It’s 9:00 AM And Your Fiber Is Still Dark

Update to “It’s 10:00 PM Do You Know Where Your Wavelengths Are” (SCTE Expo 2020)

A Technical Paper prepared for SCTE by

Justin Riggert
Principal Engineer II
Comcast
1401 Wynkoop Street, Denver, CO 80202
+1 (303) 378-4227
justin_riggert@cable.comcast.com

Joel Swan, Comcast
1401 Wynkoop Street, Denver, CO 80202
Joel_Swan@comcast.com

Simone Capuano, Comcast
1401 Wynkoop Street, Denver, CO 80202
Simone_Capuano@Comcast.com

Tony Curran, Comcast
1401 Wynkoop Street, Denver, CO 80202
Anthony_Curran@cable.comcast.com

Scott Johnston, Comcast
1401 Wynkoop Street, Denver, CO 80202
Bryan_Johnston@cable.comcast.com

Table of Contents

Title **Page Number**

List of Figures

Title **Page Number**

1. Introduction

Last year's paper, titled "It's 10 PM: Do You Know Where Your Wavelengths Are?" provided an overview of Comcast's move into Distributed Access Architectures (DAA) and the need to reinvent how we manage and monitor fiber assets. The DAA architectures call for individual fiber nodes to be smaller and placed farther out into the network which leads to a significant increase in the number of fiber assets that are being installed. All this new fiber needs to be monitored and managed.

"It's 10 PM: Do You Know Where Your Wavelengths Are?" highlighted several innovations in fiber monitoring using a triad of tools. This includes a headend racked Optical Time Domain Reflectometer (OTDR) and Optical Spectrum Analyzer (OSA) monitoring device capable of continuous monitoring of 48 fiber links, a handheld optical meter, and cloud integration software and storage. With these tools it becomes possible to quickly identify fiber cuts and other service impacting fiber degradation events. The tools are used to accurately locate fiber cuts with closest address and cross streets and determine the service impact caused by these events.

But we still find ourselves with a tremendous amount of fiber unmonitored. DAA calls for a great deal of new construction of fiber, and that infrastructure gets much attention and focus. At the same time, we still maintain a huge legacy network. Existing analog fibers, commercial subscribers, and fiber to the premise products also have fiber assets to manage and monitor.

When any unmonitored fiber is cut, a human technician must identify the root cause of the damage. This can sometimes take hours of time -- just to isolate the location of the cut. Yet the goal is that our fibers will not be left alone or dark for long. Whether DAA or legacy infrastructure, digital or analog, residential or commercial services, all services can and will benefit from improved fiber monitoring tools.

"With the CPM (Continuous Pervasive Monitor), we provide infinite attention to individual fiber links with continuous and pervasive monitoring." -- Venk Mutalik, Executive Director / HFC Architecture, Comcast, 2021, in an interview for this paper

In this paper we will explore the steps being taken to expand coverage of our fiber monitoring capabilities. This includes process changes in our operational and development organizations, configuration optimizations and automation to help manage information on hundreds of thousands of fiber links and introduce a new optical passive hardware solution to address physical limitations such as bad optical test ports. We will also cover some of the latest features that have been built into these tools. Enhanced GIS mapping and location of fiber events. Network DVR and time averaging to play back data over time. Refined dispatch tools that combine information about our fiber optics with real time customer equipment status, commercial power outage impacts, and natural disaster events. And we have learned about specific event signatures that allow us to build workflows to automatically route alarms and instruct a fix agent on what to do in easy-to-follow steps, removing a lot of the human guesswork necessary to isolate root cause and required fix. Join us in our ongoing documentary as we improve our fiber monitoring capabilities.

2. DAA Systems

In a DAA system, a CMTS core is located at the Primary Headend (PHE) sending digital signals over fiber optic strands out to a Secondary Headend (SHE). The SHE contains a collection of equipment organized together into a DAA Switch Point of Deployment (DAAS POD).

In the POD, one of the components is the new Continuous Pervasive Monitor (CPM). The CPM is a 48-port rack-mounted device which includes a 1611nm OTDR and an OSA for monitoring individual fiber links. This monitoring unit is capable of continuously tracking fiber length with the OTDR, to isolate physical abnormalities within the fiber strand, while the OSA is full fledged spectrum analyzer on the C-Band and provides monitoring of all wavelengths of light present on the fiber. These monitoring capabilities allow us, in near real-time, to detect when a fiber length shortens, indicating a fiber cut. This monitoring unit also allows us to track when power levels on existing wavelengths go down, when specific wavelengths disappear, or when wavelengths show up that were previously not there.

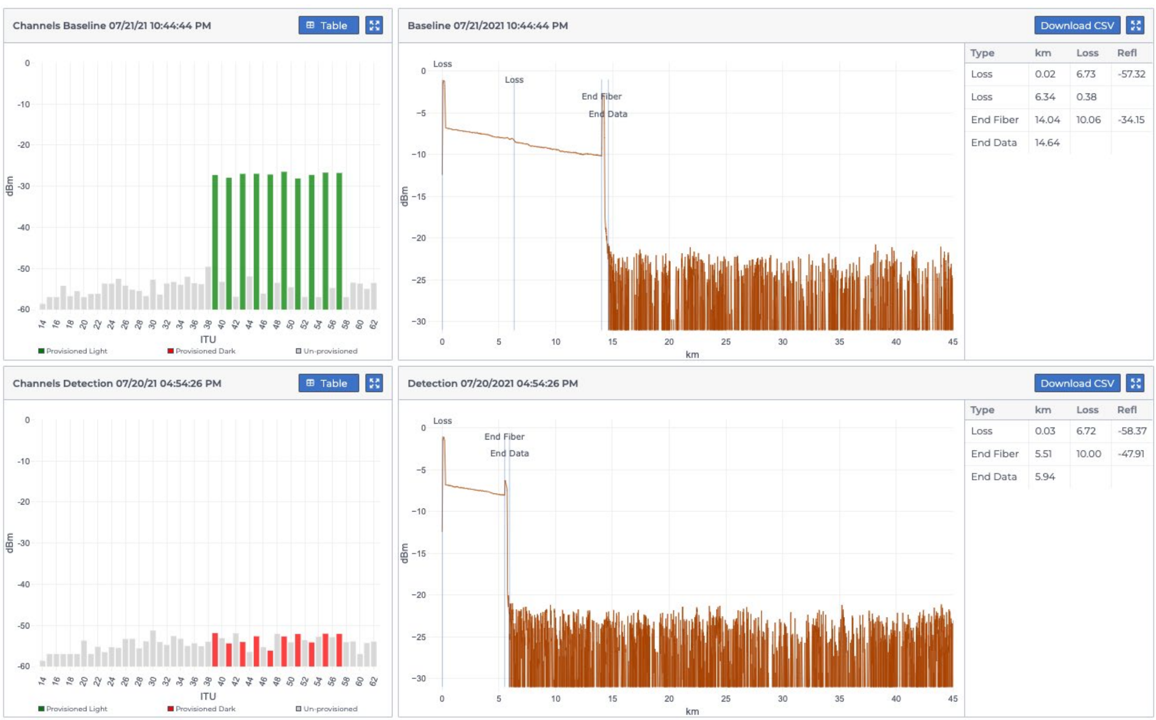

Figure 1 – Event View: Baseline vs Fiber Cut Side by Side

In a DAAS POD, each CPM port is connected to the Inside Plant Multiplexer (ISP MUX) test ports for monitoring of the fiber links and wavelengths served by this DAAS POD. The ISP MUX is a hardware component that takes many different wavelengths of light and combines them together onto a single fiber strand, enabling dozens of wavelengths to share transport on a single fiber. The ISP MUX is paired with an Outside Plant MUX (OSP MUX) in the field to separate those wavelengths back out and send them on to individual fiber nodes.

These new monitoring and troubleshooting tools provide next generation capabilities to pair with our next generation networks, allowing us to pinpoint root cause of a major outage event within minutes. Not only are we alarming on the outage in 90 seconds, on average, but also immediately identifying the root cause of the outage and where the break in the network is located -- both as a distance from the headend, and with an estimated geo-location, including latitude and longitude, and a list of all impacted services. This detailed data combined with plant design data allows us to know where to drive to find the cut, what kind of fiber is installed there and if it's aerial or underground plant, and how many other fiber strands are in the same bundle as the fiber in alarm. 100% of new DAA installations are required to be installed with these next-generation tools.

3. Legacy Systems

Although DAA currently takes the spotlight and the most focus on fiber monitoring coverage, we still maintain a tremendous amount of legacy architecture with existing fiber links that serve millions of subscribers. They also need to be monitored better than we do today. The good news is the CPM monitoring tool is not specific to DAA architectures and can be deployed as a monitoring tool on legacy systems as well. That said, there are some specific hurdles to overcome for legacy-facing deployments.

For example, one advantage of DAA is that for new construction, we use all the latest technology, including ISP MUXes that have consolidated test ports. These consolidated test ports provide convenient access for monitoring fiber assets with the CPM, because a single test port can connect to a single monitoring port and provide monitoring capabilities for both OTDR and OSA features. Legacy architectures are not as consistent on what is available for test ports on older equipment. In many cases there are no functional test ports available at all, presenting challenges about how to connect the headend monitoring equipment.

For these cases where there are no available test ports for our monitoring equipment, there is a new rack-mounted device with inline optical test points that can be placed in-line between the ISP MUX and Outside Plant (OSP) MUX. This device samples a small amount of light from the fiber optic strands, for the CPM to monitor. Connecting this equipment in-line removes the dependency on available and functional test ports. This optical device only reduces the optical power levels by about 0.5dBm, which in practice has negligible effect on plant performance. The gains that we see in improved fiber monitoring are well worth the small loss of power.

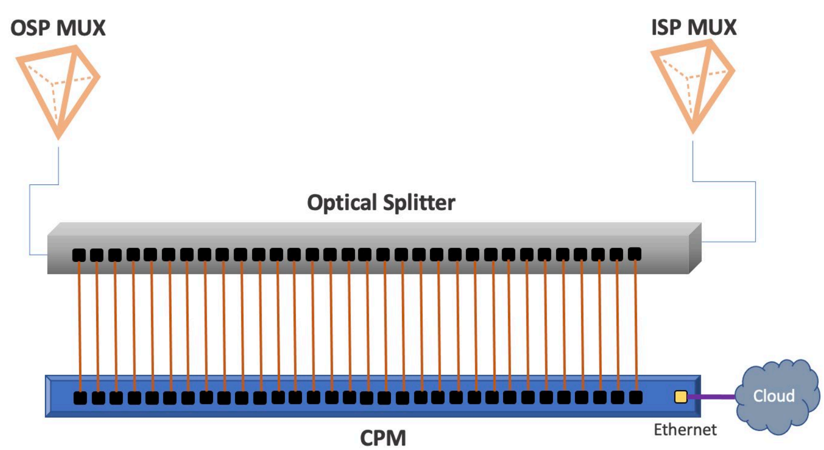

Figure 2 – Inline Optical Test Points Connected to CPM

In other situations, we do have functional test ports available, but they do not support consolidated OTDR and OSA measurements. In these cases, we have modified the CPM software to logically combine 2 physical ports for monitoring of a single fiber link. In this situation, we configure one port to perform the OTDR functions, and another port measures the OSA channels. The application then combines these two ports for monitoring and alarming purposes, so we represent them as a single fiber link to the end user.

Other legacy scenarios include the need to monitor analog optics, or to monitor fibers with wavelengths that are outside the range of the OSA. Both the OTDR and the OSA feature of the CPM are capable of operating independent of each other. The OTDR feature can monitor a fiber for length and physical abnormalities on its own in cases where we do not have visibility into the wavelength power measurements. And the OSA feature can be used independently to monitor wavelengths in places where the 1611nm laser is blocked from giving us monitoring visibility of the physical fiber attributes. We have many reasons to be optimistic about our legacy networks benefiting from these new innovative monitoring technologies.

4. Handheld Optical Multimeter & OTDR

This past year brought many new powerful features to the handheld unit. The home screen has new intuitive control bar and menu selection area for the technician. The control bar provides real-time status on both the handheld unit and the SFP connected to it. There is a real-time indicator for laser status, whether the SFP is programmable, the current ITU wavelength configured on the SFP, and a threshold warning if there is too much power coming into the OSA or OCC ports. There is now an SSO login, for technicians to connect their scans to their account in the cloud. The control bar also provides status on WIFI connection, power status, and battery levels.

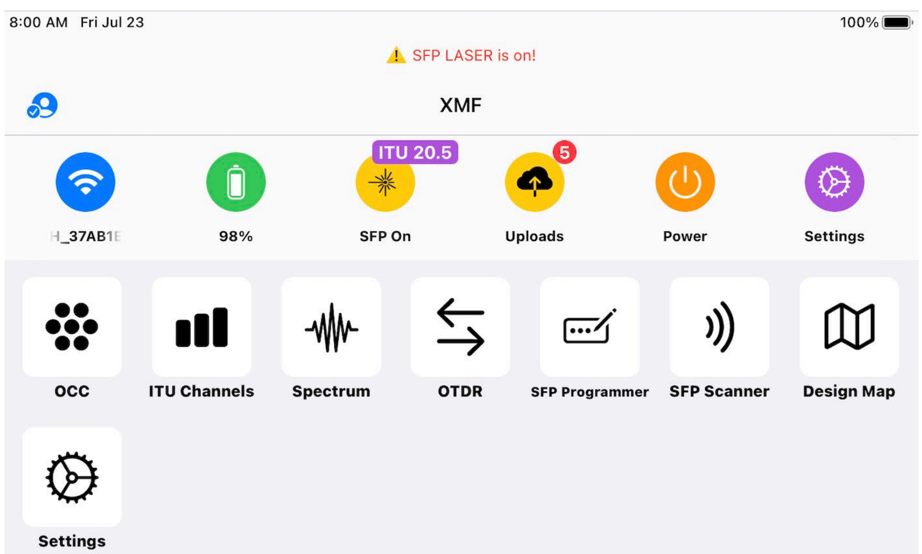

Figure 3 – Handheld Unit – Control Bar and Menu

With the SSO login integration and ability to upload scans to the cloud, we now can search and view those scans by technician, job ID, node, or geographical bounds drawn on a map. This allows the user to compare different scans taken at different times or locations, view progression of a particular job, and hand off information about a particular job from one technician to another.

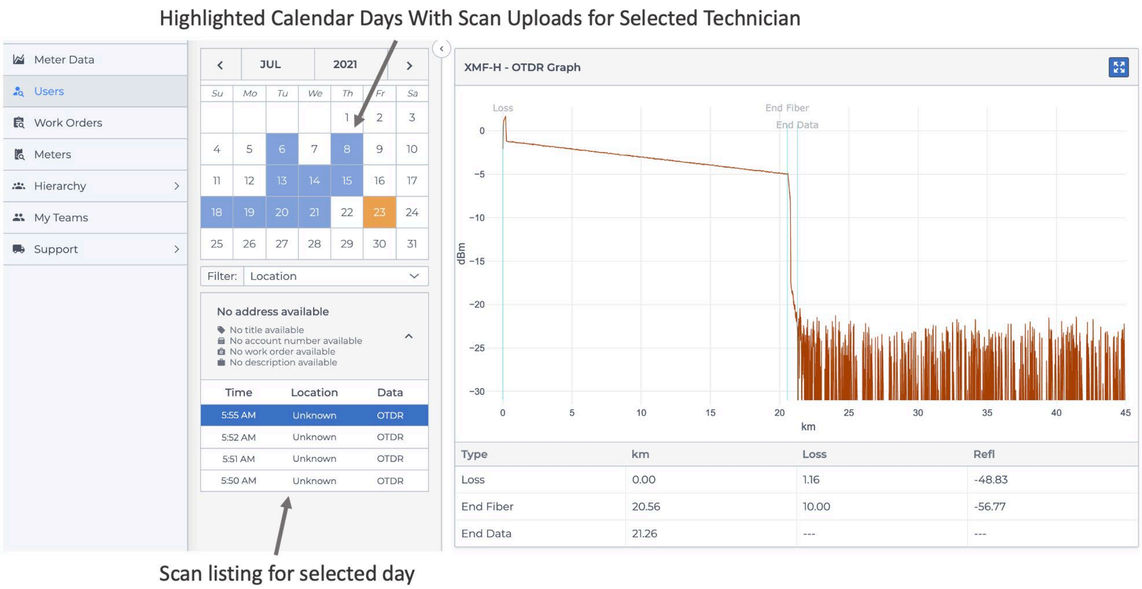

Figure 4 – Cloud Navigation for Uploaded Scans (Technician View)

The handheld device also includes an Optical Channel-band Checker (OCC) which is a quad-band power meter that can sense power levels on the fiber. The OCC provides power measurements across the entire usable spectrum. It measures and displays the detected power levels, grouping them into four bands:

- 10G EPON Downstream (L-Band 1577 mm)
- BAU DWDM (C-Band 1550 nm)
- 10G EPON Upstream (O-Band 1270 nm)
- All Other Bands not specified above

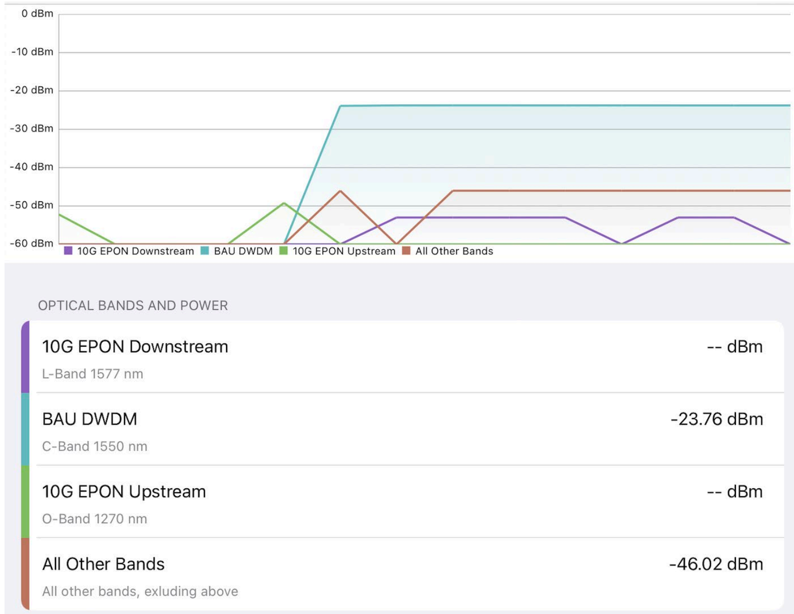

Figure 5 – Optical Channel Checker Application View

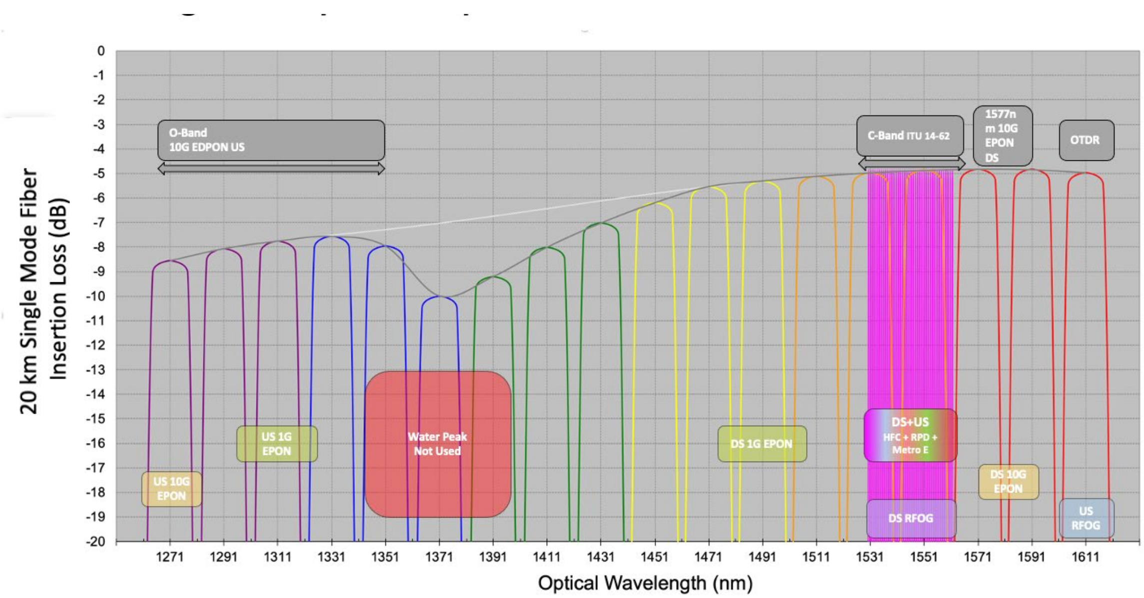

Figure 6 – OCC Wavelength Band Overview

Another powerful new feature on this platform is the integration of the handheld device with the headend rack-mounted CPM. With these technologies integrated with the cloud, a technician can be out in the field troubleshooting an outage. While physically located miles away from the headend, the technician can remotely search the system for the fiber being tested, and connect to the CPM that is monitoring the same fiber link. The technician can trigger an OTDR from the headend, down the fiber link, and within seconds shoot the fiber from their current location back towards the headend with their handheld device.

With cloud storage, all measurements are stored for future playback and analysis, and to provide visibility to other technicians who may need to assist with the same outage. The combination of headend and handheld equipment is designed with a similar look and feel, and with comparable features on both platforms. This helps to foster a common language and a shared platform used by both the headend and field technician, where the two disciplines now overlap in ways that were not previously possible.

While connected to the remote CPM in the headend, another benefit to the technician is the ability to be "virtually hands-on" with a fiber strand located miles out into the network, taking measurements of the fiber from the perspective of the headend CPM. For example, by creating a bend in a fiber strand, the technician can look for loss in the micro bend on the OTDR traces of the CPM, enabling validation of the fiber strand and where it connects. Changes to the network can be made instantly and verified by the changes in the receive power at the headend.

While troubleshooting the network and requesting live traces from the CPM, the software is also configured so that the continuous monitoring feature doesn't miss a beat. The CPM can quickly switch between ports as part of its ability to monitor 48 fibers with a single optical receiver. This switching capability allows a technician to request live data from the CPM, and this request is interleaved with the scans that are required for ongoing monitoring. The CPM creates a queue for any live requests coming in, and any live requests are processed in the order received. But no matter how many live requests are in queue, every other scan is still prioritized for continuous monitoring. This matters because we will never miss detecting the next major outage and creating a dispatch ticket with detailed information about that fiber cut, while in parallel we can still provide real-time troubleshooting capabilities to the technicians working in the field.

5. Installation and Configuration

With a target of 100% of DAA architecture including CPM monitoring on every fiber link, keeping up has proven challenging. The initial installation of the CPM requires power, network, and configuration for every wavelength being served. And BAU updates over time need to be updated on the device configurations.

Manual configuration of each fiber link and wavelength becomes a tedious and time-consuming process as the number of DAA installations increases. The hours required for manual configuration has been one of the roadblocks encountered in our efforts to get 100% adoption from the field. This led to one of the major new features enhancements this year, allowing configuration that scales and better acceptance from the user base managing these configurations. This new feature is bulk import capabilities from the fiber configuration spreadsheets used by each local headend.

Each headend is already required to maintain an up-to-date configuration of its fiber links, and the format of these configuration sheets is standardized across the various regions. By supporting bulk configuration of the data format already in place, this reduced the configuration time from a multi-hour effort to just a few minutes.

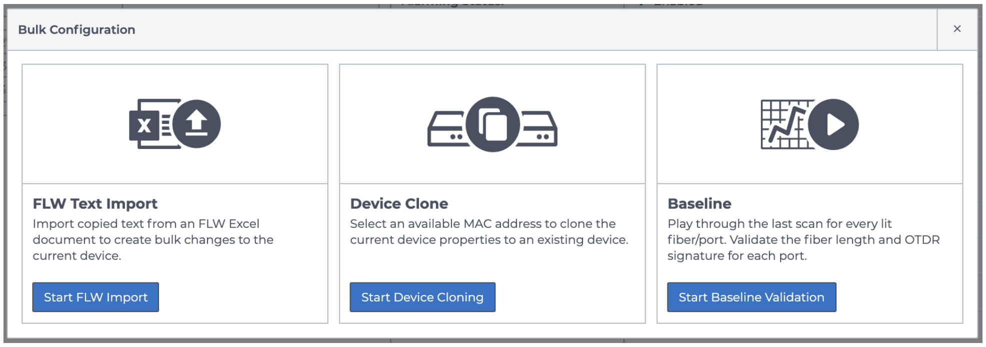

Figure 7 – Bulk Configuration Selection Screen

The next phase of configuration automation is to centralize all the local fiber configuration data into a database, with APIs the CPM can use to fully automate the configuration and relationships between ISP MUX, OSP MUX, CPM, wavelength, and fiber node. By centralizing and providing APIs to access all the fiber configuration data, the additional configuration required that is specific to the CPM becomes minimal, and the installation process for the CPM becomes scalable even for a busy field operations staff. By centralizing fiber configurations into a database, we also enable the CPM to receive real time updates as BAU configuration changes are made over time.

Another critical element of configuration is establishing a baseline of the expected fiber length, as well as the expected power of each wavelength at the receiver in the headend. The baseline is what allows us to determine if a fiber is short or if individual wavelengths are degraded from their normal operational state.

The initial plan was to manually certify each baseline by putting "eyes on glass," and allowing a person to identify flaws in the OTDR trace that may have "slipped through the cracks." This provides an opportunity to clean up bad splices or other physical flaws during the installation process and provides a better physical network that gets handed off to operations after installation and configuration.

Although manual verification was well-intentioned, as we started to deploy monitoring on what quickly became thousands of fiber links, it became a roadblock to field adoption of the tool and willingness to put in the time to configure. So, we pivoted to an automated baseline feature where the software looks for trends over time. When we have specific wavelengths that stay continuously lit for a specified period, this triggers that wavelength to become eligible for ongoing monitoring. And during this time, when we flip wavelengths from unmonitored to monitored, the automation software updates the baseline for that link with the current length of the fiber and the power levels of the wavelength. In addition to the automatic creation of fiber baselines, the automation software also must be aware of trends over time and watch for fibers that may have been decommissioned or changed monitoring ports.

Another installation and configuration feature that has been added is related to how we monitor various fibers with different physical attributes. For DAA, we see fiber lengths ranging from a few hundred meters to 50 km or more. We have variations in the amount of light coming into the headend receivers. And there are various kinds of glass strand and physical anomalies in the fiber link that lead to different attenuation and refraction patterns.

With the OTDR portion of the CPM we continuously monitor the length of fiber looking for when the fiber is cut or damaged. The challenge has been that an OTDR must be tuned to accurately analyze the fiber strand based on distance and other physical properties.

One of the tuning parameters is pulse width. A short pulse width provides a small "dead zone" at the beginning of the fiber, where this dead zone represents a blind spot where it is not possible to accurately measure the end of fiber or find anomalies. A short pulse width also provides the ability to detect distinct events that are stacked close together. However, a short pulse width also reduces the dynamic range of what we can measure, so in cases where there is a high amount of attenuation in the DAAS POD installation, the short pulse width can cause the signal to get lost in noise before being able to measure the end of fiber. Short pulse width also loses its energy over long distances, so the signal gets noisy at longer distances.

Long pulse widths provide better dynamic range, but we lose monitoring capabilities within the blind spot of a longer pulse width/ larger dead zone. And we lose granularity.

Averaging time is another tuning parameter available to us. In general, the greater the averaging time, the better the results on the OTDR trace. But the cost of higher averaging time is longer time to fiber cut detection. As the CPM loops through the 48 ports, it is looking for fiber cuts and other events in real time. If the averaging time is set too short on a particular port, we gain a quick measurement but lose to a noisy signal and inaccurate analysis of what is happening on that fiber. If the averaging time is too long, we gain accuracy but lose on the time it takes to detect a significant issue like a fiber cut.

IOR (Index of Refraction) is another parameter that is important to tune so as to achieve accurate distances on the OTDR analysis. IOR is a representation of how fast light travels through a particular medium. Set IOR too low, and all the distances measured will be too long. Set IOR too high and all the distances will be too short. Inaccurate distances cost the field technician time when trying to find a fiber cut. And inaccurate distances also can cause us to misidentify which sheath the fiber is contained in, which gives us access to what other fibers are bundled together, and then what other services are connected to all those fibers in the sheath -- which may all be down, if the entire sheath is cut.

To solve these different tuning requirements, we continue to look to automated configurations based on fiber design, combined with AI and machine learning using the data collected and stored in the cloud. This allows us to customize the settings for each individual fiber link.

6. Cloud Integration

One of the most empowering new features that these new tools have added is integration with the cloud and other internal tools, to enrich the data we gather and publish. In the handheld meter, one of these features is integration with node inventory and jobs. Field technicians are often troubleshooting fiber nodes, and one of the features in the handheld meter is the ability to search for a node to tag onto existing scans. By tagging scans with a fiber node (or other equipment), when the scan is stored in cloud this data is indexed on node name. This allows anyone to search the cloud for scans that have been taken on this node over time, which provides visibility into patterns and historical context. Another feature for the field technician is "job search," where a technician can tag handheld meter scans with a job currently assigned to them. The job association allows the work the technician is doing to be visible to others, which benefits other technicians if an issue is escalated to them, or it gives more visibility to all technicians working the same job in tandem.

On the CPM headend tool, another focus over the past year has been enhanced DVR functionality. The DVR is a tool that allows the user to view a particular fiber link over time, in a movie-like experience, where every scan taken over the selected period is played back in sequence at a selectable frame rate. As the user watches the playback, they can isolate changes in pattern and visualize how the OTDR trace changes over time.

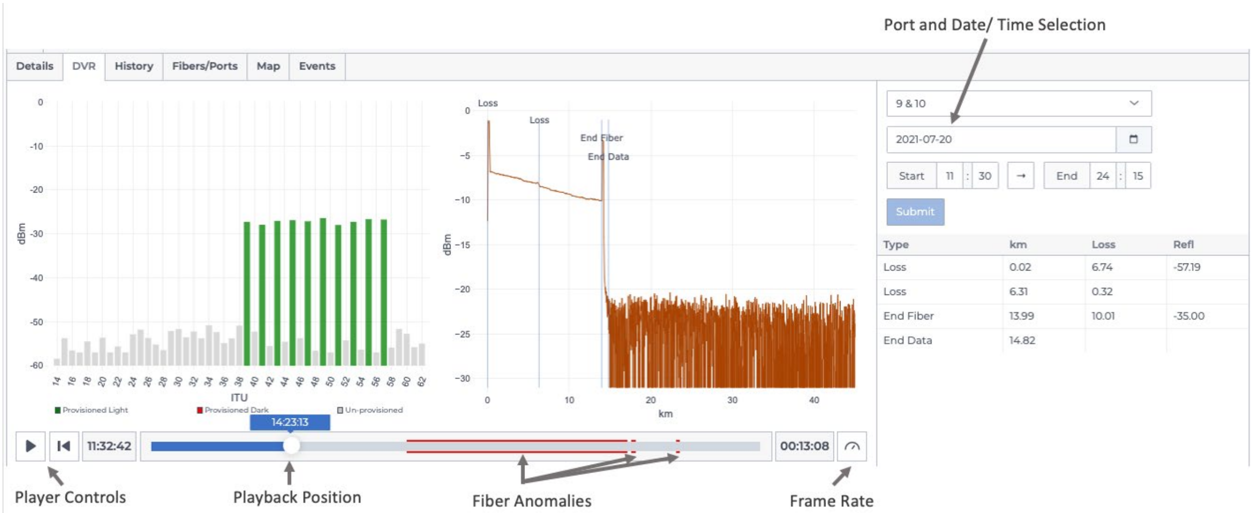

Figure 8 – DVR Playback View

An alternate tool to the DVR is the history tool, where the user can select a time window, but instead of playing frame by frame, they are presented with min, max, and average lines over the selected time.

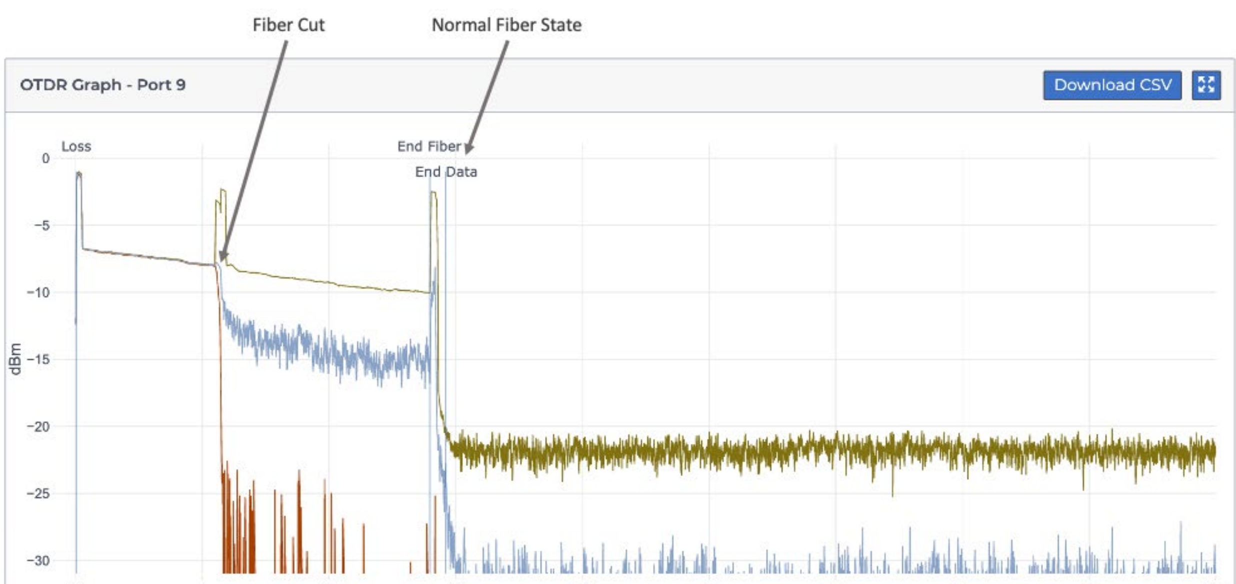

Figure 9 – Historical Averaging View

7. Validating Design Maps

One of the ongoing efforts is to validate the design data for our fiber assets. All our fiber assets are stored in a GIS asset database that includes the physical path where the fiber travels, the length of each fiber segment, and includes the helix factor, amount of sag, and amount of fiber contained in slack loops. By using the OTDR and measuring physical distance from the headend, we can audit the design data to validate distances and correct mistakes that are found. We can also store regional averages for helix, sag, and slack that let us better estimate fiber cut locations by adjusting the distance of the fiber to account for the regional helix, sag, and slack averages. One of the other benefits of our GIS asset database is that the entire fiber run is connected in the database from the fiber node to the headend. With this connectivity, we can trace from the fiber node to each splice, through MUX and various fiber sheaths, to the termination panel, OCEF, and ISP MUX in the headend. With access to all the physical connections being made along the fiber path, we can correlate specific events in the OTDR trace to specific equipment. We can also help audit the GIS asset database to flag fiber lengths that do not match the OTDR measurements and provide reports to the field that can be used to clean up bad or missing data.

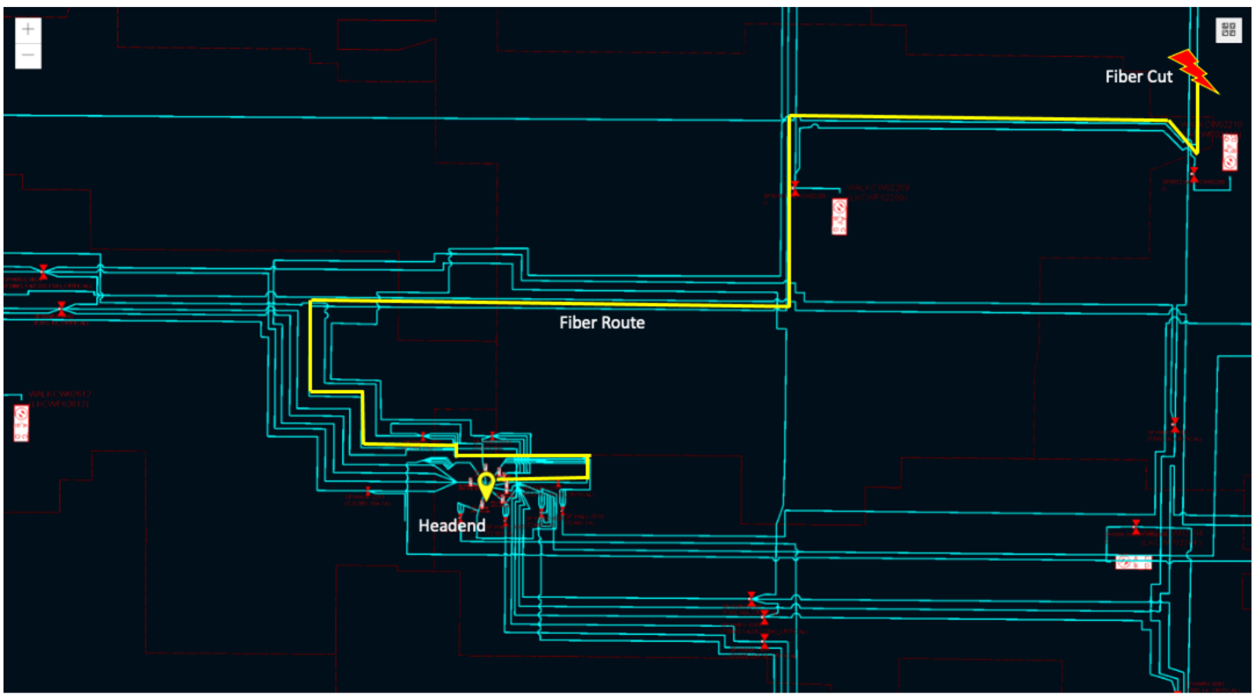

Figure 10 – GIS Asset Maps/ Route to Fiber Cut

8. Natural Disasters

Another opportunity for the CPM to provide unique value is for large scale natural disaster events. During these large events, there are an overwhelming number of alarms that are generated by all the different monitoring tools on the network. Trying to triage the alarms and work them in a prioritized order is not an easy task. The OTDR fiber cut detection capabilities of the CPM becomes an amazing tool to help with this prioritization process. With the OTDR functionality, identifying a fiber cut is highly accurate. Many of the other alarming tools deployed on our network are good at finding outages but require manual research to find the root cause of the outage. The CPM can immediately identify root cause for an outage as a fiber cut. Combining the fiber cut with configuration data that tells us what is deployed on that fiber lets us identify the scope of impact of each fiber cut that is still active and helps the field better triage which cuts they want to fix, in what order.

Another reality with natural disasters is that during large scale events there are some outages that stay open for many days, or, in rare cases, many weeks. As the CPM tools get better about learning the network and setting baselines, we also need to program the tool with a method to anticipate these large-scale events, so the tool behaves in an appropriate way in context of all open alarms. For example, one of the asks of the CPM is the change the baseline length of a fiber in cases where there has been an intentional change to the fiber length. These scenarios happen in cases like node splits, or when the headend makes physical configuration changes. If the fiber monitored by the CPM does physically change, the baseline needs to change with it. One method to automate this change is to look for configuration changes applied in the fiber configuration data. But we do not always have visibility into those configuration changes. In these cases, we can look for trends on the physical characteristics of the OTDR trace and decide when to update the baseline using those trends. But then in a disaster scenario, we want to suspend those trend-based updates, so the algorithms do not make mistakes like setting a fiber to "inactive" in a case where we have a real and ongoing customer-impacting fiber cut.

9. Conclusion

As we reflect on the past year and look at lessons learned and the new development that has gone into this monitoring platform since we last convened to describe it, the value of this innovation continues to surpass what the development team had initially envisioned. Fiber optics are a critical part of the service delivery platform serving our customers, and our fiber assets continue to expand deeper into the network. Our customers rely on this network around the clock for video, internet, phone, home security, home automation, and emergency services. Our customers depend on our network in their everyday lives; therefore, reliability is of paramount importance. Fiber optic monitoring tools are one of many ways we are improving on that reliability. We began with DAA as the target for these tools, but over time we continue to uncover so many remarkable new opportunities to provide better insight into our fiber optic networks. So many legacy systems, analog optics, commercial services, and fiber to the premise products can benefit from these monitoring innovations. And in parallel to the technology development, working with the field and operational leadership to shape process changes and training around these new products. We look forward to new discoveries of what this platform can do for our company. We also embrace this technology as just a single part of a broad effort at Comcast to build a culture of reliability across all products. We are winning the battle against fiber dark forces, ensuring that we wake up in the morning knowing our fiber is light and watched over.

10. Acknowledgements

OTDR and Optical Spectrum Analyzer technologies have been around for decades and are common tools used for monitoring and managing long haul fiber networks. But it was not until 2019 that our own Venk Mutalik, Executive Director of HFC Architecture was inspired to take these technologies used in long haul environments and apply them to the local fiber optic networks serving our residential and commercial customers. It has been a privilege for the team to follow Mutalik's technical leadership in our journey -- to take his invention and build enterprise scalable applications and tools that provide real operational value to Comcast.

Abbreviations

BAU	Business As Usual
CMTS	Cable Modem Termination System
CPM	Continuous Pervasive Monitor
DAA	Distributed Access Architecture
DAAS	Distributed Access Architecture Switch
DWDM	Dense Wave Division Multiplexing
EPON	Ethernet Passive Optical Network
GIS	Geographic Information System
ISP	Inside Plant
FLW	Fiber Loss Worksheet
OCEF	Optical Cable Entrance Facility
OCC	Optical Channel Checker
OSA	Optical Spectrum Analyzer
OSP	Outside Plant
OTDR	Optical Time Domain Reflectometer
PHE	Primary Headend
POD	Point of Deployment
SHE	Secondary Headend
SSO	Single Sign-On

Bibliography & References

1. *It's 10pm: Do You Know Where Your Wavelengths Are?* Venk Mutalik, Dan Rice, Rick Spanbauer, Simone Capuano, Rob Gonsalves, and Bob Gaydos, SCTE EXPO 2020