Boosting FTTH Network Performance: Key Strategies

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1. Introduction

As many Multiple System Operator's (MSO) focus on Fiber-To-The-Home (FTTH) for their upcoming greenfield and rural deployments, they must consider the unique challenges related to network performance over their traditional Data Over Cable Service Interface Specification (DOCSIS®) networks. A mindset shift is required to effectively monitor the end-to-end performance for your FTTH customers.

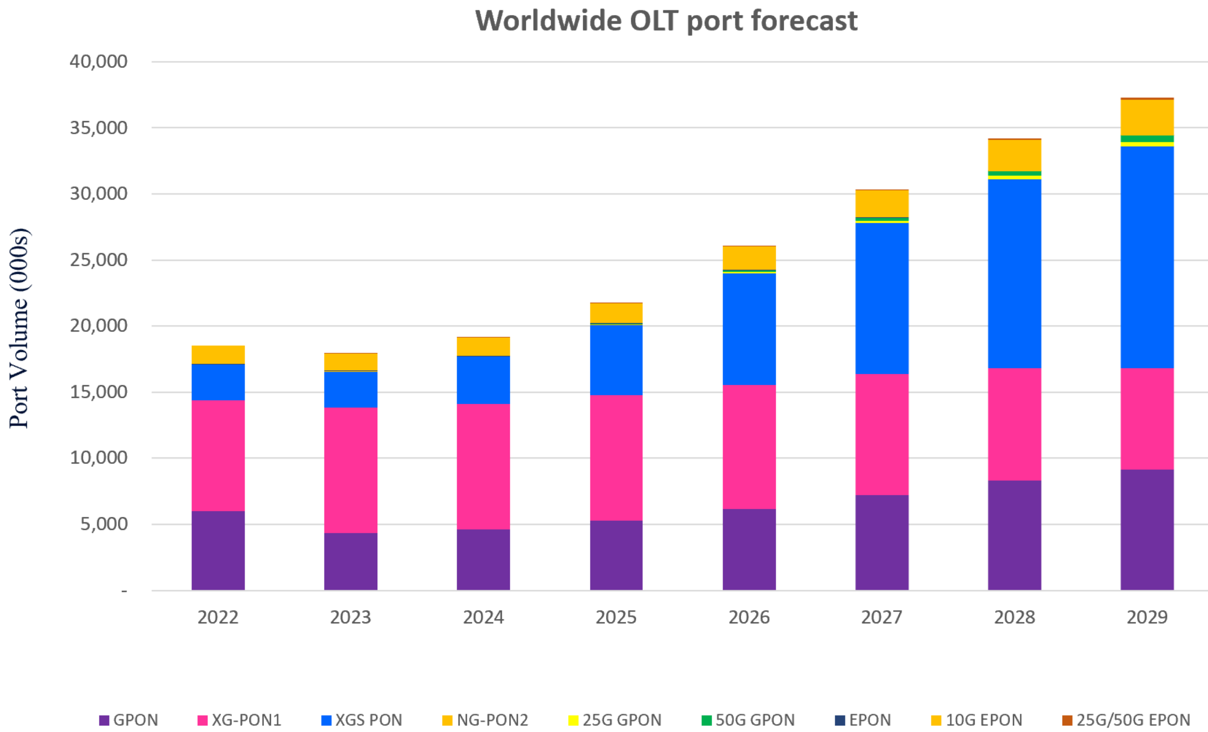
This paper focuses on how to identify the appropriate requirements to avoid common oversights. It illustrates an end-to-end performance monitoring solution that includes the Residential Gateway (RG), Optical Network Terminal (ONT), Optical Line Terminal (OLT), and Broadband Network Gateway (BNG), in your FTTH network. The architecture, protocols, telemetry, and operational characteristics pose differences that require understanding.

During our journey with our FTTH Network, we navigated through various phases, each requiring specific strategies and technical considerations. In our initial phase, we delved into our performance management strategy, grasping with issues and risks inherent to such an endeavor. We implemented robust protocols to address challenges head-on. As we progressed, we conceded our missteps and actively adapted, fostering collaboration with cross-functional teams to strengthen our approach. Moving forward, we recognized the importance of continuous improvement, identifying key enhancements crucial for deployment. Moreover, we anticipate the influence of government initiatives like BEAD (Broadband, Equity, Access, and Deployment) in the United States and UBF (Universal Broadband Fund) in Canada on our performance monitoring requirements.

Through the exploration of our FTTH performance management journey, we can highlight the key factors that can positively impact your network operations and customer experience.

2. PON Technologies

As the wireline access network evolves the need for higher speed has become a hot topic. In order to meet the ever-increasing customer demand, many new access network technologies have come onto the market. One such technology is Passive Optical Network (PON). Ethernet PON which follows the IEEE standard that can utilize the DOCSIS provisioning method was initially considered by some cable operators. However, the need for multi-gigabit bandwidth and future considerations lead to some operators to choose Gigabit Passive Optical Network (GPON), which follows the ITU-T standards. ITU-T PON has many flavors including GPON, 10 Gigabit Symmetrical Passive Optical Network (XGS-PON) and NG-PON2. XGS-PON which offers 10 Gb symmetrical speed is gaining more market share and is currently the leading PON Technology that is being adopted heavily worldwide. Figure 1 (Omdia) shows the PON growth over the next five years.

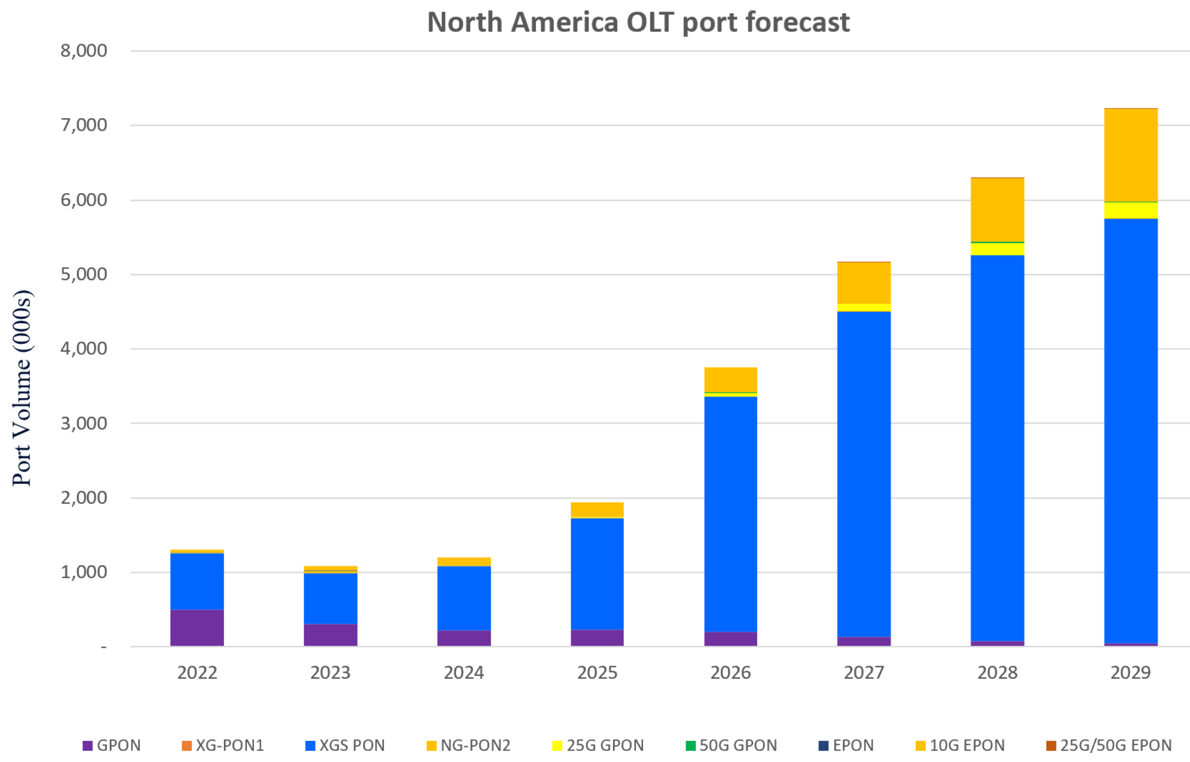


Source: Omdia

Figure 1 - PON port forecast

2.1. XGS-PON

XGS-PON is being widely deployed in North America. XGS-PON is starting to dominate the market as compared to GPON, which offers less than 2.5G downstream and 1G upstream and is slowly losing the market share. It is forecasted that XGS-PON will grow tremendously over the next five years due to multi-gigabit demands. Figure 2 (Omdia) illustrates the OLT port forecast for North America. XGS-PON will continue to play an important role in the global market.



Source: Omdia

Figure 2 - North American OLT forecast

2.2. PON Growth

It is clear that PON technology will be an important part of a market where multi-gigabit speed is needed. PON consumers include, residential customers, Small and Medium Business (SMB) customers, government entities and corporations. PON service can be utilized for wireless backhaul, business to business (B2B) and other large-scale applications that require low latency and higher throughput. Figure 3 (Omdia) shows the growth forecast for the PON technologies and their corresponding revenue for the upcoming years.

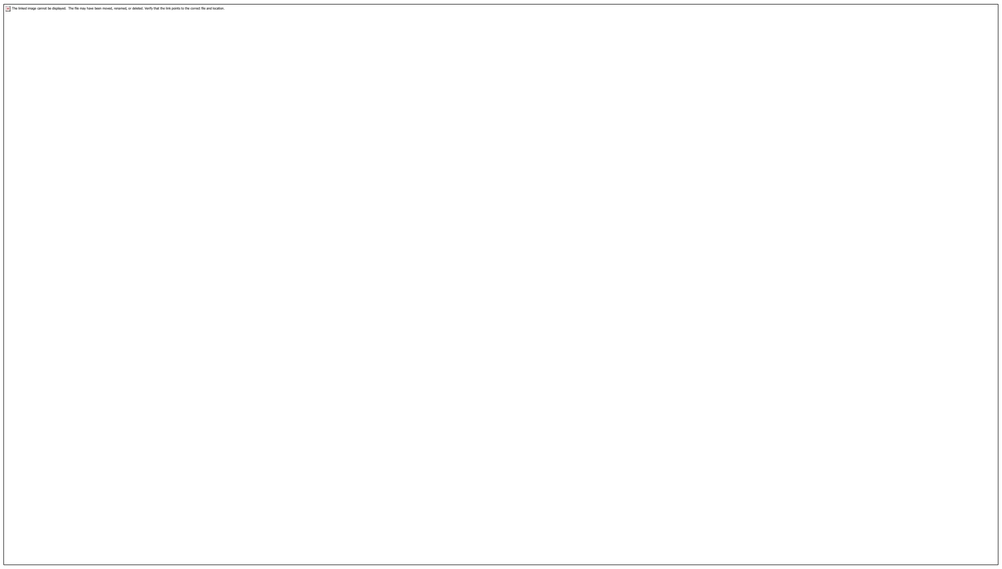


Figure 3 - Revenue by PON technology

2.3. Future of PON

As the need for speed grows, PON Technology is also evolving. 25 Gigabit PON is available in some markets for commercial use as of 2024. There are some vendors currently working on 50 Gigabit PON and even 100 Gigabit PON roadmap. As the technology evolves, PON allows us to use multiple wavelengths on a single fiber by using Next-Generation PON 2 (NG-PON2) technology which opens the door to not only to high-speed internet but also to other services such as IPTV and variety of other business solutions, all on the same fiber. The versatile nature of PON makes it an excellent choice for any scenario that needs to utilize the access network. Some of the use cases include low latency applications such as real time multiplayer videogames, mobile/wireless backhaul and 8K and 16K video. PON can interoperate, completement or enhance other access network solutions. For example, some operators are investing in the integration of 5G wireless backhaul with PON technology. High speed and low latency provided by PON is ideal for such application. There are many other benefits with PON, including being an energy-efficient and environmentally friendly access network technology.

Low latency and higher throughput provided by PON can lead to the development of many other applications that have not been thought of yet. It is imperative that with the increasing use of PON for different solutions, that operators start utilizing Key Performance Indicators (KPI) from PON network to provide more resilient and robust high-speed pipe to our customers.

3. Government Mandate

Both the Canadian government and the United States governments have allocated funding to Operators to provide affordable and reliable high speed internet services to under serviced communities such as rural areas. Eligible Operators can utilize these fundings to either upgrade their existing infrastructure or plan and deploy new infrastructure to provide high speed internet service. In the United States the federal government has allocated more than $40 billion for the Broadband Equity Access and Deployment (BEAD) program. Similarly, in Canada, the Federal government has allocated more than $3 billion dollars in Universal Broadband Fund (UBF) to provide high speed internet service to approximately 98% of Canadian residence by 2026. In addition to this, provincial governments have added additional funding to deliver high speed internet to underserved communities. The fund allocations are often paired with conditions and measurement criteria to ensure the customers are really getting what they are paying for. This is where PON network performance data comes in handy, allowing us to measure the performance to ensure our networks are delivering the quality of service we expect.

3.1. Provincial Mandate

As was the case with the federal government mandates, provinces in Canada have allocated billions of dollars to build the necessary infrastructure to provide high-speed internet to rural and underserved communities. Provincial governments have mandated that performance of the high-speed internet delivered to the customers meet certain metrics. It is vital Operators have effective solutions to monitor the performance of the network as well as to ensure we meet the government guidelines. Some of the key metrics include availability, throughput, latency, jitter and packet loss. In the upcoming sections, this paper will discuss about some of the key strategies utilized to achieve the above.

4. PON Performance vs HFC Performance Monitoring

Hybrid Fiber Coaxial (HFC) network which is used by traditional cable operators is significantly different from the PON network. Below is the list of key differences:

1. As per the name, PON network does not have any active components that need power southbound of the PON port. Whereas HFC has many active components such as the amplifiers (when configured in amplified plant) that will require power to operate.
2. PON carries purely optical signals while HFC carries both electrical and optical signals. Since PON is focused on fiber optic cables, the right performance KPIs should be in place to allow the detection of fiber breaks/degradation quickly.
3. PON performance monitoring consists of the BNG, OLT and ONT. On the other hand, in HFC, one must monitor the nodes, amplifiers, line extenders and some headend equipment built specifically for HFC.
4. Mean Error Ration (MER), electrical Signal to Noise Ratio (SNR), channel utilization, ingress and egress noise measurements are not typically involved in the PON network.
5. PON allows for symmetrical upstream and downstream bandwidth, in comparison to classic HFC which traditionally allocates more bandwidth on the downstream path. This requires a change in how KPIs are measured to maintain reliable network health to deliver both the provisioned high upstream and downstream bandwidth in the multi-gigabit range.
6. PON brings many new KPIs including optical power levels, Bit Error Ratio (BER), Optical Signal to Noise Ratio (OSNR), Quality of Service (QoS), along with throughput, uplink bandwidth utilization, latency, jitter, packet loss and availability.

Considering the above facts, one must understand the unique requirement for PON performance monitoring, which is focused on optical level trends, BER, symmetrical speeds, latency, jitter, availability, and frequent requirements for the network scalability. Shifting the approach towards PON performance monitoring allows us to provide the best possible service to our customers and meet Service Level Agreements (SLA).

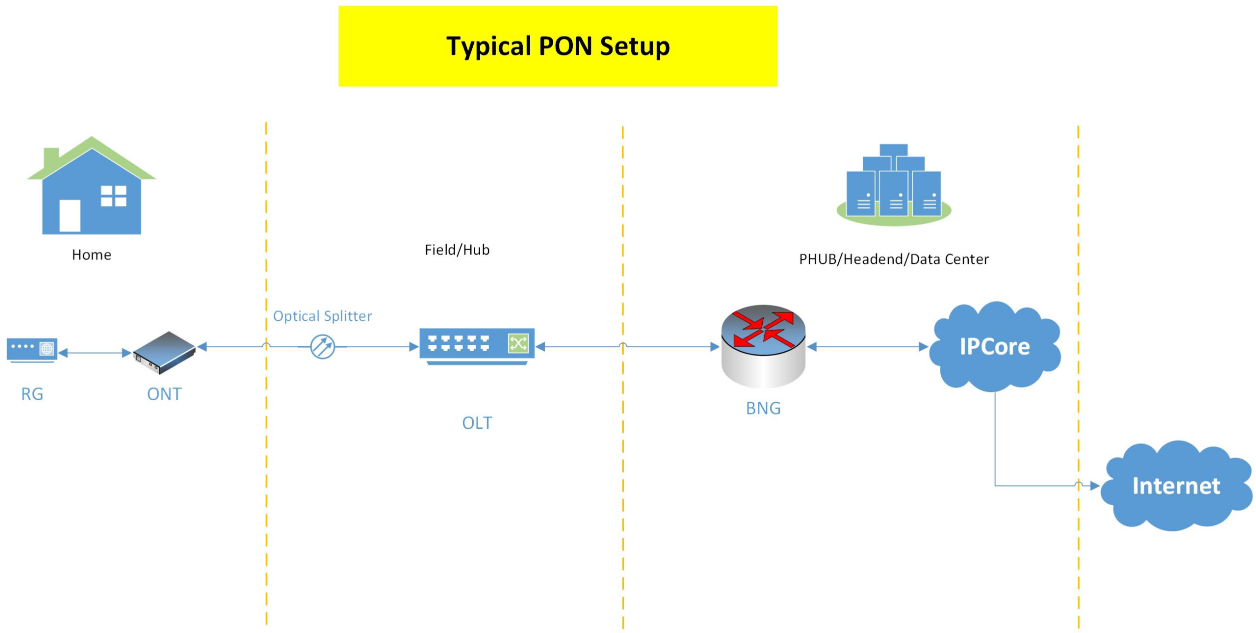


Figure 4 - Typical PON setup

4.1. Components of Typical PON Setup

Performance monitoring of PON Network typically consists of the following network components:

1. Broadband Network Gateway is the edge router that connects the PON network components to the core network. BNG is typically used for subscriber management where only authenticated users can access the network and it is usually placed close to the access network for efficient service delivery. It can be deployed in a centralized, integrated, or distributed model depending on the requirement of the network. Figure 4 illustrates a typical PON setup.

   It is also used to provide Quality of Service (QoS) to ensure services that require low latency and high bandwidth are allocated the appropriate QoS policies by working in conjunction with Policy and Charging Rules Function (PCRF) or Diameter, using Authentication, Authorization and Accounting (AAA) to securely connect subscribers to the network. It provides the service as per information received from PCRF/Diameter based on the configured Service Level Agreement (SLA) profiles for each subscriber. It ensures subscribers are getting what their accounts are provisioned for including providing appropriate speed tiers based on subscriber profile. BNG is typically situated in the headend and multiple OLTs can terminate on a single BNG.

2. OLT is a very important component of the PON network. OLTs connect to the BNG on the northbound interface. The OLT aggregates traffic coming from multiple users connected to the PON ports. OLT connects multiple ONTs to each of its PON ports. Typically, a single PON port can connect 64 ONTs in a Single-Family Unit (SFU) architecture or 128 ONTs in a Multi Dwelling

Unit (MDU) architecture. The number of ONT per PON port may vary depending on the deployment architecture selected by the Operator. The OLT also plays a crucial role in configuring and managing the firmware of ONTs. OLTs can be installed in the headend or in the field depending on the deployment design chosen by the Operator and can differ in capacity based on the customer requirements for the region. Field deployed OLTs are sometimes called remote OLTs (rOLT). Clamshell type OLTs are preferred for arial or subterranean/underground deployment. These clamshell OLTs have smaller number of PON ports as compared to the cabinet based OLTs. Clamshell OLTs are ideal for rural deployment. Cabinet based OLTs can have hundreds of PON ports depending on the OLT model chosen and they are ideal for high density deployments.

3. ONT is another important component of the PON network. ONT is located at the customer's premises. The main purpose of the ONT is to convert the optical signal received from the OLT To electrical signal that can be used by devices such as Residential Gateways (RG), switches or computers. On the upstream an ONT will take the electrical signal coming from customer premise equipment and converts it to optical signal.

4. All other components on the PON network are passive, as such they don't need power. Some of these include optical splitters and optical fibers.

PON performance monitoring encompasses all the above-mentioned components. Next sections will discuss about the performance monitoring of these elements.

5. PON Performance Monitoring

As mentioned earlier, it is vital the performance of the PON network is monitored continuously to ensure we are providing the best service to our customers. Lack of monitoring and capacity management leads to performance issues. Below sections outline the performance monitoring journey that we went through over the past few years. As a first step the solution had to be automated, which means as soon as a device is added to the PON network KPIs should be collected from it. Secondly, the data should be stored in a centralized location. As a final step the solution should be able to produce automated report that can be subscribed by variety of users. To achieve these objectives, we developed an automated data collection and reporting solution as depicted in Figure 5 that utilizes the cloud.

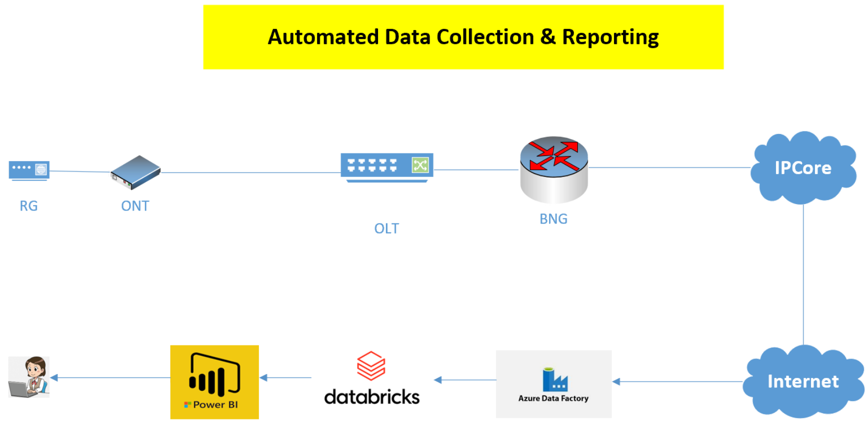


Figure 5 - PON performance data collection, storage and reporting via the cloud

5.1. BNG Performance Monitoring

BNG is a router that connects to the IP network on the northbound interface and to the OLT on the southbound interface(s). Since BNG is a layer 3 network device, there are well established standards to monitor its performance. Two Way Active Measurement Protocol (TWAMP) is a well-known protocol standardized by Internet Engineering Task Force (IETF) to collect performance metrics of IP networks. Since BNG processes IP packets, this protocol is suitable for measuring the performance on the northbound interface facing the IP Core network. However, the south bound interface of BNG will not be able to utilize this protocol as the OLT devices in the south bound typically do not support TWAMP. Thus, a protocol suitable for managing and monitoring this part of the network needed to be selected. Y.1731 is a well-suited protocol providing comprehensive performance monitoring data between the BNG and the OLT. Y.1731 is an ITU standard developed to monitor the performance of the ethernet based networks. Since Y.1731 is supported by both BNG and the OLT we implemented this solution to gather data between these two network components. Latency, jitter, frame loss and throughput are measured at a pre-set interval to ensure the performance of the network is at its best.

Along with performance statistics collected between the OLT and BNG, it is important to monitor the health and observe bandwidth trends for BNG's uplink capacity as well. This is to ensure that BNG devices can support all the traffic coming in from multiple OLTs and different service requirements. Network Operations Center (NOC) tools, which collect Simple Network Management Protocol (SNMP) data or streaming telemetry data to provide traffic flow analysis, network insights, can assist with maintaining the network health and fulfilling capacity requirements. Key strategy here is to automate the collection and reporting of the KPIs between the two network components. This will ensure any anomalies or deviation detected can be addressed immediately before they start impacting customers.

5.1.1. Upstream Utilization

The KPIs collected between the BNG, and the OLT will help with forecast and capacity planning. As the links start to get busy and as the demand increases, planners can budget accordingly and add additional links or increase the capacity of the existing links.

5.2. OLT Performance Monitoring

There are several hundred KPI counters that can be monitored to determine the performance of the OLT. However, one must find the sweet spot where the performance monitoring does not actually start to interfere with the performance of the actual component being monitored. Thus, one must be selective in choosing the counters. In our case we started with the critical aspects of the OLT such as availability of the network cards, line cards, PON ports, number of errored frames, number of frame loss, uplink utilization, discarded frames, signal levels on PON ports, device temperature, memory usage, and utilization rate of the processors. These and the other data are collected at a regular interval from the target OLTs via an automated process. Using the data collected dashboards were created to display the trends. Figure 6 illustrates the top OLT downstream utilization for a particular region. Using this data one can decide and plan where to perform the next capacity augmentation.

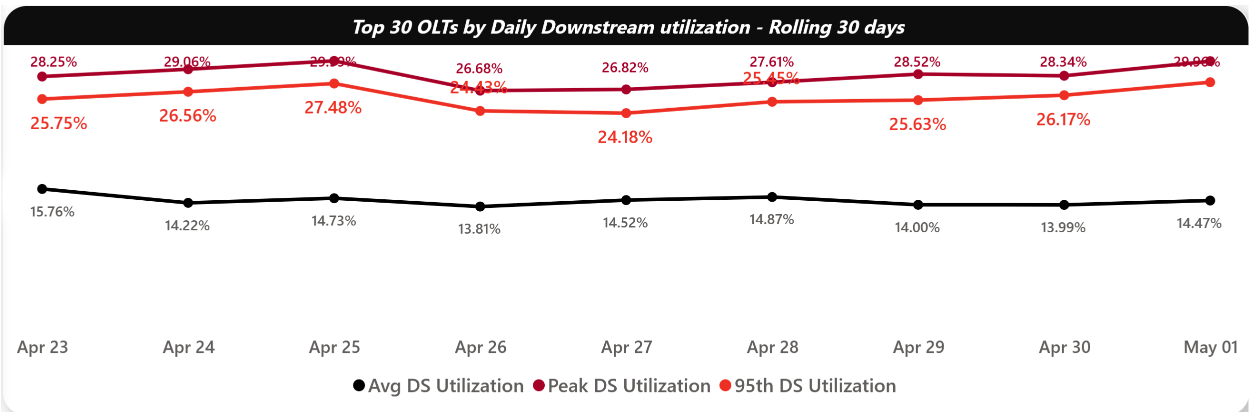


Figure 6 - Top OLT utilization for a region

The OLT outage trend is also a good chart to look at to identify any re-occurring patterns. There are a few spikes in the Figure 7 that shows the number of outages over a period of a year for a particular region. If we drill down deeper then we will be able to determine the root causes of these spikes. Some of the spikes are caused by extended power outages in the field and some were caused by either hardware or software failures. Using these data Operators can help teams better prepare for future events.

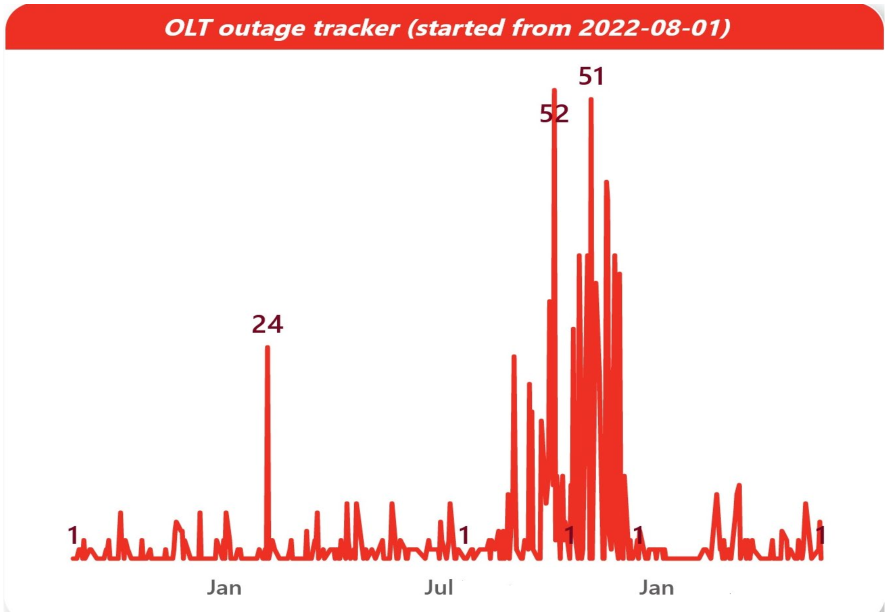


Figure 7 - OLT outage trend for a region

As per Figure 8, it can be seen the aggregate traffic from multiple OLTs, at a BNG. With this data, one can plan ahead the traffic needs of the network and increase the capacity of the BNG or create more links between OLTs and BNG. These data will help the planners tremendously as they can work to future proof network links.

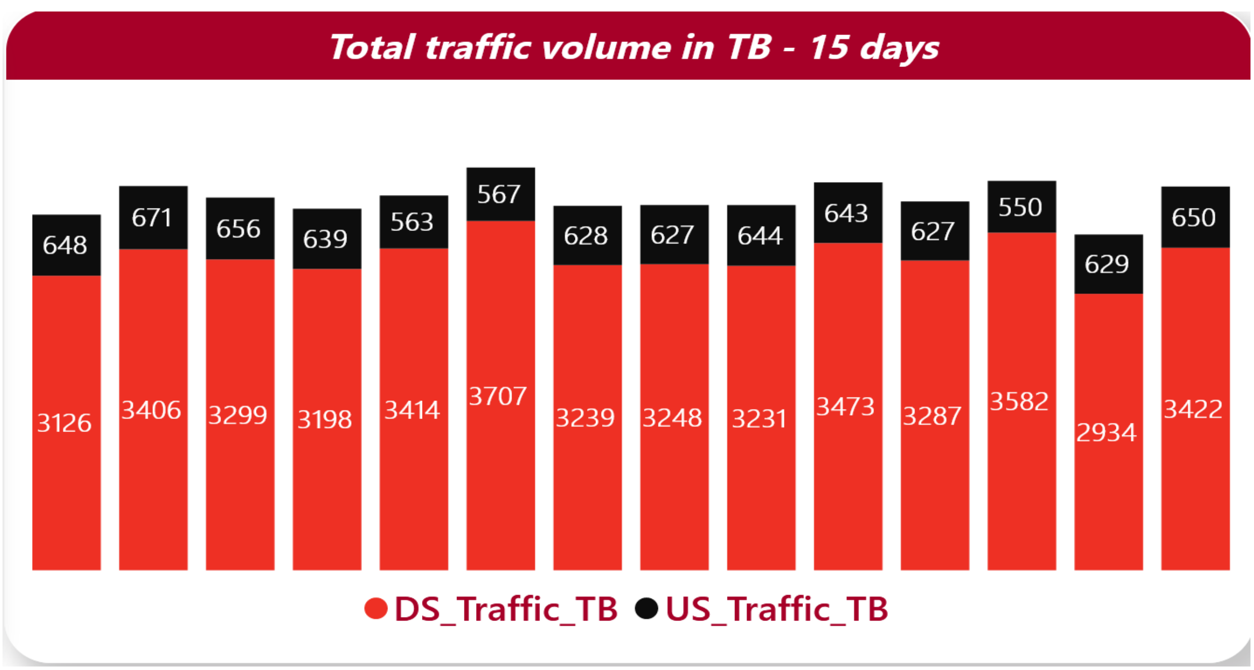


Figure 8 - Daily downstream and upstream traffic for a region

The above are some of the strategies an Operator can utilize to gather data, analyze and report to ensure the performance of the OLT is at its best. Although it might be overwhelming at first with the amount of data collected, it is vital that Operators spend a good amount of time in the beginning to automate the reporting and select specific reports that are going to be very useful to maintain a high performing network that is always on.

5.3. ONT Performance Monitoring

To provide the best customer experience possible, it is important to ensure that the ONT, which is located in the customer's premise, is performing as per the specification. There are many key managed entities (ME) that are crucial for monitoring the health of the ONT. It is important to ensure these MEs are collected for Operators to validate the health, service quality and performance of the ONT. Some of the crucial metrics include the transmit and receive optical signal levels at the ONT, signal degradation, operational status, temperature of the ONT and Quality of Service (QoS) metrics. Monitoring the performance of the ONT will ensure the Operator is compliant with the agreed upon SLA and confirm the customer experience is at its best. Figure 9 depicts an example of degraded signal in generated at the OLTs in a particular region. Micro-level analysis of these data can provide more insights into the actual problem and sometimes point to a common root cause. The strategy here is to identify the underlying issues and address them as quickly as possible before they start affecting the customers.

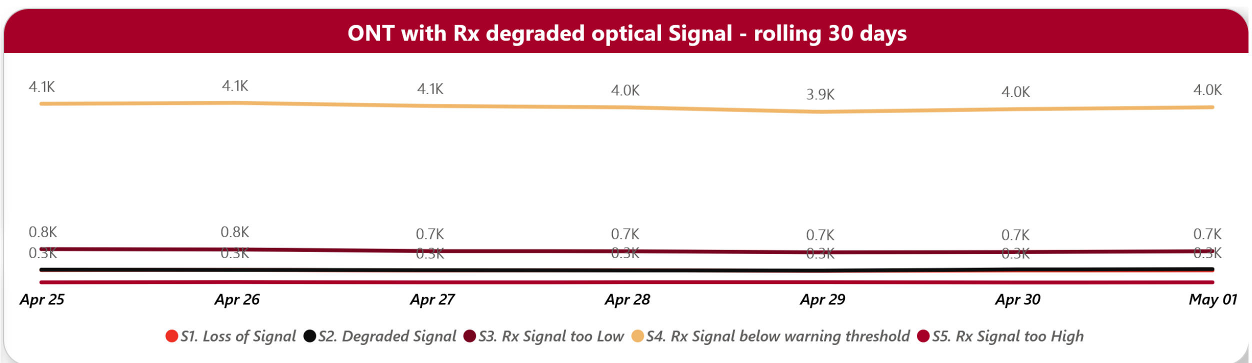


Figure 9 - ONTs with degraded signal

5.4. Residential Gateway Speed Test

When it comes to PON network performance monitoring for residential customers we can't ignore the last piece of equipment that is usually under the control of the Operators. Yes, the Residential Gateway (RG) is the device that sits in the middle and separates the customer's personal network from that of the PON network. Rogers uses Comcast certified cable modems to offer syndicated services to our customers. When these RGs are deployed in the PON network they are set to E-WAN mode. To obtain the true latency and throughput, a residential gateway speed test application is used on the RG. Rogers uses Comcast applications on the RGs and the gateway speed test application is readily available to perform various end to end test to determine the performance of the PON network.

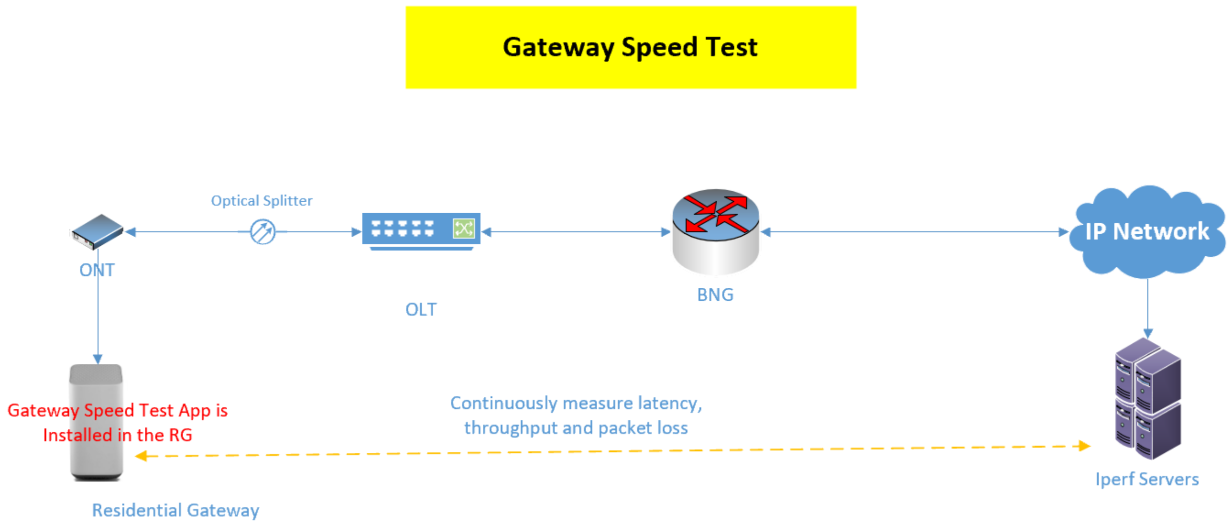


Figure 10 - Gateway speed test app to measure performance

5.5. Strategy and Approach

The PON Network performance monitoring model will vary for every network based on the service requirements, network design and unique challenges every individual network comes with.

The approach in our journey was to begin with the identifying what are the main gaps which prevent us from gaining end-to-end visibility and delivering the best customer experience. The initial analysis showed we needed to focus on:

- **Performance Management**: Collecting data on KPIs such as CPU, memory, bandwidth, discards, errors, optical power levels from all the different components of our PON network to allow us to troubleshoot and triage incidents better, e.g. detect any congestion in the network quickly, and to proactively identify trends and any potential trouble spots.

- **Capacity management:** Collect data such as peak, average, 95th percentile utilization (%), and throughput on our PON segment to allow to trigger uplink or node capacity augmentation in a timely manner on the heavily utilized nodes. This data is also used to initiate segmentation in regions as the customers continue to grow and assists with troubleshooting and triaging network related incidents.

- **Data Collection and Reporting**: Collecting syslog and SNMP data from the different PON components, use tools to parse this data and create real-time dashboards to display the current network status. This data can also be used to create threshold-based monitoring for statistics such as policy errors, authentication failures, Dynamic Host Configuration Protocol (DHCP) and Internet Protocol over Ethernet (IPoE) session related errors for effective event management especially for the BNG routers.

To achieve this, it was important to take a phased approach, identifying the immediate needs that are critical for business to be targeted in phase 1 and the more detailed KPI collection for phase 2.

- **Phase 1:** The focus in this phase was to collect information such as, the top 10 areas of improvement (high errors, discards, bandwidth), the operational status, highest bandwidth utilization, throughput, and overall health for both network and PON ports. Average Central Processing Unit (CPU) and memory load on both the BNG and OLT nodes.

- **Phase 2:** The focus in phase 2 was to collect more detailed information on the OLT at the system, slot, network & PON level and on the ONT. It was important to find the right balance for how much data we collect, especially with a limitation of the ONT KPIs using the actual OMCI channel bandwidth. Some of the key counters included, optical signal levels from both PON and the ONT, ONT signal degrades, OLT and ONT software detail and status, total dropped upstream and downstream traffic, errors, discards, distance between the OLT and ONT, traffic utilization at the ONT level and system temperature & power voltage trends.

After gathering multiple datasets, the data was then transformed using an analytics platform to create user dashboards and reports based on the gaps identified and requirements specified at the start of the project. A lot of importance was put into correlating and building the relationship between datasets to tell a meaningful story and deliver useful insights.

- **Phase 3:** After successfully completing phase 2 and giving it the proper soak in period, phase 3 involved implementing the protocol Y.1731, which allowed us to collect data such as latency, frame loss and jitter performance statistics between the BNG and OLT. We also focused on enabling data collection which allowed us to see queue drops on the BNG facing the IP network as well as the PON network.

5.5.1. Problems Encountered:

- **Identifying the right tools:** Our initial approach involved exploring different options to see which one would best fit our needs. However, due to lack of familiarity we ran into unforeseen issues, having to change or delay milestones.

- **Interoperability between different vendors/tools:** As is the case with PON, there are multiple platforms involved sometimes with different vendors and tools collecting the data. Integrating this data into a single database point proved to be a more challenging task than what was anticipated. Therefore, it's important to list down all the different vendors/tools involved and have those discussions early on to avoid complications and delays.

- **Limitations with legacy platforms:** Our main form of collection involved collecting performance monitoring stats from the node and converting those files into appropriate cloud storage format. The solution, though effective, has a challenge when you migrate to newer platforms which may be using a Kafka-based collection.

- **OMCI Channel limitations:** The ONT statistics collection uses a part of the OMCI channel bandwidth, therefore it was imperative that we choose the right number of specific KPIs instead of data that may just create noise and cause us to lose valuable information.

- **Identifying correct stakeholders:** As with any project, it is important to have defined goals/milestones and the right stakeholders for your performance monitoring solution. This allows us to define a realistic timeline for the project from start to end.

- **Defining the role of each stakeholder:** It is important to define the scope of the project and what is required from each stakeholder. Not defining these can lead to ineffective collaboration which is necessary when working with cross-functional teams which is common when working on the PON technology.

- **Having the right support:** For any tools, vendor platforms involved, it is important to have SMEs identified for each of those to be able to resolve any issues encountered effectively. Not having the proper training and vendor support can cause significant delays which in turn reduces the customer experience. We utilized tools and components from multiple vendors to integrate the final solution. It is important to ensure these components can complement each other and work together to achieve the intended goals.

5.5.2. Automating the Results

As the number of PON network components multiply due to service expansion, more and more customers have access to low latency and high bandwidth internet. Thus, the sheer volume of data that comes from thousands of data points on the PON network render the traditional performance monitoring solutions ineffective. An automated and a data science driven solution was needed. Rogers has utilized automation in collecting, analyzing, and reporting. Rogers data collection platforms collect data from various points on the network and send the data to Microsoft Azure data lake for storage. Data analysis is done by utilizing business analytics tools such as Microsoft Power BI (Business Intelligence). Microsoft Power BI provides dynamic visualization and business intelligence capabilities that are easy to use by end users. Using automation, the users create the dashboards based on their business needs utilizing the data from Azure cloud storage. The visual representation of the data can be very useful in correlating and identifying PON performance issues. When doing trend analysis, if any anomalies are detected in the PON performance immediate actions are taken to address the issues before they start impacting customers.

5.5.2.1. Automating PON Port Moves

Rogers has built several tools to facilitate the automatic resolution of the PON performance challenges. One such tool is the automatic PON port move. Whenever a possible degradation is observed on a particular PON port via the PON performance monitoring solution. The technician simply has to remove the fiber from the affected PON and move it to another available PON port. An automation solution in the backend would automatically re-provision all the affected ONTs on the network and IT platforms utilizing the new information. By moving the fiber to the target PON port, any potential issues can be resolved immediately, and the Technicians or Engineering specialists can troubleshoot the affected port without impacting the customers.

5.6. PON Power Supply Monitoring

One of the operational deficiencies that was noted during PON deployment was the lack of enhanced monitoring of the OLT. Power Supply Monitoring (PSM) solution was developed to monitor the battery life and charge remaining on them. To ensure we have an efficient and a cost-effective monitoring solution we designed and implemented a PSM solution for the OLTs in the field. Figure 11 below depicts the typical PSM solution. The power supply is connected to an ONT and picks up an Internet Protocol (IP) address via a Dynamic Host Configuration Protocol (DHCP) server. Once the power supply is assigned with an IP address it can communicate with the monitoring server at the backend. With this solution Operators could see enriched alarms that can provide details of the battery health and how many hours of back up is available on the batteries. Moreover, easily identify where the fault may be located, and take the appropriate actions instead of having more diagnosis/intervention to isolate the problem. Without this solution the Operations teams are blind to historical trends and unable to determine the time span of available back up power due to faults in main hydro power.

Furthermore, preventative maintenance programs can quickly target aging and/or problematic power supply systems instead of waiting for a failure to happen and frustrating the customers.

With this in place, the maintenance dispatch team along with NOC technicians can look at the battery health during a power outage and determine whether a maintenance call is needed. Based on the analysis NOC Technician can mobilize a generator or divert maintenance technicians to other impacting outages.

In addition to this, maintenance call outs can be prevented when the battery backup is working effectively, reduce unnecessary truck rolls, and reduce or prevent the number of customer base calling due to service outage. Overall, PSM solution for OLT is a win-win situation for both the customers and the Operator.

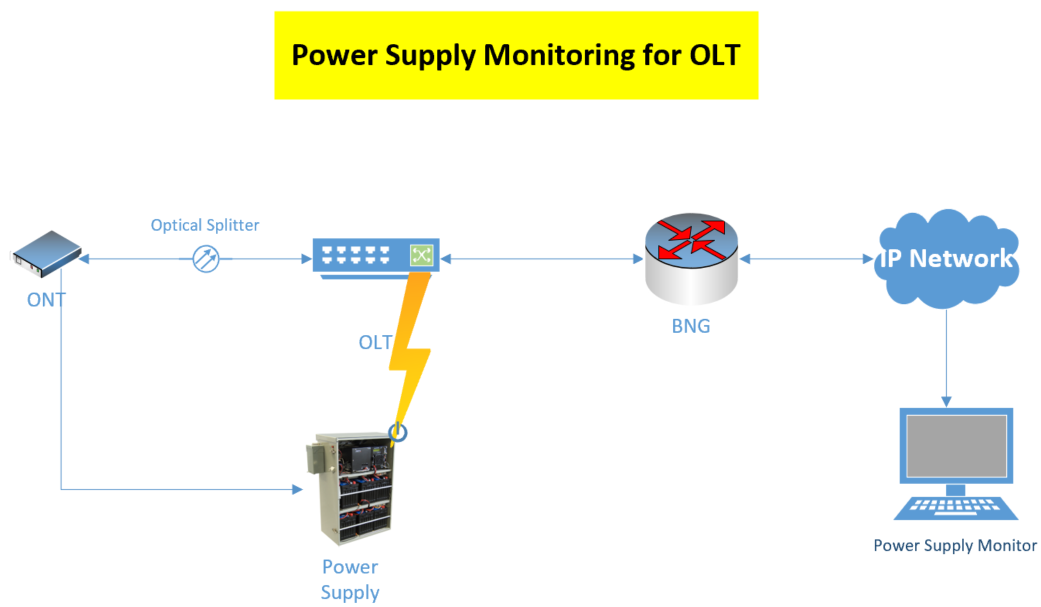


Figure 11 - Power supply monitoring

6. Unique Problems

With PON Performance Monitoring in place we were able to identify very interesting problems before customers started to complain. Some of these problems may not have had any visual impacts on the customer's end. However, if left untreated they could have had a snowball effect on the systems if these issues started to spread to other customers. While monitoring the PON network, we were able to detect and solve the following interesting problems.

6.1. Line Card Resets

As there are thousands of line cards in the network it will be very difficult to perform trend analysis on them to detect any potential issues without an automated solution. Using automated PON performance monitoring, it was discovered one line card was resetting intermittently but recovered automatically. Customers may have been impacted for a few seconds, but the services would have restored quickly. Issues like this are hard to catch in real time. Utilizing the trend analysis tool, it was discovered that this particular type of card, was auto-recovering very intermittently. Based on the performance counters that were triggered the vendor was able to determine the root cause and provided a fix for the solution. Subsequent analysis of the same counters did not show any anomalies or resets of the line cards post the application of the fix.

6.2. ONT Handshake with RG

Another interesting problem that was discovered via the PON performance monitoring solution was a handshake issue between a particular ONT model and the Residential Gateways (RG). The ONT and RG negotiate their connection parameters when they are connected for the first time to establish the communication channel. Due to a bug, this ONT and RG were sometimes not auto-negotiating at the highest allowed speed. This anomaly caused some customers to experience slower upstream speed as the two devices were stuck at a very lower negotiated speed. The performance data collected from the ONT pointed to a handshake issue between the two elements. Rogers worked with both vendors to further analyze and to isolate the problem. Based on the finding a software fix was recommended to rectify this problem.

6.3. Signal Degradation Alarm

Signal Degradation (SD) alarms would arise if the received (Rx) and or transmitted (Tx) signals at the OLT and ONT would fall into certain categories. One of the interesting problems we observed was OLTs receiving SD alarms when the ONT Rx signal fell between certain range. The range is -15 to -17dBm. There shouldn't be any alarms for this range as it is within operatable specification. Upon further investigation with the research and development (R&D) team of the vendor. The root cause was identified within the way a particular PON Small Form Factor Pluggable (SFP) handled the received signal level coming to the OLT within this particular range. The OLT would drop some of these signals and report them as a degraded signal. This would not have had significant visual impact on the customer as the ONT would re-transmit again. We had to resolve this issue as this could have had a snowball effect. The vendor's R&D team came up with a solution to update the EPROM of that SFP. As it can be seen in Figure 12 the reported SD alarms became flat after the recommended solution was applied to the affected PON port.

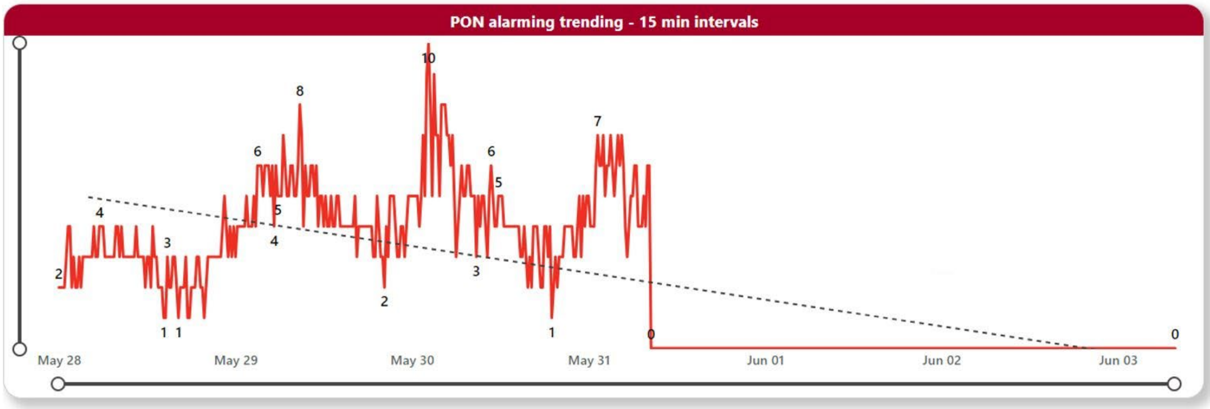


Figure 12 - Signal degradation alarm before and after the resolution

7. Conclusion

PON performance monitoring is critical to providing the most reliable, always available and a very resilient service to our customers. The demand for low latency network with higher throughput continues to increase and it is vital for Operators to maintain the performance of the PON network at an optimal level at all times. There are many PON technology vendors who may have their own proprietary set of tools, techniques, and solutions to achieve the above objectives. Since PON is an evolving technology, CableLabs' Optical Operations and Maintenance (OOM) working group, composed of technologists, vendors, and Operators, are collaborating to bring alignment within the industry with regards to architecture and telemetry. This paper presented a subset of available options: KPIs collected via PON performance monitoring allows the Operators to gain valuable insights into the network and obtain important statistics and usage patterns. Armed with invaluable data, Operators can continue to make the necessary changes to the part of the network that requires attention. This will ensure Operators are meeting their SLA commitments and providing a reliable and a robust service to our customers. Thus, PON performance monitoring is an extremely useful and a critical component to the network Operators.

Abbreviations

AAA	authentication, authorization, and accounting
BNG	broadband network gateway
FEC	forward error correction
CWDM	course wavelength division multiplexing
DHCP	dynamic host configuration protocol
DOCSIS	data over cable service interface specification
DSCP	differentiated services code point
DWDM	dense wavelength division multiplexing
EMS	element management system
EPON	ethernet passive optical network
EPROM	erasable programmable read-only memory
E-WAN	ethernet wide area network
FTTH	fiber to the home
GPON	gigabit passive optical network
HFC	hybrid fiber coaxial
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IP	internet protocol
IPoE	internet protocol over ethernet
ITU	International Telecommunication Union
KPI	key performance indicator
NG-PON	next generation passive optical network
MDU	multiple dwelling unit
ME	managed entities
MSO	multiple system operator
OOM	optical operations and maintenance
OMCI	ONT management control interface
ODN	optical distribution network
OLT	optical line terminal
ONT	optical network terminal
ONU	optical network unit
OSS	Operations Support System
PCP	priority code point
PCRF	policy and charging rule function
PHUB	primary hub
PM	performance monitoring
PON	passive optical network
PSM	power supply monitoring
QoS	quality of service
SCTE	Society of Cable Telecom Engineers
SFU	single family unit
SLA	service level agreement
SNMP	simple network management protocol
SPDR	subscriber policy database repository
TWAMP	two-way active measurement protocol
XGS-PON	10 Gbps symmetric passive optical network

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