4W use case presents certain difficult challenges for telecom operators. Personally identifiable information (PII) must be protected throughout the analytical platform.

- *From service billing point of view*: Obviously, the operator must have enough information to provide an accurate billing to the correct user, but this information must be protected from anyone who does not have a specific need to see it and does not comply with the explicit consent of the customer.
- *From healthcare point of view*: With health-related information, even the operator is prohibited from seeing it. However, the information and analysis are only valuable to the customer if the customer (or the stakeholders) can explicitly see the analysis of the information personally associated with them.
- *From wellness point of view*: While healthcare is tightly regulated, the challenges solved and hence the information handling constraints in the wellness area are less stringent. The stakeholders and their incentives can be addressed without being impeded by healthcare rules. But the PII and consent-related concerns must be honored in the case of wellness also.

From these three categories of information management, the level of scrutiny on the dos and don'ts can be analyzed. In the remaining section we provide requirements and approaches for solving them.

Table 2: Importance of different concerns against billing, wellness, and healthcare

Concerns	Billing	Wellness	Healthcare
Consent	Low	Medium	High
Privacy	Medium	Medium	High
HIPAA	Medium	Low	High
Inference	Medium	Low	High

4.1. Consent

The first step is user consent. The user must understand to some level of detail who will have access to what information, how/where the information is stored, and for how long. This needs to be presented to the customer in an understandable way. Except in rare circumstances, the access should be denied unless explicitly granted by the user with identification of the risks and benefits of allowing access. Care must be taken in designing the user interaction to both meet the regulatory requirements and to have permission to collect the requisite data to provide the service. As shown in Table 2 above, this requirement is high priority for healthcare related applications, but for billing and wellness it is less of an issue.

4.2. Privacy

Modern encryption systems, security methods, and good verifiable processes make it possible to provide valuable data analysis while protecting the privacy of customers. A person and that person's PII can be separated for analysis and later combined (without being exposed to the cable operator) to be delivered as specified by the consumer. Even though the privacy needs are not mandatory for billing and wellness needs, we recommend developing and practicing such techniques for all the T4W applications.

4.3. HIPAA

HIPAA (or equivalents such as PIPEDA in Canada, so on) protects the privacy of sensitive information from a regulatory perspective. Naturally, this is a minimum requirement for service providers for healthcare (not for billing and wellness) applications. The techniques described above must be tested and continuously monitored for HIPAA compliance. Fortunately, the goals are the same. It is just a matter of how to achieve them while still being able to provide services that customers want.

4.4. Indirect information and inference

Information about the consumer that can be analyzed can come from direct or indirect sources. Direct sources are essentially measurements that can be taken for things like vital signs. Since direct sources are measuring patient parameters, they clearly must be protected from a privacy perspective. Indirect information is less definitive; it might indicate when a bathroom door is opened or when a room is occupied. For a person not living alone, this makes the information somewhat ambiguous. Still, this information can be used to infer things about the customer or other persons in the home. If the same privacy policies applied to direct information are also applied to indirect information, the operators should establish security, access, and privacy norms prior to offering T4W services.

5. Example algorithms for different challenges

Once identifying information is removed, redacted, or otherwise kept private (as with privacy enhanced computing, PEC), the data can be safely analyzed and even combined with different massive datasets for global studies. In general, these challenges will likely be resolved through (or equivalent to) big data machine learning (ML) algorithms. This usually involves collecting enormous amounts of data and associating that data in context with known events. Processes can be established for logging remarkable events and allowing the ML algorithms to find correlations, clusters, and patterns in a large data set. Those patterns can then be observed to predict future events. The following table summarizes distinct categories of algorithms from data interpretation to complex ML needs. More details are provided in the later subsections.

Table 3: Different algorithms required for solving T4W challenges

Algorithm	Direct Trend	Ambient Trend	Direct Prediction	Ambient Prediction
Trend plotting	X	X	X	X
Threshold crossing	X	X	X	X
Averaging	X	X	X	X
Quartiles	X	X	X	X
Range	X	X	X	X
Basic conclusions	X	X	X	X
Correlation		X	X	X
Confidence level		X	X	X

Missing data substitutions	X	X	X
Predictive algorithms		X	X
Basic learning		X	X
Decision making		X	X
Enhanced correlation		X	X
Enhanced decision making			X
Machine learning			X

5.1. Direct trending challenges

Direct trending challenges involve direct measurement of relevant information from the patient or tracking of patient behavior. Examples of this include measurement of vital signs, opening and closing of doors, verification of taking medicine, and measurement of other activities. Similarly, trending is a relatively straightforward statistical analysis. Collected data can be plotted (for example against time) and the average trend line can be mathematically determined. Experience with the data over many tests can also be used as a check to understand the trend lines that are expected for common cases. Future values can be predicted forward in time using best fit analysis and plugging the future time into the equation. Direct measurement and statistical trending analysis is sufficient for many analytical problems. Variance beyond certain thresholds from the expected trend can be noted and highlighted for more detailed analysis and to determine if conditions might be of concern. Variance from the norm can be further analyzed with respect to the direction and magnitude of the variance in comparison to the applicable common cases previously determined. It is often convenient to select two variables and plot data from multiple cases on a two-dimensional graph. A threshold can then be plotted in both dimensions (dividing the graph into quartiles) and the resultant groupings can be evaluated for common results based on common conditions.

Most of this analysis can be automated and updated in real time as new data is collected from patient measurements or direct observation of events. The caregivers and other stakeholders can be automatically alerted to conditions that deserve further analysis. This is a multiple win scenario. Patients can directly take their own measurements at home without requiring the assistance of a caregiver. Caregivers can work more efficiently as they are only notified if conditions require their attention. Other stakeholders (such as family and friends) can be notified if something is concerning or just assured periodically that everything seems okay.

5.2. Ambient trending challenges

Ambient trending challenges are like direct trending challenges with the difference being how the data is collected and interpreted. Rather than directly measuring patient conditions (like blood pressure and temperature), the data is collected based on passive observations. While this sometimes means direct measurement of activities (like a door opening or closing), it often extends to inferences from multiple data sources. While going to the kitchen might or might not mean the patient is preparing breakfast, when presence in the kitchen is combined with opening the refrigerator, turning on the coffee maker and switching on the morning news, it is much more certain that the user is preparing breakfast and following a normal routine.

The analytics around this are again based on simple trending statistics. When the data falls within expected thresholds and the correlation between expected activities is strong, a statistical assumption can be made with a measurable level of certainty. Missing data, like the refrigerator not opening because breakfast was just black coffee and a pastry this morning, can be noted and potentially ignored if enough other parameters are in range. Ambient measurements can also be less reliable than direct measurements. Since they are logging observable events and making assumptions, those assumptions and be wrong. For example, a passive RF fall monitoring system might register something as a fall when the patient is simple bending over to pick some crumbs from the floor.

All the features and benefits of direct trending also apply to ambient trending. However, ambient trending is no burden on the patient. The patient does not need to do anything special. They just go about their day as they normally would. Caregivers and stakeholders get the same benefits as they would with direct measurement with the caveat that the information may be a little less certain.

5.3. Direct prediction challenges

Direct prediction was described in section 5.1. The logical result of direct trending is a prediction of the future values of data. This can be highly effective if the condition represented by the data is well-understood and the number of samples are statistically significant. However, either of those conditions can fail or the measurements themselves can be faulty. The good news is that the caregivers are being regularly informed. Data that seems concerning can be reported to the caregiver and the caregiver can investigate further to determine if the patient's condition is changing or if the measurements (or method of measurement) are just unreliable.

The reliability of the data can be further enhanced using ML techniques or artificial intelligence (AI). Rather than simple quartile analysis, ML can group data into any number of correlated groups automatically and recursively (where the ML algorithm itself is altered by the data and outcomes over time). The commonality in the input data can be correlated with other conditions and the importance of a small number of measurements can be evaluated against a much larger data set (for example statistics of all patients in the United States). While the correlation can be identified without any identification of the cause, an ML model can be greatly enhanced by correlating measured conditions with observed results. This is known as training the model. If a high percentage of patients with similar conditions contract a certain disease, then the model can predict what might happen with greater accuracy. One of the major benefits of ML is that it can work on enormous sets of data and identify correlations that would be difficult or impossible for humans to notice.

Similarly, AI algorithms and techniques can be used to infer important conditions that humans might overlook. ML is just one AI technique. There are other methods continually being developed that allow AI to make more accurate assumptions and decisions. AI can be used as a caregiver tool to allow the caregiver to be more effective, but it can also be used to automatically make decisions and take actions that are sufficiently trusted or of lower risk and allow highly trained caregivers to focus on more difficult issues.

5.4. Ambient prediction challenges

The final category in our analysis is the area of ambient prediction. We alluded to some of this in section 5.3. AI and ML techniques can be used with direct measurements to interpret them with more accuracy and to take reliable actions safely. With ambient measurements, however, this becomes even more important. As previously mentioned, ambient measurements are less reliable as they require additional inference beyond measurement. AI and ML are ideal tools for this situation because they become more accurate with more data and more feedback. Since ambient measurements require no user interaction and no divergence from what the patient would otherwise be doing, they can be taken at a higher frequency. An ambient RF sensor that identifies falls can learn to distinguish between a human fall and simply an object being dropped by analyzing millions of measurements and identifying the subtle clues that would not be noticed by humans.

Many people now have some familiarity with AI with the proliferation of Amazon Alexa and Google smart speakers. While amusing mistakes are sometimes made, these voice interfaces are amazingly accurate and are relied on every day to take billions of actions. If a fall is detected by an ambient RF sensor, a smart speaker can just ask if the patient has fallen. If no response is given within a time threshold, the appropriate stakeholders can be notified. If the patient responds and says everything is fine, notification can be deprioritized, and the patient feedback can be used to improve the accuracy of the ML model used by the RF sensor.

6. Conclusions and recommendations

In this paper we have discussed how telecom operators can enhance their existing analytical infrastructure to meet the needs of telecom for wellness (T4W). In the process we have shown the enhancements are incremental to the challenges they are addressing in T4W space. To demonstrate the incremental enhancements, we segmented the T4W challenge space into four easily understandable groups of problems. These challenges are further analyzed to gain insights into the operator's analytical architectural impacts, data sets to be collected, and algorithms to be implemented.

T4W offers a spectrum of opportunities to cable operators. We recommend operators to follow these recommendations:

- Pick your T4W challenge space based on your risk tolerance.
- Understand the needs of the challenges and evaluate how to support the needs with your capabilities.
- Bring in the problem-solving capabilities based on the scope of your T4W solution (realizing most of them are straight forward interpretation).
- Enhance your privacy and security infrastructure to the needs of T4W.

7. Abbreviations

7.1. Abbreviations

AI	artificial intelligence
AIP	aging in place
HAH	home as a hospital
HIPAA	Health Insurance Portability and Accountability Act
ML	machine learning
SCTE	Society of Cable Telecommunications Engineers
SNG	sensor network gateway

T4W	telecom for wellness
PII/PHI	personally identifiable information/personally identifiable health information
QoE	quality of experience

8. References

[1] Sudheer Dharanikota, Jason Page, *Metadata/Telemetry support from Cable Operators to address Telecom for Healthcare opportunity*, SCTE Expo, 2021

[2] Duke Tech Solutions market Research, *Telehealth market report – A Telecom-based opportunity analysis*, available A

[3] Sudheer Dharanikota, Ayarah Dharanikota, *Why are cable operators natural fit to support Telehealth? An inter-industry perspective*, SCTE Expo, 2020

[4] Ian Wheelock, Charles Cheevers, Sudheer Dharanikota, *The Business Case for Aging in Place with Cable Operators*, SCTE Expo, 2020

[5] Sudheer Dharanikota, Ayarah Dharanikota, Dennis Edens, Bruce McLeod, *Aging in Place business case for cable operators*, SCTE Journal, June 2021

[6] Sudheer Dharanikota, Ayarah Dharanikota, Dennis Edens, Bruce McLeod, *Aging in Place Market Landscape from a Cable Operators Perspective*, SCTE Journal, June 2021

[7] Sudheer Dharanikota, Ayarah Dharanikota, Dennis Edens, Bruce McLeod, *Telehealth business case for cable operators*, SCTE Journal, September 2021

[8] Sudheer Dharanikota, Ayarah Dharanikota, Dennis Edens, Bruce McLeod, *Telehealth Market Landscape from a Cable Operators Perspective*, SCTE Journal, September 2021

[9] Sudheer Dharanikota, *Summary of Telecom for Wellness interviews*, Oct 2021, available at https://duketechsolutions.com/telecom-for-healthcare-SCTE/

[10] Sudheer Dharanikota, Clarke Stevens, *End to End Telecom for Healthcare Architecture – A Cable Industry Perspective*, SCTE Expo, 2021

[11] Clarke Stevens, Sudheer Dharanikota, *Aging in Place and Telehealth Use Cases from the Cable Operator Perspective*, SCTE Journal, March 2022

[12] Data Standards Subcommittee, Working Group 3, Aging in Place

[13] Data Standards Subcommittee, Working Group 4, Telemedicine

[14] Sudheer Dharanikota, *Understanding the basics of Quality of Experience – Gaming focused*, DTS white paper, March 2020

[15] HHS.gov, *Health Information Privacy*, available here

[16] Rajesh Abbi, Charles Chapman, Sudheer Dharanikota, Kyle Haefner, Clarke Stevens, *Requirements for the IoT Infrastructure in the Customer Premises*, SCTE Expo, 2022

[17] Sudheer Dharanikota, Charles Cheevers, *The Cable Home is the Wellness and Telemedicine home – lets now deliver these new solutions*, SCTE Expo, 2022

Sustainable Supply Chain Assessment for Cable Ops

A Report Developed for SCTE's Cable Operator Member Companies to Help Improve Sustainability Profiles

A Technical Paper prepared for SCTE by

Mario Aleman (Villanova University)
Mariah Bodine (Villanova University)
Yen Leng Chong (Villanova University)
Queen Okon (Villanova University)

Advisor
Prof. Karl Schmidt (Villanova University)

Table of Contents

List of Figures

List of Tables

1. Introduction

The emergence of sustainable supply chain (SSC) models has become a critical approach for the technology industry to address public interests and achieve goals for their stakeholders while simultaneously considering the optimization of environmental, social, and governance (ESG) aspects. A recent report on sustainability and consumer behaviors [1] indicates that an average of 30% of consumers will purchase from organizations in the electronics industry that provide sustainable products and services. Sustainable practices from these organizations include but are not limited to a) committing to ethical working practices; b) respecting human rights; c) reducing waste in the manufacturing process, d) reducing their carbon footprint, and e) supporting the adoption of circular practices.

An appropriate corporate sustainability model can have positive impacts such as maximizing economic benefits by reducing material waste, improving efficiencies, and reducing carbon footprint. Secondly, it increases revenue growth through market share and profitability. Thirdly, it leads to effective risk management by managing regulatory and compliances risk. From a customer perspective, it enhances consumer loyalty, innovation, and employee quality of life [2].

Incorporating sustainability frameworks in the supply chain such as a circular economy and a social, technological, economical, environmental and political (STEEP) analysis can help industries adopt best practices in their corporate, social, environmental and economic systems. In this report, we identified the challenges and best practices based on a benchmarking analysis of numerous SCTE member telecommunications companies, a literature review, and further investigation of ESG practices and impacts.

The objective of this study is to review and develop a generic 'green' supply chain model for SCTE's cable operator member companies to help improve their sustainability profiles. This assessment includes a review of baseline inventory and a highlight of relevant supply chain best practices, such as supplier management, codes of conduct, key performance indicators (KPIs), and strategic partnerships for member companies.

2. Sustainable supply chain frameworks

The word "sustainability" was first introduced by the Brundtland Report in 1987 by the United Nations' World Commission on Environment and Development. The goal of business shifted from focusing only on generating shareholder value to creating long-term stakeholder value and sustained growth that considers the environmental, social and governance (ESG) performance of companies. Investors are increasingly interested in companies' sustainability strategies and approaches to better understand their exposure to various ESG risks and their ability to manage and mitigate those risks and create business value [3].

These three factors are intrinsically interconnected in business value. A comprehensive approach to business management, incorporating ESG considerations alongside financial ones, will serve as a sound business model that supports business continuity and competitiveness over the long term. Environmental and social (E&S) issues, for example, are highly relevant to be incorporated into the governance structure as shown in figure 1. ESG indicators are intended to provide basic comparable sustainability information which is relevant for corporate reporting as well as to measure and demonstrate actual impact and progress in those areas.

Figure 1 - ESG in Corporate Value and Reporting [3]

By definition, a supply chain model is a network of all entities involved in producing and delivering a finished product to the final customer. This may include but not be limited to the suppliers, manufacturers, distributors, retailers, and customers.

From a holistic, business perspective, a supply chain integrates different sets of functions, as shown in figure 2, which are important to help us in the following areas:

- Develop a plan that best meets sourcing, production, and delivery requirements;
- Deliver goods and services to meet planned or actual demand;
- Transform product to a finished state to meet planned or actual demand;
- Provide finished goods to meet demand including order management, transportation, and distribution; and
- Return service and products post-delivery and provide customer support.

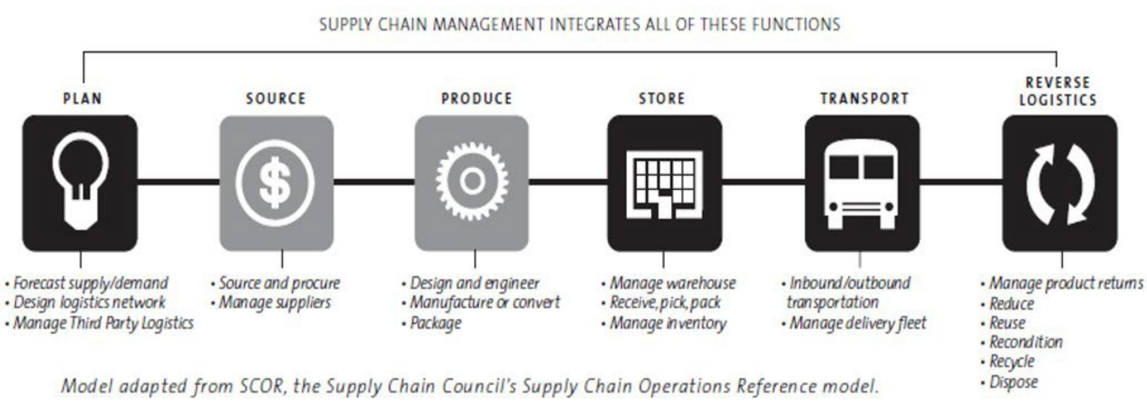


Figure 2 - The Business View of Supply Chain Management

The fundamental aspects of supply chain management relate to a) product and process design, b) purchasing and logistics, and c) product end-of-life management. Successful management of these aspects must integrate with a sustainable business strategy that is supported with proper data collection, measurement indicators and reporting. A sustainable supply chain strategy also seeks to incorporate specific environmental and social features and benefits along the discrete operational functions.

Many companies across industries of varying sizes, and at different points in their corporate life cycle have given life to their sustainability goals via sustainable supply chain management. Companies need to understand how sustainability issues intersect, as seemingly responsible choices in one realm—often demanded by consumers and stakeholders—may have untold consequences in another realm, thereby undermining a company's efforts to be truly sustainable.

In the context of globalization, it is important for broadband cable companies to understand what is happening across their supplier tiers and avoid subsequent fragmentation of their supply chain. Organizations can be aware of abuse at their suppliers' facilities by understanding the complexity in their supply chain tiers as illustrated in figure 3.

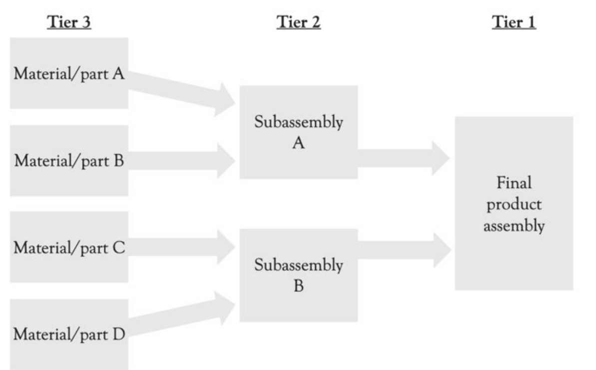


Figure 3 - Supply Chain Tiers in a Global Scope

A literature review of generic best practices is highlighted for each of the supply chain phases to successfully integrate ESG-positive activities in your business, including consideration of negative externalities such as the production of greenhouse gas (GHG) emissions as shown in figure 4.

Figure 4 - Activities and Best Practices In A Sustainable Supply Model

One of the most important indicators in a sustainable supply chain is end-of-life best practices. Many companies find product-specific improvement challenging, particularly when applied to products, technologies, and processes that change rapidly. Considering a product's end-of-life experience during the design phase of work will increase the profitability of implementing a reverse supply chain. Packaging is also an area where many companies can find opportunities for improvement. Examples include use of lighter weight materials, more recyclable materials, a move towards material homogeneity, and elimination of problematic materials. Managers should be able to incorporate approaches that could reduce their reliance on landfills and be able to turn product end-of-life management into a competitive advantage [4].

Moving from linear supply chains to circular supply chains is one of the main approaches to consider in the end-of-life product stage. Implementing a circular economy framework could not only improve product use extension but also provide resource recovery across all stages as illustrated in figure 5.

Some of the main benefits of adopting a circular economy are financial transformation at the corporate level, commitment to climate change mitigation and adaptation, resiliency, carbon footprint reductions, and competitive advantage.

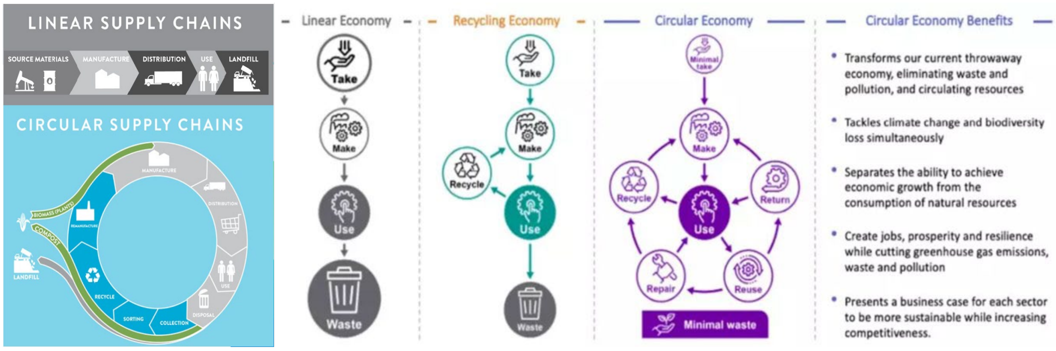


Figure 5 - Circular Supply Chain as a Model of Circular Economy and its Benefits

A sustainable supply chain helps improve productivity and competitiveness and saves money at the same time. By using sustainable techniques, such as the implementation of a circular economy framework, you increase the efficiency of equipment and industry activities at a significant cost saving.

3. Methodology

The following includes a list of activities performed to conduct a sustainable supply chain assessment of fifteen (15) SCTE members companies.

- Review of corporate social responsibility reports;
- Conduct interviews and surveys;
- Perform benchmarking analysis and develop companies’ baseline;
- Review sustainable supply chain metrics and indicators; and
- Evaluate findings using a STEEP analysis.

SCTE corporate members included in this Resilient Innovation through Sustainable Engineering (RISE) project attended SCTE Cable-TEC Expo 2022 in person on Wednesday, September 21, 2022, at the Pennsylvania Convention Center. The RISE student team was given access to attend Expo to learn from SCTE’s cable operator member companies and understand their sustainability profiles. The team prepared a list of questions for these selected companies and spoke with representatives to gauge understanding. All responses and contact information were collected to follow up with additional survey questions if necessary.

Furthermore, the SCTE management team arranged interviews with some SCTE members' companies for our RISE team. The interviews yielded more information on these members’ current policies, usage of tools and metrics, challenges, and future goals and plans in establishing sustainability across their supply chains. The team also conducted a literature review including member Corporate Social Responsibility reports, ESG reports, Sustainability Reports, various case studies, and other news reports. The effort was focused on reports and companies from the information and communication technology sectors to align with SCTE’s member population. Based on our findings from the literature review and company interviews, we concluded that we needed to evaluate the 15 SCTE member companies based on three types of analyses: level of sustainability engagement, key indicator behaviors of sustainable Supply chain; and STEEP. We coded the 15 companies as Companies A-P so company information could be kept confidential. General descriptions and our classification of “level of sustainability engagement” for each company is shown below in table 1.

Table 1 - General Description of Company A-P and its level of Sustainability Engagement

Company	Brief Descriptor of Company's Industry Role	Classification by Level of Sustainability Engagement
A	Manufacturer of wire and cable used in the transmission and distribution of electricity	Sustainable supply chain company
B	Provider of broadband internet, video, fixed-line telephony, and mobile telephony service	Sustainable supply chain company
C	Manufacturer and provider of connectivity solutions for the broadband service provider market	Beginning of sustainable supply chain
D	Manufacturer of computer hardware and software and provider of cloud computing and data analytics services	Sustainable supply chain company
E	Manufacturer and provider of hardware infrastructure and software intelligence	Sustainable supply chain company
F	Manufacturer and provider of industrial batteries and energy storage system	Sustainable supply chain company
G	Manufacturer of industrial batteries and electronics	Beginning of sustainable supply chain
H	Provider of broadcasting and digital cable television service	Green supply chain company
I	Manufacturer and provider of routers, network processors, and products for telecom infrastructure	Sustainable supply chain company
J	Manufacturer and provider of electrical power handling equipment, energy, and digital automation solutions	Sustainable supply chain company
K	Manufacturer and provider of cable, broadband, and automotive services	Green supply chain company
L	Manufacturer of electronic and fiber optic connectors, cable, and interconnect systems	Sustainable supply chain company
M	Manufacturer and provider of hardware infrastructure, software intelligence, and telecommunications equipment	Sustainable supply chain company
N	Provider of IT networking products, such as routers, switches, and IT security products	Sustainable supply chain company
O	Manufacturer and provider of software and computer services	Sustainable supply chain company

4. Results and analysis

The first analysis performed was to analyze companies' level of sustainability engagement. We determined the companies surveyed fell into three levels of engagement – 1) sustainable supply chain (SSC), 2) green supply chain (GSC) and 3) beginning phase of SSC. An SSC-level company is an organization that has a sustainability profile with a holistic approach addressing the ESG impact of their supply chain operations. We determined that 73% of member companies are at the sustainable supply chain level. SSC is a company that has a sustainability profile with a holistic approach addressing the ESG impact of their supply chain operations. The GSC level describes a company that focuses solely on the environmental impact of their supply chain operations. We determined that 13% of member companies are at green supply chain level. The remaining 13% member companies are in the beginning phases of developing a sustainability strategy for their own operations and have not yet shifted externally to the sustainability of their suppliers, which we called the beginning phase of SSC. These categorization results are shown in figure 6 below.

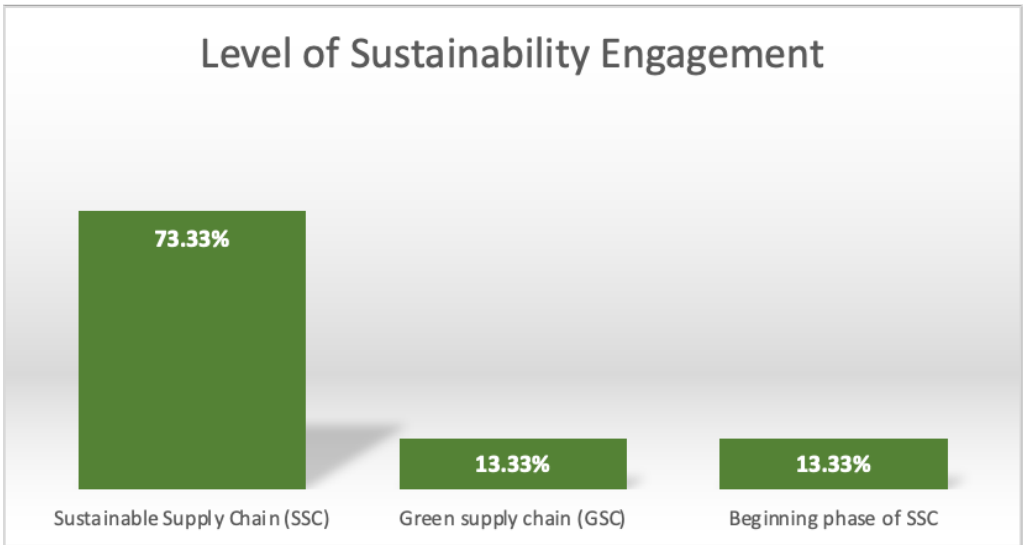


Figure 6 - Cable Industry Level of Sustainability Engagement

The second analysis of survey results examines supply chain management performance. Based on literature reviews of companies at the SSC level, as shown in Table 1, we identified these SSC companies that have strategic objectives and actionable tasks with measurable aspects of environmental, economic, or social systems. We identified six key performance indicators (KPIs) based on research literature that are deemed to be important in achieving a sustainable supply chain. These six KPIs, which are based on the potential supplier incentive for performance in literature review, include: 1) formal reporting, 2) supplier code of conduct, 3) stakeholder engagement, 4) supplier audits, 5) sustainability strategies for suppliers and 6) metrics for key performance indicators (KPIs). The results from our KPI analysis are shown in figure 7.

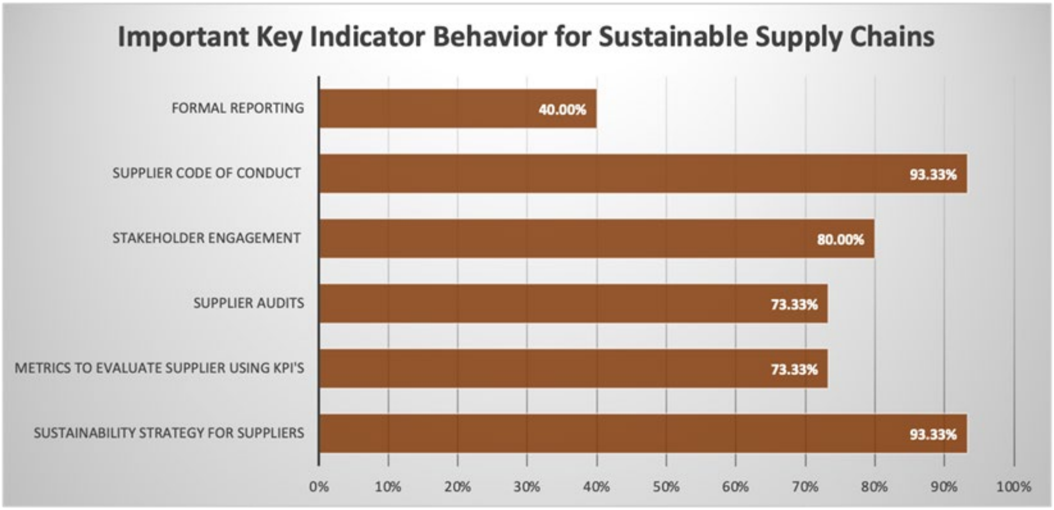


Figure 7 - Percentage of Cable Industry Companies Demonstrating each Key Indicator Behavior for their Sustainable Supply Chain

4.1. Formal reporting

The best way to ensure relevant performance tracking and information sharing is to use a formal standard that allows suppliers to report in a structured and transparent way. However, there is currently no universal platform for companies to report on their sustainability progress unless companies take extra initiatives in reporting their ESG goals. For example, Company A requested their global suppliers to participate in RBA-validated audits to gauge their degree of conformance to the RBA code. From the audit, they publish their survey results and identify non-conformance issues in labor, health & safety, environment, ethics, and management system. The report also identified an improvement in their non-conformance rate compared to their previous year's audit. Social performance is one of the only results shown, however, they also have tracked and published results about environmental and governance factors. GSC companies collect information focused more on environmental factors. For example, Company K measures its suppliers' sustainability initiatives on emissions, water, and waste progress and published their suppliers' progress through publicly available reports. From the data, only 40% of the companies are actively tracking and publishing their results. Despite low adoption, this metric reporting on full environmental, social, and governance factors is as important as other key indicators to increase transparency across companies' supply chains.

4.2. Supplier codes of conduct

A supplier code of conduct is a legal document to communicate the mission of the company, standards, and expectations of their employees in correlation with social and environmental matters. Of the companies we evaluated, up to 90% of the companies have a supplier code of conduct. The leaders of the SSC group set forth detailed standards and guidelines for each supplier to adhere to using international labor and environmental standards. For example, Company M requires suppliers to comply with all environmental laws and material content restrictions, adhere to the Responsible Business Alliance (RBA) code of conduct, implement the RBA code of conduct (which includes conflict minerals due diligence), and conduct audits in suppliers' facilities, and develop corrective actions to ensure compliance. Companies that are within the GSC group provide high-level standards and regulations they expect suppliers to comply with. For example, Company H expects suppliers to comply and adhere to social and environmental laws following the applicable laws and regulations in the states and countries in which the suppliers operate. While the company provides contact information for suppliers if they identify any unethical practices or audit issues, they do not require suppliers to comply with certain international regulations or further commit to addressing issues. Companies in the beginning phase of SSC practices do not disclose supplier codes of conduct documents on their website or report.

4.3. Stakeholder engagement

A valuable early step when building a sustainable supply chain is fostering active engagement with all stakeholders. By involving various groups such as employees, non-governmental organizations (NGOs), government agencies, investors, and local community members to understand their priorities and opinions regarding sustainable business practices, a company can determine how to tailor their strategies to meet the desires of its most valued stakeholders. Of the companies that we evaluated, 80% reported involving their stakeholders in some capacity when determining important criteria for supplier management. Leaders in sustainable supply chains, such as Company A and Company E, proactively conduct materiality assessments with all stakeholder groups to learn what is important to them in a supply chain. Both companies also form an open line of communication and encourage feedback from their stakeholders on supply chain practices to review on an ongoing basis. Working to make progress in the areas that valued groups have identified as top priorities drives a business toward making meaningful and effective change across the value chain. These companies additionally use material results to identify risks and subsequently develop training for both their suppliers and internal procurement teams. The assessments also highlight opportunities for growth within internal and external operations. For companies that have focused largely on the environmental impacts, such as Company H, they incorporated stakeholders' opinions on the main goal of greening the supply chain. By determining what the order of priorities was regarding natural resources, emissions, and pollutants, Company H can appropriately focus its efforts. Since a truly sustainable supply chain is determined by the combined ESG factors, those with GSC levels can further engage their stakeholders to determine where progress is needed to round out their supply chain practices. We found that for businesses just starting out on their sustainable supply chain journeys, such as Company C, their stakeholder engagement was commonly a one-way communication on current goals and practices.

4.4. Supplier audits

A strong way to continuously verify supplier behaviors in accordance with codes of conduct and other contractual agreements is through regular supplier audits. Many companies perform audits at the onset when choosing a supplier, but as priorities change and as companies grow, the weights of these audit results develop as well. Supplier audits can be used routinely to review and monitor partners. Of evaluated companies, 73% disclosed conducting some form of supplier audits on a "regular" basis. Companies A, D, and E have well-established sustainable supply chain practices and conducted multiple and often third-party verification audits to confirm their suppliers were performing up to defined standards. These companies also used audits to determine where opportunities for growth lie in their supply chains and how they could help facilitate better conduct. Cable industry companies that focused mostly on green supply chains, such as Company K, also conducted audits on their suppliers but tended to focus solely on the environmental indicators of those results. Although SCTE member companies in the beginning phase of their sustainable supply chain endeavors did not disclose specific sustainability audits, many reported that they did conduct audits for their suppliers which is a strong starting point for incorporating sustainability-specific topics.

4.5. Sustainability strategy for suppliers

With the increasing demand for corporate organizations to incorporate sustainability into their supply chains, developing or cascading a sustainable strategy across the supply chain is a foundational element. These strategies should go beyond setting sustainability expectations for suppliers, to supporting or partnering with suppliers with corresponding actions to drive sustainability performances within their supply chains. Out of the 15 cable industry companies we surveyed, 93% indicated that they had sustainability strategies in place for suppliers. Amongst the companies surveyed, Company J serves as an excellent example of a company that has successfully expanded its sustainability program to its suppliers. Practical steps through which Company J has been able to achieve this stem from various customer engagements, such as monthly community calls in which suppliers brainstorm about practical sustainability strategies to foster collective knowledge sharing. On top of that, Company J provides one-on-one support to suppliers. They also provide a dedicated web portal for suppliers to provide leadership support, research, training, case studies, and tools to help improve suppliers' sustainability performances. As a result of these practices, Company J has been able to engage 1,000 of its top cable industry suppliers to commit to reducing their operational CO_2 emissions by 50% by 2025. From the survey, it was observed that the leaders in the sustainable supply chain management practices group help their suppliers develop ESG/sustainability strategies while leaders in the green supply chain management practices group help their suppliers develop only environmental sustainability strategies.

4.6. Metrics to evaluate suppliers using KPIs

One of the current major challenges of sustainable supply chain management is the lack of transparency and visibility across the supply chain, especially across supplier networks that involve multiple tiers of suppliers. As a result of this, there is an increased interest in the deployment of quantitative KPIs to measure and monitor supplier sustainability performance in order to improve sustainability performance across the supply chain. Out of the cable industry companies surveyed, 73% indicated that they have metrics to evaluate suppliers using KPIs. Company J is a great example of a company that has leveraged digital tools and analytics to successfully track its supplier's sustainability strategies quantitatively in real time through KPIs. From the deployment of both intra-company and third-party tools, Company J has made supplier interactions more fluid and has increased visibility across the supply chain. An example of the third-party KPI used by Company J is the Eco Vadis platform which leverages ISO 26000 guidelines.

5. STEEP Analysis

The final analysis that we conducted examined the approach that SCTE member companies took to achieve a sustainable supply chain using a social, technological, environmental, economic, and political (STEEP) framework. For each component of the STEEP analysis, we evaluated the company's sustainability on their policies and actions. Regarding policies, we observed if companies had established guidelines, standards, principles, or goals with which they expect and/or require their suppliers, stakeholders, and business partners to follow and comply. Regarding actions, we observed the actions taken by the company in addressing challenges and opportunities through engagement with suppliers, stakeholders, and business partners. The findings of the analysis results are presented below:

5.1. Social

Companies that have established social goals, standard policies, actions, and results have been observed as having a sustainable supply chain. In terms of policy, 93% of companies we reviewed have global human and labor rights policies, 80% have responsible sourcing of minerals policies such as conflict minerals (3TG), and 66% have hazardous chemical policies to protect workers' health. Out of the 93% of companies with social policies, 73% of the companies are a member of the Responsible Business Alliance (RBA), Responsible Minerals Initiative (RMI), and Clean Electronics Production Network (CEPN). These companies are mostly within the level of SSC. However, only 66% of the companies are engaged in supplier collaboration through online training, learning, and capacity-building initiatives. More detailed information can be found in figures 8 and 9.

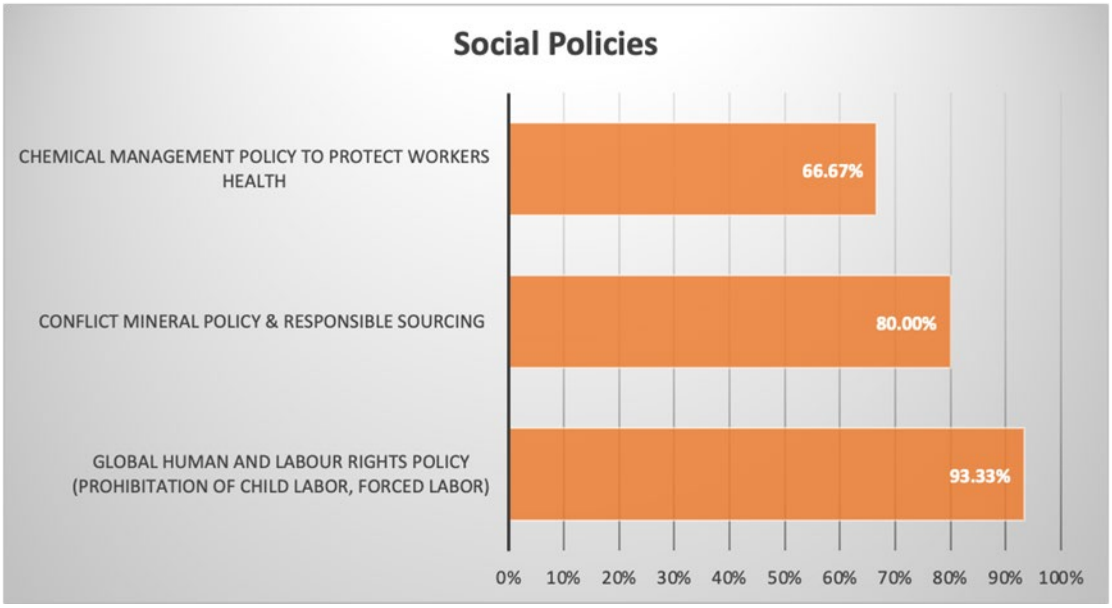


Figure 8 - Social Policies Adopted in SCTE Member Companies

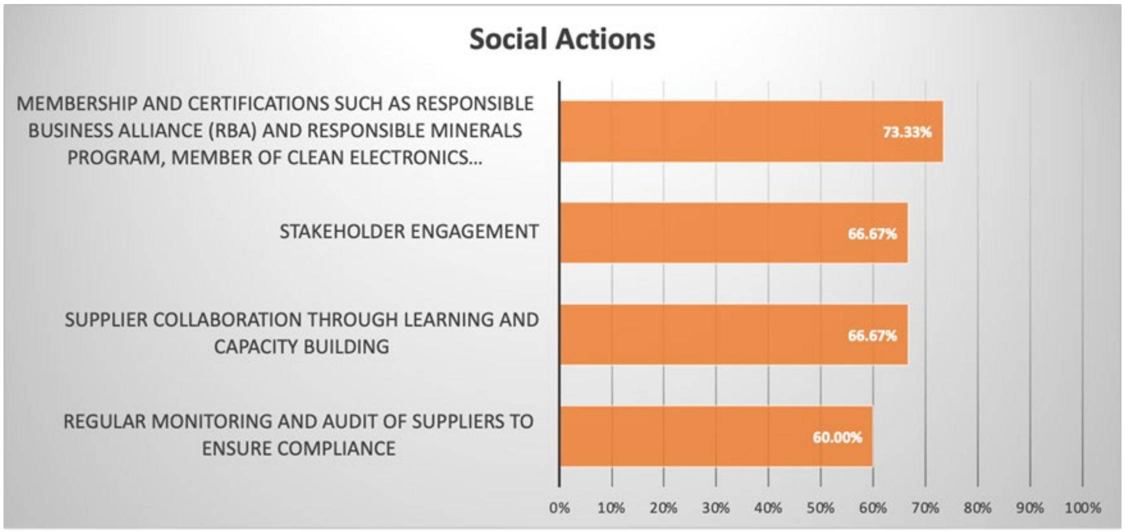


Figure 9 - Social Actions Adopted in SCTE Member Companies

5.2. Technological

There are numerous software applications, cloud-based and online platform tools that can facilitate tracking suppliers' sustainable performance progress. A global enterprise company has very different ESG reporting needs and complexities compared to a small or medium business. Smaller organizations need an easy-to-use, automated, lower-cost solution that can likely be used by one or two administrators to share data with larger customers and answer questionnaires. By comparison, global organizations have larger teams and more resources, but also require enterprise workflow and governance support, ESG report audit and approval workflows, and strict IT security. Unfortunately, fewer than 50% of companies surveyed required their suppliers to provide data and reports. That means many broadband cable industry companies have not yet set mandatory rules for their suppliers with regards to reporting. On the bright side, we identified that 80% of SCTE member companies have been tracking their energy, water, and waste using Eco Vadis, CDP, Dow Jones, and other sustainability tracking tools for STEEP analysis such as Pestle Analysis Tool [11]. See figures 10 and 11 for further explanation of the sustainable technological actions observed in the surveyed companies.

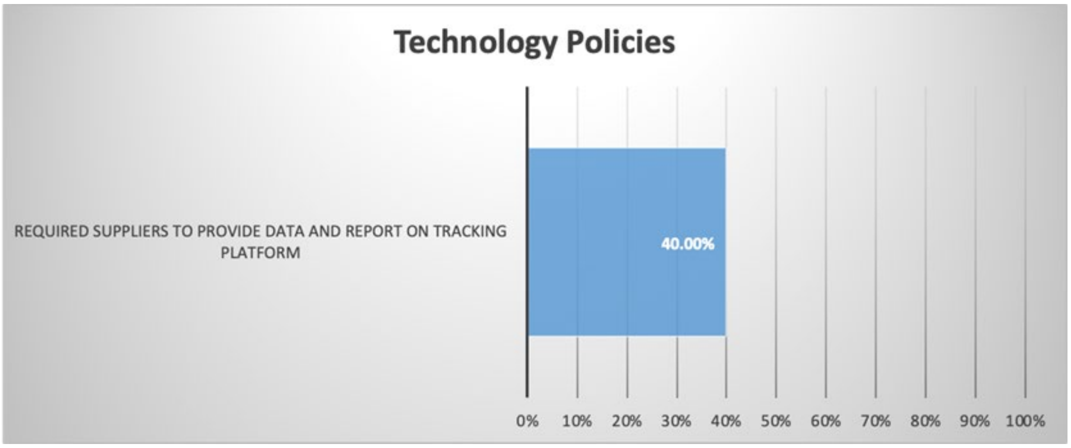


Figure 10 - Technology Policies in SCTE Member Companies

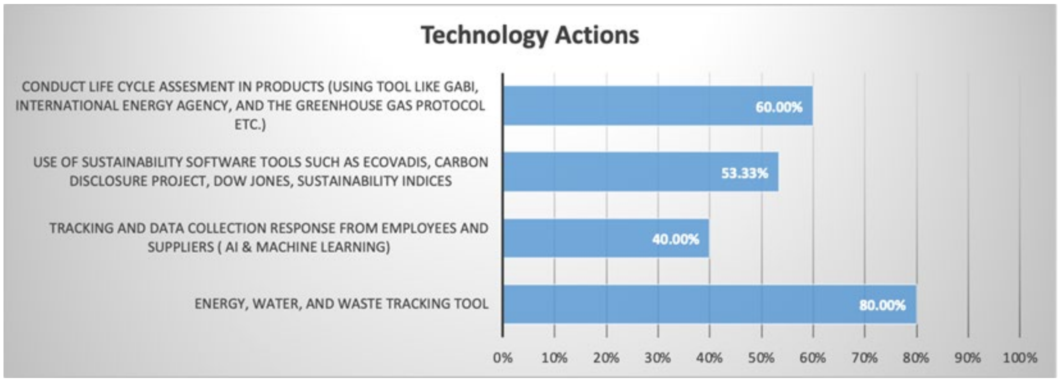


Figure 11 - Technology Actions in SCTE Member Companies

5.3. Environmental

Through our analysis of surveyed companies' sustainable supply chain practices, we determined that the largest attention was placed on environmental impact, as it is a common starting point for companies beginning their sustainability journeys and the focus of green supply chains. We were able further to identify environmental initiatives into categories of 1) energy and carbon dioxide emissions, 2) products & materials, 3) water consumption, and 4) circularity. For each of the four environmental categories, some actions were more commonly adopted for the companies to meet their goals. To reduce energy and carbon emissions, 93% of cable companies reported targeting energy efficiency with their suppliers to lessen overall impact. When considering input materials, reducing waste materials in manufacturing and redesigning products, and packaging to increase material efficiency are tied as the most common practice by 86% of companies. For water consumption, the emphasis is on reducing water usage across the value chain with 80% of companies making strides toward that goal. Finally, for circularity, 100% of broadband cable industry companies mentioned incorporating product circularity with their suppliers in terms of reuse, repair, refurbishment, or recycling practices. Please see figures 12 and 13 for policies and actions in environmental assessment.

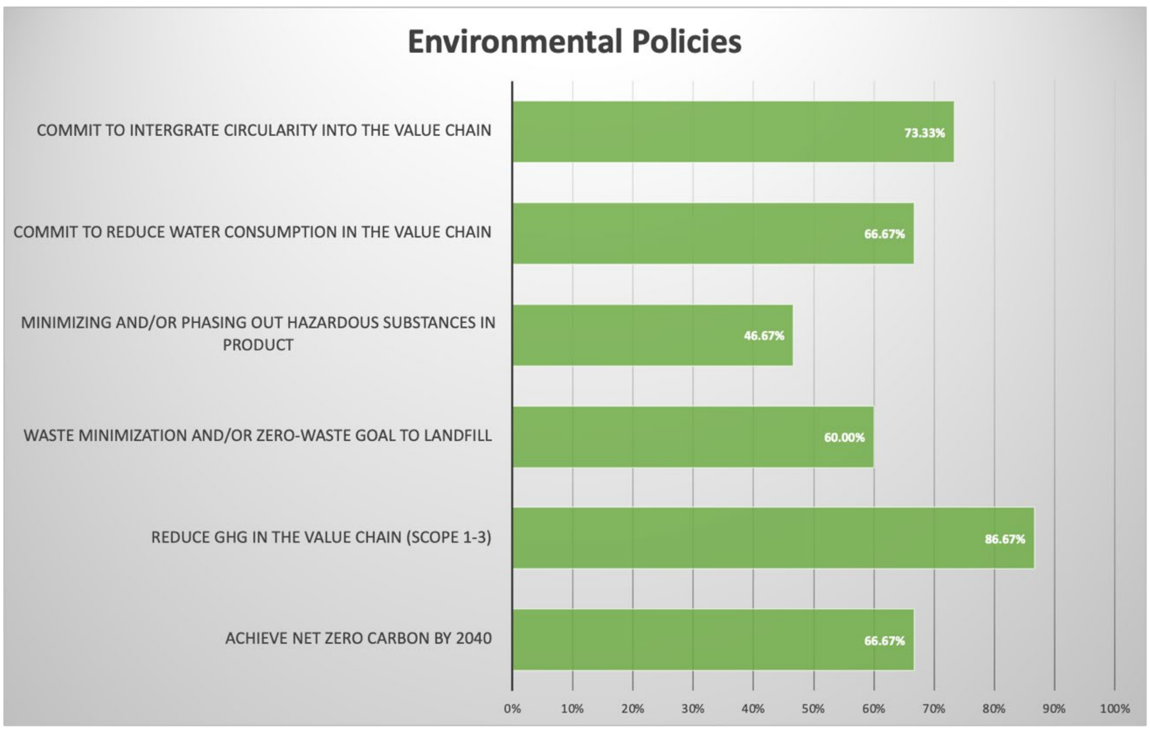


Figure 12 - Environmental Policies in SCTE Member Companies

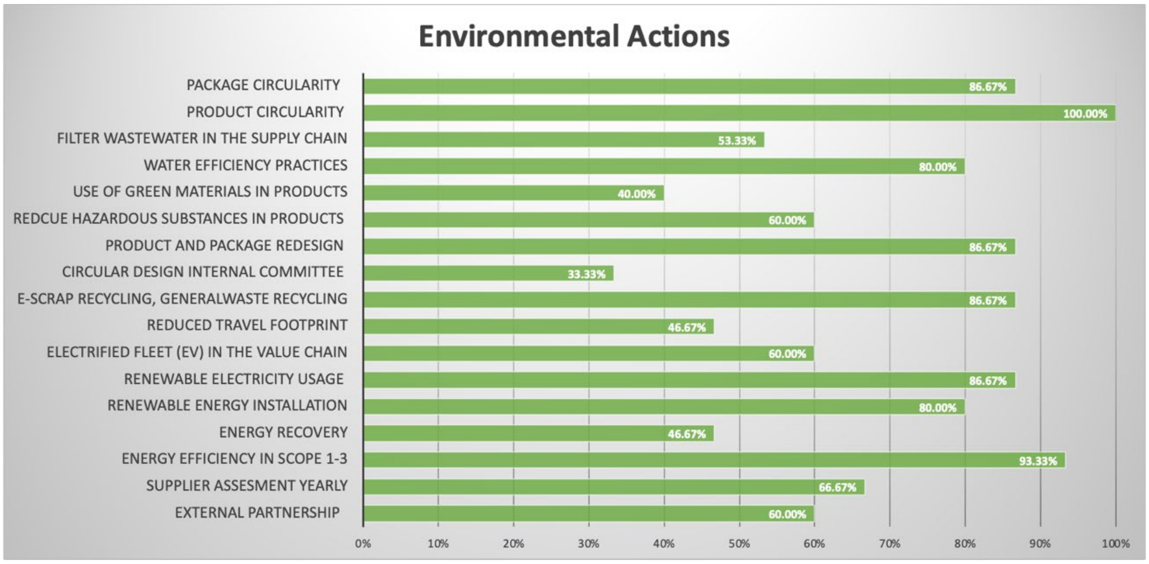


Figure 13 - Environmental Actions in SCTE Member Companies

5.4. Economical

Of the SCTE member companies surveyed, 67% indicated that they observed cost reduction in the value chain because of their sustainability efforts. This can be attributed to the reduction in material waste in production processes because of circular economy practices implemented by these companies, and in the reduction in water, electricity, and fuel consumption which also led to a reduction in their environmental footprint. Of companies surveyed, 33% indicated investments in improving sustainability across the value chain, such as an investment in digital tools, data analytics, and/or information-sharing platforms. These investments are used to capture metrics, develop supplier scorecards, set benchmarks against KPIs, and subsequently establish governance policies or investments in renewable sources of energy to reduce dependence on fossil fuel-based electricity, etc. See Figure 14 for analysis of economic actions.

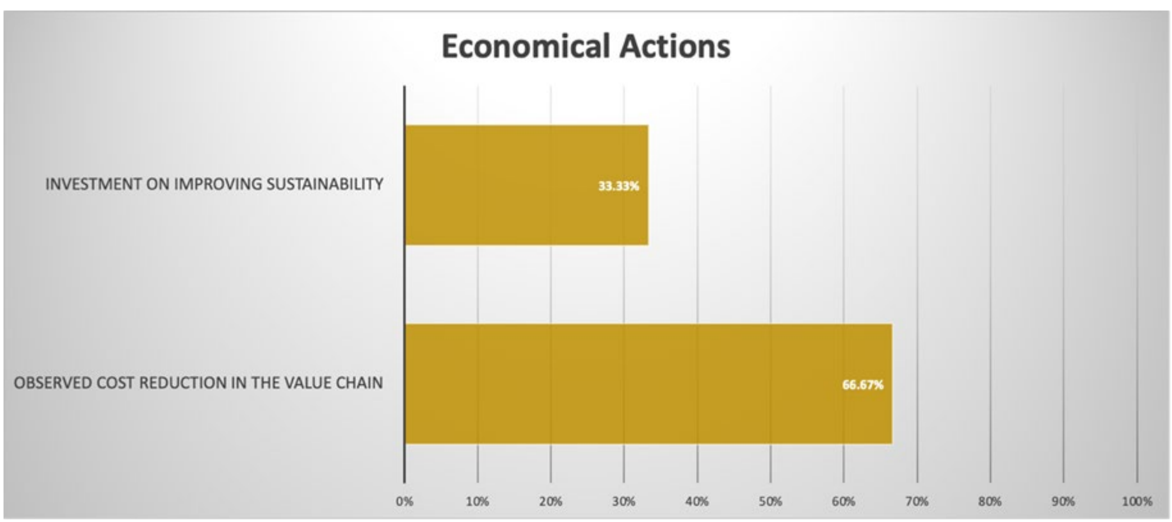


Figure 14 - Economical Actions in SCTE Member Companies

5.5. Political

All 15 broadband cable industry companies surveyed indicated that they comply with global and national regulatory requirements and laws and require the same compliance from their suppliers. Apart from compliance with regulations, transparency and visibility of sustainability performance across the supply chain is a foundational part of effective business management and is crucial for maintaining trust in businesses. Out of the 15 companies surveyed, 67% indicated indexes against frameworks, standards, and platforms such as Sustainability Accounting Standards Board (SASB); Global Reporting Initiative (GRI); Climate Disclosure Standards Board (CDSB), formerly known as Carbon Disclosure Project (CDP); World Economic Forum (WEF); and other climate-related financial disclosures. This indicates that there is still work to be done where company disclosure of sustainability performance is concerned. See figure 15 for percentage of cable companies taking these described political actions. Other governance recommendations include but are not limited to the reviewing and guiding corporate strategy, major plans of action, risk management policies and procedures, annual budgets and business plans; setting performance objectives; monitoring implementation and corporate performance; and overseeing major capital expenditures, acquisitions and divestitures [8].

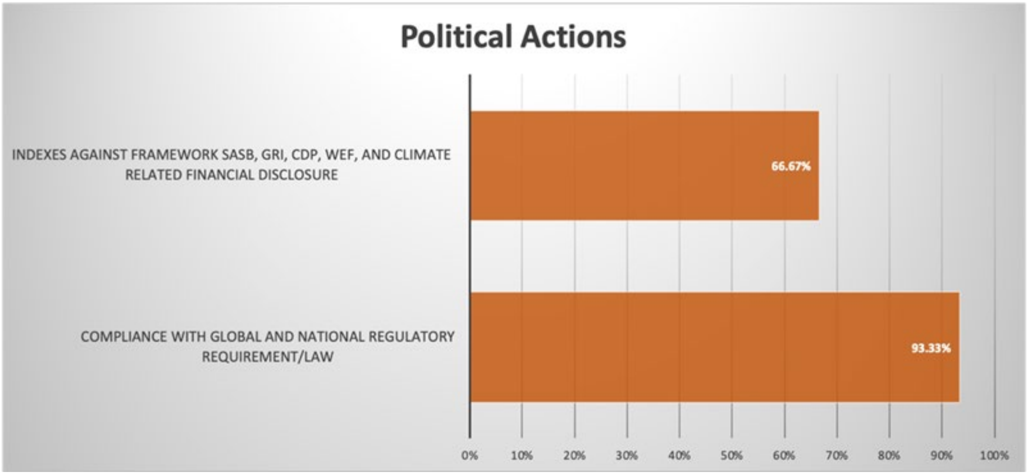


Figure 15 - Political Actions in SCTE Member Companies

A **STEEP** analysis is one of the most insightful assessments for a sustainable supply chain, particularly when the aim of "greening" the different processes and metrics as well as best practices playing a vital role. Figure 16 shows a list of recommendations and best practices to consider at the corporate level, in particular policies that could be adopted and transformed.

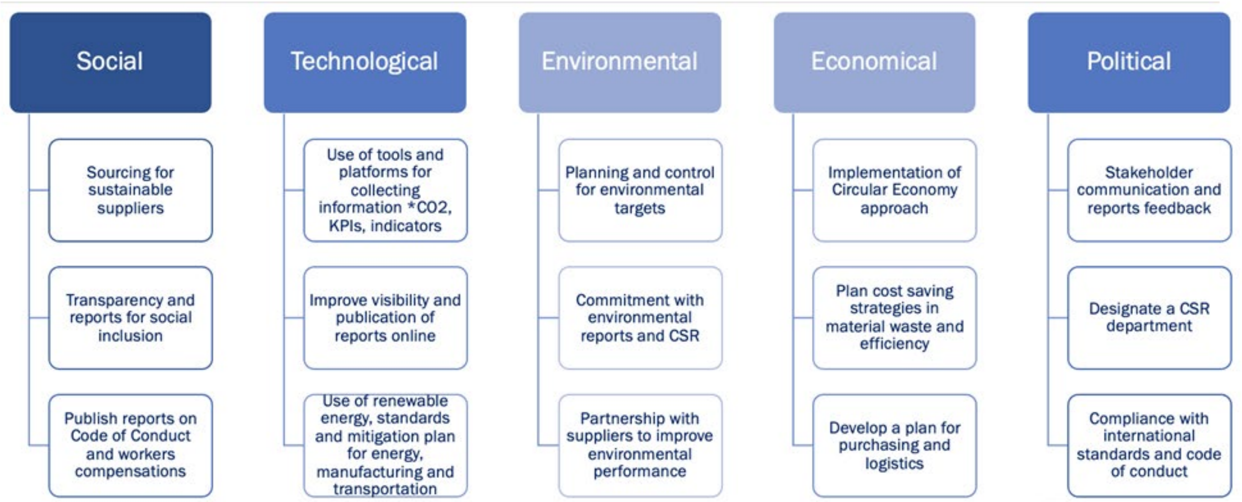


Figure 16 - STEEP Analysis and Best Practices for "Greening" the Supply Chain Model

6. Conclusions and recommendations

Through our survey data and literature review of effective sustainable supply chains, we have compiled documented best practices that can be implemented at any information communication and technology (ICT) organization, regardless of their stage in sustainable supply chain management. Both the survey results and STEEP analysis (above) highlight numerous social, environmental, and economic best practices for companies to consider. The more mature companies (from the survey) and external best practice companies (e.g. Apple, Cisco, Siemens, HP, Schneider Electric, to name just a few) appear to excel at executing the foundational elements we highlighted earlier in the report;

- **Effective Supplier Management:** strategy deployed with clear goals and objectives for all suppliers including codes of conduct addressing the most relevant ESG issues for all tiers; conducting audits with corrective action plans established; providing training/assistance where needed.
- **Metrics that Matter:** identification, collection and monitoring the most critical KPIs that will drive the company's performance toward achieving overall sustainability goals; alignment with nationally recognized reporting systems (e.g.- GRI, CDP, SASB) that will facilitate transparency with stakeholders.
- **Collaboration:** Engagement with internal/external stakeholders to identify and assess current and emerging opportunities and risks that are material to the company; consideration of partnering with external NGOs and think tanks on the most challenging issues.

Some of the potential supplier incentives for performance may also include:

- Reduce the number of audits conducted;
- Establish a preferred supplier program;

- Increase business volume;
- Provide recognition and awards;
- Allow participation in strategic buyer/supplier planning meetings;
- Share costs for sustainability improvements; and
- Provide assistance for capability building.

For ICT companies, obviously technology applications can facilitate greener, more efficient processes, products and packaging. Digitization of supply chains, artificial intelligence (AI), and the Internet of Things (IoT) enable companies to monitor inventories, energy use, and emissions in real time while advances in material engineering and 3DP (additive manufacturing) can lead to significant innovation in product/process design. Even tools such as life cycle assessments (LCA) are being used to highlight the most important areas for supply chains to focus on reducing their overall footprint and improve sustainability. Other software tools could improve the collection of relevant data for reporting purposes.

Visibility across the entire value chain can be one of the biggest inhibitors to establishing and monitoring a sustainable supply chain and so many of these practices aim to open those lines of communication and benefit everyone in the process. Creating a sustainable supply chain is not a one-time event or the same for every organization, but instead, an ongoing adaptive journey that will grow and change along the way.

7. Abbreviations

7.1. Abbreviations

AI	artificial intelligence
CDP	Carbon Disclosure Project
CEPN	Clean Electronics Production Network
GHG	Green House Gases
GRI	Global Reporting Initiative
GSC	Green Supply Chain
ICT	Information, Communication and Technology
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
RBP	Responsible Business Alliance
RISE	Resilient Innovation through Sustainable Engineering
RMI	Responsible Minerals Initiative
SASB	Sustainability Accounting Standards Board
SSC	Sustainable Supply Chain
STEEP	Social, Technology, Economic, Environmental, Political
3 DP	Three Dimensional Printing

8. References

[1] "Sustainability & Consumer Behaviors 2022," Deloitte United Kingdom (link)

[2] "How sustainable supply chains are driving business transformation." EY | Building a better working world (https://www.ey.com/en_gl/supply-chain/supply-chain-sustainability-2022) EYG no. 007702-22Gbl 2202-3978345 ED None

[3] "ESG and Sustainability Reporting Guidance for Mongolian Companies" (link)

[4] M. Pullman, M. Sauter "Sustainability Delivered – Designing Socially and Environmentally Responsible Supply Chains" Business Experts Press, LLC, 2012 (link) ISBN-13: 978-1-60649-319-9 (e-book)

[5] G. Hedstrom "Sustainability What It Is and How to Measure It", Nov 2018

[6] M. Pullman, M. Sauter "Sustainability Delivered – Designing Socially and Environmentally Responsible Supply Chains" Business Experts Press, LLC

[7] "The Green House Gas Protocol" The World Resouces Institute (link)

[8] "G20/OECD Principles of Corporate Governance" OECD (link)

[9] H. SZIGETI1, M. MESSAADIA2, A. MAJUMDAR3, B Eynard "STEEP Analysis as a Tool for Building Technology Roadmaps" Conference paper October 2011.

[10] European Environment Agency (2010, November 28). SOER_2010_GLOBAL_MEGATRENDS. (link).

[11] M. Morrison. PEST/ PESTLE Analysis Tool -History and Templates (link)

[12] "Sustainability Reporting Guidance for the Oil and Gas Industry" IPECA, 4th (link)

[13] Global Reporting Initiative (GRI) (link) including Reporting Principles in GRI 101: Foundation (link)

[14] United Nations (UN), 2015: About the Sustainable Development Goals (link)

Reflecting on Energy and Broadband Thoughts from Colorado 2022

Letter to the Editor prepared for SCTE by

Derek DiGiacomo, Senior Director, Energy Management Programs and Business Continuity
SCTE

It was a cold snowy day in Colorado, and I made my way from the local hotel to the CableLabs office as the sun was coming up. It was Day Two of our energy meetings hosted at headquarters. This meeting felt different from the April 2022 meeting that was so close to the pandemic unofficially winding down. This November meeting had a good feel: more ease in the conversation, more comfort being present with attendees; and the program was expanded to a full day. During my walk over I was thinking about questions surrounding the day. Will there be any new content? Who had to leave after Day One? How will the commute be to the airport as more snow was expected? How were things back home with family and friends?

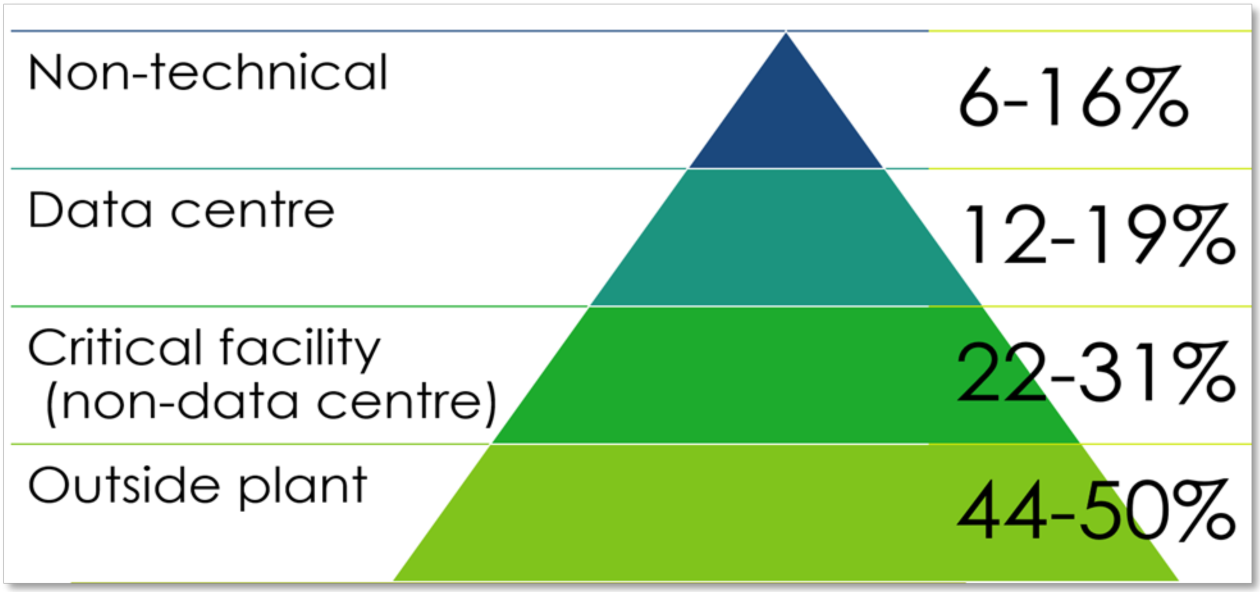
Day One's materials and discussions were an inspiration for our working group meetings that were looming the next morning. During my Day Two opening conversation with our Energy Management Subcommittee chairman, Ryan Capone, Vice President, Network Facilities & Energy at Comcast, our discussion spurred the idea of how artificial intelligence and machine learning could play a part in making energy decisions. I wanted to follow up and take a moment to ask additional questions.

Artificial intelligence was featured in science fiction movies and was not in the toolbox of broadband providers when we began the Energy 20/20 program in 2014. Today, we have a very productive SCTE working group focused on that very topic, chaired by Srilal Weera and Veronica Bloom, both with Charter Communications. Since its inception a few years ago the team has generated a number of articles and hosted numerous presentations over a wide range of projects. A timely topic that could be covered is energy. Microgrids with multi-power sources have become more accessible. Putting energy and this new powerful technology-aided decision-making tool together can drive reliability, favorable cost, and more optimized greenhouse gas emission controls. A key is knowing what questions to ask. This leads me to the heart of the letter, the questions.

Thought One: "Where in the cable plant can renewables impact our energy experiences the most?" Any energy strategy in 2023 should plan for renewable energy production and procurement. It is the responsible thing to do. Whether it is purchasing green power or self-generation with the deployment of solar, fuel cells, or even micro wind turbines, how can artificial intelligence help us answer that question? Where should we self-generate? Where should we prioritize procurement of renewable power (besides everywhere)? What competitive advantages can renewable energy provide?

Thought Two, "How can the customer's experience improve when operators embrace passive networks as much as possible?" SCTE has hosted several presentations demonstrating that a passive network can be much more energy efficient and even more reliable than a traditional copper/deep HFC cable plant. It has been discussed that optical networks require less physical plant maintenance but can be capital intensive. How can artificial intelligence engines in 2023 answer that question for each operator? Each provider has their own unique scenario and will require different input variables to calculate and demonstrate what makes the most sense. Thanks to better data access, we have an improved picture of where our primary consumers of power reside. The pyramid picture below tells that story.

SCTE 2021 Power Pyramid



Thought Three, “How can we embrace a mentality of ‘use only the energy needed to support the demand?’” We as humans, have an affinity for extra – extra money, extra food, extra physical objects, etc. With the idea of growing but fluctuating power demands, how can we leverage artificial intelligence capabilities on our networks to make positive change and embrace peak load shaving? For example, several years ago Google shared the Deep Mind for cooling needs that impacted their data centers (https://www.deepmind.com/blog/deepmind-ai-reduces-google-data-centre-cooling-bill-by-40). A 40 percent savings is significant, given how many of these large centers Google operates.

Following demands across the cable infrastructure only makes sense. Why run the engine at maximum speed if your demand is getting to the grocery store that is five minutes away and you have an hour to complete the task? The same can be true of our network. How can we enable that transactional mentality that Google embraced? Only consume what matches the demand. Of course, there are a few caveats such as not putting the network into a “total coma” mode where remote monitoring isn’t available, and the customer becomes the quality assurance device; that would be several steps back in our reliability experience. How can we accelerate with the help of a new intelligence engine to shape that true end-to-end energy control vision we crafted for our industry in 2017 with the release of APSIS (https://www.scte.org/standards/library/catalog/scte-216-adaptive-power-system-interface-specification/).

Thought Four, “How is an energy circularity mindset going to impact our ability to grow the service offerings?” At some point, we may hit a pivotal juncture where technology can provide “near limitless” capacity only limited by the amount of power available at any given geographic location. What if our services are no longer limited by the size and scale of the pipe but by the volume of power readily available? Could there be other industries also competing for this limited power resource? How can we be sure that we are prioritized in that availability? Maybe we will have no choice but to self-generate power in addition to grid. Maybe the efficiency of solar convertible power can far exceed our expectations. Maybe a new form of power generation has yet to be developed. Or maybe our technology will advance so much that like many personal devices, fewer and fewer electrons will be required to perform their functions so that power itself returns to that state of being taken for granted.

These are four questions I reflected upon while enroute to the office. The pace of change is fierce, the need for reliable power is consistently growing, and costs of doing business are not forecast to shrink. New technologies like artificial intelligence can help hedge some of these questions as the algorithms and modes of thought in the compute space mature, although I do realize that the platforms of artificial intelligence computing require significant power.

Perhaps Task One is to program AI to examine itself to reduce its own power…but that process may break the matrix.

SCTE
a subsidiary of CableLabs®

140 Philips Road, Exton, PA 19341-1318 | 800.542.5040 | **scte.org**