Coherence After Turbulence:

Coherent Links for Hurricane Relief in the Sunshine State

A Technical Paper prepared for SCTE by

Venk Mutalik
Fellow
Comcast
1800 Arch Street, Philadelphia, PA 19103
+1 (860) 262-4479
Venk_Mutalik@Comcast.com

Amarildo Vieira, Principal Optical Engineer

Dan Rice, Vice President

Eric Moore, Engineer

John Chrostowski, Executive Director

Scott Wood, Engineer

Elad Nafshi, Chief Network Officer

Table of Contents

Title **Page Number**

List of Figures

Title **Page Number**

1. Introduction

Travel sites are filled with glowing reviews of Sanibel and Captiva Islands on the West Coast of Florida, just south of Fort Myers. Home to the famed J.N 'Ding' Darling National Wildlife Refuge, Sanibel Island is connected to the mainland via the Sanibel Causeway, its lifeline to the mainland [1].

So powerful was Hurricane Ian that when it made landfall in late September of 2022 the winds and storm surge that followed collapsed the Causeway. With it, communication lines between Sanibel Island and the mainland were also cut. Of course, widespread destruction on the Island also destroyed much of the infrastructure. Most heartbreaking of all, the human toll approached 150 lives, with nearly half of those in Lee County alone [2].

With sustained winds approaching 155 mph, the winds and storm surge caused by Hurricane Ian caused parts of Florida to be without power for weeks. Cleanup took even longer. During this time, it was all hands-on deck at Comcast, as Comcast focused on restoring connectivity to locations impacted by the storm. This paper is a case study of our efforts to provide connectivity to Sanibel Island in the aftermath of Hurricane Ian.

After initial rescue efforts, power restoration, and cleanup were in full swing, it became clear that connectivity to the region was just as important as well. With respect to Sanibel Island, an initial survey of fiber infrastructure showed limited accessibility from the mainland to the island, but that the secondary site on the island could be brought up with backup power. To conserve limited fiber and available critical infrastructure, Coherent optics were used to light up the trunk link and bring up the nodes one by one with backup power, thus, restoring connectivity to affected customers as quickly as possible. This paper will focus on innovative technologies deployed and the great efforts undertaken by Comcast teams to provide connectivity to this part of Florida.

2. Background: Comcast Architectures

Providing capacity while also enhancing reliability is at the heart of innovation at Comcast. With two years of Covid behind us at the time, Comcast had already begun implementation of the Distributed Access Architecture (DAA) and fine-tuned many aspects of deployment that aided in providing unprecedented insight into our network health in real time.

2.1. Distributed Access Architecture (DAA):

In previous years [3], we have reported on how Comcast has pioneered the DAA that has virtualized CMTS functionality and separated the PHY layer from the CMTS and distributed it out into nodes in the field. These are now called Remote PHY Device (RPD) nodes.

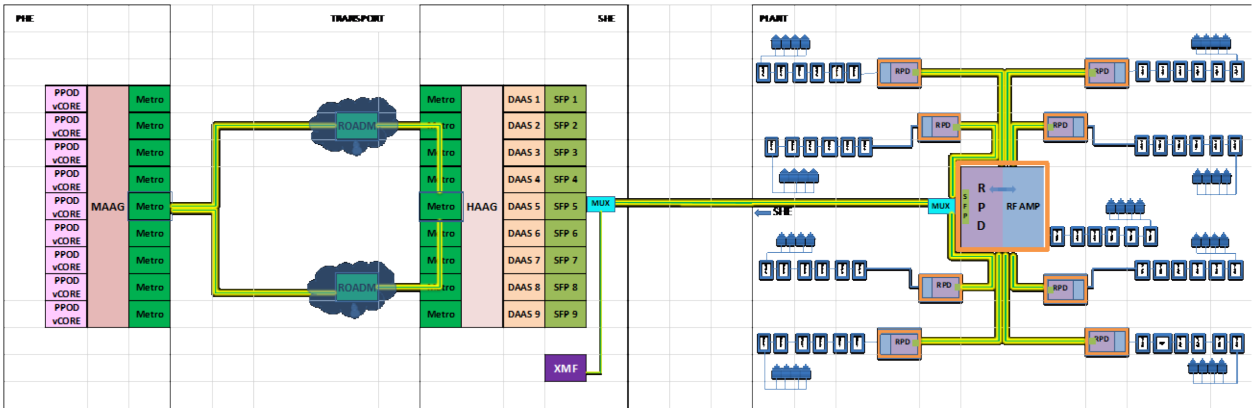

Figure 1 – Illustrating the DAA Network

Shown above is a simplified version of the DAA system. While the Primary to Secondary connections are based on 100G or higher capacity Coherent optics, the connections from the DAAS to the DAA nodes (RPD nodes) in the access domain, are always 10Gbps DWDM-based signals. vCMTS (virtual Cable Modem Termination System) cores from the Primary headend are connected to DAA switches (DAAS) via Highly Aggregated Switches (HAAGs) in the Secondaries, typically via Comcast's own Metro networks. Once out of the DAAS, both the US and DS 10G wavelengths are multiplexed on a single strand of fiber using a novel passive with consolidated test ports and sent over into the field, where they are demultiplexed at an Outside Plant (OSP) enclosure location. From there, dual strands of fiber carry the 10Gbps signals over to the various RPDs in the immediate location. The distance from the Secondary to the field OSP mux is called the trunk fiber, while the fiber from the OSP Mux location to the various RPDs is called the distribution fiber. On the trunk fiber, Comcast has a 100GHz ITU WL (wavelength) Plan standard that has adjacent odd and even pairs of ITU channels serving each node beginning at ITU 61/60 pair to ITU 15/14 pair. Thus, all in all, 24 pairs of wavelengths are available on each trunk fiber capable of serving 24 different remote devices. While the DAA program is on pace to upgrade all traditional nodes and CMTSs to the vCMTS based digital nodes in the next few years. In Sanibel Island, when the hurricane hit, however, all the nodes were still analog nodes served via a Hub in South Fort Myers hub.

2.2. Continuous and Pervasive Monitoring (CPM) of Optical Assets

Our current network base is a mix of single and dual fiber CWDM (Coarse Wavelength Division Multiplexing) and DWDM (Dense Wavelength Division Multiplexing) connections. Many of our current business customers that require fiber to their premises require 1G to 10G services and could be in the vicinity of existing OSP Mux enclosures. For a go-forward plan, since these are digital signals, these customers can be served by the same strand of trunk fiber that would connect analog and digital nodes. This is an important way to relieve capacity on our fiber assets by enabling more efficient use. In addition, it enables a common way to monitor optical assets continuously and pervasively, which is described in a subsequent paragraph.

Figure 2 illustrates a converged system that is a combination of residential and commercial services, incorporating Coherent and direct detect systems, all capable of running on a single fiber. Since all services can be multiplexed on a single fiber, the current series of optical passives in Comcast has consolidated test ports that provide access to view forward and return wavelengths of live links. Furthermore, the test ports also allow unrestricted 1611 nm (nano meters) access for the use of Optical Time Domain Reflectometers (OTDRs) to scan live links and provide fiber impairment and cut information.

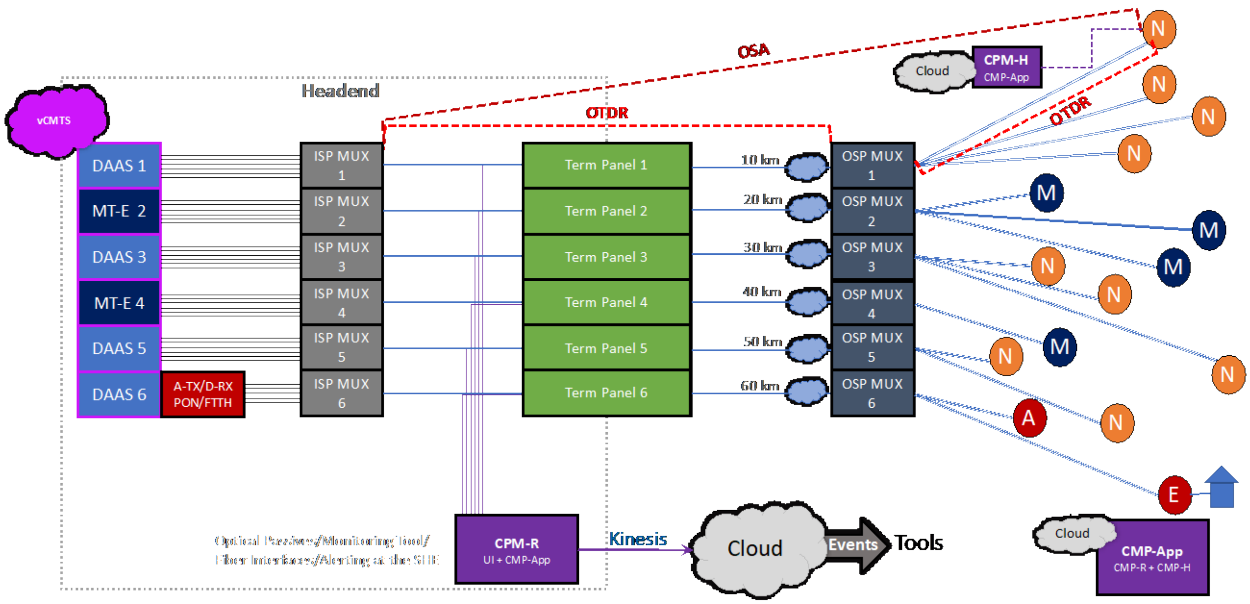

Figure 2 – Illustrating Continuous Pervasive Monitoring

The continuous and pervasive monitoring paradigm in Comcast was described in earlier SCTE papers [4]. By way of summary, all optical passives are connected to a continuous monitor comprising an OSA and OTDR as well as an optical switch. This arrangement continuously monitors connected fibers in a round-robin fashion and generates fault information comprising either fiber impairments or individual wavelength impairments on average within 90 seconds. The entire information set is sent into the cloud for storage to aid in longer term analysis, but alarms and events observed are sent to fix agents in real time.

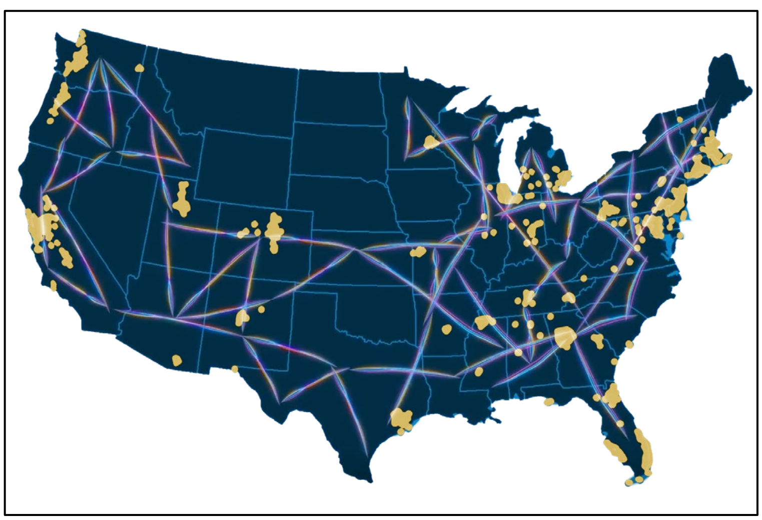

Figure 3 – Illustrating Continuous Pervasive Monitoring Coverage

To promote a common language between headend and field technicians across the Comcast footprint, a version of the monitor is available as a handheld device that has the same cloud connectivity as the headend version. Connecting the headend unit, the hand-held unit, or both to the cloud allows the entire region, division, and company to view all events in real time and resolve important issues impacting customers.

3. Coherent Optical Links in the Access Domain

Not only is fiber expensive to deploy, but it also takes a long time to do so. One way to be efficient about fiber usage is to be able to use fibers bi-directionally. Not only is this efficient, but also it promotes resiliency as a fiber cut can be repaired by just one splice repair. This is easier to do with 10G optics and indeed the entire DAA footprint is designed with bi-directional links. But in cases where fiber is limited and higher capacity is needed, commonly used Coherent Optics, which can provide 100Gbps or more of capacity, usually require a dual fiber option. We describe in this section, a single fiber Coherent Optical link option that enables the use of high capacity (100Gpbs or more) and works well with an active 10Gbps fiber plant. Such an option needs a new set of dual laser bi-directional Coherent pluggable transceivers and a Coherent Mux-ponder (CMP) terminating device [5]. We describe these in more detail in this section.

3.1. Dual Laser Single Fiber Bi-Directional (BiDi) Coherent Links in Access Networks

Coherent optics rely on having a laser on the transmitting end to send out phase and amplitude information in the form of QAM (Quadrature Amplitude Modulation) constellations to a receiver. At the receiver, the incoming signal is 'beat' up against a laser that has, in effect, the exact wavelength of the transmitting laser and it teases out the phase and amplitude information. Since information is coded in phase and amplitude as opposed to only amplitude in direct detect systems, the information carrying capacity of the Coherent system is vastly superior to as that of direct detect systems for the same amount of bandwidth available.

To reduce cost and to ensure that the wavelengths are identical, most of the pluggable transceivers available in the market use just one laser in each plug and split its light to do double duty, in effect to act as the encoding transmitters and the decoding receiver. This is illustrated in the top half of Figure 4 below.

The industry has gotten quite good at this type of design and has successfully used it to provide 100s of Tbps (Tera bits per second) over 1000s of km in core and metro networks. Unfortunately, this approach always requires two separate fibers, one for downstream and another for upstream information. When a fiber can be fully loaded with data, say for 100s of Tbps, this approach seems reasonable. But when the fibers are unable to be fully loaded, like what happens in access networks, an approach of this kind is very inefficient and can result in severe fiber exhaustion.

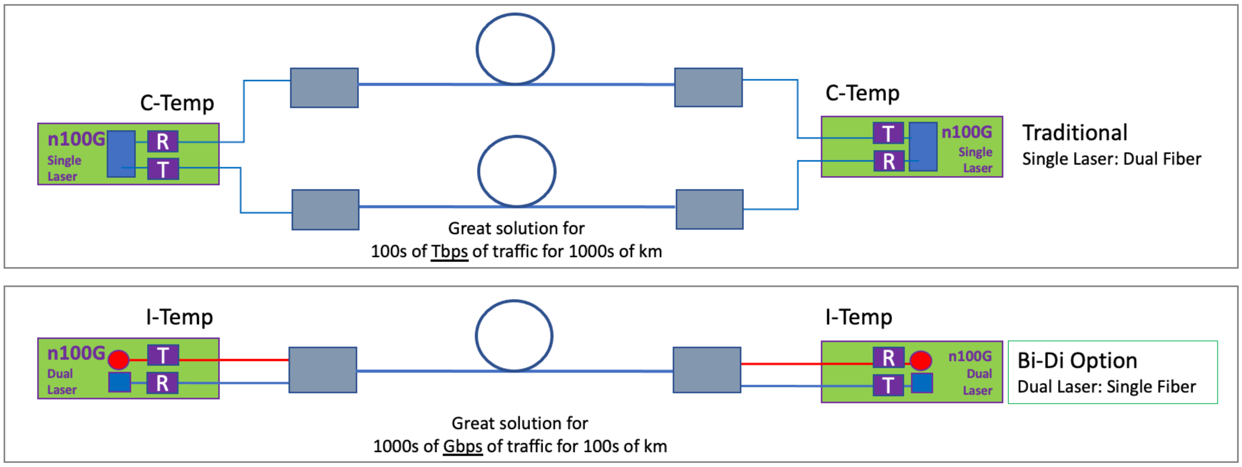

Figure 4 – Illustrating Bi-Directional Coherent Systems

Therefore, a novel approach to accommodate Coherent optics in the access domain needed to be developed. This approach enabled both high-capacity wavelengths that feed our residential DAA systems and support our business customers as standalone high-capacity wavelengths as well.

While the use of optical circulators is a valuable option and could potentially allow the same wavelength to traverse in opposite directions, that approach is prone to fiber plant reflections and Rayleigh backscattering which could limit the link budget. A more robust solution is needed for wide bi-directional deployments that envision the use of existing fibers with other bi-directional signals already running on them.

A robust solution to this problem could be to have a separate laser for the transmitter and the receiver at each end. The dual laser approach enables the two wavelengths to be multiplexed (or combined) together and transmit bidirectionally (Bi-Di) on the same single strand of fiber. In fact, many Coherent optical wavelengths could be multiplexed on the same fiber along with direct detect wavelengths, leading to a converged system described in the previous section.

Interestingly, low earth orbit (LEO) satellite communications systems have also come up with the same requirement of dual laser bi-directional transmission. In free space, Coherent optical modules communicate with adjacent satellites and hop signals from satellite to satellite to minimize the need for ground stations. But the vast speeds of the LEO satellites and their relative speeds to other satellites create the familiar doppler shift in frequency sufficient to thwart the use of a single laser design. So, in this effort of defining a dual laser plug, we have had the unusual conjoining of space requirements as well.

With this in mind, Comcast has specified dual laser, bidirectional, fully C-Band tunable, industrial temperature C Form-factor Pluggable 2 (100Gbps) (CFP2) plugs for use in access networks, much aligned with the CableLabs point-to-point Coherent specification [4]. Current systems support 100Gbps rates with Quadrature Phase Shift Keying (QPSK) modulation at 32GBaud with a 25dB link budget, enough to support point-to-point links up to 100kms. Due to their limited reach requirements, there are no ROADMs (Reconfigurable Optical Add Drop Multiplexers) in the access plant and there are no non-reciprocal elements in the system, this allows for the relaxation of certain specifications and needs for chromatic dispersion compensation that enable these new innovative devices to be cost-effective as well.

While 100G Coherent systems can exist on their own and support individual wavelength services for our commercial customers in the converged access architecture described in the previous section, a particularly important application of the dual laser BiDi system is to support DAA systems. Often these DAA systems have to operate out of smaller extension sites or secondary cabinets that make direct metro transport system connections difficult due to limited critical infrastructure. Adding additional fiber to the trunk line is an expensive and time-consuming effort. In such cases, we have developed a system that takes in 10 of the 10Gbps streams and electronically converts it to a 100Gbps stream that is modulated in the CFP2 which is then multiplexed to a single fiber and sent over to the secondary. Such a device is called the Coherent Mux Ponder (CMP) and two such devices are bookended one each at the Primary - after the DAAS for aggregating the 10Gbps streams to 100Gbps - and the Secondary extension site – for disaggregating the 100Gbps streams into its constituent 10Gbps streams. Once the 10Gbps streams are recovered, the CMP uses standard full band tunable 10Gbps SFPs and optical passives to serve DAA nodes out in the field. It is as if the DAAS has now been extended in a compact form factor into a much smaller extension side enclosure.

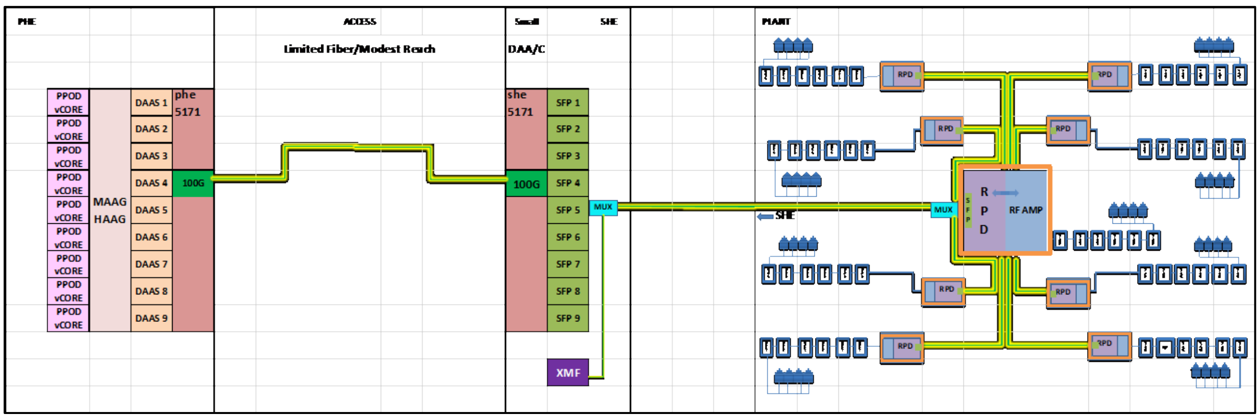

Figure 5 – Illustrating Coherent Muxponder solution for DAA

The CMP system designed can support up to 40 of the 10Gbps streams in 2RU of space and is shallow enough to be placed in tight extension sites. The entire system can be scaled up to serve up to 240 of the 10Gbps services all on a single strand of fiber. Converged Optical Architecture in the Access Domain

Section 2 provided a simple description of Comcast's network. Although the path towards digitization and distributed access is evident, we still need to address multiple legacy architectures, including analog DS wavelengths and potentially analog or digital US wavelengths, during the DAA transition. In addition, one interesting aspect of the access plant is that most of the businesses that require separate optical wavelengths are also interspersed among residential customers. Techniques to intersperse analog and digital WLs on the same fiber has been described in earlier papers and not repeated here.

Converged architectures are an important way to relieve capacity on our fiber assets by enabling their more effective use. In addition, it enables a common way to continuously and pervasively monitor optical assets which is described in a subsequent section.

But what is interesting in the Converged Access Network in Figure 6 is that we have now been able to incorporate Coherent optics in the access plant in much the same way as direct detect has been deployed. This type of convergence requires the innovative technology of bidirectional dual laser pluggable optics used at Comcast in recent years and is described in this section.

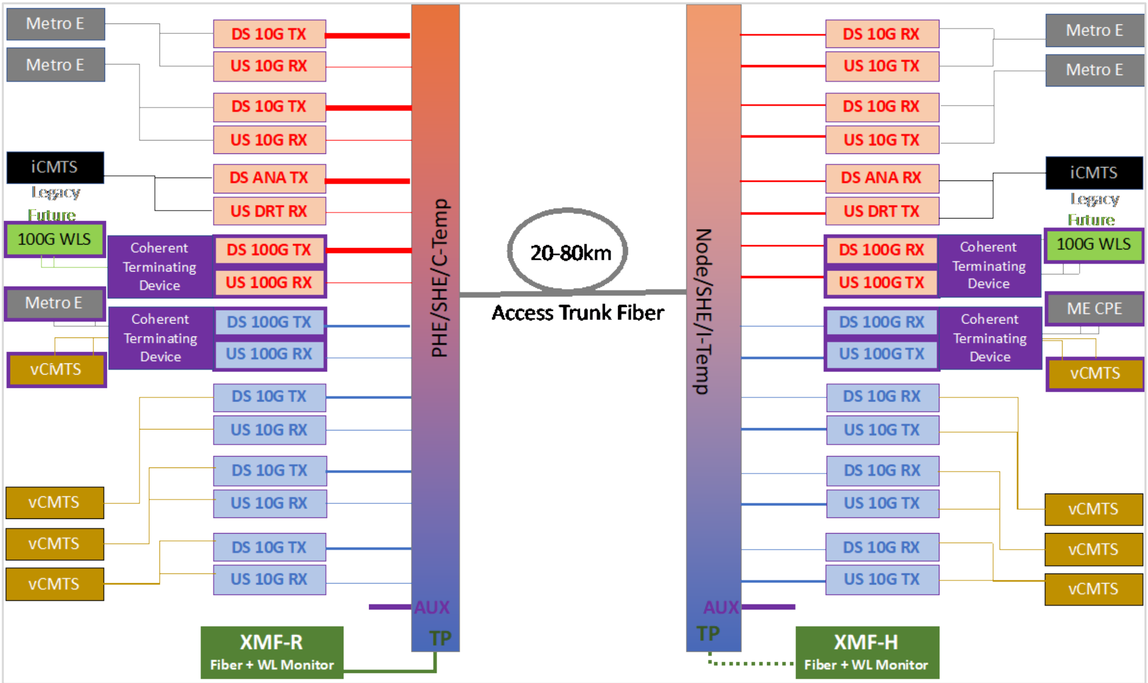

Figure 6 – Illustrating the Converged Access Network

Since ROADM cascades are not used in our DAA access networks due to modest fiber lengths, the design of high-capacity (100G – 800G) solutions could be elegant as there is no additional degradation due to these devices. Furthermore, these links can support bidirectional transmission quite easily since there are no non-reciprocal elements in the fiber path. Indeed, the relaxed relatively modest fiber reach required in DAA enables us to innovate on optical devices as well as reduce cost, oftentimes by innovating on the otherwise saturated edge of technology.

3.1. Converging the Coherence

While the CMP is a muxponder and intentionally does not participate in any switching or stat muxing regimes, it is an additional active element in the system. As such, it is a perfect vehicle to converge multiple services such as 10Gbps metro-e services, 5G cell back hauls and the DAA services which also use 10Gbps line rates not only on one fiber, but also on the same wavelength. Additionally, even 100Gbps services could be offered to those that needed it. Such convergence enables commonality of infrastructure and makes the network strong and elastic.

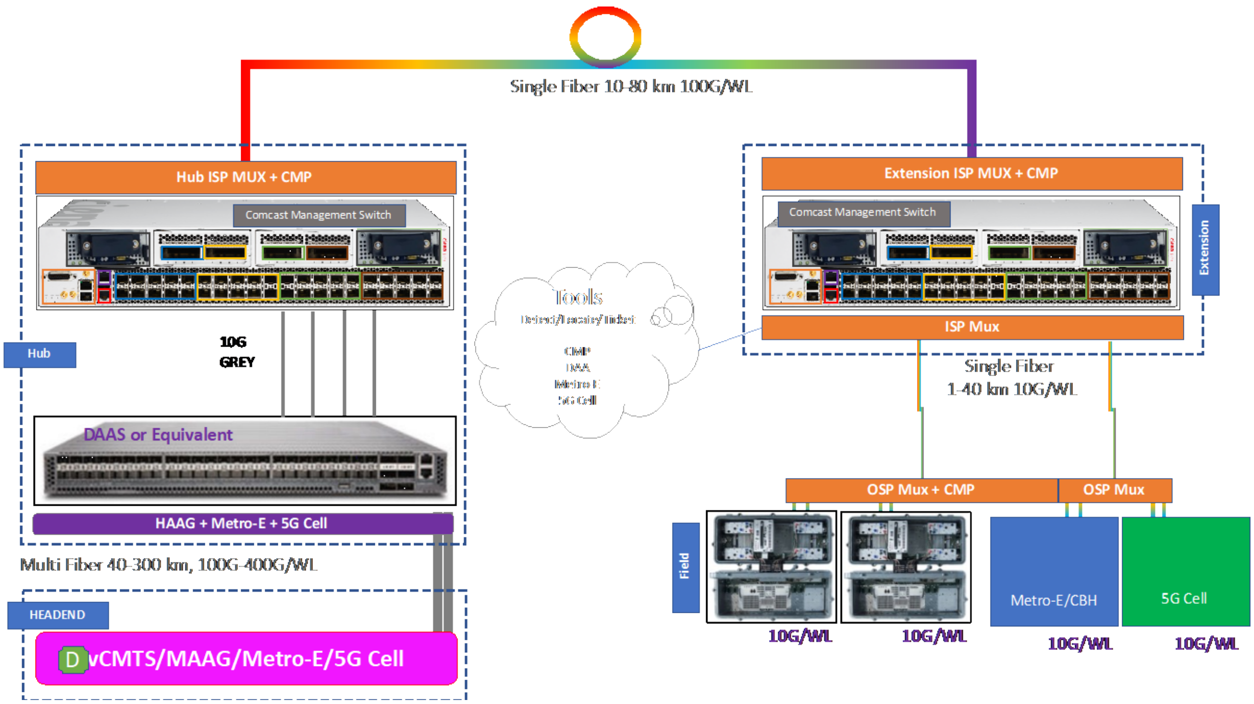

Figure 7 – Convergence of Services, Optics and Tooling

4. Ground Zero for Hurricane Ian

As Hurricane Ian barrelled towards the country, Comcast implemented its storm-mode protocol. Under this protocol, Comcast's Network Operations Center (NOC) postpones non-critical scheduled work on applicable equipment infrastructure. Postponing non-critical scheduled maintenance activities decreases other noise that may appear on the NOC's (Network Operating Center) monitoring dashboards. The Storm Mode keeps critical components available to help support the unknown stress the storm will unleash. Accordingly, key support teams can focus on the remediation process necessary to restore services to our customers once the impacted area has been deemed safe to work in. Storm Preparation mode concludes by identifying the areas affected by the storm, assessing the safest areas to start restoring services to and prioritizing the equipment restoration to allow for the best impact for our customers.

4.1. After Hurricane Ian

In the aftermath of Hurricane Ian, restoring power and communications was a top priority of Sanibel Island. At Comcast, this was an 'all hands-on deck' moment. Comcast personnel had to be ferried to and from the island every day to perform any work on the island. Comcast responded by placing Wi-Fi hotspots on trucks in major landmarks so folks could come in get connections and possibly charge their phones. Comcast is the only non-wireless internet service provider for Sanibel Island. Getting services restored to municipal facilities was critical for search and rescue services as well as providing additional resources for those stranded on the island.

Figure 8 – Before and After Pictures of the Sanibel Causeway [6]

The existing Sanibel Island facility was a cabinet that housed a DC power plant, some optoelectronics and fiber patch panels. The 6-foot storm surge completely flooded the cabinet and ruined everything inside. Before the cabinet could be re-used, it would have to undergo a thorough cleaning and have all electrical components replaced.

In the meantime, a check on fiber connections showed that the main route of fiber from South Ft. Myers along the Causeway was cut (see above figure) and there was no secondary route available. Through local partnerships, Comcast secured limited fiber between the mainland and a location near the Pine Island hub. Comcast was then able to restore a damaged fiber path that could be used to restore services to Pine Island and eventually to Sanibel Island.

The issue now was to supply signals to the Sanibel Extension from a new site and make all the nodes operational. At this time, all of Sanibel Island was supplied by conventional analog optics, which had limited reach and was based in the South Ft. Myers hub. Accordingly, fiber availability from Pine Island did nothing to improve connectivity due to the long distances from Pine Island to Sanibel Island and the limited reach of analog optics. It was therefore decided to move the entire Sanibel Island footprint to the DAA to supply connectivity. A more detailed description of DAA has already been given and it is good to recall that DAA pre-supposes 2 10G wavelengths of DWDM light for each node lit up.

A detailed survey of Sanibel from design maps showed us that there would be up to 57 fiber nodes in Sanibel Island serving over 11,000 passings. We also found that critical sections of the fiber path had single strands of fiber and also that the extension site in Sanibel -would not support the form factors of DAA leaf and spine access switches as well as routers and the transport gear needed (see Figure 10).

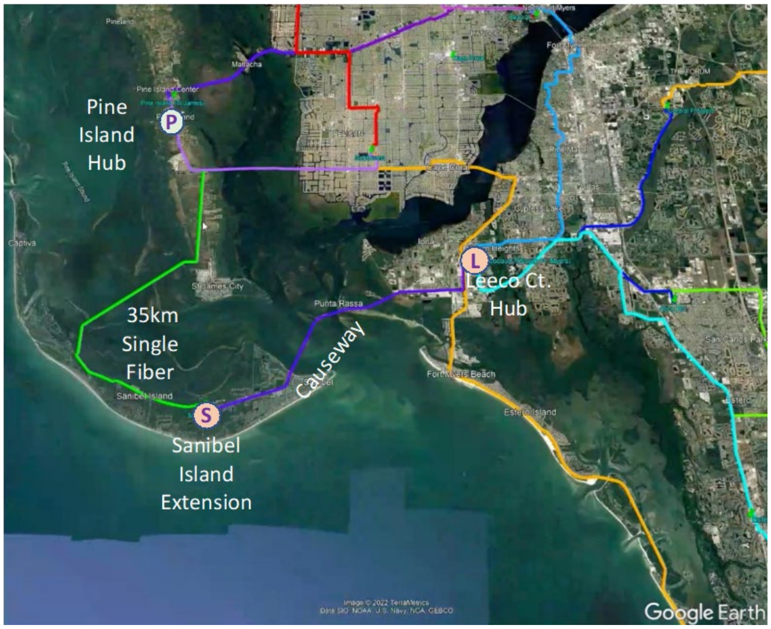

Figure 9 – Fiber Availability on the Causeway and from Pine Island

Figure 10 – Extension Site on Sanibel Island

It was at this point that division leadership reached out to the National organization with a request for technology that would enable lighting up to 120 digital nodes as a practical maximum on one single strand of fiber, and also ideally having a low profile so as to fit in extension cabinets with minimal critical infrastructure requirements. This extremely compact and critical-infrastructure-conserving solution would also ideally serve 10G Metro E customers and 5G cell towers on the same strand.

Coherent mux Ponder (CMP solution fitted this bill and furthermore, Central and West Division Leadership had seen this setup in action during the SCTE Show at the Comcast Technology Center a month before.

At this point, our Leadership decided to support this request and participate in Hurricane Relief as a priority and shipped out the needed CMPs, the 100Gbps BiDi transmitters, the tunable and grey SFPs and optical passives necessary along with management switches and pervasive optical monitoring equipment and shipped these out as well to Central. With the necessary preparations complete, it was time to proceed with the task of organizing and installing the equipment, as well as undertaking the meticulous but crucial process of activating digital nodes throughout the entire island.

5. Solving the Supply Chain: Equipment for Florida

While Covid-19 lockdowns had been lifted in many parts of the world by 2022, we continued to face its impact for a significant portion of the year. Additionally, global supply chain disruptions persisted, leading to ongoing delays in procuring materials and equipment across various industries, even at present. Despite these challenges, we managed to secure an adequate amount of equipment, including spare CMPs and BiDi CFP2 modules for deployment in West and Central divisions.

Our first step was to stage the solution to make sure everything was properly configured and set before the equipment was sent out to the deployment areas. The staging consisted of uploading the latest approved software, the required switch licenses, the approved switch configurations for the local and remote sides and setting up IP addresses (these could be changed by the local teams). Once this was completed, the available CFP2 modules were inserted in the switches and the 100G link availability was verified. After that, the approved gray optics SFP+s (small formfactor pluggables) were inserted in the local and remote CMPs. Using a 10Gbps Viavi T-BERD connected to these SFP+s, we were able to pass error-free traffic for a short period of time (30 min) to validate the systems. The next step was to pack and ship the systems into the region and start the deployment phase.

That was the time when the Storm Mode lifted, and we moved to recovery mode. Since the equipment was already staged, configured, and tested, the only local changes to be made were providing console port and management port connectivity. Such configuration could serve up to 40 optical nodes bundles very quickly. As the RPDs in the optical nodes began to successfully light up and were provisioned, it was the beginning steps towards bringing back connectivity to the Island.

5.1. Redesigning Analog Links to DAA

To provide immediate connectivity, Comcast opened Wi-Fi access points for the public use for free, across the island thus helping people find critical resources like food, water, and social services.

Our first step was to light up the Sanibel extension site with the CMP, and have it connected to the Pine Island hub (also called the St. James Hub). The St. James Hub CMPs were all connected to DAAS at that location, while the Sanibel Extension site CMP was made ready with all the optics to connect out to individual DAA nodes. But before the DAA nodes started lighting up, as mentioned once before, since the existing nodes were all analog nodes, Comcast's Planning and Design department had to re-design all the Sanibel nodes as DAA nodes.

The Sanibel extension site was powered up and made functional even while the redesign process of designing DAA nodes in place of the existing analog nodes was being carried out. However, connecting said nodes was an intricate process. The following picture shows what the remediation team saw when they arrived at where a node was supposed to be on a pedestal.

Figure 11 – Pedestal Node Location – Post-Hurricane

First the links from the individual node locations to the Sanibel extension site had to be restored. Once that was done, the node was then to be set up and activated and could be put into a full production state with only the addition of a fiber jumper into the Coherent Muxponder Chassis. The Coherent Muxponder allowed for everything at the source site up to the extension site Coherent Muxponder Chassis to be connected in advance of the node turnup. Due to the elegance and simplicity of this platform, each node was ready to be configured and set up extremely quickly. Each pair of CFP2 optics enabled the team to activate 10 additional nodes. Eventually, all nodes were restored much sooner than if a legacy technology had been used.

5.2. Generators to the Rescue

A major issue however was that a majority of the island was without power, and so, activating nodes was not really possible even if connectivity with the Sanibel extension site was established. But Comcast had deployed many portable generators that were used to power Wi-Fi hotspots.

By enabling Wi-Fi in the affected areas, emergency restoration crews were able to establish a communication network. This network played a crucial role in aiding and assisting in a more strategic remediation plan, as well as providing progress reporting to facilitate effective response and recovery efforts. For the island's residents, it provided a comforting sense of connection to friends, family, and the outside world for status and news updates [7].

Comcast team followed that playbook and deployed many portable generators to power connected nodes and went about ensuring that they were up and running even before the power was restored so that when power did come back, the nodes were ready for operation. Each DAA node was brought up, activated, verified and then brought down and connected to line power when power began to get restored.

5.3. A Word on Optical Connectivity and Monitoring

When Comcast initially verified fiber connectivity between Sanibel and Pine Islands, a 1x48 DWDM mux was installed on a single fiber on each end of the link. These muxes were used for the Coherent optics connecting the CMP chassis. Once the link connectivity and back-office connectivity were established node activations described above could begin [8]. At the Sanibel side, multiple Muxes were used to connect to clusters of DAA nodes as determined by the optical design team. All of these Muxes were monitored by pervasive monitoring technology within Comcast and real time data of the fiber network was available to technicians in the field. The importance of real time fiber monitoring especially in times of disaster recovery cannot be overstated. If fiber connectivity is well established and known in real time, other barriers to connectivity - such as power outages or equipment connections - can be more easily isolated thus ensuring a more stable restoration environment.

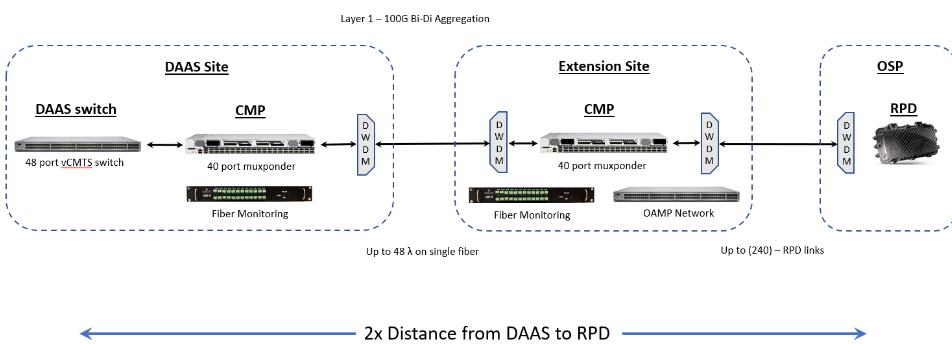

Figure 12 – Illustrating Monitoring of the Coherent Mux Ponder Solution

Thus, fiber assets across Pine Island to Sanibel Island were located, Coherent Optics then spanned the across these assets and lit up Sanibel Island providing great capacity and reach. Services were then converted from analog to DAA nodes, and the nodes lit up using portable generators while awaiting power restoration. Once power was restored, the nodes were converted to line power and connectivity was restored all in record time.

6. Conclusions

In this paper, we have provided a glimpse into the extraordinary efforts of Comcast personnel, from line technicians to senior leadership, to implement recovery efforts on Sanibel Island after Hurricane Ian. While this exceptional effort highlights disaster recovery, such efforts display the norm for technology advancements with a tight loop of learning and feedback that helps pass information from the field to divisions to leadership.

Coherent optics are an essential part of access technology, especially in fiber-starved or extension sites where space is limited. At the heart of the innovation is a dual laser single fiber pluggable transceiver design that transforms every access link into a high-capacity and highly reliable converged link Moreover, this development opens up possibilities for our converged access architecture, allowing for the integration of services like residential, commercial, and 5G onto a single unified platform.

7. Acknowledgements

It is not often that work done on a technical level find use so quickly in the field and at such a critical juncture so as to support our customers in their time of need.

Our thanks go to the division leadership for their innovativeness, hard work, and timely authorization of Coherent link deployment. We acknowledge all our teammates and vendors that worked with us on this project.

We end this paper again with our thoughts on the Hurricane Ian victims and our thanks to the first responders. Our thanks are also due to our own Comcast personnel that enabled connectivity with grit and grace as soon as they did in the affected areas.

Abbreviations

Gbps	GigaBits per second
BERT	Bit Error Rate Test
BiDi	Bi-Directional
C Band	Conventional Band (1530 to 1565 nm)
CMP	Coherent Mux Ponder
CFP2	C Form-factor Pluggable 2 (100Gbps)
CWDM	Coarse Wavelength Division Multiplexing
DAAS	Distributed Access Architecture Switch
DAA	Distributed Access Architecture
DS	Down Stream
DWDM	Dense Wavelength Division Multiplexing
Hz	Hertz
ISP	Inside Plant
LEO	Low Earth Orbit
nm	Nano meter
NOC	Network operating Center
OSP	Outside Plant
OTDR	Optical Time Domain Reflectometry
QAM	Quadrature Amplitude Modulation
QSFP	Quad Small Form-factor Pluggable transceiver (40, 100Gbps)
QPSK	Quadrature Phase Shift Keying
RFC 2544	Benchmarking Methodology for Network Interconnect Devices
ROADMs	Reconfigurable optical Add Drop Multiplexing
SCTE	Society of Cable Telecommunications Engineers
SFP+	Small Form Factor Pluggable +
SCTE	Society of Cable Telecommunications Engineers
SMF	Single Mode Fiber
Tbps	Terabits per second
US	Up Stream
WL	Wavelength
vCMTS	Virtual Cable Modem Termination System

Bibliography & References

[1] https://www.nationalgeographic.com/travel/article/sanibel-island-florida-hurricane-ian#:~:text=Everything%20changed%20when%20the%20hurricane,car%20traffic%20to%20the%20island.

[2] https://www.tampabay.com/news/environment/2022/12/22/hurricane-ian-florida-landfall-sanibel-island-causeway-lee-county/

[3] Accelerating the Virtualization: Introducing Hybrid Fiber Shelf into the Mix, Venk Mutalik et. al., SCTE Expo 2020

[4] It's 10PM, do you know where your wavelengths are? Venk Mutalik et. al., SCTE Expo 2020

[5] Photon Avatars in the Comcast Cosmos, Venk Mutalik et., al., SCTE Expo 2022
[6] https://abcnews.go.com/US/hurricane-ian-images-show-destruction-sanibel-island-fort/story?id=90919034
[7] https://corporate.comcast.com/press/releases/comcast-free-xfinity-wifi-hotspot-network-hurricane-ian
[8] https://santivachronicle.com/news/comcast-service-restored-well-ahead-of-schedule-on-sanibel/
[9] Fiber QAM vs. RF QAM, Amarildo Viera et. al., SCTE Expo 2023

