Weaving Real-Time Fiber Data Analysis Into a Reliable Network

A Technical Paper prepared for SCTE by

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1. Introduction

Fiber network problems have historically been difficult to diagnose, requiring dispatching multiple teams to locate and fix the issue. However, today's availability of real-time data from both sides of the link and common fibers has enabled faster and more accurate problem identification and resolution. Comcast, as the largest provider of multi-gig speeds to homes and businesses, has implemented a range of hardware and software telemetry tools to monitor its network.

Cable operators can leverage real-time data to improve the monitoring and reliability of fiber networks. By combining multiple metrics, the level of intelligence is amplified, enabling the early detection of problems that would have otherwise gone unnoticed. When the fiber path degrades, diagnosis is possible within minutes, and the impacted fiber of the fiber path is isolated for technician dispatch. Small Form-Factor Pluggable (SFP) metrics and the common fiber-monitoring platform are used to measure fiber loss in both directions, enabling the detection of failing fiber jumpers in hubs and single-wavelength fibers past the Optical Multiplexor (Mux) in the field. This approach has reduced repair time and can help avoid unplanned outages.

We will cover new insights into how real-time data analysis can enhance fiber network reliability and help providers avoid costly downtime for customers. The methodology and findings presented may be of interest to other providers looking to improve their network performance through data-driven insights.

2. Remotely Detectable Networks

Moving to an all-digital network has opened up a new world of devices sending us telemetry. To ensure effective remote detection capabilities, it is essential to incorporate them into network design from the onset. The ability to remotely detect complex issues on a network necessitates that operators have control over the variables within the network designs. By carefully considering and limiting the number of variables during the design stage, operators can create networks that are easier to troubleshoot, with predictable failure points.

The establishment of controllable variables requires alignment among design and construction teams through operational standards. It is important to evaluate each component of the network with the objective of standardizing unmeasurable components and measuring components that cannot be standardized. This means taking in to account the loss passive devices introduce and the way the impact the light need to be predictable. By achieving uniformity and consistency across the entire network, remote detection and prompt dispatch to address issues become feasible.

Optical components need to have common parameters and be compatible with accepted design standards. One-off designs that deviate from the established design principles are hard to quantify and remotely monitor.

Devices that should be standardized:

- **DWDM Mux** – Standard throughput loss, channel sets, and monitoring ports.
- **SFP/Optics** – Standardized optics with a narrow, accepted transmit level and minimum receive level.
- **Monitoring** – All Muxes and wavelengths need to be accounted for and maintained.

3. Fiber Monitoring and Telemetry

The fiber-monitoring system interfaces with a new evolution of C-Band Dense Wave Division Multiplexers (DWDM) that are equipped with a converged test point combining the forward and return C-Band spectrum into a single 20dB down test port as well as adding a low insertion-loss band-pass for a 1611nm Optical Time-Domain Reflectometer (OTDR). This converged test port configuration allows the fiber monitor to measure C-Band wavelength power levels bi-directionally via an Optical Spectrum Analyzer (OSA). Approximately every three minutes the fiber monitor samples both the C-Band spectrum via the OSA and OTDR of each fiber to monitor for new impairments or sudden impacts such as a fiber cut.

The OTDR has a clean insertion point to measure the fiber with minimal loss to dynamic range allowing for a single fiber connection per monitored Mux. Utilizing a 1611nm OTDR allows the fiber monitor to not interfere with existing C-Band customer traffic so that it can co-exist and be pervasive.

Standardized wavelength assignments (forward and return) are then enriched with design details assigning devices to each wavelength pair. This opens the door for new logic paths that can compare expected losses with observed levels to determine optical path health both end-to-end at scale and through automation.

4. Weaving the Telemetry Together

Fiber metrics have power in numbers. Fiber links have many metrics to evaluate performance. Traditionally we have minimum and maximum values and if a metric falls between these numbers it is considered a PASS. When we look at the link performance end to end, the numbers add context and meaning to each other and start to identify the performance characteristics of smaller segments of the larger optical link. In turn, contextual measurements can then be used in a larger logic algorithm that shows the entire end-to-end link. This new knowledge of organized measurements gives the team a clear view of the network.

When measuring from pluggable optics, like the transmit or receive level of light, it is very important that each model be evaluated. Measurements queries can be impacted by firmware or outside environmental factors like heat. When an SFP starts reading erroneous levels or returning no information, these need to be addressed as a loss of telemetry.

4.1. Inside Plant (ISP) Transmit Fiber Measurement

To calculate the integrity of the transmit light to the field, the SFP transmit level minus the monitoring port level should equal the known Mux loss value. When this number is below an acceptable threshold, we have a bad link between the SFP and the Mux, the Mux and the monitoring port, or a bad port on the Mux.

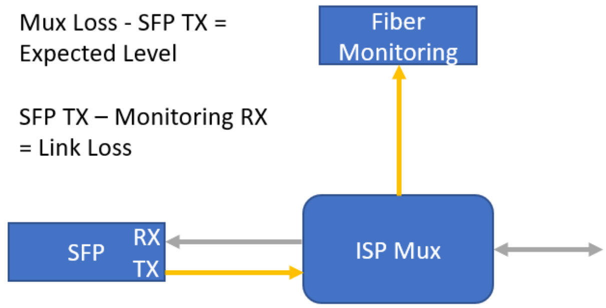

Figure 1 – Measuring TX Fiber Jumper Loss

4.2. ISP Receive Fiber Measurement

To calculate the integrity of the receive light from the field, the SFP receive level minus the monitoring receive should equal the difference of insertion loss of the two ports. If the loss is too small the fiber to the SFP is bad, if the loss is too great the fiber to the monitoring port is bad. In either situation a bad Mux port could also be the cause, but most times a dirty connection is most probable.

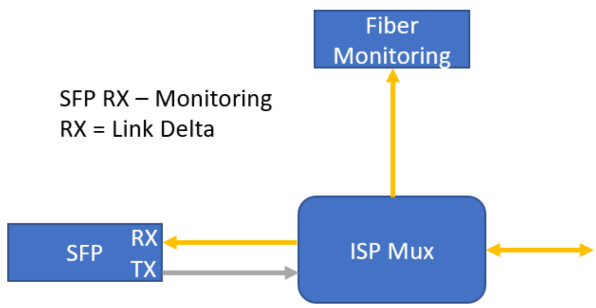

Figure 2 - Measuring RX Fiber Jumper Loss

4.3. ISP Common Fiber Measurement

When we look at the common fiber from the Mux to the field, dirty connections and bad jumpers can cause excessive loss and the OTDR of the fiber-monitoring system will fail to return a distance. This failure can be used to identify a bad common fiber. When we also look at the light levels received, it can be determined if a fiber is disconnected or if the OTDR failure is due to a poor connection.

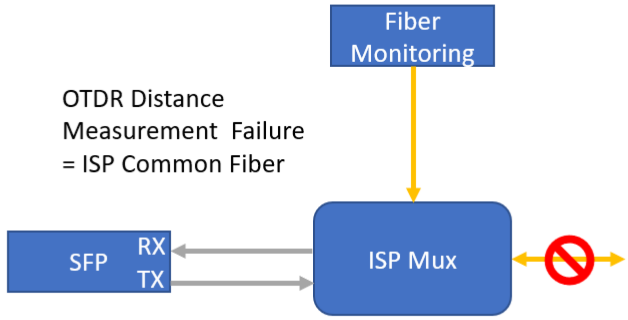

Figure 3 - ISP Common Fiber Link

4.4. Bi-Directional Link Delta

Utilizing end-to-end link loss calculations, we can identify single fiber impairments in the Outside Plant (OSP). To calculate a single direction loss, we use the SFP receive level minus the far side SFP receive level to determine the directional loss. Then take both link losses of the duplex connection to create a bi-directional link loss. Bi-directional link loss should be zero or close to it, within the tolerances of the SFPs. When one direction has more loss than the other a bad fiber between the SFP and the Mux is probable.

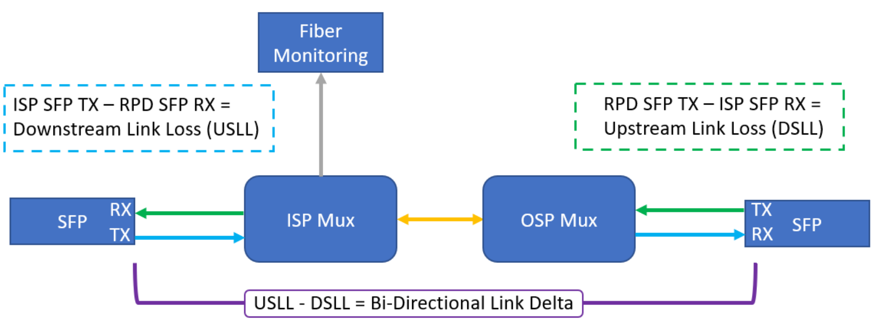

Figure 4 - Bi-Directional Link Delta

4.5. Multi-Metric Logic

Metrics alone get us halfway there; we are moving toward real-time remote divide and conquer of the optical network. However, logical assumptions can be made using the new metrics detailed above and existing metrics like fiber cut detection and low light. The individual readings are used to triangulate impairments in the optical network. The metrics together will validate the fiber or point teams to what does or does not need attention.

- When we can eliminate the ISP fibers as impacting light levels, but show a bi-directional delta impairment, this indicates an OSP impairment on a single fiber past the OSP Mux.

- When a fiber link is down and no light is received at the ISP SFP, we can eliminate or verify a common fiber cut impairment and confirm the SFP transmit fiber light to the Mux.
- When a link is down, but we are receiving light, we can identify the impacted fiber location ISP transmit fiber jumper, common fiber, or post OSP Mux transmit fiber.

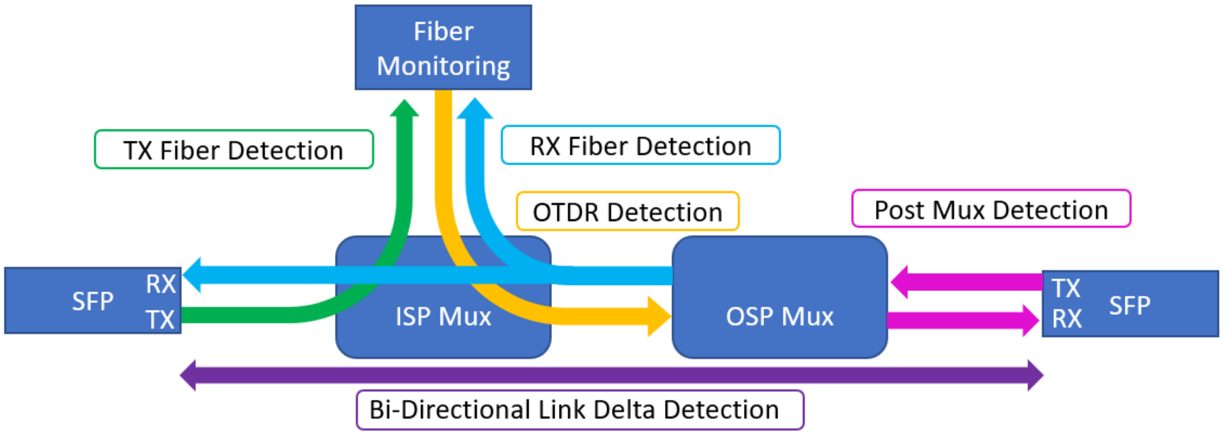

Figure 5 - Multi-Metric Logic

4.6. Next Steps

All the metrics mentioned previously can be measured in real-time with no historical context or baseline. When trending and deviations in levels are added with design information, the value is amplified to the next level and leads to component level reliability measurements.

5. Operational Evolution

As we move toward the future, teams that build and maintain optical networks will utilize intelligent tools. Real-time monitoring of the way we build, certify, and maintain fiber networks enhances the reliability and speed efficiency of how the network is maintained. With remote detection of individual fibers, we can focus the troubleshooting activity by quickly identifying the impacted fiber and dispatch a field technician to fix the issue. Currently, we troubleshoot the entire fiber link, which requires multiple teams. This is both resource-inefficient and time consuming.

5.1. Construction and Certification

The construction of new fiber links requires many individual components to work together properly. Traditional certification is limited to bi-directional OTDR traces and light-receive levels compared to the design link loss budget. When we add real-time measurements using monitoring and SFP data we can validate with a high degree of certainty that the link will work as expected prior to moving traffic to the fiber.

5.2. Proactive Monitoring

By leveraging real-time monitoring with enhanced detection logic, even slight variations outside of the expected thresholds can be identified and corrected, thereby improving the reliability of the link. Many initially stable connections may become vulnerable to fiber-jumper impairments caused by bending, stretching, or disruptions to the ports, resulting in misalignment of the connections.

Prior to and following scheduled maintenance that involves fiber work, we have transitioned from merely validating network connectivity to remotely detecting issues such as dirty connections or faulty jumpers. This enables our network operations teams to gather valuable information and enhance reliability while our technicians are on-site, optimizing the scheduled maintenance process.

5.3. Fiber Restorations

When a fiber link is down, teams can quickly verify and isolate the state of ISP fibers. This removes steps where multiple teams would need to take measurements and combine to isolate the cause of the problem. In remote areas with unmanned locations this reduces the outage by eliminating drive times and troubleshooting steps. After restoration, links can be quickly verified that all components are operating as designed. This new insight and ability to direct teams to the fiber-impairment locations will improve device uptime and network reliability.

6. Conclusion

Fiber networks are becoming rich with data. Organizing and utilizing these new data streams will change the way we manage optical networks. Individual measurements have meaning when given context within the network design. The optical impairment detection methods serve as a map to isolate and identify fiber segments not operating correctly. This new methodology reveals where light is being lost, which is something that simple min-max and pass-fail criteria miss.

When teams are empowered with this new information, network reliability is increased and restoration times decreased. Bad connections, splices, optical ports, and stressed fibers can be identified by the team responsible for fixing them. Direct ticketing to teams with reduced troubleshooting steps and reduced referrals to other teams improves the customer experience.

Fiber networks are an integral part of connecting people, and a clear picture of this network will ensure we are always connected.

Abbreviations

DWDM	Dense Wave Division Multiplexer
ISP	Inside Plant
MUX	Optical Multiplexor
OSP	Outside Plant
OTDR	Optical Time-Domain Reflectometer
SFP	Small Form-factor Pluggable

