WHITE PAPER

Open Optical Transport Networks – A Framework to Success

Dense wavelength-division multiplexing (DWDM) product offerings have been dominated by vertically integrated solutions, with the optical hardware and software coming from a single vendor. To minimize operational complexity, network operators have commonly used a 'best practice' of relying solely on a single vendor's closed proprietary optical platform; or if utilizing multiple vendors, separating them out by geographic region with minimal interoperability. This approach has allowed for vendor lock-in, often resulting in higher capex cost and slower innovation cycles for network operators.

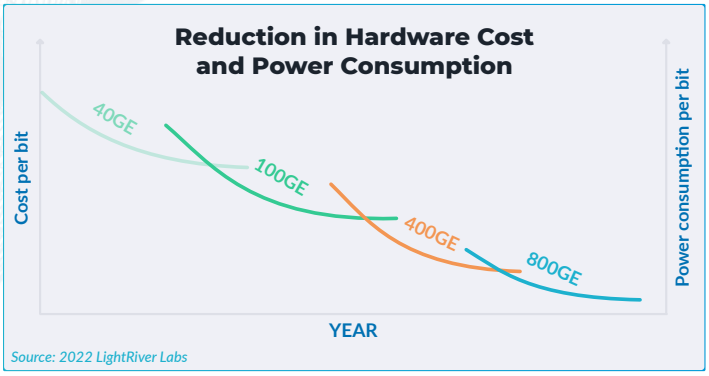

Figure 1: Reduction in Hardware Cost and Power Consumption

In today's increasingly competitive market, service providers seek open optical systems that allow the latest technology advancements to be readily leveraged to enable new service offerings at reduced capex and opex. They want a practice to rapidly take advantage of the cost curve shown in Figure 1. Technologies such as 400Gbs and 800Gbs compact modular based transceivers and the latest in pluggable transceivers including 400 ZR/ZR+ have the promise of driving the cost per gigabit down dramatically. However, the ability for service providers to purchase these technologies based solely on performance and cost across multiple vendors is inhibited by challenges that stand in the way of open optical, including:

- No clear lab findings of the interoperability of one vendor's optical line systems with a competing vendor's compact modular or pluggable 400 ZR/ZR+ transceivers.
- A large installed base of DWDM line systems with available wavelengths, but which are tightly bound to an Original Equipment Manufacturer's (OEM) management software with constrained 'alien wavelength' support.
- Poor Day 2 operations and customer experience driven by the operational complexity of monitoring and trouble-shooting multi-vendor solutions without cohesive network management software.

LightRiver is the premier optical systems integrator in the U.S. As such we deploy at mass scale some of the largest disaggregated optical systems in North America. This white paper discusses LightRiver's findings and methodology from our interop lab proof of concept testing, multi-vendor automation, and large-scale deployments. We lay out a framework for success for overcoming the challenges to open optical for both greenfield deployments with the latest open line systems, as well as brownfield applications with legacy line systems that are already in production. We demonstrate that Network Disaggregation and its desired outcomes can be achieved with the correct Network Methodology, Engineering Optimization, and Automation Framework. Our goal is to provide network operators the ability to unlock the benefits around significant capex reductions and increased innovation cycles by readily leveraging the latest technologies, including 400 ZR/ZR+, while simultaneously lowering the opex of managing these disaggregated networks at scale.

Network Disaggregation and its desired outcomes can be achieved with the correct Network Methodology, Engineering Optimization and Automation Framework.

Network Methodology & Findings

400G ZR/ZR+

With the onset of 400G ZR/ZR+, network operators are looking at shifting from a traditional transponder-based network to an IP-over-DWDM architecture. However, implementing a 400G ZR/ZR+ network has many unique challenges for both greenfield and brownfield networks that are not present in traditional coherent networks. Utilizing our industry leading, multi-vendor, multi-technology optical disaggregation lab (Area 51), we are able to simulate real-world network environments to optimize use of 400G ZR/ZR+ over greenfield and brownfield optical networks. LightRiver can work directly with both our customers and the OEMs to test any permutation of any vendor's Compact Modular ZR/ZR+ over any other vendor's line system.

Through this process, it became clear that with launch powers of <-10dB for these 400G ZR/ZR+ optics, the end result was not always 'plug and play.' This provides challenges when integrating with existing line systems that are optimized to handle higher launch powers of traditional coherent signals associated with compact modular platforms or DWDM line card based transceivers. In our lab, we have created a test bed to allow better integration of pluggables with traditional coherent signals. One example is the use of pre-amplification. Without pre-amplification, the ZR/ZR+ will drop below the RX power threshold required by many ROADMs to identify and transport the signal. Pre-amplification allows ZR/ZR+ performance to be optimized while maintaining maximum performance on adjacent wavelengths from traditional transponders. Otherwise, those adjacent waves will need to be lowered in power drastically decreasing performance.

Along with physical interoperability, many operational challenges exist with integration of ZR/ZR+ over competitors' DWDM line systems. Multi-vendor networks inherently lose many OAMP automation features because there is a lack of implementation of standardized communication protocols for internal communication between the ZR/ZR+ host device and the optical line system. Without these communication protocols, most OAMP functions must be performed manually. To overcome these barriers, LightRiver leveraged the netFLEX® optical domain orchestration and control solution to standardize OAMP across disparate suppliers and technologies. This also minimized the need to swivel back and forth between multiple vendors' EMS/NMS during our lab evaluations.

Current ZR+ signals can reach ~1400km pushing IP-over-DWDM into metro-regional and regional-long haul networks. Many operators have existing line systems populated with compact modulars and/or legacy transponders, so adoption of ZR/ZR+ will require cohabitation of these transponders and ZR/ZR+. Likewise, next-generation high performance compact modulars will be utilized for long-haul networks and may be cohabitated with some ZR/ZR+ links. It is imperative that the operators understand the operational challenges and physical limitations of building these networks.

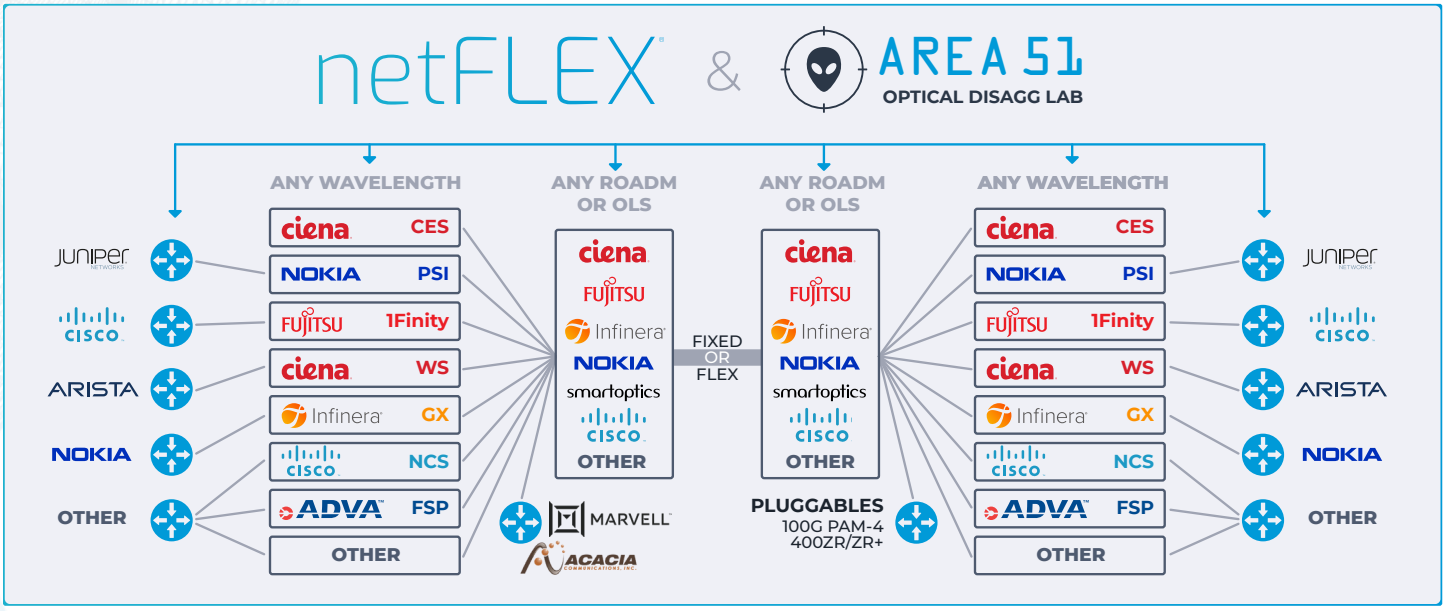

Figure 2: LightRiver Area-51 Interop Lab (Alien Aware Networking®)

Compact Modular Transponders

One of the primary benefits to deploying a multi-vendor open optical network is to take advantage of faster innovation cycles with transponder evolution. This includes adopting best-of-breed next generation transponders on both new greenfield builds, as well as utilizing legacy optical line systems within pre-existing brownfield deployments.

To fully understand the capabilities and limitations of different compact modular solutions, LightRiver vetted

basic interoperability of compact modulars from Ciena, Cisco, Nokia, Infinera and Fujitsu over competing optical line systems. One of the basic limitations we ran into with integrating 600Gbps and 800Gbps transceivers during our testing cycles, was integrating high baud rate signals into existing line systems. Due to limitations in flex spectrum granularities, the available spectrum within a DWDM channel may not be as wide as expected and the transceiver modulation may have to be reduced to fit within a fixed channel or flex spectrum DWDM line system. This in turn reduces the maximum channel throughput of the system. In one of our customer use cases, these findings caused them to consider converting a brownfield DWDM system from Fixed to Flex spectrum. The flex ROADM upgrade allowed us to provide a preamp that further enabled ZR/ZR+.

Some line systems that are advertised as open optical line systems require expensive licenses to transport alien wavelengths or they will trigger alarms on the system. We encountered a variety of different limitations when deploying alien wavelengths over these (not so open) line systems. In most cases, the limitations included lack of visibility, lack of performance monitoring statistics and/or minor alarms. In some cases optical line systems prohibited the signals completely in which case, overcoming alien wavelength licensing restrictions required commercial solutions with the line system vendors.

After confirming basic interoperability, LightRiver utilized a variable noise source to inject noise onto the line system to simulate the increased noise associated with adding ROADMs and in-line amplifiers onto optical line systems. LightRiver then plotted the performance of various compact modulars (and ZR/ZR+ optics) over the optical line systems as we increased the noise.

Figure 3 shows a sample graph of performance plotted as noise is increased.

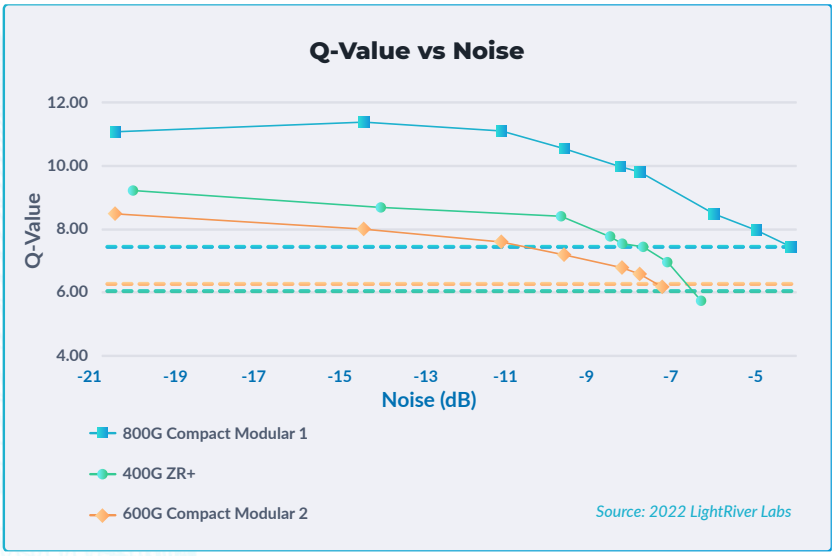

Figure 3: Q-Value vs Noise

Vendor Specific NMS/EMS

Increasing noise on the line system and simulating fiber degradation provided an ideal test bed to evaluate the various supplier EMS/NMS system capabilities to monitor performance of the alien wavelengths from the near-end transceiver through the line system to the far-end transceiver. Our findings confirmed the current state of the industry still reflects proprietary network management on a per supplier basis. These traditional Optical Networking solutions reflect purpose-built Network Management System (NMS) as an Element Management System (EMS)

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or Domain Controller in more modern systems. Although these NMS/EMS platforms serve their intended purpose for a closed, single-vendor network; this becomes problematic as an Open Optical disagg-network requires a multi-vendor management solution to gain visibility and performance metrics where currently a 'swivel chair' workflow is required to manage an Alien Wavelength across disparate HW/Technology. This is further complicated as some of the latest optical line systems, pluggables and even routers/switches that sit within an Open Optical end-to-end service path are limited to CLI or a basic shelf-GUI.

The biggest contributor to the lack of a unified management solution is that OEMs share limited NMS systems information with each other even though these industry leading optical suppliers participate on several Open Optical committees and/or forums. Instead, OEMs rely on their own proprietary northbound interfaces (NBI) to a hierarchical controller (or Multi-Domain Service Orchestrator (MDSO) and likewise for southbound interfaces (SBI) to their Network Element (NE) hardware. Our findings validate that each OLS, Transponder/Muxponder, pluggable, and router/switch is uniquely different with respect to network management and related command/control interfaces to the NEs (whether an EMS or Domain Controller exists), and likewise to OSS/BSS via NBI. Worse yet, this even changes on a per Operating System (OS) variant for respective NEs and their related NMS/EMS/Shelf-GUI/CLI.

To overcome these barriers, LightRiver leveraged the netFLEX automation platform to increase OAMP management and found it to be suitable for all types of alien wavelengths including pluggable coherent DWDM optics placed in routers and compact modular platforms. The key was being able to see on a single-pane-of-glass, as well as single set of normalized APIs, all of the network elements in a circuit path across multiple vendors and technologies, including readily validating each NE was performing within expected parameters at service instantiation and the life-cyle of the service thereafter.

Overall Findings

In all cases, LightRiver was able to successfully transmit alien wavelengths from both ZR/ZR+ and compact modular platforms concurrently across all line systems tested in our 'Area 51 Test Bed;' leading to the conclusion that the latest iteration of IP-over-DWDM and Routed Optical Networking utilizing currently available ZR/ZR+ optics including those being offered by Cisco (Acacia) - are viable and deployable in both greenfield and brownfield applications. However, it is not always plug-and-play, and often the solution needs to be optimized both in terms of the network hardware and the inclusion of a multi-vendor automation platform.

Conclusion... the latest iteration of IP-over-DWDM and Routed Optical Networking utilizing currently available ZR/ZR+ optics including those being offered by Cisco (Acacia) - are viable and deployable in both greenfield and brownfield applications.

Optimizing and Managing Disaggregated Networks

Networking Hardware

Ideally, the latest generation open optical line systems will allow network operators to optimize their network, by deploying the right compact modular or ZR/ZR+ pluggable for each application. This would include optimizing between bandwidth, reach, rack-space, power, and cost. This allows operators to 'right size' each application with higher performance compact modulars for ultra-long-haul and subsea applications and ZR/ZR+ in metro-regional and regional-long haul applications. Within our test bed, LightRiver validated that from a pure hardware interoperability perspective, these objectives are achievable with a new generation of line systems including the Ciena RLS, Infinera FlexILS, SmartOptics DCP and Nokia 1830-CD. However, true interop-software management and automation need a more thoughtful and standardized approach.

In brownfield applications, ZR/ZR+ optics work best in optical line systems that have DWDM multiplexors that include a pre-amp to overcome the low launch power in these pluggable optics. An alternate, but more cumbersome approach is to place a pre-amp after a fully passive multiplexor specifically dedicated to ZR/ZR+ wavelengths. It is also important to note that ZR pluggable optics generally adhere to well defined OIF standards and showed good interoperability in the lab allowing for different pluggable vendors on each end. In contrast, to increase performance of the ZR+ optics, OEMs commonly deviate from standards, such as incorporating proprietary FEC to close longer distances making them less interoperable.

In interoperating compact modular and ZR/ZR+ systems with competing OEM line systems, network modeling is a challenge. OEM optical line system design tools are set up to model their coherent DWDM transceivers over their line systems and do not provide options for modeling specific competing vendor transceivers. One of the values of LightRiver creating the BER vs Noise curves illustrated in Figure 3, is to gain comparative reference points of the different transceivers to one another that can be easily extrapolated and used in the various OEM design tools. As a multi-vendor optical transport systems integrator, LightRiver is in a position to use a combination of vendor specific design tools, vendor specific technical specifications and lab testing to accurately model a multi-vendor system. This modeling can be quickly vetted in our 'Area 51 Lab' and then in the field.

Automation Framework

The industry has made incremental progress toward defining reference architectures and data/service models that Optical Hardware and Software suppliers can develop toward. The Telecom Infra Project (TIP) and Open ROADM forums lead this effort today as they have defined Specifications and Data Models in early forms.

Whereas Network Disagg for L2/L3 is more open standards in nature for interop and standardized interfaces and control, this is not the case for Optical Networking. The referenced open forums efforts are still not widely embraced in a truly 'standard' way for device (SBI) and control automation (NBI) as we continue to prove out within our technology validation labs. None of this reflects true plug-and-play without 'network abstraction and normalization,' through advanced SW, to allow this to 'all look the same.' As highlighted within TIP, the MEF, ONF, and broader, Optical Domain Orchestration and Control is required within Open Optical to uniquely manage and control the disaggregated NEs across multi-vendor and multi-technology. This automation framework plays a 'command and

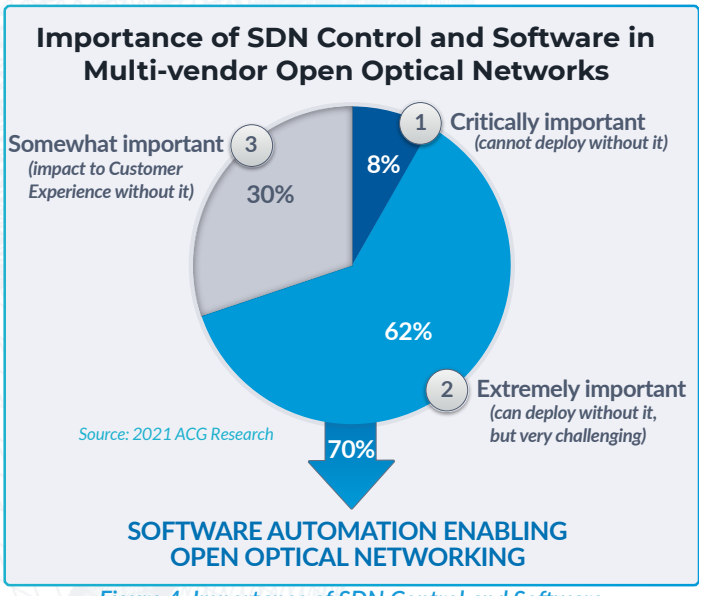

Figure 4: Importance of SDN Control and Software

control translation' role to support next generation NEs, legacy (brownfield), as well as non-traditional optical NEs to include pluggables within routers/switches. This support must reflect lifecycle of OS-versioning where the command/control interfaces are subject to change and each release must be validated and possibly modified to ensure continued end-to-end visibility and control.

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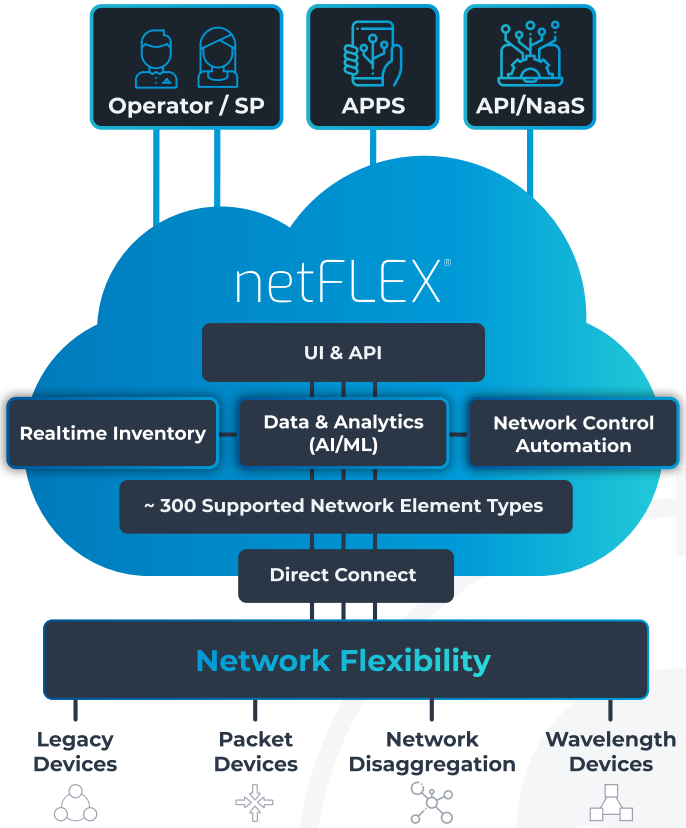
Through LightRiver's 'Area 51 Lab' work and field deployments we have been able to validate that LightRiver's netFLEX software platform has the core automation and control requirements needed for optimizing and managing disaggregated optical networks. Specifically:

Realtime Inventory - Discovered from the 'live' network. This inventory attribution provides both the physical and logical circuits and services of the network and end-to-end visibility. Inventory is the true foundation of the overall automation framework and a dependency for path computation for design and activation, topology, capacity management, incident/impact and control-loop use cases as correlated to any collected or derived data/analytics.

Data and Analytics - 'all' telemetry, end-to-end test, active PMs, and whatever might be available from an individual NE or broader network/service is collected, stored and available for advanced algorithms and reporting. As mentioned just prior, all of this data attribution can be mapped

LightRiver's netFLEX software platform has the core automation and control requirements needed for optimizing and managing disaggregated optical networks.

to realtime inventory to understand context and correlation (network and customer impacts and outage resolution, proactive network health and capacity planning, intent based networking, and countless others). The objective – make the data 'actionable' across the lifecycle of network and service assurance.



Network Control Automation - as the name infers, control in this context reflects any Add, Move, Change or Disconnect of a network or service. Yet again, an understanding of full network and service inventory is required to know what services exist, what capacity is available down to shelf, card, port, spectrum/wavelength assignment and

related, as the inputs for path computation and activation automation. Additionally, correlation of the referenced data/analytics to also know the 'health' of a network or span is critical before a service is added/changed and likewise as the enablement of control-loop interworking for any of the above.

Conclusion

After performing comprehensive lab validations across multiple Tier 1 and broader vendors' legacy and next generation line systems with competing vendors' multi-rate modular and pluggable coherent transceiver solutions, LightRiver has been able to endorse specific open optical Line Systems as ready for production networks. Notable and complementary to these efforts, LightRiver has readily recommended to several customers to incorporate the latest ZR/ZR+ optics in both greenfield and brownfield applications. The key for many customers has been the inclusion of the netFLEX automation platform to enable uniform multi-vendor management for realtime inventory, data, analytics, and control of the full network and service life-cycle.

Feel free to reach out to LightRiver to see if we can expedite your organization's ability to take advantage of the vast benefits of network disaggregation within Open Optical to drive out significant costs, drastically improve innovation cycles, and enable comprehensive automation to improve employee and customer experiences.

For more information, visit ***lightriver.com***

About LightRiver

LightRiver is the premier provider of next generation, multi-vendor, Factory Built Networks® and netFLEX® vendor neutral, Optical Domain Control Software solutions. LightRiver is an expert in Packet Optical, DWDM/ROADM, Open Optical and Alien Aware Networking®, MPLS and Carrier Ethernet systems and designs, engineers, commissions, automates and supports next generation, software controlled, transport networks for mission-critical clients that require the highest capacity, reliability, resiliency and manageability that today's optical communications technology can deliver. LightRiver delivers unique value with turnkey hardware and software solutions, carrier-grade quality and unparalleled customer care in multi-technology networking.